Geostatistics Tutorial

IF WE ask the right questions we can change the world.

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Product

Surpac™ 6.6.1

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Introduction

Overview

Geostatistics is used in fields such as mining, forestry, hydrology, and meteorology in order to understand how data values change over distance. Probably the most common use of geostatistics is to make estimations, such as the specific gravity of rock for an area where there are only a few known sample values. This is often done in three-dimensional space. A set of estimated points in space is known as a “model”. As George Box, a professor of Statistics at the University of Wisconsin in the United States, once said, “All models are wrong. Some are useful.”

Requirements

Before proceeding with this tutorial, you need to have installed Surpac. Additionally, you should have a good understanding of the following concepts in Surpac:

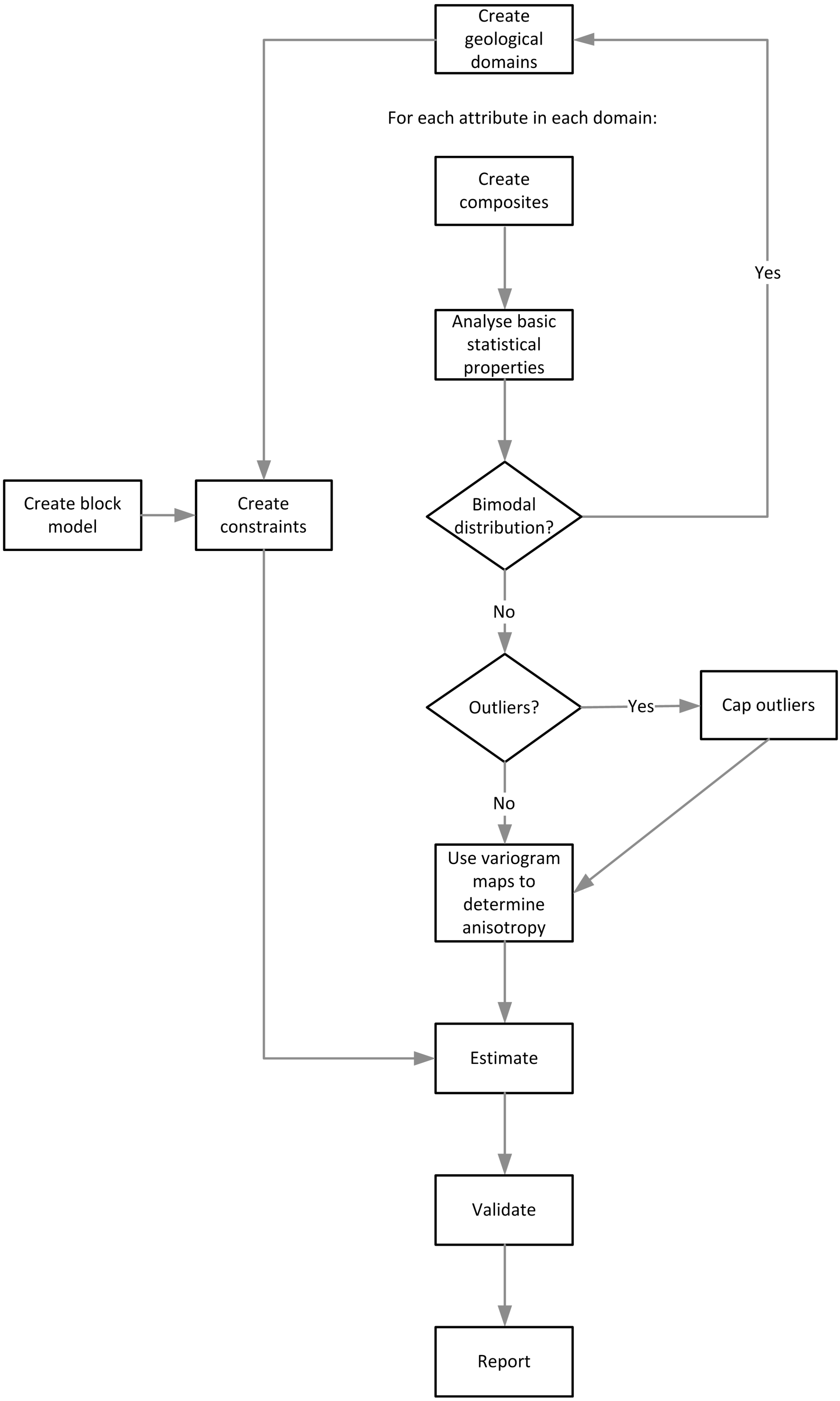
- geological database
- solid modelling
- block modelling (how to create and constrain a model)
- tcl scripts

Caution: If you do not have a good background in these subjects, many parts of this tutorial could be difficult to follow.

Workflow

There can be many different workflows for applying geostatistical techniques. The decision of which techniques to apply, and which order they are applied in is usually something that only experience will teach you.

Here is a generic process for performing a geostatistical analysis:


Create geological domains
For each attribute in each domain:
Create composites
Analyse basic statistical properties
Bimodal distribution?
Yes
No
Outliers?
Yes
Cap outliers
No
Use variogram maps to determine anisotropy
Create block model
Create constraints
Estimate
Validate
Report

Required files

Overview

This chapter will help you find the files required for this tutorial.

Requirements

In order to perform the exercises in this tutorial, you should:

- Install Surpac v6.6.

The files and directory structure for each tutorial are present if you have installed the software from the DVD.

If you have **not** installed the software from a DVD:

1. Create the following directory:

***<installation directory>*/demo_data/tutorials/geostatistics**

Note: ***<installation directory>*** is **c:\users\public\GEOVIA\Surpac\66** for Windows 7.

2. Download the geostatistics tutorial data (contained in a single zip file):

   a. Go to http://www.GEOVIAsupport.com.
   b. Log in.
   c. Click the Downloads link.
   d. Click Surpac downloads.
   e. Click Tutorials.
   f. Click 6.4 tutorials to download the zip file.

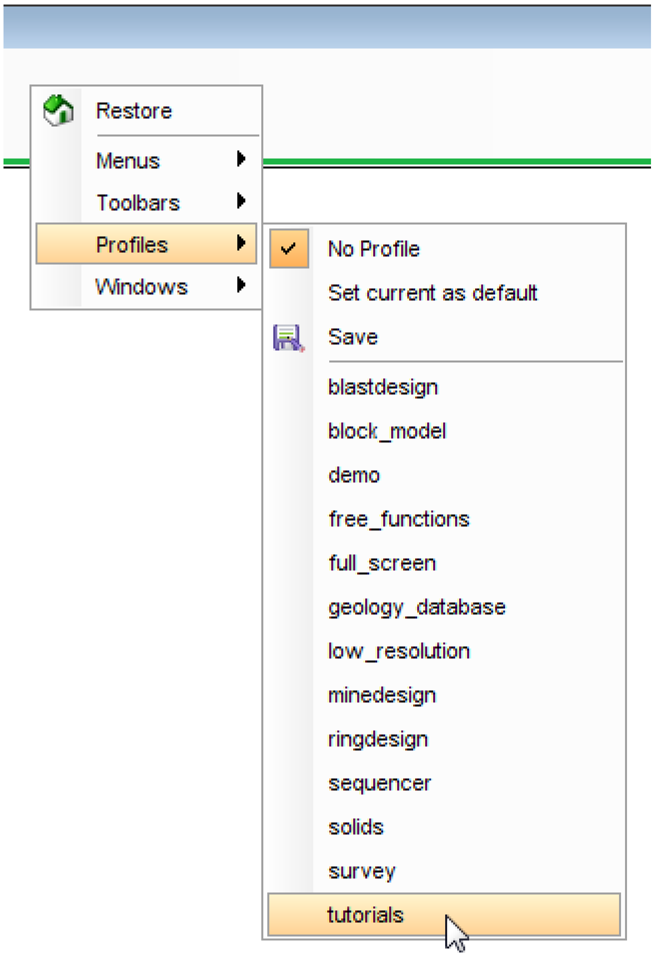
3. Unzip the file **geostatistics.zip** into the directory you created.

Tutorial profile

Profiles are a collection of menu bars and toolbars. The tutorial profile contains a set of menus that assist you with learning various aspects of the software.

Task: Display the Tutorials profile

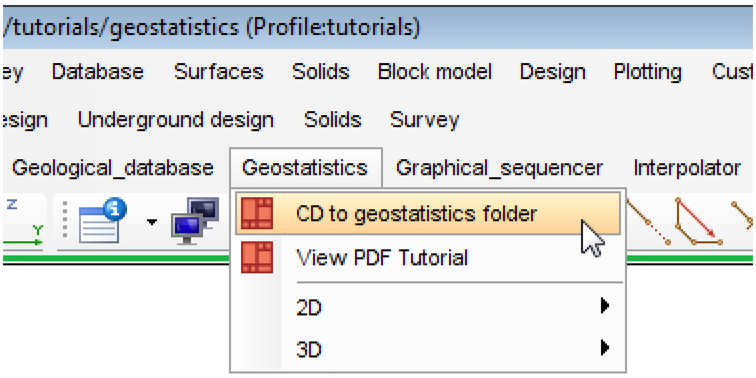
1. Right-click in the blank area to the right of the menus.
2. From the shortcut menu, choose **Profiles > tutorials**.



A new menu bar is displayed, listing all available tutorials.

3. Choose **Geostatistics > CD to geostatistics folder**.

   Note: There are two **Geostatistics** menu items. Select the one on the tutorials menu bar, as shown:



This should set your working directory to:

***<installation directory>*/demo_data/tutorials/geostatistics**

This directory contains all of the files required to perform the steps in this tutorial.

Important concepts

Overview

In order to reduce estimation errors, you should:

- understand the domains
- validate the input data
- understand estimation methods and parameters
- validate the output model

Requirements

There are no requirements for reading this chapter, but you may find some of the principles easier to understand if you:

- have some understanding of basic statistics
- know what a geostatistical model is or
- have previously performed a geostatistical estimation

Understand the domains

It is important to recognise separate "regions" or "domains" within a model. After you have identified the domains, it is important to group all sample data contained within each domain into distinct subsets. After that, you can analyse each subset individually, and use data from each separate domain to make estimations within that domain.

Validate the input data

The saying "Garbage in = Garbage out" is certainly true in geostatistics. Although sampling theory and laboratory quality control practices are important concepts which impact the quality of any estimation made using a set of data values, these subjects are outside the scope of this tutorial.

Assuming that the quality of the data is as good as you're going to get, there are a couple of potentially hazardous characteristics of the data which you should look for: "bimodalism" and "outliers". You can look for both of these features with a histogram. A data set is said to be "unimodal" if the histogram shows a single peak. If there are two peaks, the data is said to be "bimodal". If you use some of the more common estimation techniques to create a model based on a bimodal distribution, it is likely to contain more estimation errors than a model created from a unimodal data set. Additionally, "outliers", or values which are significantly distant from the majority of the data, can cause estimation errors.

Understand estimation methods and parameters

There are a large number of estimation methods, and a large number of parameters within each method. Before using a particular estimation method, you should have a good background in basic statistics, as well as basic geostatistical principles.

There are a number of functions that the geostatistics module will perform for you. However, it is important that you understand the underlying principles of geostatistics, so that you understand the impact of performing a function on the final result.

Validate the output model

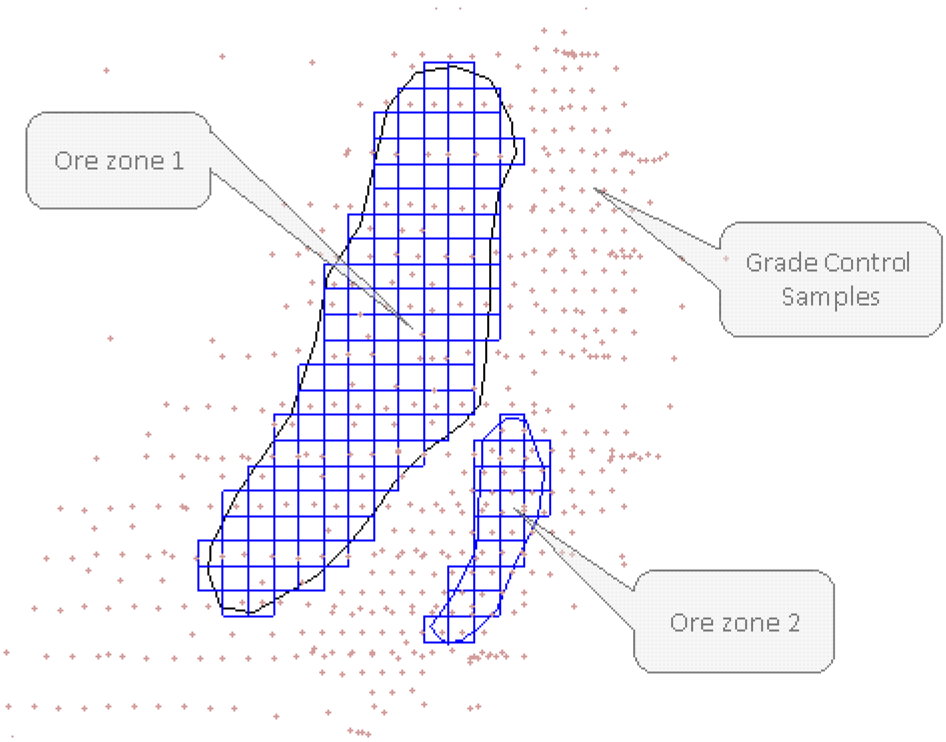
A final method you should use to check the quality of estimation is to take time to examine the output. Histograms of estimated values, contours of plans, cross-sections of block models, colour-coded and rotated in three-dimensional space are all methods which can be used to verify the output values.

2D case study: grade control

Overview

This is a sample project which presents many geostatistical concepts in a common workflow in Surpac. There are many different types of deposits and the techniques demonstrated here may or may not be relevant to you.

The concepts presented here use a two dimensional data set representing an area of grade control. You should examine this before moving on to the three dimensional case.



Domains

Overview

One of the most important aspects of geostatistics is to ensure that any data set is correctly classified into a set of homogenous "domains". A domain is either a 2D or 3D region within which all data is related. Mixing data from more than one domain or not classifying data into correct domains can often be the source of estimation errors.

You will learn about:

- the effect of domains on estimated values
- viewing and using domains

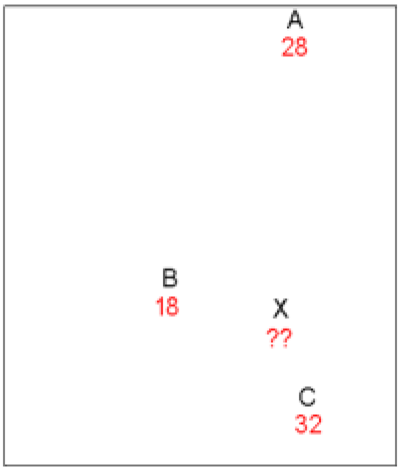
Requirements

In order to understand this information, you should know how to:

- display Surpac string files
- run a Surpac macro

The effect of domains on estimated values

Imagine that you are a meteorologist, and you are given three air temperatures measured at locations A, B, and C, as displayed below. Based on the values shown, what would you guess the temperature is at location X? Would you guess that the temperature at location X was greater than 25?

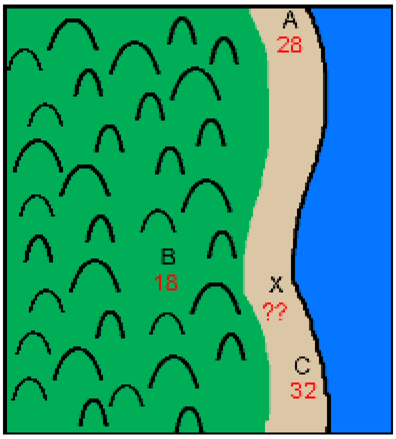


Using the information above, you may have the following thoughts:

1. Because location A is relatively distant from X, the value at A might have little or no influence on the estimated temperature at X.
2. Because locations B and C are about the same distance from X, they will probably have equal influence on the estimated temperature.
3. Given the previous two points, the temperature at X would probably be the average of the temperatures at B and C: (18 + 32) / 2 = 25 degrees
4. Because the influence of A has not been accounted for at all, and the estimate is exactly 25 degrees, it is difficult to say with certainty if the temperature at X is above 25 degrees.

Now consider the following. Imagine that you want to go to your favourite beach, but only if the temperature is 25 degrees or more. You have three friends who live near the beach you want to go to, and you call them up and ask each one what the temperature is at each of their homes. You draw the map below, with the locations of each friend (A, B, and C) and the temperatures they give you.

Your favourite beach is at location X. Note that the friend at location B lives high up in the mountains, while friends at A and C live near the beach.



Using the information above, you may have the following thoughts:

1. The data from B can be ignored, because temperatures high up in the mountains are usually not good estimates of temperatures on the beach.
2. A and C are on the beach, so they can be used to guess the temperature at X.
3. Because X is between A and C on the map, the temperature at X will probably be somewhere between the temperature at A and the temperature at C.
4. Therefore, the temperature at X will be somewhere between 28 and 32 degrees
5. Because the temperature range of 28 to 32 degrees is greater than the minimum value of 25 degrees, you would probably decide “Yes, I’m going to the beach!”

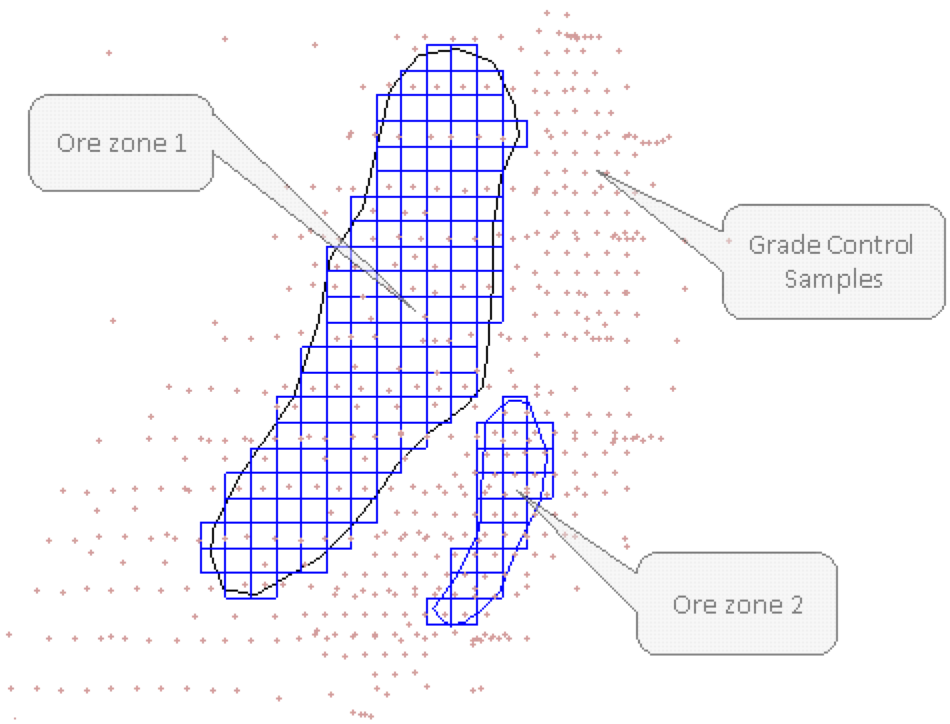
Compare this example with the first one. In both cases, all of the locations and temperatures are exactly the same. However, in the second case, when you took account of the domain which contains the data, you came up with a considerably different result. The point is that separating data into similar regions, or domains, is a very important part of making any geostatistical estimation.

Viewing and using domains

Task: View domains

1. Open **gc130.swa**.
   This data represents some grade control samples, ore zone outlines, and a block model

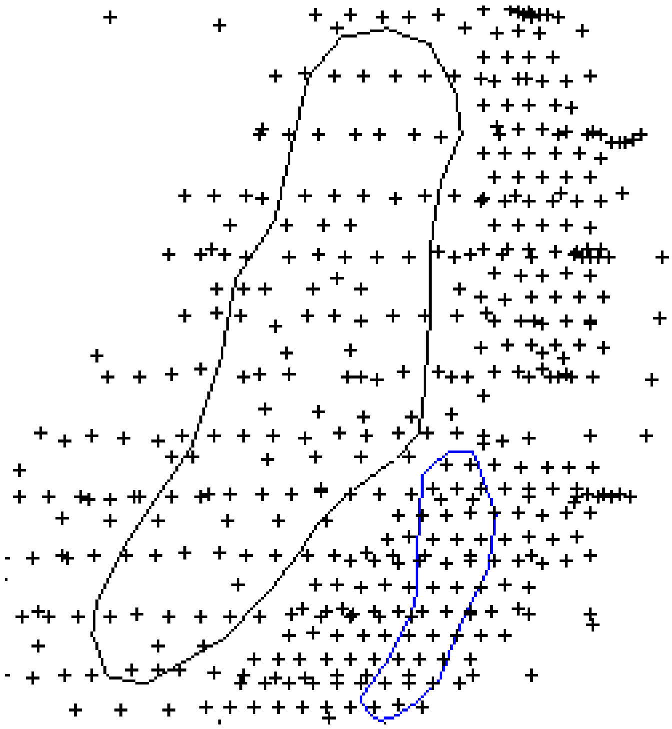
(constrained by two ore zones) on a single mining bench, or elevation of 130.



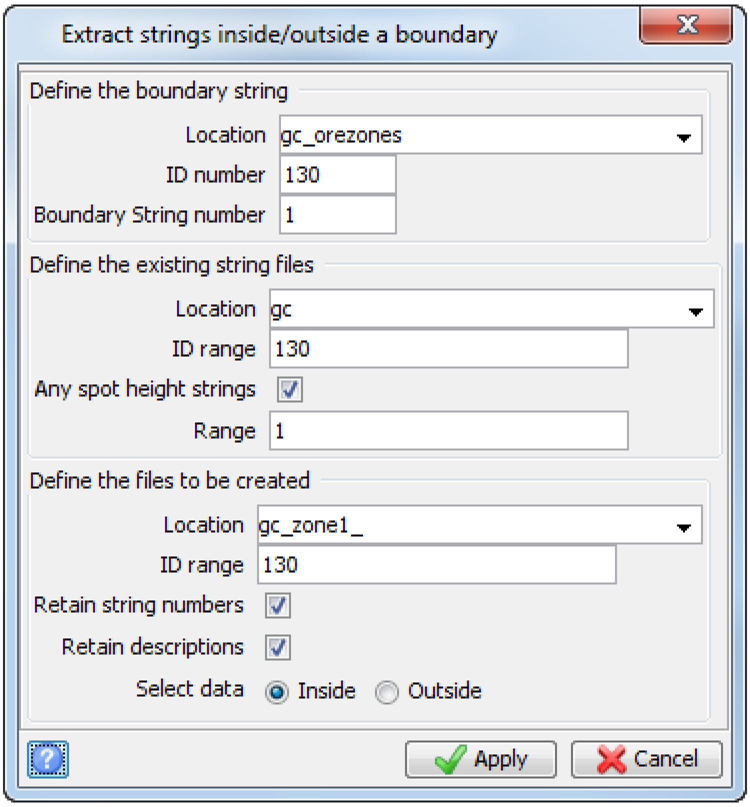
Task: Separate data for each domain

Using the ore zone outlines as domains, only those grade control samples which are inside each ore zone should be used to estimate blocks inside that ore zone.

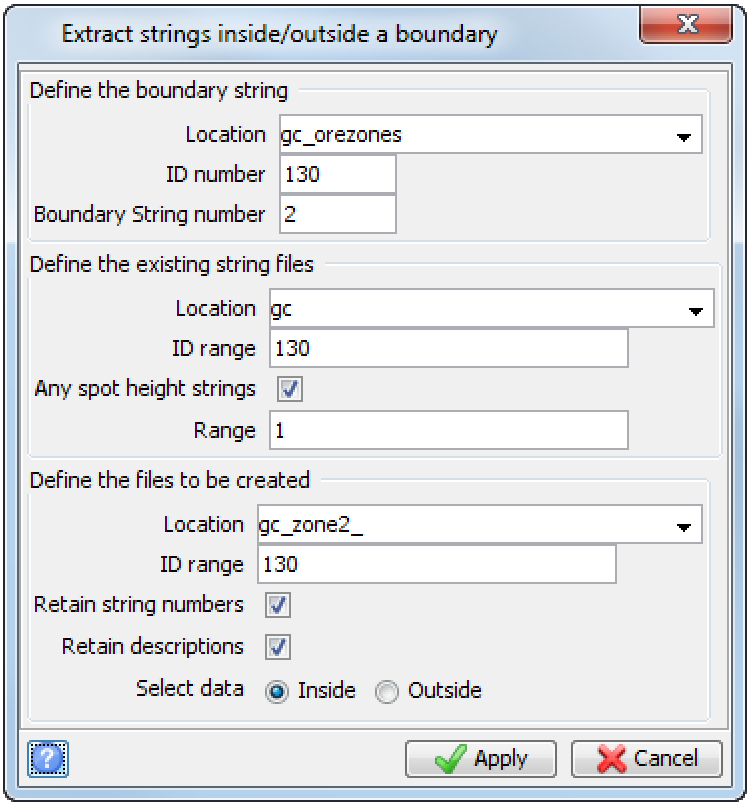
1. Click **Reset Graphics**.
2. Open **gc130.str**
3. Display all strings as markers.
    a. Select **Display > Point > Markers**.
    b. Select **Display > Hide strings > As lines**.
4. Open **gc_orezones130.str**.
   Notice that **gc130.str** contains the samples for the entire bench.



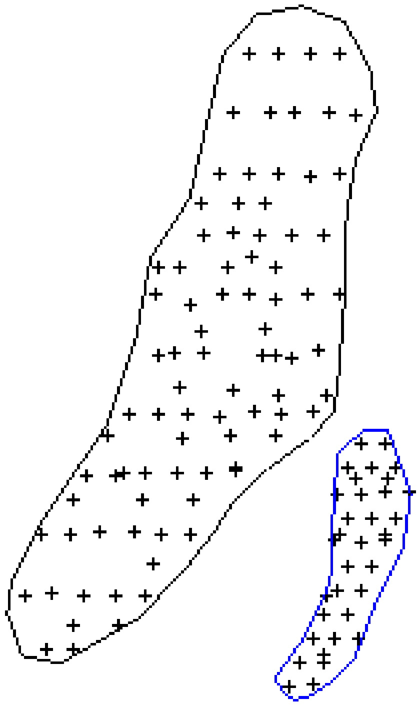
5. Choose **File tools > Apply boundary string**.
6. Enter the information as shown, and click **Apply**.



7. Choose **File tools > Apply boundary string**.
8. Enter the information as shown, and click **Apply**.



9. Click **Reset Graphics**.
10. Open **gc_zone1_130.str**.
11. Display all strings as markers.
12. Open **gc_zone2_130.str**.
13. Display all strings as markers.
14. Open **gc_orezones130.str**.
    Notice that the samples within each domain are now contained within separate string files.



Note: This process applies to two dimensional domains. There is a different process for three dimensional data.

To see all of the steps performed in this task run **2d_01_apply_boundary.tcl.**

Menu commands:

Select...	to...
File tools > Apply boundary string	apply a boundary to drillhole data.

Basic statistics

Overview

One of the important preliminary steps in performing a geostatistical evaluation is to understand the statistical properties of the data. Two characteristics which can potentially reduce the quality of your estimations are bimodalism and outliers. You can use a histogram to identify both of these.

You will learn about:

- histograms
- bimodal distributions
- creating a histogram.

Requirements

In order to understand this information, you should:

- be familiar with Surpac string files
- know how to run a Surpac macro.

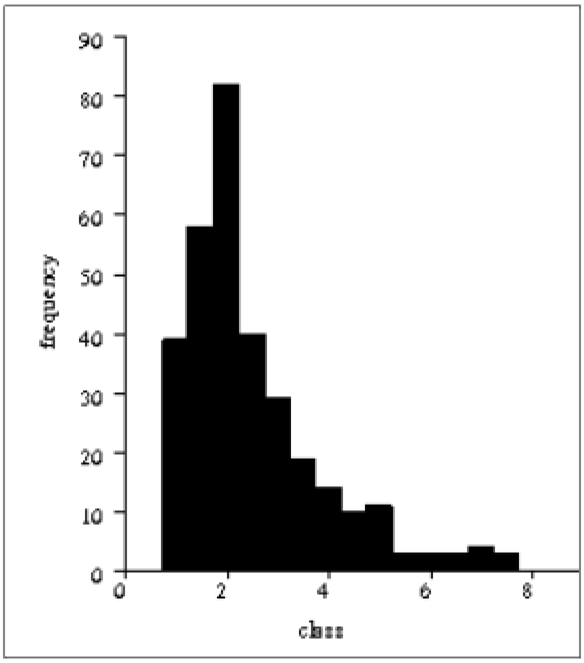
Histograms

A histogram is a statistical term which refers to a graph of frequency against value. A histogram is the graphical version of a table which shows what proportion of cases fall into each of several non-overlapping intervals of some variable.

For example, you could represent a distribution of gold grades with the following table:

Gold (g/t)	Number of samples (frequency)
0.0 - 0.5	0
0.5 – 1.0	40
1.0 - 1.5	58
1.5 – 2.0	82
2.0 - 2.5	40
2.5 – 3.0	29
3.0 - 3.5	18
3.5 – 4.0	10
4.0 – 4.5	12
4.5 – 5.0	5
5.5 – 6.0	5
6.0 – 6.5	5
6.5 – 7.0	5
7.0 – 7.5	8
7.5 – 8.0	5

You can display this same data in a histogram as shown:



Bimodal distributions

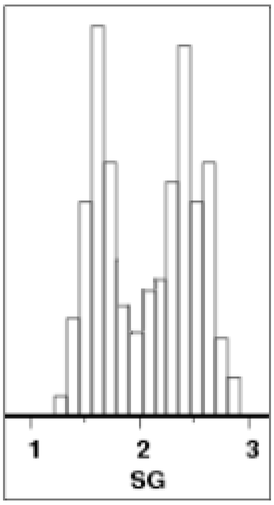
The "mode" is the most commonly occurring value in a data set. For example, in the following data set, the number 8 is the mode:

1 3 5 5 8 8 8 9

"Bimodal" means that there are two relatively "most common" values which are not adjacent to one another. In the following data set, the numbers 2 and 8 are equally common, and the distribution is said to be "bimodal":

1 2 2 2 3 5 5 8 8 8 9

Imagine that you are studying the average specific gravity, or density of rocks in a coal deposit. A histogram of all rock samples might look like this:



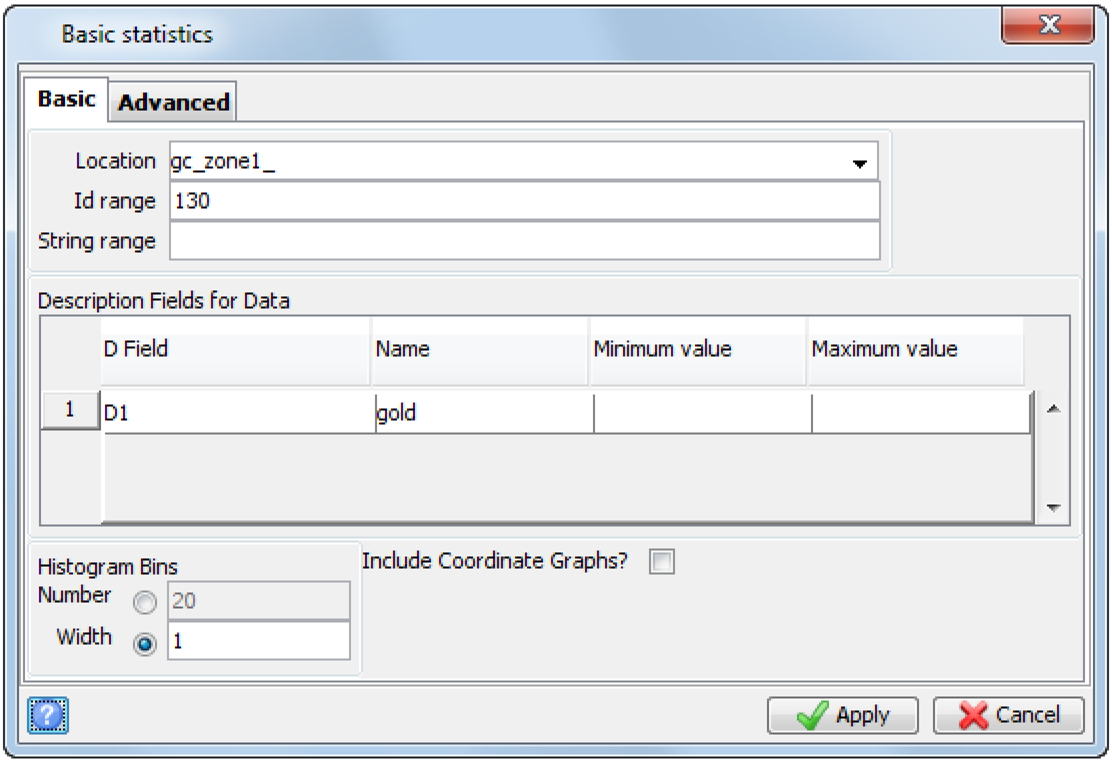
Any histogram which displays two peaks, as in the previous example, is said to be "bimodal". You can explain the bimodal distribution in the previous example by the fact that the data set is comprised of coal samples as well as intervening sandstone and mudstone bands. The specific gravity values between 1 and 2 are representative of the coal, while specific gravity values between 2 and 3 represent the intervening rock.

Often the source of a bimodal distribution can be two domains being mixed into a single data set. In order to minimise estimation errors, you should make every attempt to separate any data set which has a bimodal distribution. In the example above, simply segregating the data based on rock type would result in two separate normal distributions.

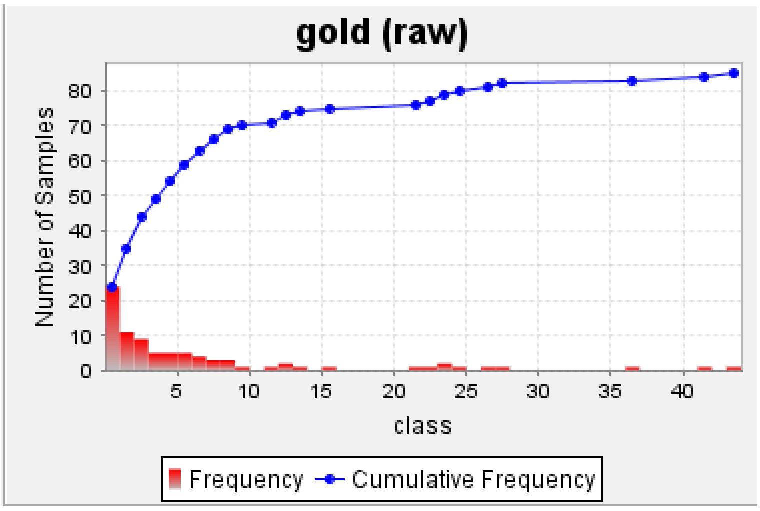
Creating a histogram

Task: Create a histogram from string data

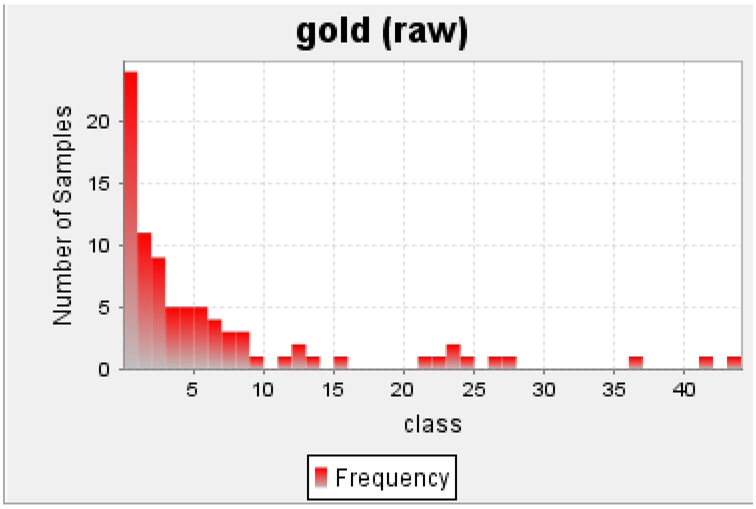
1. Choose **Geostatistics > Basic statistics**.
2. Choose **File > Load data from string files**.
3. Enter the information as shown, and click **Apply**:



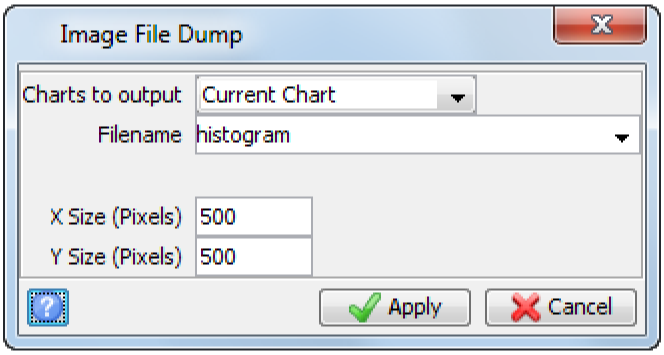
The histogram and cumulative frequency are displayed:



4. Choose **Display > Histogram**.
   The histogram is displayed:

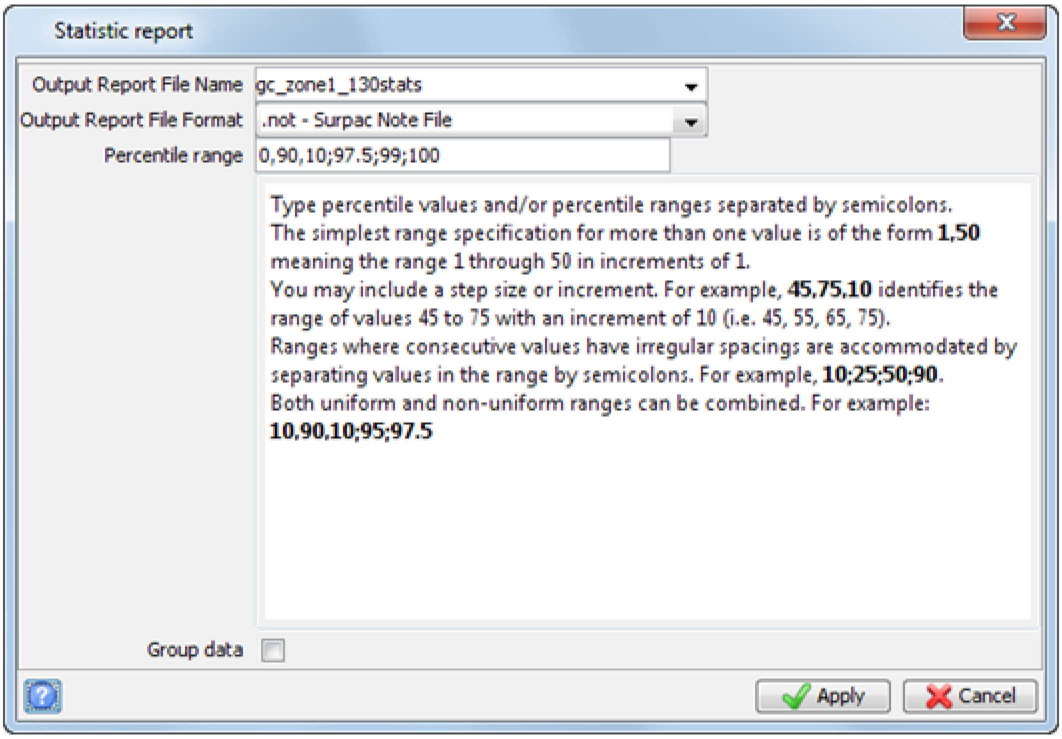


5. Choose **File > Save as > Image file**.
6. Enter the information as shown, and click **Apply**:



The image (as above) is saved in the current working directory.

7. Choose **Statistics > Report**.
8. Enter the information as shown, and click **Apply**:



The file **gc_zone1_130stats.not** is created and displayed:

```
Output Filename: gc_zone1_130stats
                                        Statistics Report

File                                    Gc Zone1 130.str
---------------------------------------------------------------
String range                                         All
Variable                                            gold

Number of samples                                     85
Minimum value                                   0.010000
Maximum value                                  43.530000

                                          Ungrouped Data
Mean                                            6.490118
Median                                          2.650000
Geometric Mean                                  2.222684
Variance                                       86.579051
Standard Deviation                              9.304786
Coefficient of variation                        1.433685

Moment 1 About Arithmetic Mean                  0.000000
Moment 2 About Arithmetic Mean                 86.579051
Moment 3 About Arithmetic Mean               1808.520391
Moment 4 About Arithmetic Mean              58094.981937

Skewness                                        2.244937
Kurtosis                                        7.750201

Natural Log Mean                                0.798716
Log Variance                                    2.947087

0.0 Percentile                                  0.000000
10.0 Percentile                                 0.170000
20.0 Percentile                                 0.470000
30.0 Percentile                                 1.160000
40.0 Percentile                                 1.880000
50.0 Percentile (median)                        2.650000
60.0 Percentile                                 4.215000
70.0 Percentile                                 5.900000
80.0 Percentile                                 8.650000
90.0 Percentile                                22.500000
97.5 Percentile                                38.815000
99.0 Percentile                                42.355000
100.0 Percentile                               43.530000

Trimean                                         3.353750
Biweight                                        3.071914
MAD                                             2.766914
Alpha                                           0.184082
Sichel-t                                        9.311888

Normal Histogram Tabulation
gold
```

Class From	Class To	Count	Mean	Freq %	Cum Count	Cum Mean	Cum Freq %	Dec Count	Dec Mean	Dec Freq %
0.010000	1.010000	24	0.357500	0.282	24	0.357500	28.2353	85	6.490118	100.0000
1.010001	2.010000	11	1.435455	0.129	35	0.696286	41.1765	61	8.902951	71.7647
2.010000	3.010000	9	2.414444	0.106	44	1.047727	51.7647	50	10.545800	58.8235
3.010000	4.010000	5	3.512000	0.059	49	1.299184	57.6471	41	12.330732	48.2353
4.010000	5.010000	5	4.240000	0.059	54	1.571481	63.5294	36	13.555556	42.3529
5.010000	6.010000	5	5.518000	0.059	59	1.905932	69.4118	31	15.058065	36.4706
6.010000	7.010000	4	6.437500	0.047	63	2.193651	74.1176	26	16.892692	30.5882
7.010000	8.010000	3	7.446667	0.035	66	2.432424	77.6471	22	18.793636	25.8824
8.010000	9.010000	3	8.493333	0.035	69	2.695942	81.1765	19	20.585263	22.3529
9.010000	10.010000	1	9.690000	0.012	70	2.795857	82.3529	16	22.852500	18.8235
11.010000	12.010000	1	11.510000	0.012	71	2.918592	83.5294	15	23.730000	17.6471
12.010000	13.010000	2	12.430000	0.024	73	3.179178	85.8824	14	24.602857	16.4706
13.010000	14.010000	1	13.560000	0.012	74	3.319459	87.0588	12	26.631667	14.1176
15.010000	16.010000	1	15.670000	0.012	75	3.484133	88.2353	11	27.820000	12.9412
21.010000	22.010000	1	21.420000	0.012	76	3.720132	89.4118	10	29.035001	11.7647
22.010000	23.010000	1	22.500000	0.012	77	3.964026	90.5882	9	29.881111	10.5882
23.010000	24.010000	2	23.390000	0.024	79	4.455823	92.9412	8	30.803750	9.4118
24.010000	25.010000	1	24.090000	0.012	80	4.701250	94.1176	6	33.275000	7.0588
26.010000	27.010000	1	26.640000	0.012	81	4.972099	95.2941	5	35.112000	5.8824
27.010000	28.010000	1	27.760000	0.012	82	5.250000	96.4706	4	37.230000	4.7059
36.010000	37.010000	1	36.450000	0.012	83	5.625904	97.6471	3	40.386667	3.5294
41.010000	42.010000	1	41.180000	0.012	84	6.049167	98.8235	2	42.355000	2.3529
43.010000	44.010000	1	43.530000	0.012	85	6.490118	100.0000	1	43.530000	1.1765

1/1

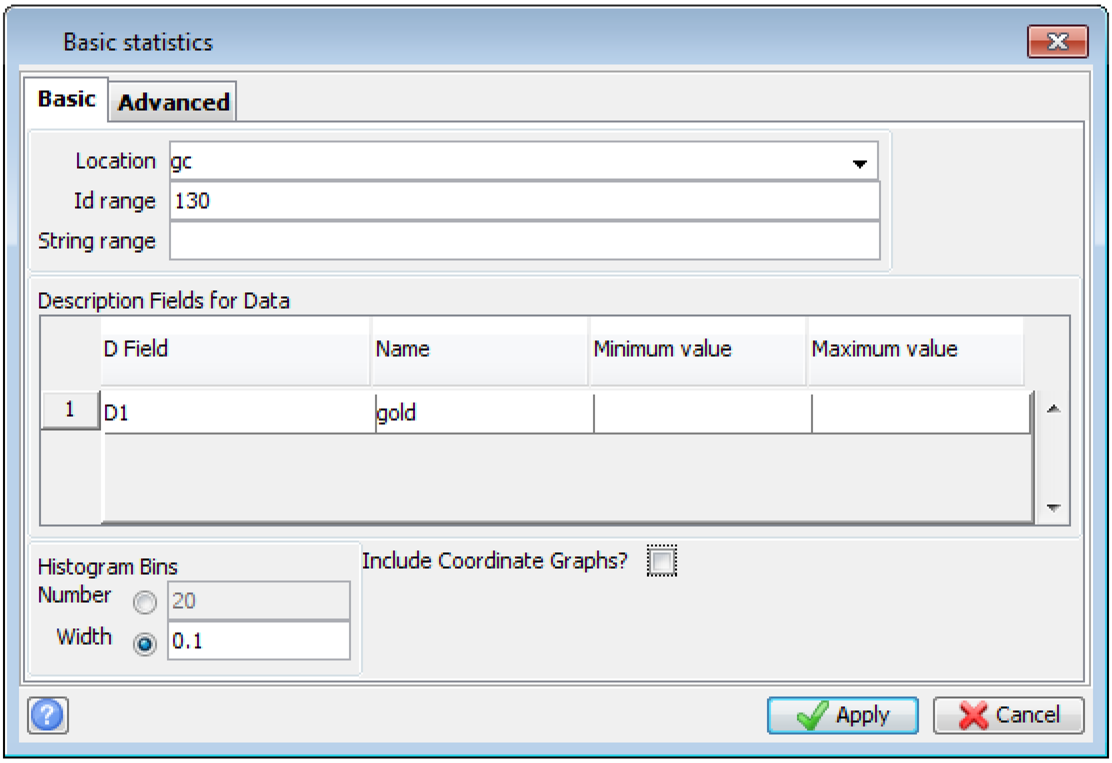
9. Close the **Basic Statistics** window.

To see all of the steps performed in this task run **2d_02a_basic_statistics_histogram.tcl.**.

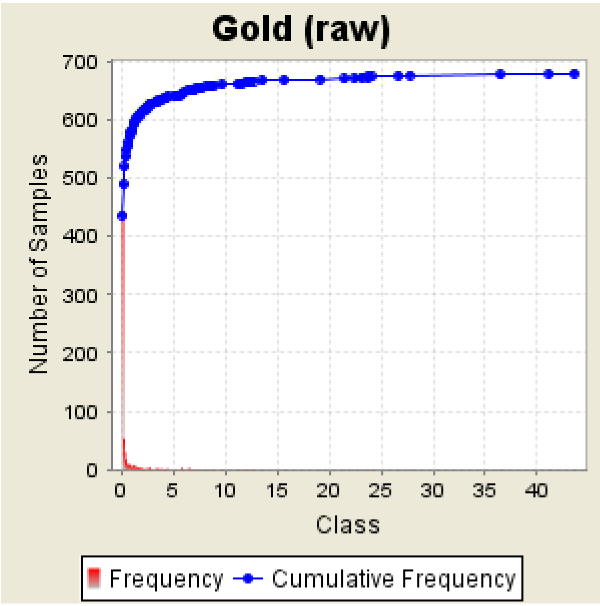
📝 **Note**: The **Basic Statistics Window** must be closed when running the file.

Task: Create a log-probability plot from string data

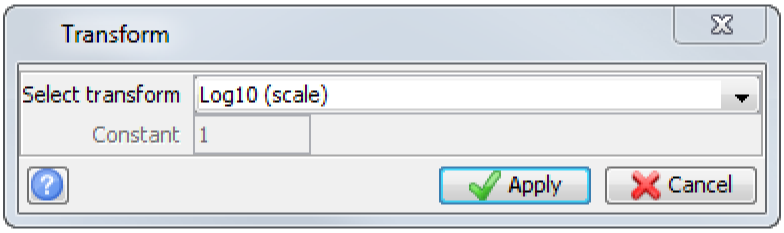
1. Choose **Geostatistics > Basic statistics**.
2. Choose **File > Load data from string files**.
3. Enter the information as shown, and click **Apply**:



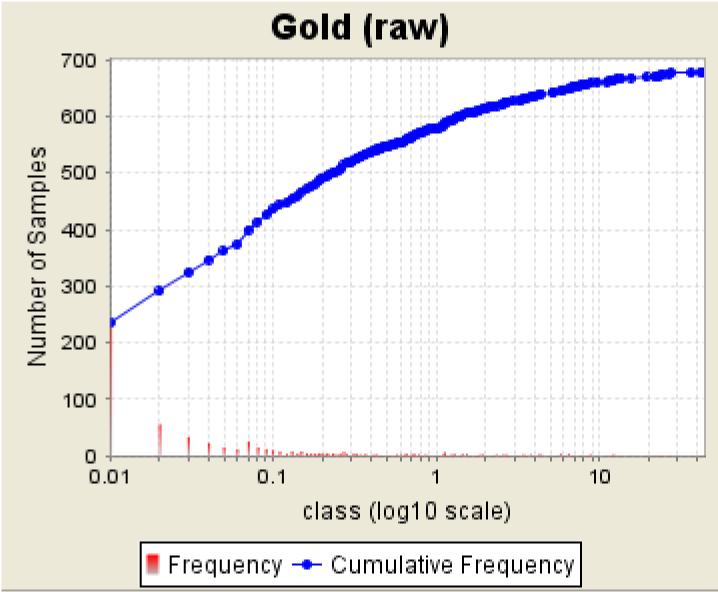
The histogram and cumulative frequency are displayed for the D1 values in **gc130.str**:



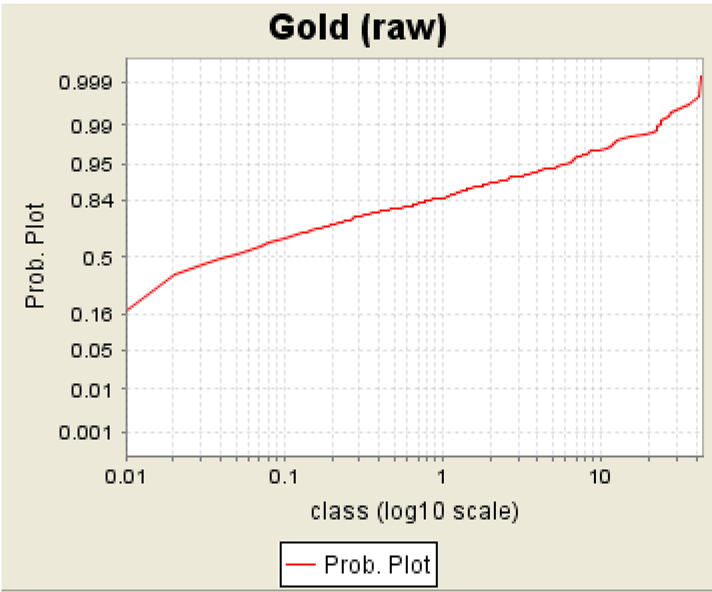
4. Choose **Statistics > Transformations**.
5. Enter the information as shown, and click **Apply**:



The histogram and cumulative frequency for the transformed data are displayed:

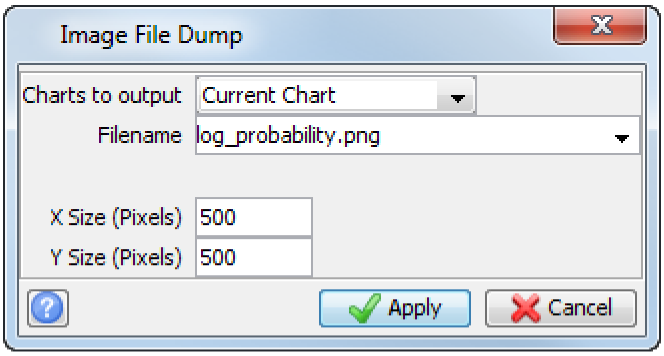


6. Choose **Display > Probability Curve**.
   The histogram and cumulative frequency are displayed, as shown:



Note: The Log-Probability graph will be a straight line for a true lognormal distribution.

7. Choose **File > Save as > Image file**.
8. Enter the information as shown, and click **Apply**:



The image (as above) is saved in the current working directory.

9. Close the **Basic Statistics** window.

Notes:

- To see all of the steps performed in this task run **2d_02b_basic_statistics_log-probability.tcl.**
- The **Basic Statistics Window** must be closed.

Menu commands:

Select...	to...
Geostatistics > Basic statistics	open the Basic Statistics window.
From the Statistics Window:	
File > Load data from string files	load the drillhole data.
Display > Histogram	create a histogram.
Statistics > Report	create a report.
File > Save as > Image file	save the histogram as an image.
Statistics > Transformations	scale the data.
Display > Probability Curve	create a log probability plot.

Outliers

Overview

Outliers are data values that are much higher (or much lower) than most data values in a single domain. You should either "cut" them down (or up) to some value, or remove them.

You will learn about:

- outliers and topcuts
- methods of determining a topcut value
- applying a topcut

Requirements

In order to understand this information, you should:

- be familiar with Surpac string files
- know how to run a Surpac macro

Outliers and topcuts

An "outlier" is a statistical term for a value that is significantly different than the majority of all other values in the data set. For example, in the following data set, the number 236 would be considered an outlier:

1 3 5 5 8 8 8 236

Outliers can cause "noisy" experimental variograms, which are difficult to model. Additionally, if you use outliers in an estimation, they can cause unrealistic results. One technique to reduce the effect of outliers is to apply a "cutoff", or "topcut" to them. In the example above, the value of 236 could be "cut" by changing it to a value of 9:

1 3 5 5 8 8 8 9

The alternative is to remove the outlier value:

1 3 5 5 8 8 8

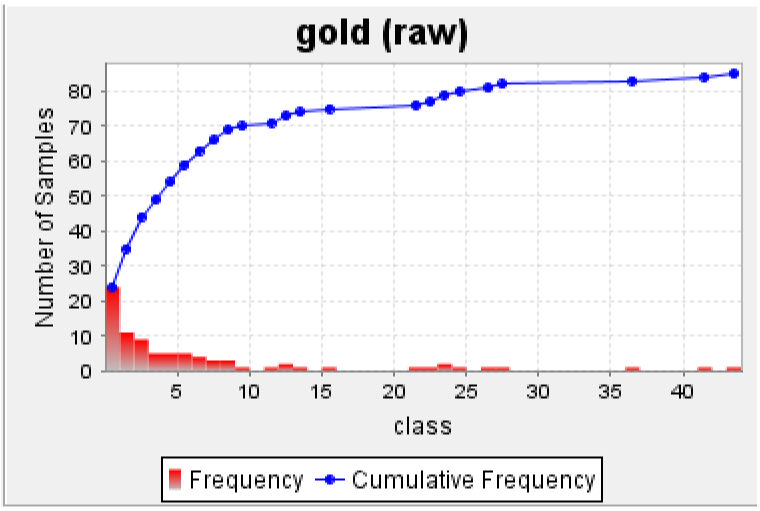
Methods of determining a topcut value

There are many methods that you can use to determine a topcut value, using:

- histogram
- confidence interval
- percentile
- experience

Histogram

You can use the point at which the cumulative frequency curve "flattens out" as the cutoff. In the following situation, the curve appears to be fairly flat at a value of 25.



A histogram can also help visually substantiate the choice of a topcut value obtained by other means.

Confidence interval

A confidence interval is an estimated range of values which is likely to include a given percentage of the data values, assuming that the data is normally distributed. The calculation for the upper limit of a 95% confidence interval (CI) is:

*95% CI = mean + (1.96 * standard deviation)*

For example, if a data set has:
mean = 6.49 and standard deviation = 9.30.

*95% CI = 6.49 + (1.96 * 9.30)*

95% CI = 24.718

Percentile

A percentile is that data value at which a given percentage of all other data values fall below. Any given percentile value could be selected as the outlier cutoff, such as the 90th, 95th, or 99th percentile. For example, you could choose one of the following (from the previous Basic Statistics report):

90.0 Percentile: 22.5

95.0 Percentile: 27.2

97.5 Percentile: 38.8

99.0 Percentile: 42.4

Experience

Topcut values are often chosen based on knowledge of a deposit. For example, if part of an ore zone has been mined, information from grade control samples and reconciliation studies may provide a good idea of what the maximum mined block value will be. If the deposit has not yet been mined, information from similar deposits may be useful in determining the outlier cutoff.

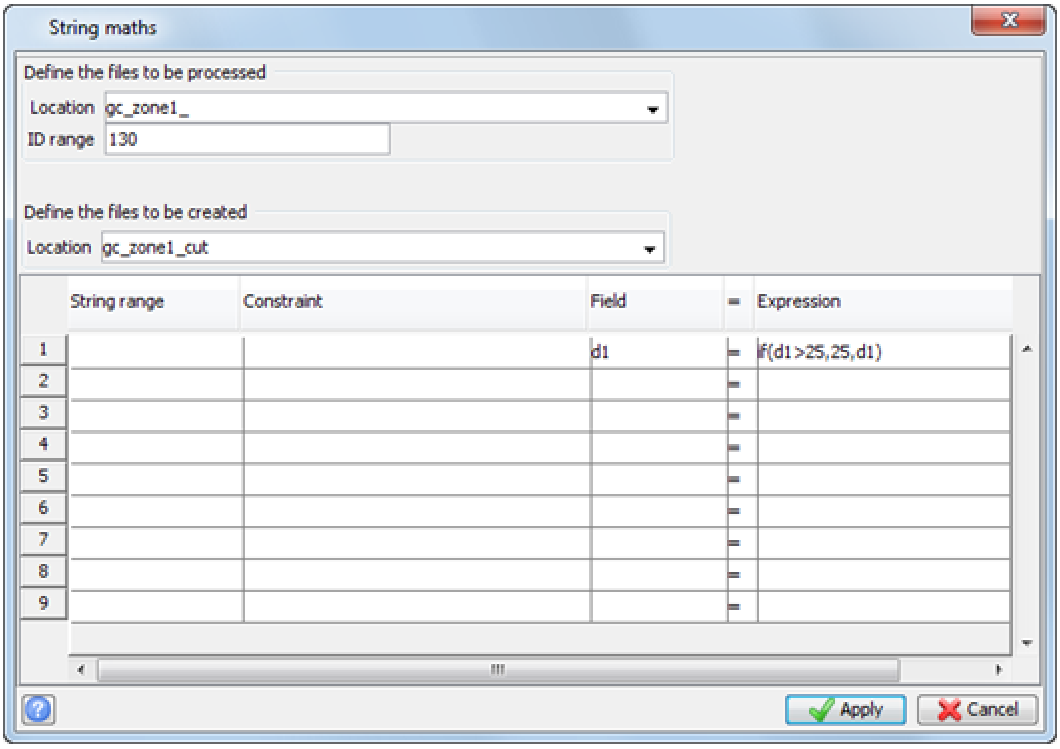
Topcutting outliers

The process of determining a topcut is usually much longer and more difficult than applying a topcut in Surpac. Whatever method is chosen, you can cut values in a description field in a string file using STR MATHS.

Task: Applying a topcut

You will apply a topcut value of 25 to the gold values in the D1 field of the file **gc_zone1_130.str**.

1. Choose **File tools > String maths**.
2. Enter the information as shown, and click **Apply**.



The expression states:

If the value of d1 is greater than 25,

then set the value of d1 equal to 25,

else leave the value of d1 as it is.

To see all of the steps performed in this task, run **2d_03b_cut_outliers.tcl**.

Menu commands:

Select...	to...
File tools > String maths	apply a topcut value.

Anisotropy

Overview

An important aspect of performing any geostatistical evaluation is to understand how data values change with regard to direction. The term "anisotropy" explains this concept.

You will learn about:

- isotropy and anisotropy
- geostatistical estimation using isotropy
- geostatistical estimation using anisotropy
- Ellipsoid Visualiser

Requirements

In order to understand this information, you should:

- be familiar with Surpac string files, and how to display them
- be familiar with the geometric shape and deposition of economic geological deposits
- understand the concept of a centroid of an individual block in a block model

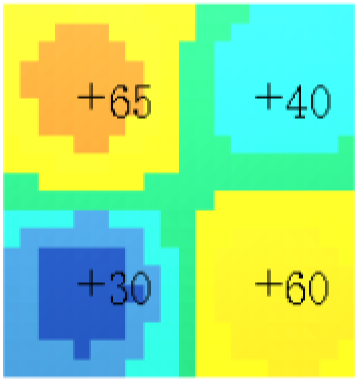
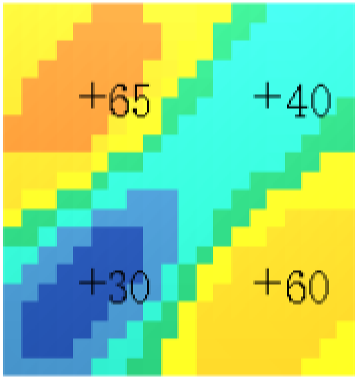
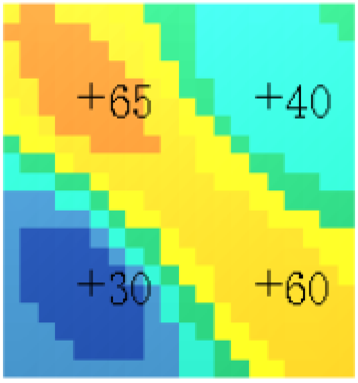
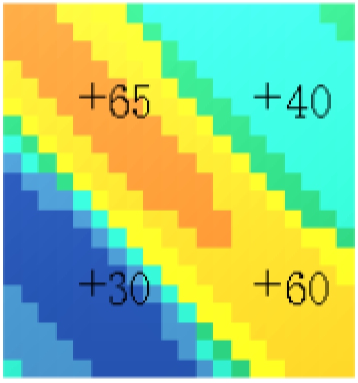
Isotropy vs. anisotropy

In order to understand anisotropy, it is helpful to know what the term isotropy refers to. Here is a definition of each term:

Isotropy: The property of being isotropic; having the same value when measured in different directions.

Anisotropy: The property of being anisotropic; having a different value when measured in different directions.

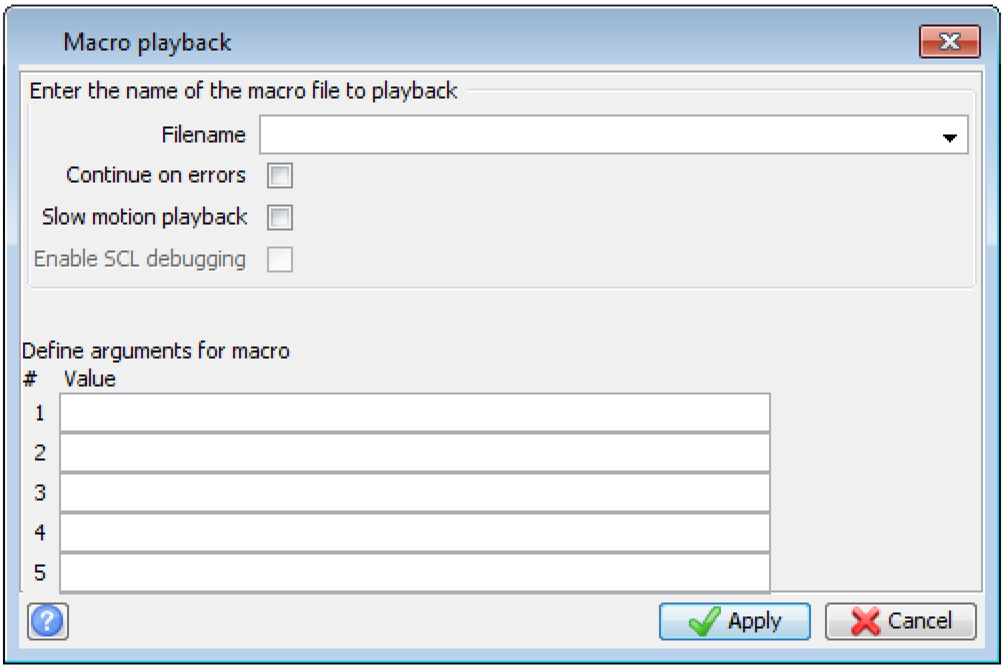
When estimating values in a block model, the amount and direction of anisotropy can have a significant impact on the end result. For example, the three models shown below were created from the same data set, but different amounts of anisotropy were used.

	
No Anisotropy (Isotropic)	2:1 Anisotropy Azimuth 45
	
2:1 Anisotropy Azimuth 135	5:1 Anisotropy Azimuth 135

Task: Display block models created with anisotropy

1. Run **2d_04_anisotropy.tcl**
2. Click in **Graphics** after each model is displayed.

If you use the **Macro playback** button, you can see all values on the forms by selecting **Slow motion playback**:



In geostatistical terms, isotropy, or an isotropic condition, is said to exist when the rate of change of data values is the same in all directions. A true isotropic condition in three dimensions is rare for most types of data. However, an isotropic condition in two dimensions is more common. For example, the rate of change of alumina values in a large horizontal bauxite deposit beneath relatively flat topography may be isotropic in the XY plane.

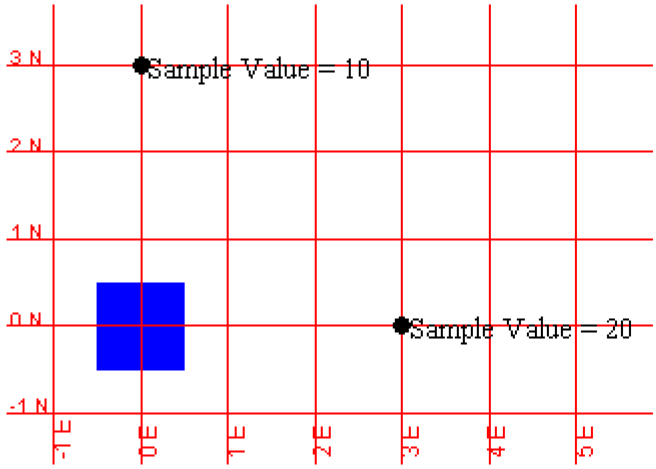
Conversely, anisotropy, or an anisotropic condition is said to exist when the rate of change of data values is different in different directions. This is probably the most common case. For example, an epithermal gold vein may have different rates of change in each of any three mutually perpendicular directions: along strike, down dip, and perpendicular to the dip plane.

The remainder of this chapter will explain the use of isotropy and anisotropy in performing geostatistical estimations. To understand how you determine whether a data set is isotropic or anisotropic, and how to calculate the direction and amount of anisotropy, you will need to study the chapters on variograms and variogram maps.

Geostatistical estimation using isotropy

In geostatistical estimation (for example, inverse distance weighting, ordinary kriging, and indicator kriging), one or more points, usually representing sample locations, are used to estimate a value at a location where there are no samples. For example, in the image below, the sample locations are represented by two points in a Surpac string file. In this string file, D1 contains the sample values (D1=10 for one point, and D1=20 for the other point). The location to be estimated is the centre position, or "centroid" of a 1 x 1 x 1 block of material.

In this example, you will assume that all data is in the XY plane (that is, the sample points and the block centroid each have the same Z value). You will also assume that you are estimating a value at the block centroid (at coordinates 0N, 0E), and that only the two samples shown will be used for the estimation. Notice that both samples are the same distance (3 metres) from the block centroid. If you assume that the material surrounding the block and samples is homogenous (all the same), you can assume that there is no "directional continuity" within the data, and the two samples will contribute equally to the estimation. Another way of stating this is that the "weight" applied to both samples will be equal.



In this situation, where only two samples are used to estimate the value for the block, the "weight" for each sample will be 0.5. The calculation of the block value is:

*(sample value1 * weight1) + (sample value2 * weight2) = block value*

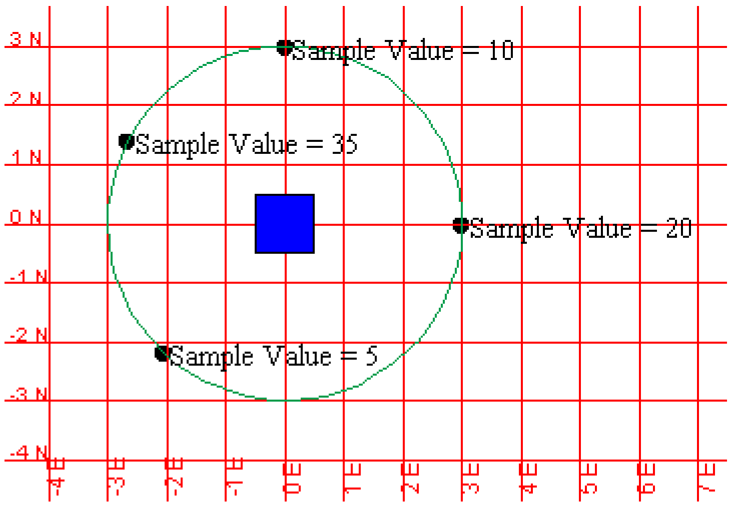
*(10 * 0.5) + (20 * 0.5) = 15*

Throughout this tutorial, you will assume that the sum of the weights must equal 1. In other words,

weight1 + weight2 = 0.5 + 0.5 = 1.0

When you assume that there is no directional continuity within the data, you say that you have an "isotropic" condition. In the example below, again assuming that all data is in the XY plane, any sample whose location is on the following circle will be given the same weight as any other sample on that circle during the estimation of the value of the block centroid. In two dimensions, when the shape defining the line of equal weights is a circle, you are said to be performing an "isotropic" estimation.

This means that you are assuming that the direction from the point being estimated to the sample is not important, and that only the distance from the sample to the block centroid is important.



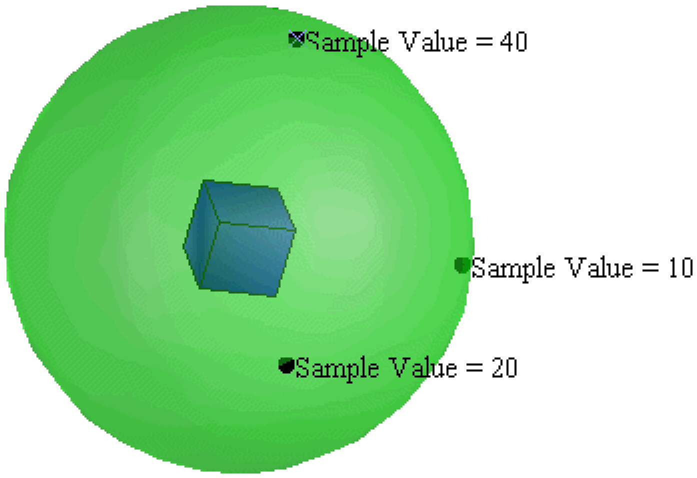
In the previous example, because all sample locations are the same distance from the block centroid, all samples are given equal weight. The calculation of the block value is:

*(5 * 0.25) + (10 * 0.25) + (20 * 0.25) + (35 * 0.25) = 17.5*

As mentioned before, the sum of all the weights must be equal to 1.0:

0.25 + 0.25 + 0.25 + 0.25 = 1.0

In three dimensions, during isotropic estimation, any samples falling on the surface of the same sphere are given equal weight.



In the example above, all sample locations are on the surface of the same sphere, and are thus the same distance from the block centroid. In this three-dimensional example of an isotropic condition, all samples are given equal weight. The calculation of the block value is:

$$(10 * 0.333) + (20 * 0.333) + (40 * 0.333) = 23.333$$

Again, the sum of all the weights is 1.0 (assuming that 1/3 + 1/3 + 1/3 expressed as decimals equals 1):

$$0.333 + 0.333 + 0.333 = 0.999 = 1.0$$

In Surpac, when you are performing an estimation, you are prompted to fill in values defining the orientation of the "major axis" and the "anisotropy ratios". You will cover these topics later. For now, if you wish to perform an estimation assuming that the data is isotropic, use the following values:

BEARING OF MAJOR AXIS: 0 (or any value from 0 to 360)

PLUNGE OF MAJOR AXIS: 0 (or any value from -90 to 90)

DIP OF SEMI-MAJOR AXIS: 0 (or any value from -90 to 90)

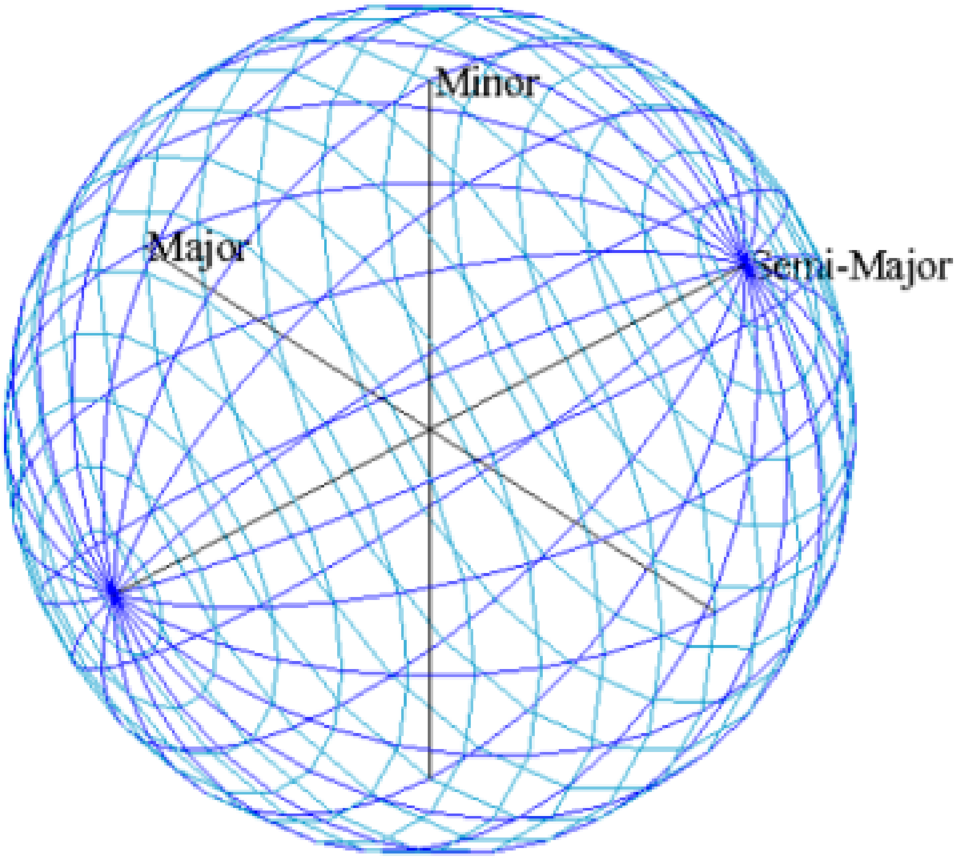
MAJOR/SEMI-MAJOR ANISOTROPY RATIO: 1

MAJOR/MINOR ANISOTROPY RATIO: 1

Task: View an example of an isotropic sphere

1. Open **isotropic_ellipsoid1.str**.
2. Display the D1 values for string 1

The isotropic ellipsoid is displayed, with all axes labelled.

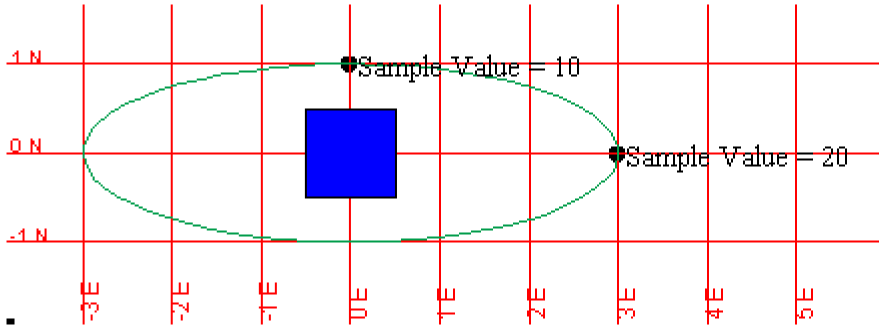


The concepts of "major axis", "semi-major axis" and "minor axis" are explained later. For now, just understand that the lengths of all of these axes are the same for an isotropic ellipsoid.

Geostatistical estimation using anisotropy

As previously stated, an anisotropic condition is said to exist when the rate of change of data values is different in different directions. This is the case for nearly all data sets which represent samples taken from the earth. Anisotropic conditions can result from geological conditions, such as fracturing or deposition method. For example, in plan view, the correlation, or similarity, of samples taken along strike in a gold-bearing quartz vein may be better than the correlation of samples taken across strike. In a sedimentary deposit, such as a flat-lying coal seam, samples may be better correlated within the horizontal plane than vertically through the seam. When a data set has anisotropy, the direction from the point being estimated to a sample location is important.

How much anisotropy is present is also important. The determination of the magnitude of anisotropy for a data set may be done qualitatively or quantitatively (by intuition or by numerical calculation). For example, after becoming familiar with a silver deposit consisting of a vertical vein trending east to west (strike: 90 degrees, dip: 90 degrees) a geologist may say that "there's about 3 times more continuity along strike (horizontally) than across strike (horizontally)". As rough and unsubstantiated a statement as this may seem, many times this type of qualitative judgement is actually used in geostatistical estimation. In this situation, you would say that there is a "3 to 1 anisotropy ratio" in the horizontal plane. This is commonly written as "a 3:1 anisotropy ratio". The direction of maximum continuity is referred to as the "major axis". In the silver vein example, the major axis could be defined as a bearing of either 90 or 270 degrees - they are both the same in geostatistical terms. In two dimensions, you can represent a 3:1 anisotropy ratio with a major axis bearing 90 degrees with an ellipse, such as shown below:



When you want to use anisotropy during an estimation, the direction from the location being estimated to the sample is important. In this example, you will assume that the point being estimated is the centroid of the block, and that you will use only two samples, as shown above, to estimate a value for the block.

Even though the sample, that has a value of 10, is 1 metre from the block centroid, and the sample that has a value of 20 is 3 metres from the block centroid, the two samples would be given the same weight in this situation. This is because "anisotropic distances" are used in the calculation of the weights, and not actual distances. Recall that you have indicated that there is a 3:1 anisotropy ratio and the bearing of the major axis is 90 degrees. Samples oriented due north or south of the block, such as the sample whose value is 10, will have their anisotropic distances calculated as the actual distance (1, in this case) multiplied by the anisotropy ratio (3, in this case). Thus, the anisotropic distance calculated for the sample whose value is 10 is:

Actual Distance x Anisotropy Ratio = Anisotropic Distance

1x3=3

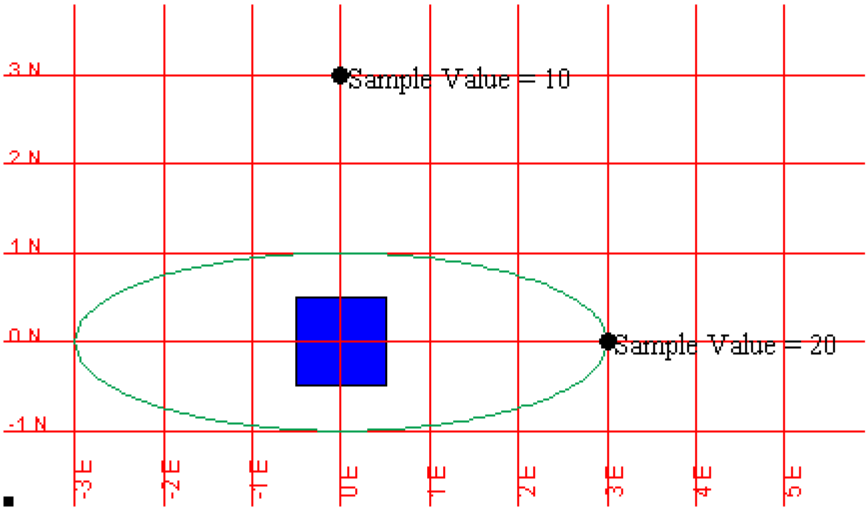
This calculation is displayed in the following table for both samples:

Sample Value	Sample Bearing	Actual Distance	Anisotropy Factor	Anisotropic Distance	Weight
10	0	1	3	3	0.5
20	90	3	1	3	0.5

Because the anisotropic distances are the same, the weights for the points are the same. The calculation of the block value is:

$$(10 * 0.5) + (20 * 0.5) = 15$$

If the sample whose value is 10 is moved to a position at Y=3, X=0, and you again use a 3:1 anisotropy ratio with the bearing of the major axis at 90 degrees (or 270 degrees), as shown below, the weights assigned to both samples will change.



The anisotropic distance of the sample whose value is 10 is now 9: Actual Distance (3) X Anisotropy Ratio (3) = Anisotropic Distance (9). This calculation is displayed in the following table for both samples.

Sample Value	Sample Bearing	Actual Distance	Anisotropy Factor	Anisotropic Distance	Weight
10	0	3	3	9	0.25
20	90	3	1	3	0.75

The weights of the samples now change to take account of the new anisotropic distances. The calculation of the block value is now:

*(10 * 0.25) + (20 * 0.75) = 17.5*

Notice that the calculation of the weights here is only approximate to demonstrate the effects of anisotropy. In actual practice, the geostatistical method you decide to use will affect the values of the weights.

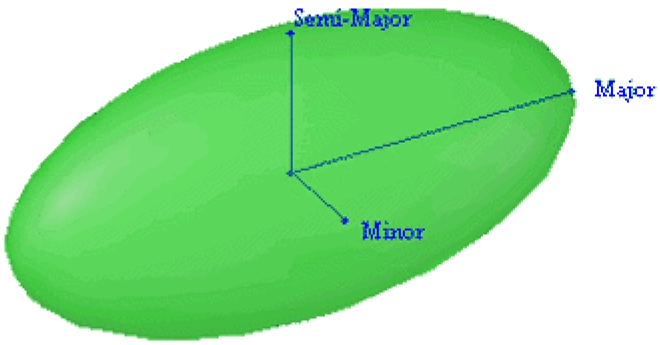
Assuming that our geologist has another opinion that "there is about 2 times more continuity horizontally along strike than vertically (up and down) within the plane of the vein", you would say that there is a "2:1 anisotropy ratio" in the vertical YZ plane. In two dimensions, an ellipse represents the line where weights are equal. In three dimensions, this shape is called an "ellipsoid". So now you have a 3:1 anisotropy ratio in the horizontal XY plane, and a 2:1 anisotropy ratio in the vertical YZ plane. You distinguish between these ratios by defining three axes for the ellipsoid:

Major axis

Semi-major axis

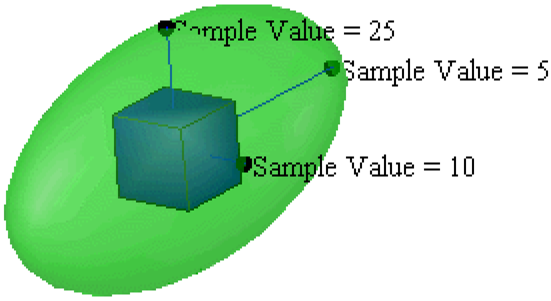
Minor axis

By definition, the major axis is the longest, the semi-major axis is the second longest, and the minor axis is the shortest. Also, all three axes are mutually perpendicular to one another.



The ratio between the length of the major axis and the length of the semi-major axis is defined as the MAJOR/SEMI-MAJOR ANISOTROPY RATIO. The ratio between the length of the major axis and the length of the minor axis is defined as the MAJOR/MINOR ANISOTROPY RATIO.

When you perform an estimation, and want to use three-dimensional anisotropy, any samples falling on the surface of the same ellipsoid will be given equal weight. In the example below, all sample locations are on the surface of the same ellipsoid, and so, all the samples are all considered to be the same anisotropic distance from the block centroid:



With the axes oriented as above, as well as a major/semi-major anisotropy ratio of 2, and a major/minor anisotropy ratio of 3, the calculation of the weights for the data as shown is:

Axis	Sample Value	Sample Bearing	Sample Dip	Actual Distance	Anisotropy Factor	Anisotropic Distance	Weight
Major	5	90	0	3	1	3	0.333
Semi-Major	25	0	90	1.5	2	3	0.333
Minor	10	180	0	1	3	3	0.333

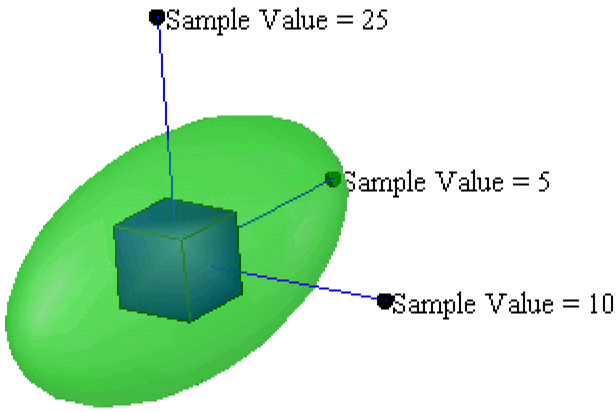
Because the anisotropic distances are the same, the weights for the points are the same. The calculation of the block value is:

*(5 * 0.333) + (25 * 0.333) + (10 * 0.333) = 13.3333*

Again, the sum of all the weights is 1.0 (assuming that 1/3 + 1/3 + 1/3 expressed as decimals equals 1):

0.333 + 0.333 + 0.333 = 0.999 = 1.0

If the distance from the block centroid to each sample is now the same, the weights will change. For example, in the view below, the distance from each sample to the block centroid is now 3, but you are still using the same anisotropy ellipsoid:



The calculation of the weights is as follows:

Axis	Sample Value	Sample Bearing	Sample Dip	Actual Distance	Anisotropy Factor	Anisotropic Distance	Weight
Major	5	90	0	3	1	3	0.74
Semi-Major	25	0	90	3	2	6	0.18
Minor	10	180	0	3	3	9	0.08

The calculation of the block value is:

*(5 * 0.74) + (25 * 0.18) + (10 * 0.08) = 9.0*

Again, the sum of all the weights is 1.0 :

0.74 + 0.18 + 0.08 = 1.0

Ellipsoid visualiser

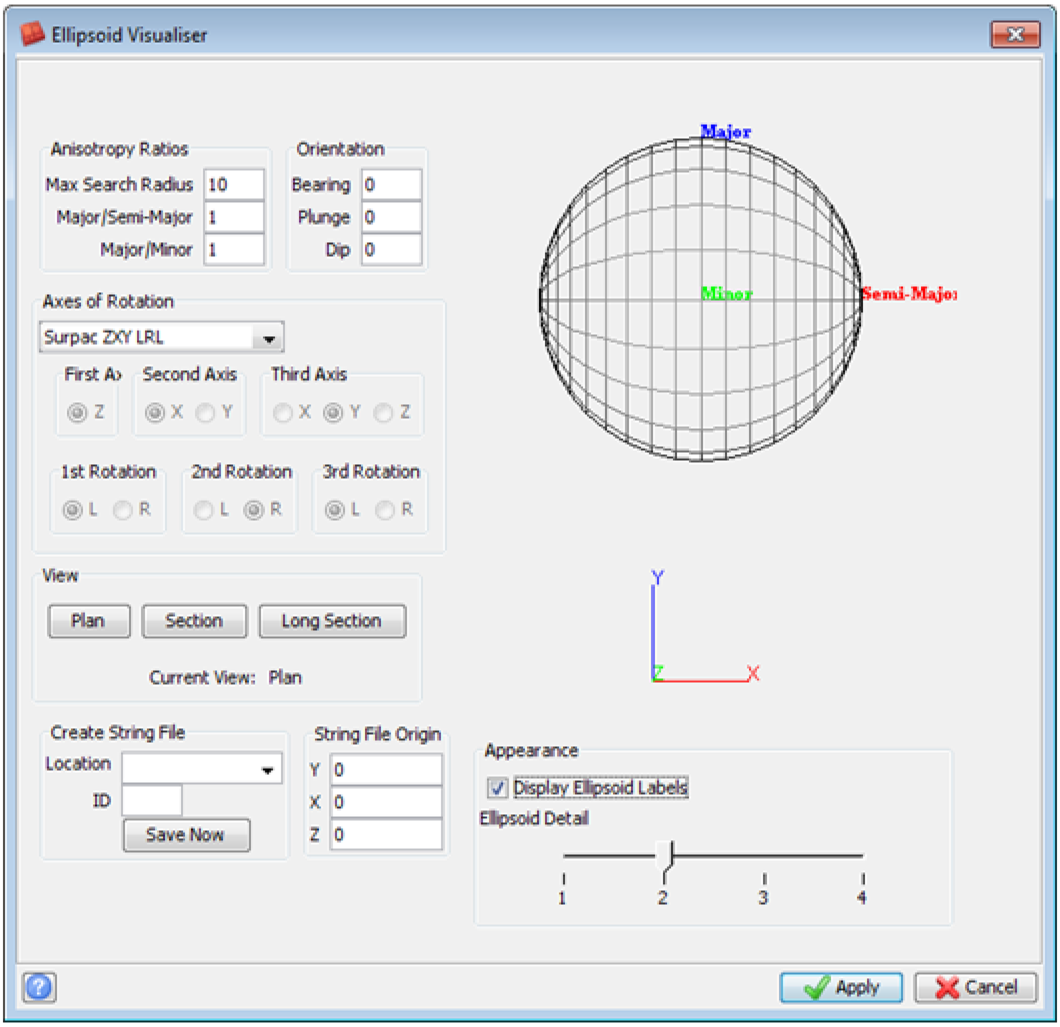
Using our previous example where you have a major/minor anisotropy ratio of 3, and a major/semi-major anisotropy ratio of 2, you would get an ellipsoid, but you need to establish the orientation of the ellipsoid. In Surpac, this can be accomplished in several different ways, including the "Surpac" method. The examples which follow use the "Surpac" method, which encompasses the following three terms:

Term	Min	Max	Description
Bearing of major axis	0	360	azimuth of major axis in XY plane
Plunge of major axis	-90	90	dip above or below horizontal plane
Dip of semi-major axis	-90	90	rotation of semi-major axis around major axis

The Ellipsoid Visualiser is a tool which can assist you to understand the orientation of the anisotropy ellipsoid. You will now use it to create several anisotropy ellipsoids, and save them as Surpac string files.

Task: Display anisotropy using the ellipsoid visualiser

1. Choose **Geostatistics > Ellipsoid visualiser**.



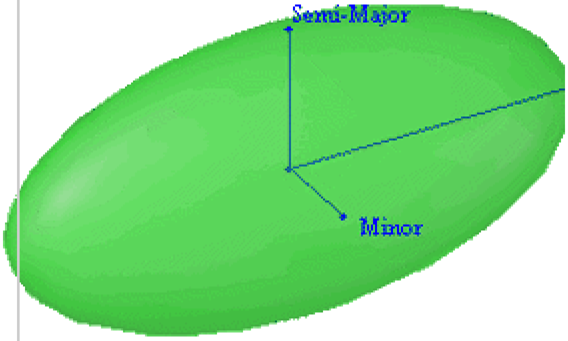
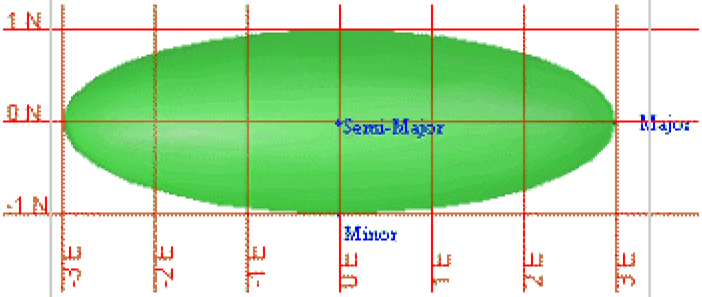
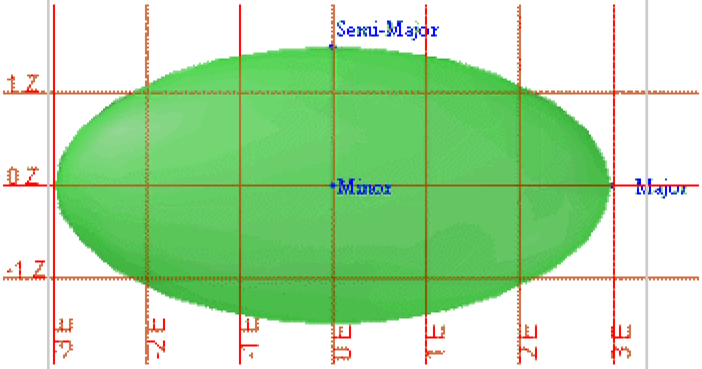
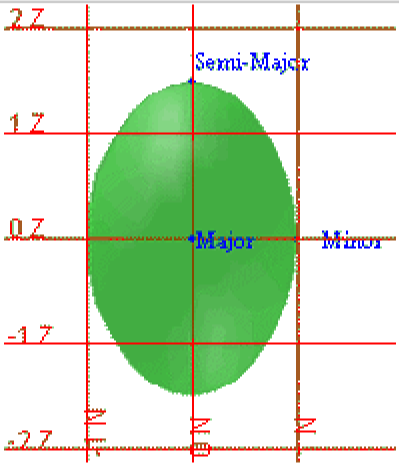
For each example below:

2. Enter the values of bearing, plunge, and dip.
3. Click and drag the image of the ellipsoid to rotate it.

Example #1:

You could use this ellipsoid to estimate gold values within a vertical vein that has strike: 90 degrees and dip: 90 degrees.

Bearing of major axis	90
Plunge of major axis	0
Dip of semi-major axis	-90
Major/semi-major anisotropy ratio	2
Major/minor anisotropy ratio	3

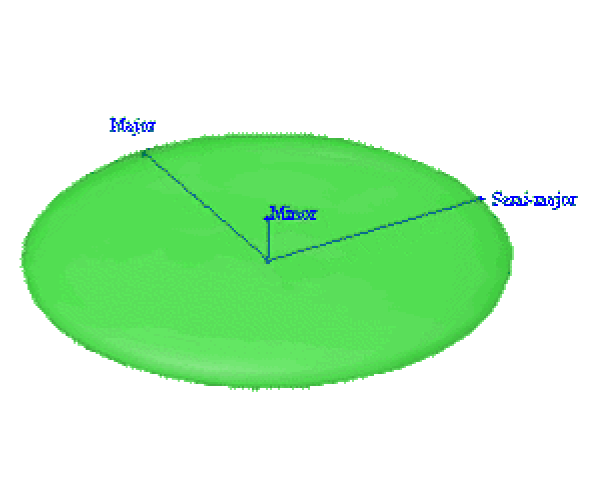
<table>
<tr><td>3D View</td><td>Looking down on XY plane
major/minor anisotropy ratio: 3</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Looking north at XZ plane
major/semi-major anisotropy ratio: 2</td><td>Looking west at YZ plane
dip of semi-major axis: 90</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Example #2:

This ellipsoid could be used to estimate values within a horizontal coal seam or other data from flat-lying sedimentary rocks, where continuity within the seam is the same in the XY plane (major/semi-major anisotropy ratio: 1), but the continuity is significantly less in the vertical direction.

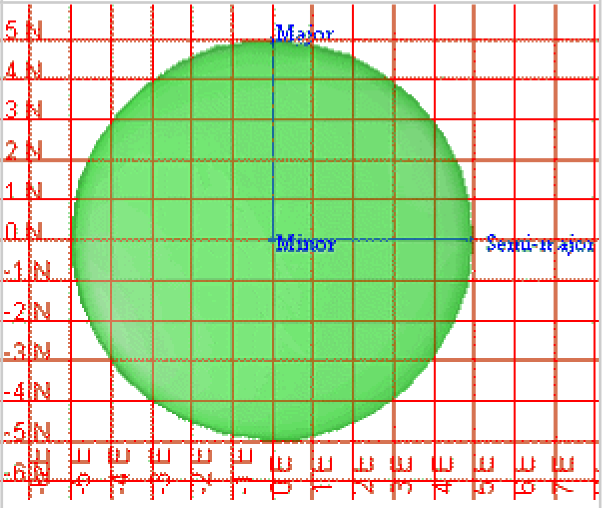
Bearing of major axis	0
Plunge of major axis	0
Dip of semi-major axis	0
Major/semi-major anisotropy ratio	1
Major/minor anisotropy ratio	5

3D View



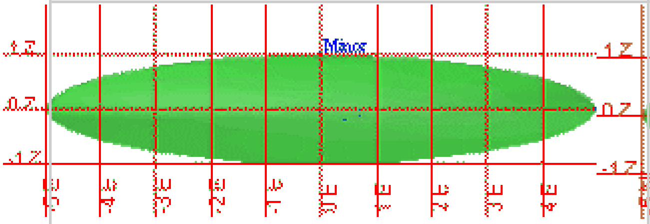
Looking down on XY plane

major/semi-major anisotropy ratio: 1



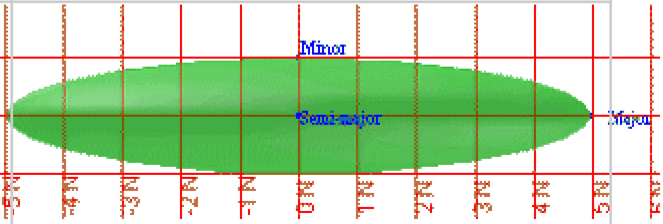
Looking north at XZ plane

dip of semi-major axis: 0



Looking west at YZ plane

major/minor anisotropy ratio: 5

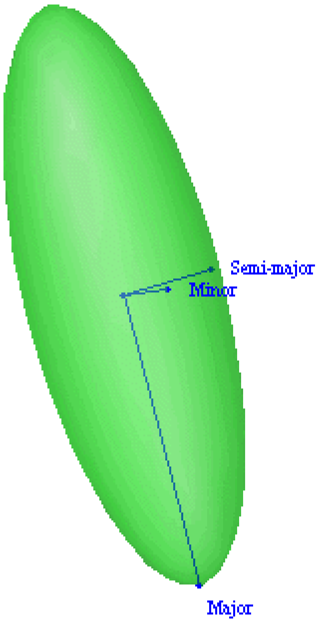


Example #3:

This ellipsoid could be used to estimate values from a kimberlitic diatreme, or diamond-bearing "pipe" type ore body, which plunges to the south at a dip of 60 degrees below the horizontal.

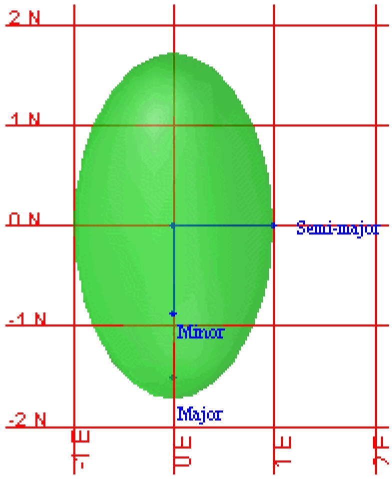
Bearing of major axis	180
Plunge of major axis	-60
Dip of semi-major axis	0
Major/semi-major anisotropy ratio	3
Major/minor anisotropy ratio	3

3D View



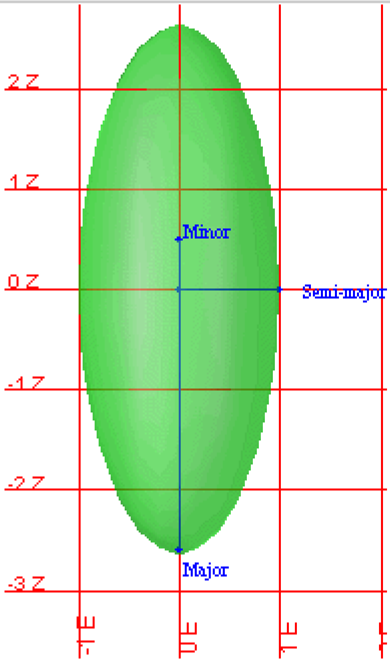
Looking down on XY plane

major/semi-major anisotropy ratio: 3



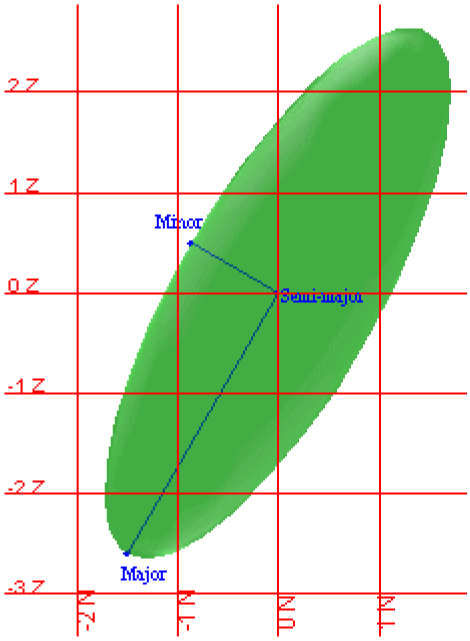
Looking north at XZ plane

dip of semi-major axis: 0



Looking west at YZ plane

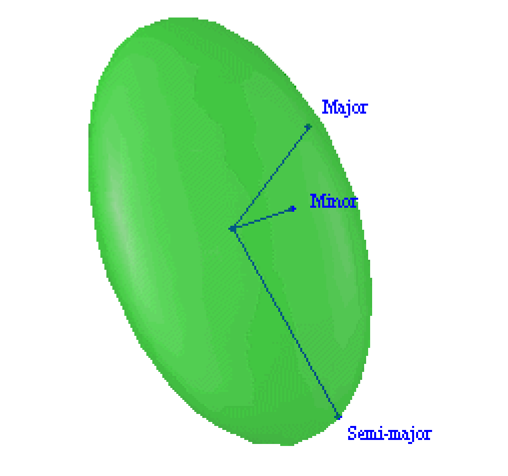
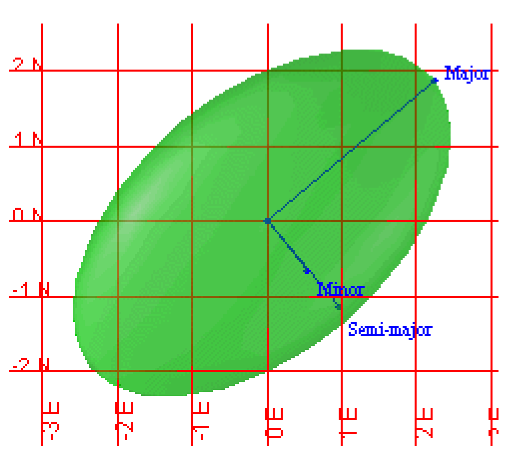
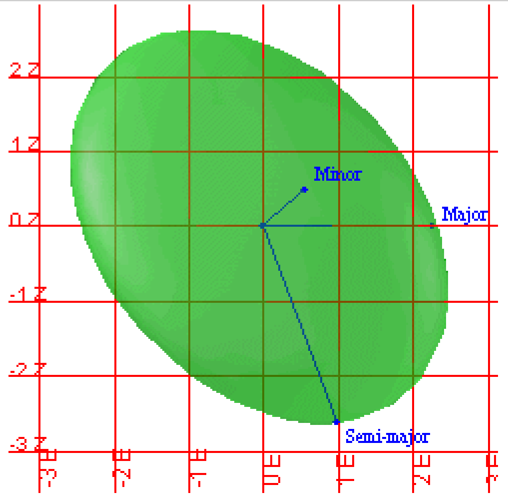
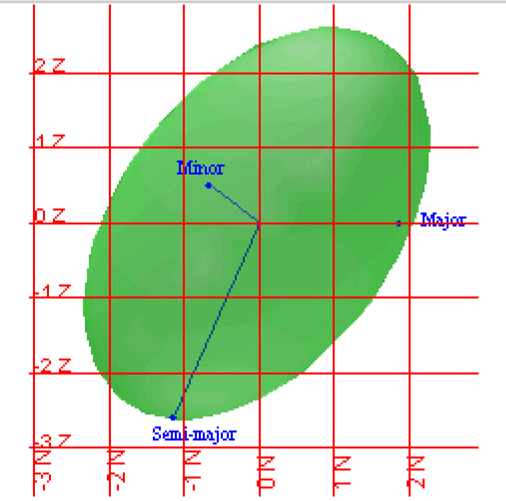
major/minor anisotropy ratio: 3



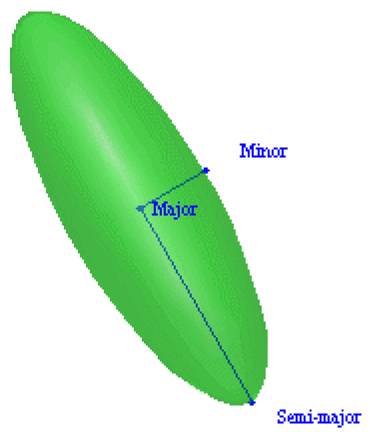
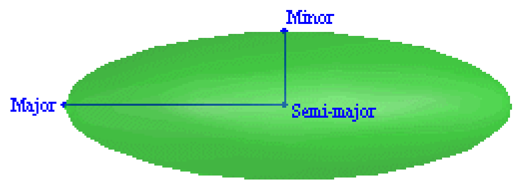
Example #4:

This ellipsoid could be used to estimate values from an epithermal vein, with strike of 50 degrees and dip to the southeast of 60 degrees below the horizontal, where continuity within the vein is the same in all directions (major/semi-major anisotropy ratio: 1).

Bearing of major axis	50
Plunge of major axis	0
Dip of semi-major axis	-60
Major/semi-major anisotropy ratio	1
Major/minor anisotropy ratio	3

<table>
<tr><td>3D View</td><td>Looking down on XY plane</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Looking north at XZ plane</td><td>Looking west at YZ plane</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Example #4(continued)

<table>
<tr><td>Looking horizontally along strike: az 50 degrees, dip 0
Note dip of semi-major axis is -60 degrees
major/semi-major anisotropy ratio: 1</td><td>Looking downdip: azimuth 140 degrees, dip -60
Note major axis is along strike, semi-major is downdip
major/minor anisotropy ratio: 3</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Menu commands:

Select...	to...
Geostatistics > Ellipsoid visualiser	view the ellipsoid.

Variogram Concepts

Overview

An important aspect of performing any geostatistical evaluation is to understand how data values change over distance and direction. A variogram is a graphical tool which can be used to describe these concepts.

You will learn about:

- basic variogram concepts
- variogram calculation
- the impact of modifying the lag distance
- omnidirectional variograms
- directional variograms

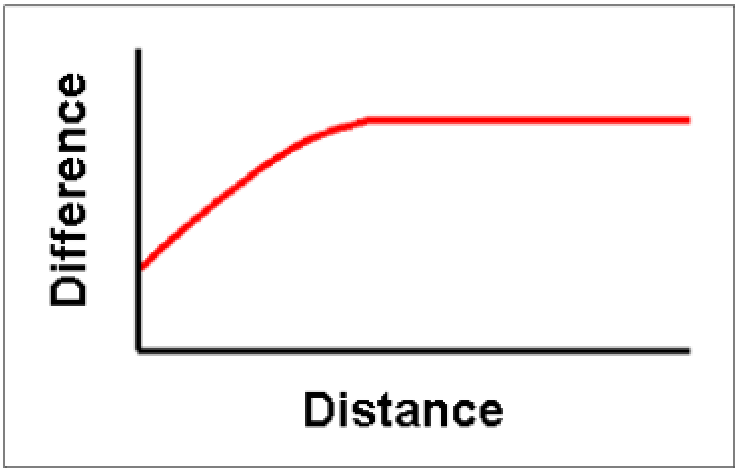
Requirements

In order to understand this information, you should:

- be familiar with Surpac string files
- know how to run a Surpac macro
- understand basic statistical concepts such as mean and variance

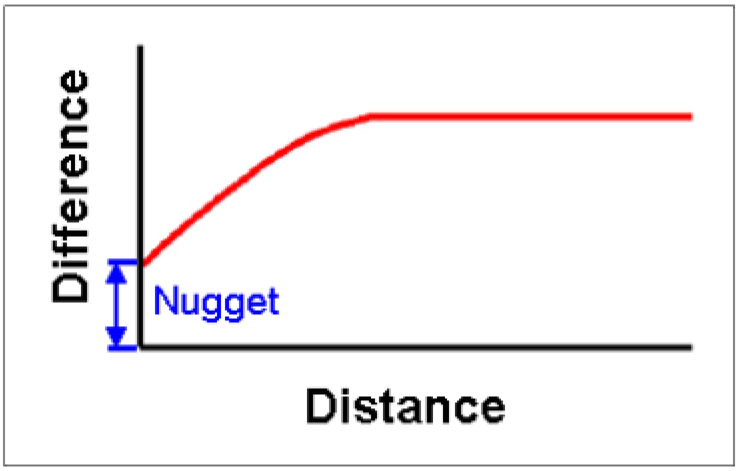
Basic variogram concepts

A variogram is a graph that compares differences between samples against distance:



Nugget

If you split a single sample, and send it to two different labs, very often you will get two different values. Thus, at a sample separation distance of zero, there is some difference. This difference is called the "nugget", also abbreviated as "c(0)". The nugget value is noted as a difference at a sample separation distance of zero:



The term "nugget" comes from a situation that often occurs in coarse gold deposits where a sample is split, and one half contains a gold nugget, while the other half does not contain any gold. The type of deposit significantly influences the nugget. Gold deposits, with their uneven distribution of metal, usually have a high nugget value. Iron ore deposits, with their fine grains and even distribution, usually have a low nugget value.

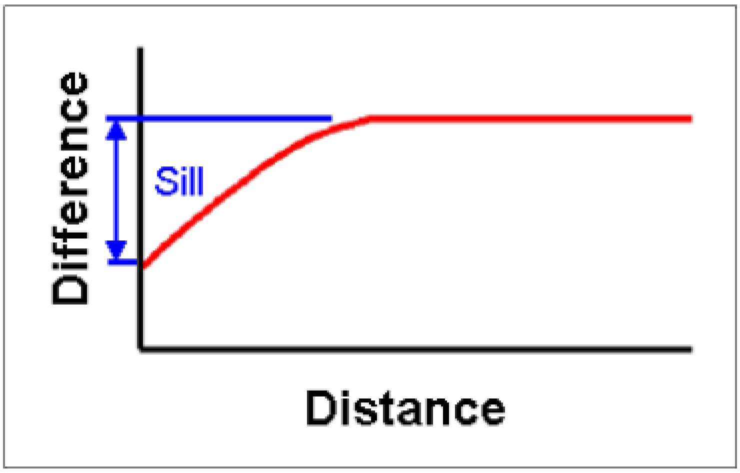
Although differences between sample "splits" is often responsible for the nugget, human error can also be a factor. Errors occur in sampling, in the lab, and during data entry. Any or all of these can contribute to the nugget. Although these areas are beyond the scope of this tutorial, you should be aware of them, and their impact on the nugget and subsequent geostatistical evaluations.

Sill

If you compare two samples that are some distance apart, you would expect the difference to be greater than samples which are closer together. The portion of the graph of the variogram which rises up and to the right of the nugget point, represents this situation.

At some point, the difference between the samples cannot get any greater. For example, the maximum sample value minus the minimum sample value gives us the greatest difference between samples. On the variogram, this maximum difference is displayed as the flat portion of the graph.

Two values describe the point at which the variogram reaches its maximum value – the sill and the range.

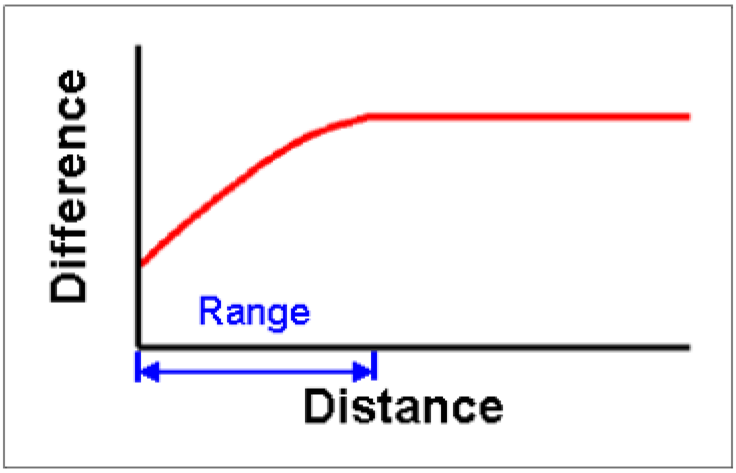


The sill (sometimes abbreviated as the letter "C"), as shown above, is the difference between the maximum difference and the nugget. The term "nugget to sill ratio" is used to describe what percentage of the "total sill" the nugget comprises, and is calculated as:

nugget to sill ratio = nugget / (nugget + sill)

Range

The range is the distance at which the sill is attained.



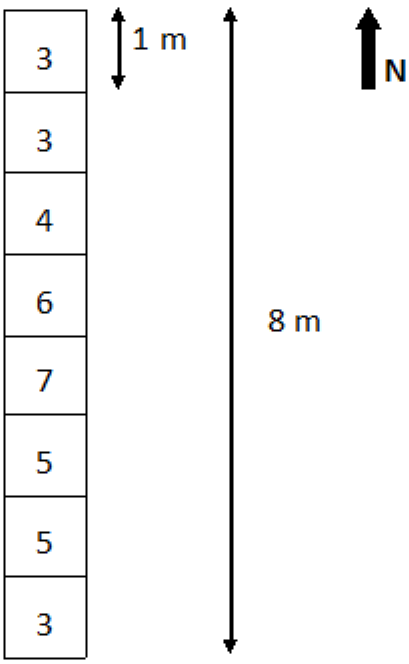
The range (sometimes abbreviated as the letter "A") represents the maximum distance which sample pairs can be said to have some relationship to their separation distance. Beyond the range, there is no relationship.

Variogram calculation

To calculate a variogram, a data set is grouped into "pairs", which are separated by a given distance, or "lag". Then the following calculation is performed on all samples in each bin:

gamma(h) = sum of (difference between sample values) squared / 2 x number of pairs

To demonstrate this, you will use the following data. Assume that the values represent samples taken at 1 metre intervals along a north – south line:



To create the variogram graph of "Distance vs. Difference", you first decide upon a lag distance, or "lag interval". You then group the data into sample pairs which fall into each lag interval. For the first lag interval of 1, you get the data pairs of 3-3, 3-4, 4-6, and so on... The difference between the two values is squared, and the sum of all squared distances is calculated:

Lag = 1			
Pair	Pair Values	Difference	Squared difference
1	3 – 3	0	0
2	3 - 4	-1	1
3	4 - 6	-2	4
4	6 - 7	-1	1
5	7 - 5	2	4
6	5 - 5	0	0
7	5 – 3	2	4
		sum:	14

*gamma(h) = **sum of squared differences** / 2 x number of pairs*

= 14/2x7

= 1.0

Next, all samples separated by lag distances of 2 are paired off, and the calculation is performed again:

Lag = 2			
Pair	Pair Values	Difference	Squared difference
1	3 – 4	-1	1
2	3 - 6	-3	9
3	4 - 7	-3	9
4	6 - 5	1	1
5	7 - 5	2	4
6	5 – 3	2	4
		sum:	28

gamma(h) = sum of squared differences / 2 x number of pair s

= 28 / 2x6

= 2.3

The results of lag distances of 3, 4, and 5 are below:

Lag = 3			
Pair	Pair Values	Difference	Squared difference
1	3 – 6	-3	9
2	3 - 7	-4	16
3	4 - 5	-1	1
4	6 - 5	1	1
5	7 – 3	4	16
		sum:	43

gamma(h) = sum of squared differences / 2 x number of pairs

= 43/2x5

= 4.3

Lag = 4			
Pair	Pair Values	Difference	Squared difference
1	3 – 7	-4	16
2	3 - 5	-2	4
3	4 - 5	-1	1
4	6 – 3	3	9
		sum:	30

*gamma(h) = **sum of squared differences** / 2 x number of pairs = 30/2x4 = 3.8*

Lag = 5			
Pair	Pair Values	Difference	Squared difference
1	3 – 5	-2	4
2	3 - 5	-2	4
3	4 – 3	1	1
		sum:	9

gamma(h) = sum of squared differences / 2 x number of pairs

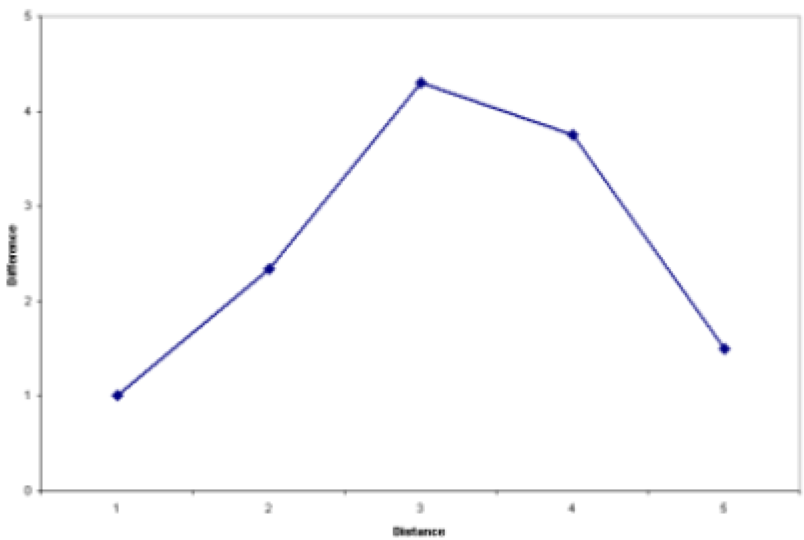
= 9/2x3

=1.5

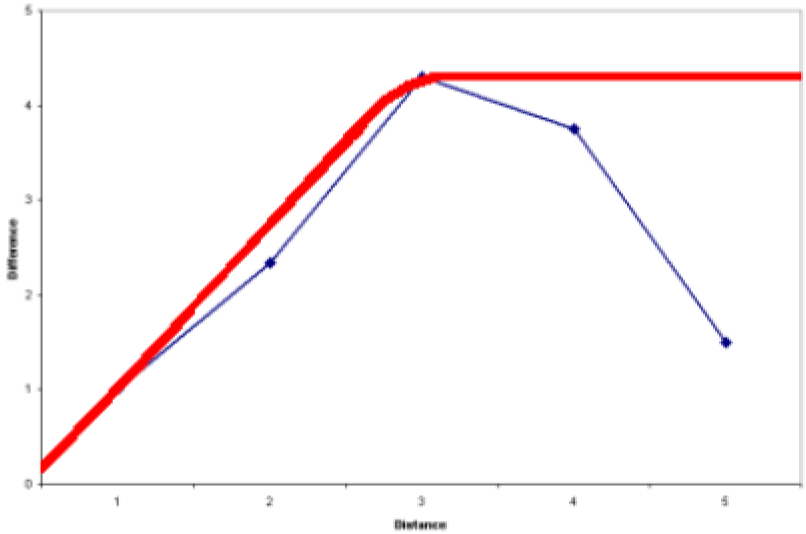
All of the results and lag distances are then compiled:

Lag (distance)	gamma(h) (difference)
1	1
2	2.3
3	4.3
4	3.8
5	1.5

A graph of the results looks like this:



This graph of calculated gamma(h) values versus lag distance is called an "experimental variogram". This is used to calculate the variogram displayed in the previous version - a "variogram model". The variogram model can be described by a mathematical equation, and is subject to the interpretation of the person who is analysing the data. A variogram model, as shown in the previous section, starts at a nugget, increases by the sill at a point defined by the range, then continues infinitely to the right at the total sill value. A variogram model has been fit to the experimental variogram below:



In this example, all relevant parameters of the model would be recorded:

Nugget: 0.2
Sill: 4.0
Range: 3.0
Nugget/Sill ratio = 0.2 / (0.2+4.0) = 0.05

The effect of modifying the lag distance

Although the previous example generated a well-formed experimental variogram, often it is necessary to modify the lag distance to obtain such a good-looking variogram. In the previous example, a lag interval of 1 was used. The term "Lag=1" actually meant "all sample pairs whose separation distance is between 0.001 and 1". "Lag=2" meant "all sample pairs whose separation distance is between 1.001 and 2". "Lag=3" meant "all sample pairs whose separation distance is between 2.001 and 3".

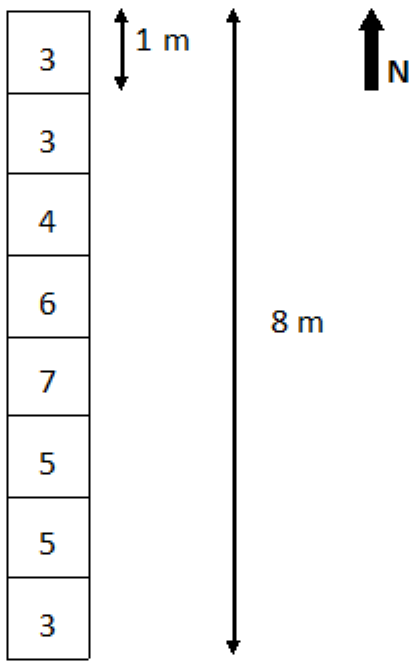
To demonstrate the effect of the value chosen for the lag, you will recalculate the variogram in the previous example, but using a lag interval of 2. You will calculate three "lag bins":

Lag=2 sample pairs whose separation distance is between 0 and 2.

Lag=4 sample pairs whose separation distance is between 2.001 and 4.

Lag=6 sample pairs whose separation distance is between 4.001 and 6.

Here is the data again, representing samples taken at 1 metre intervals along a north – south line:



For the 0-2 lag bin, you now get the following data pairs:

Lag = 2			
Pair	Pair Values	Difference	Squared difference
1	3 - 3	0	0
2	3 - 4	-1	1
3	3 - 4	-1	1
4	3 - 6	-3	9
5	4 - 6	-2	4
6	4 - 7	-3	9
7	6 - 7	-1	1
8	6 - 5	1	1
9	7 - 5	2	4
10	7 - 5	2	4
11	5 - 5	0	0
12	5 - 3	2	4
13	5 - 3	2	4
		sum:	42

gamma(h) = sum of squared differences / 2 x number of pairs

= 42/2x13

= 1.6

For the 2-4 lag bin, you now get the following data pairs:

Lag = 4			
Pair	Pair Values	Difference	Squared difference
1	3 - 6	-3	9
2	3 - 7	-4	16
3	3 - 7	-4	16
4	3 - 5	-2	4
5	4 - 5	-1	1
6	4 - 5	-1	1
7	6 - 5	1	1
8	6 - 3	3	9
9	7 - 3	4	16
		sum:	73

gamma(h) = sum of squared differences / 2 x number of pairs

= 73/2x9

= 4.1

Lag = 6			
Pair	Pair Values	Difference	Squared difference
1	3 - 5	-2	4
2	3 - 5	-2	4
3	3 - 5	-2	4
4	4 - 3	1	1
5	3 - 3	0	0
		sum:	13

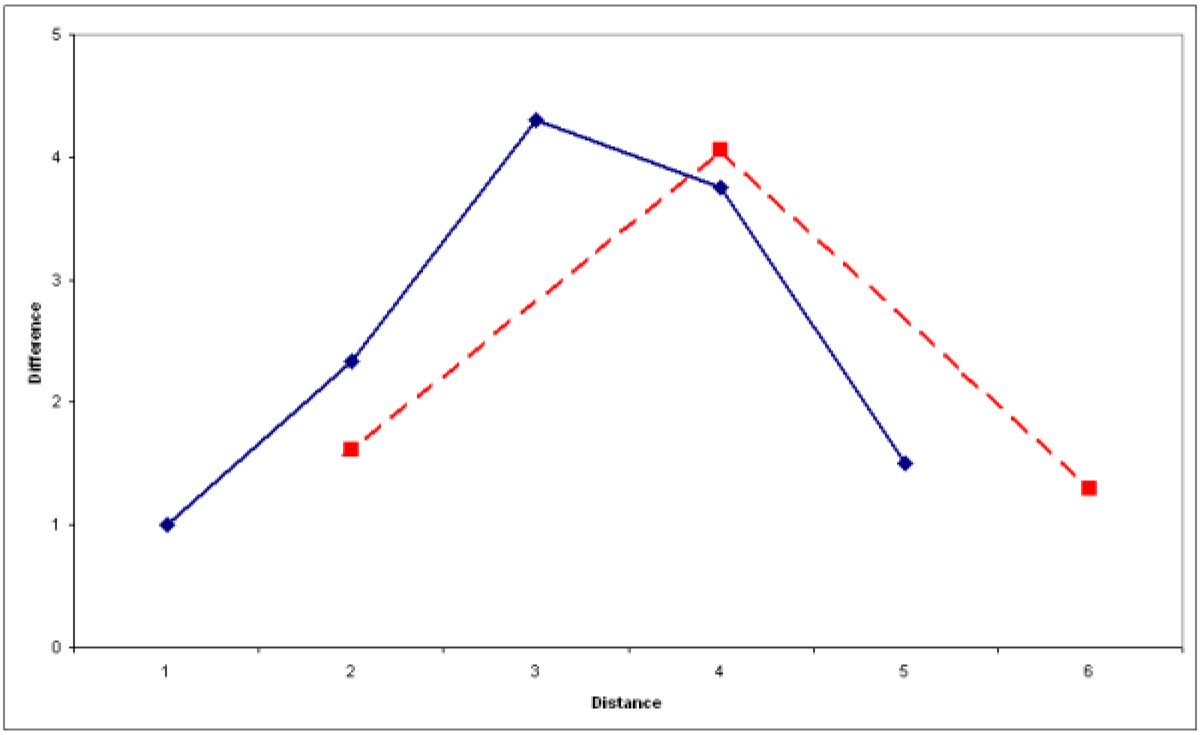
gamma(h) = sum of squared differences / 2 x number of pairs

= 13/2x5

= 1.3

All of the results and lag distances are then compiled and graphed:

Lag (distance)	gamma(h) (difference)
2	1.6
4	4.1
6	1.3



Experimental variograms with lags of 1(solid) and 2(dashed)

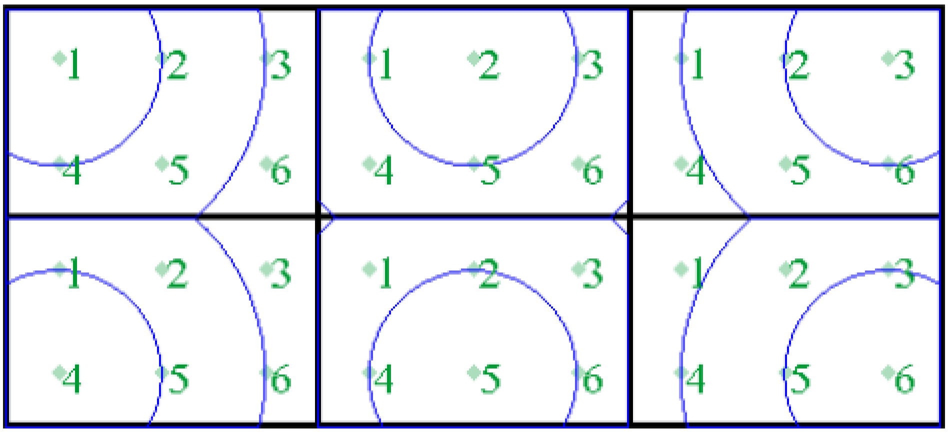
Omnidirectional variograms

The variogram in the previous exercise was an example of a "directional" variogram. All samples used were aligned north-south. Another type of variogram is known as an "omnidirectional variogram". In this type, the pairs are selected based only on their separation distance, and not on the orientation of the pairs.

The example below demonstrates how sample pairs would be selected for a data set. All samples are on a 1x1 grid, and lag values of 1, 2, and 3 are used. The way in which the software determines pairs is this:

1. Move to the first point.
2. Determine which other points in the data set are within the first lag tolerance distance from this point, and add these pairs to the first "lag bin" (Lag=1).
3. Determine which points not selected are within the second lag tolerance distance from this point, and add them to the second "lag bin" (Lag=2).
4. Repeat until all points have been put into a lag bin.
5. Move to the next point.
6. Remove the previous point from consideration.
7. Repeat steps 2 to 6 until all points have been considered.

In an omnidirectional variogram, the orientation of the sample pairs is irrelevant. For example, sample pair 1-2 is oriented east-west, sample pair 1-4 is oriented north-south, and yet both pairs are used for the "Lag=1" bin.



Lag selection circles

Sample pairs selected for each lag in an omnidirectional variogram:

Lag=1	Lag=2	Lag=3
1-2	1-3	1-6
1-4	1-5	3-4
2-3	2-4	
2-5	2-6	
3-6	3-5	
4-5	4-6	
5-6		

Note: The example here is two-dimensional. In three dimensions, the search from each point takes the shape of a sphere.

Directional variograms

A directional variogram is one in which all sample pairs are oriented in a particular direction. In the first example, all samples were aligned north-south. There was no other possible orientation for the sample pairs to take, so the only variogram possible was a directional variogram.

However, in most data sets, there are many data pair orientations. In a directional variogram, the software selects only those data pairs which are oriented in a particular manner, plus or minus some angular tolerance. In Surpac, this angular tolerance is known as the spread.

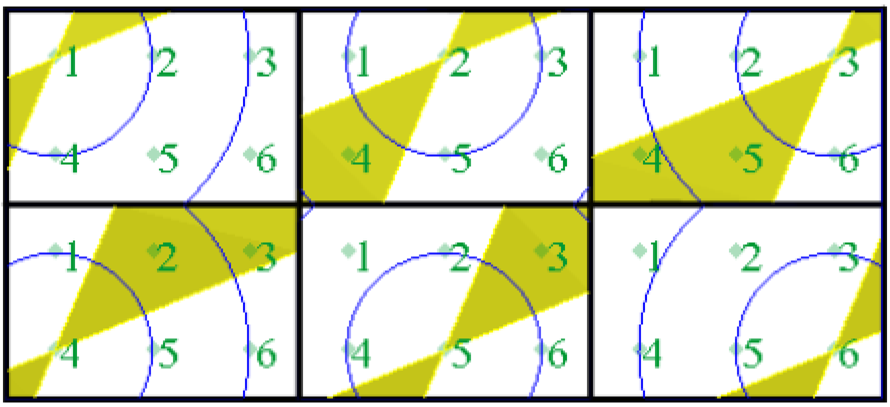
The following example demonstrates how sample pairs are selected for a data set, using a northeast – southwest orientation of 45 degrees, plus or minus a spread tolerance of 22.5 degrees either side of that direction. Thus, if a sample pair is oriented between 22.5 and 67.5 degrees (or 202.5 and 247.5 degrees), it will be included in the calculation.

All samples are on a 1x1 grid, and lag values of 1, 2, and 3 are used. The way in which Surpac determines pairs is shown below:

1. Move to the first point.
2. Determine which other points in the data set are within the first lag tolerance distance from this point AND within the angular tolerances, and add these pairs to the first "lag bin" (Lag=1).
3. Determine which points not yet selected are within the second lag tolerance distance from this point AND within the angular tolerances, and add them to the second "lag bin" (Lag=2).
4. Move to the next point.

5. Remove the previous point from consideration.
6. Repeat steps 2 to 5 until all points have been considered.

In a directional variogram, the orientation of the sample pairs is important. For example, sample pairs 1-2 and 1-4 are both within the first lag tolerance, but neither are within the angular tolerance of 45 degrees plus or minus 22.5 degrees. In fact, there are only three data pairs in the entire data set which have an orientation that is within the defined limits. These are the data pairs: 2-4, 3-4, and 3-5.



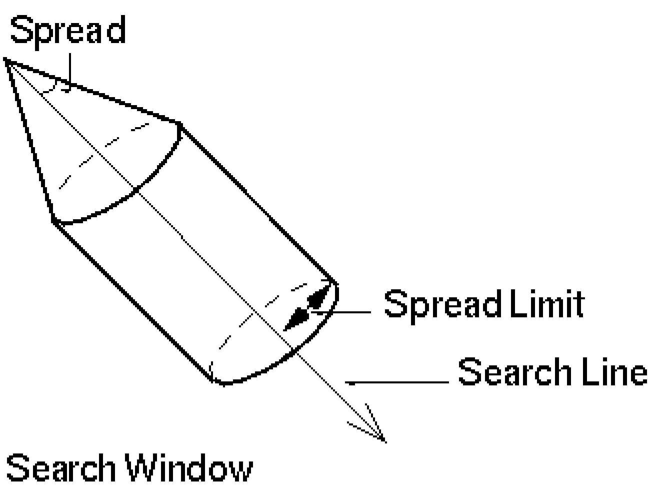
Lag selection circles with directional tolerance search

Sample pairs selected for each lag for a directional variogram (orientation 45 +/- 22.5):

Lag=1	Lag=2	Lag=3
	2-4 3-5	3-4

As you can see, using directional variograms reduces the number of sample pairs. As the tolerance angle decreases, so does the number of pairs. If a tolerance angle is too small, the quality of the experimental variogram may be reduced to the point that a model cannot be fitted with any confidence. If the tolerance angle is too large, the concept of a "directional" variogram could be questioned.

Note: The example here is two-dimensional. In three dimensions, the search from each point takes the shape of a cone. Additionally, Surpac has the option to restrict the radius of the cone to a maximum using a "spread limit". This has the effect of turning the search cone into a cylinder with the radius of the spread limit.



Calculating an experimental variogram

Overview

An experimental variogram is calculated from pairs of data points, which can be limited to points that are aligned in a specific orientation (directional), or without limiting them to an orientation (omnidirectional). The experimental variogram is used as the basis for creating a variogram model. In order to create a variogram model, the experimental variogram must appear relatively smooth. Adjusting the lag distance can help to create a smooth variogram. If the data contains outliers, or a small number of data points, the experimental variogram can appear jagged, or "noisy". It often takes several iterations and combinations of parameters to create experimental variograms that are acceptable for modelling.

You will learn about:

- calculating omnidirectional and directional variograms
- changing the display
- saving a variogram

Requirements

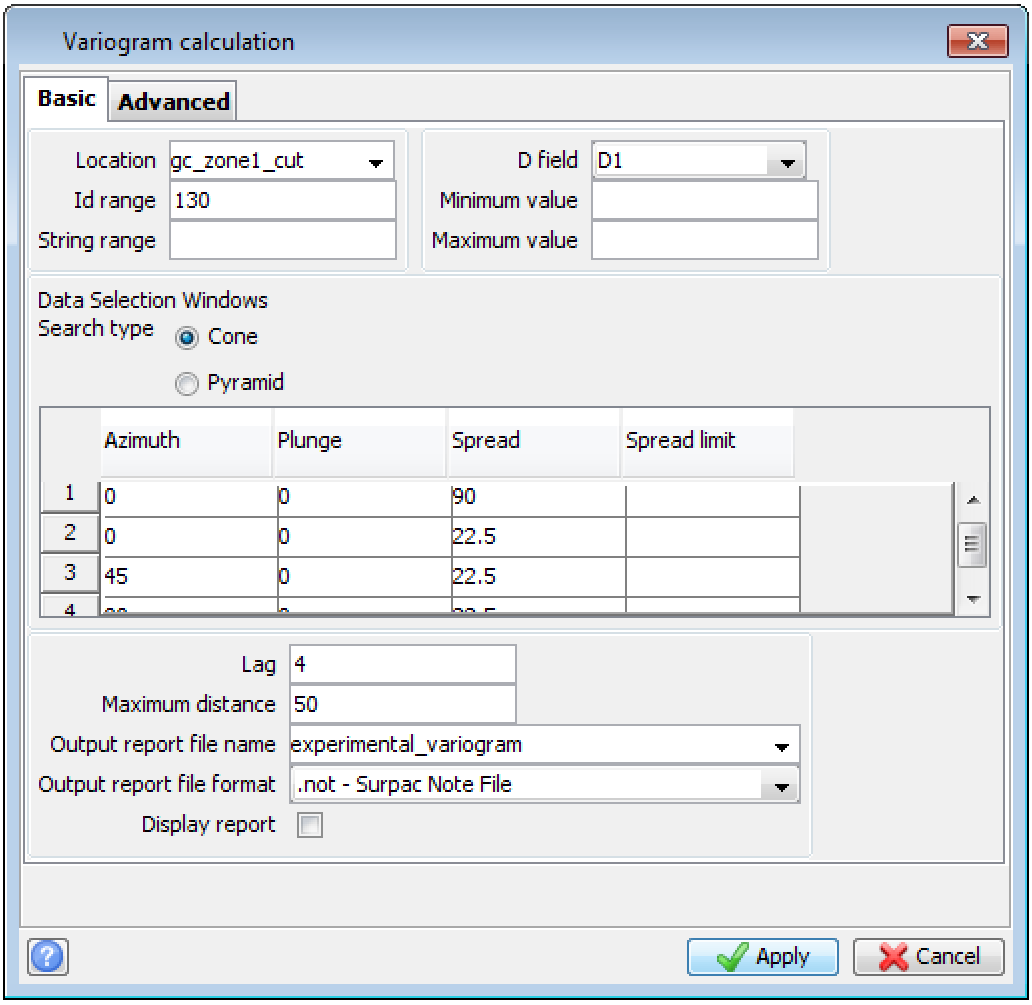
In order to understand this information, you should:

- be familiar with Surpac string files
- know how to run a Surpac macro
- understand basic variogram concepts, such as nugget, sill, and lag
- understand the difference between omnidirectional and directional variograms

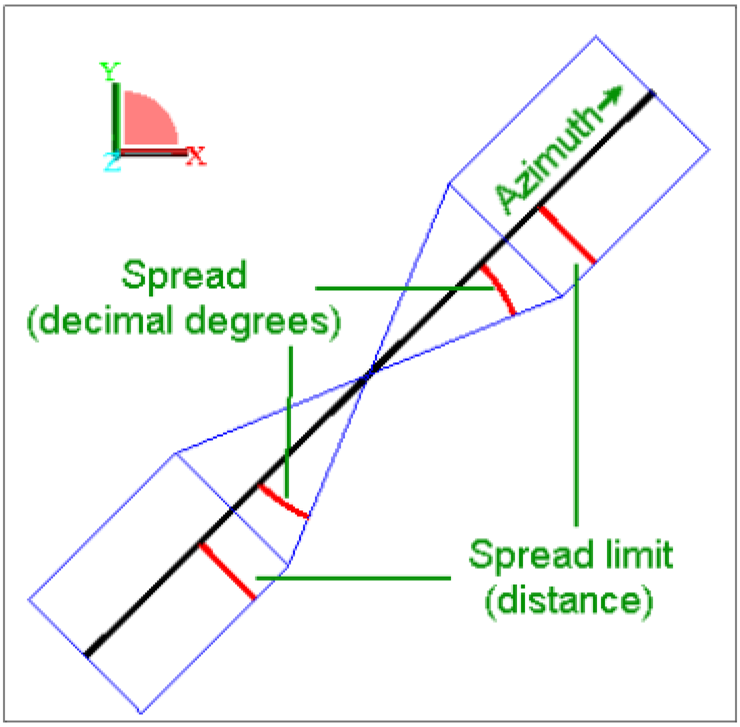
Task: Create and view experimental variograms

This you will calculate omnidirectional and directional variograms from the D1 field of the file **gc_zone1_cut130.str**.

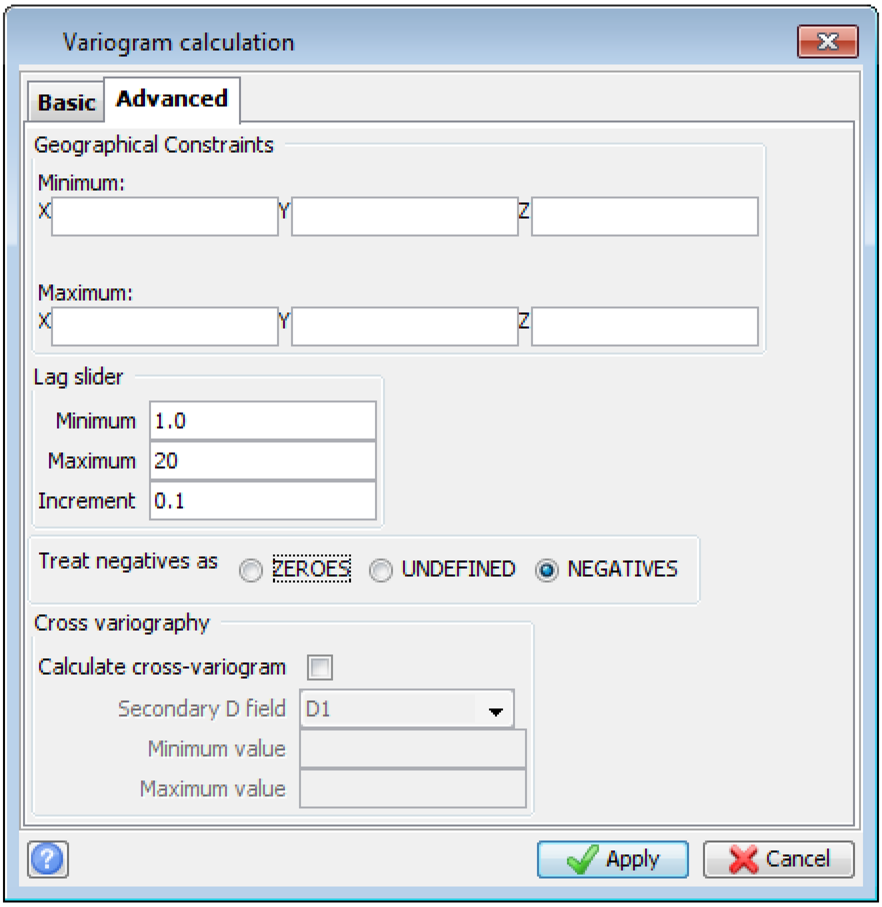
1. Choose **Geostatistics > Variogram modelling**.
2. Choose **File > New > String file variogram**.
3. On the **Basic** tab, enter the information as shown.



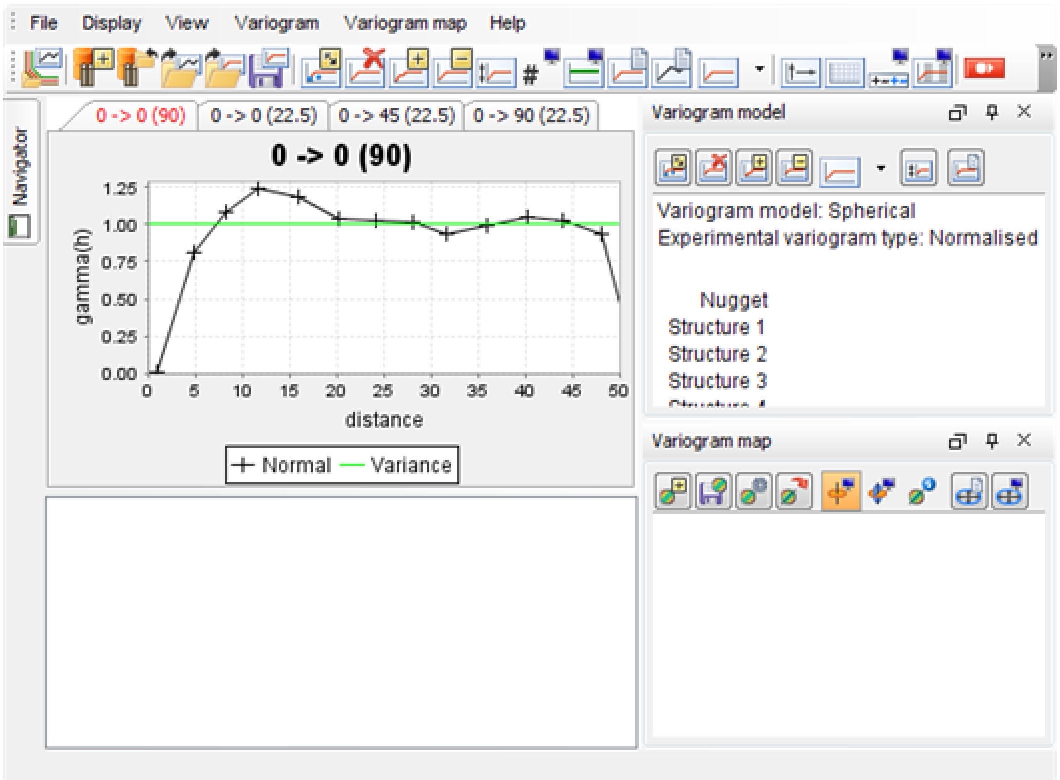
Note: To calculate an omnidirectional variogram, set the **Spread** to 90.



4. On the **Advanced** tab, enter the information as shown, and click **Apply**.

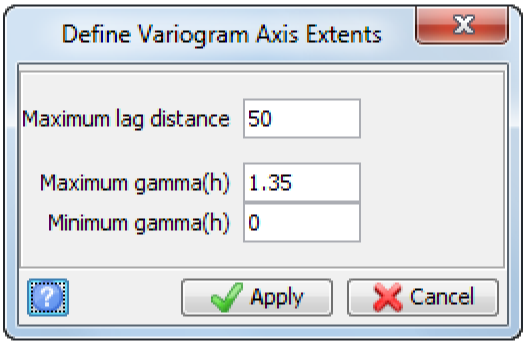


The omnidirectional variogram will appear on the first of four tabs.

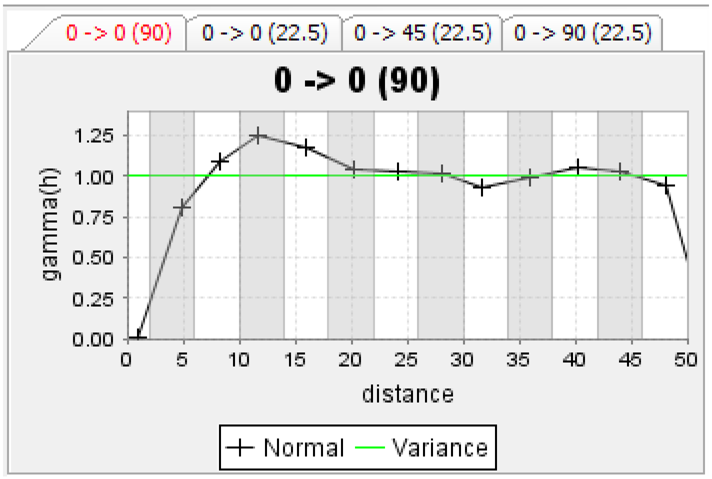


5. Click each tab to display the variogram for that orientation.
6. Choose **Display > Set axis limits**.

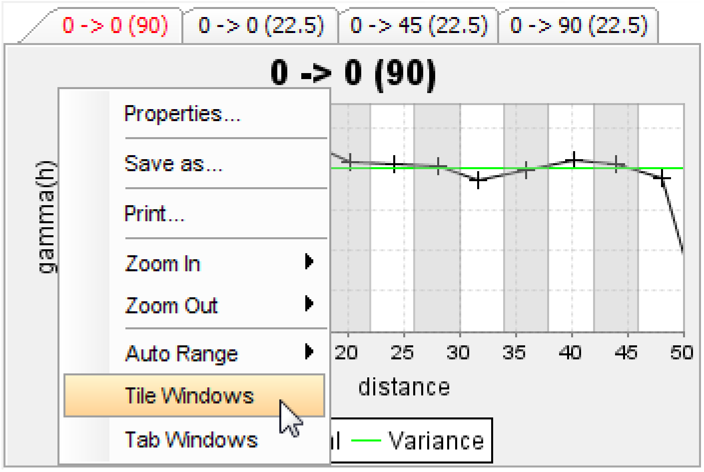
7. Enter the information as shown, and click **Apply**.



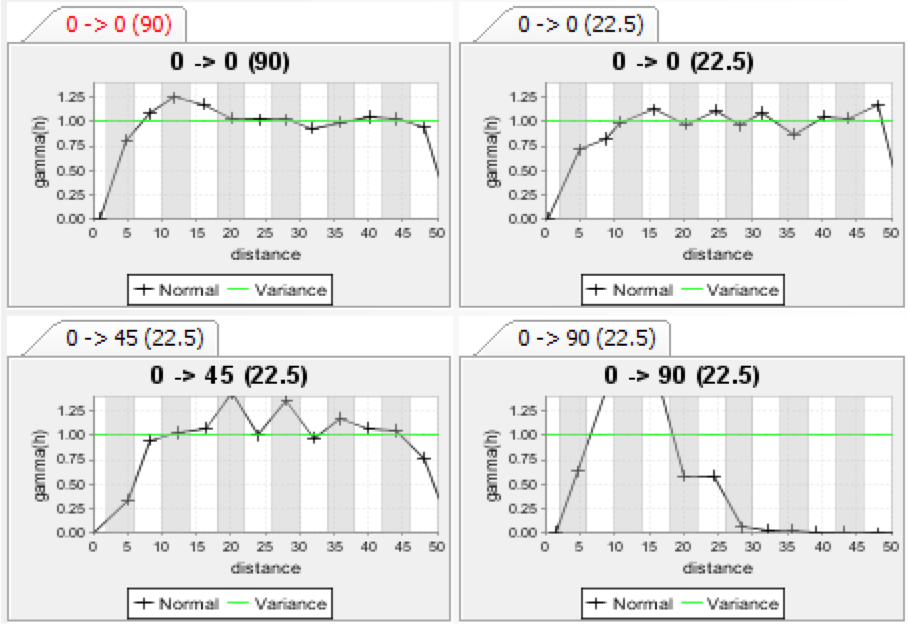
8. Choose **Display > Display / Hide lag intervals**.
   The lag intervals appear.



9. Right click anywhere on the variogram window, and then select **Tile Windows**.

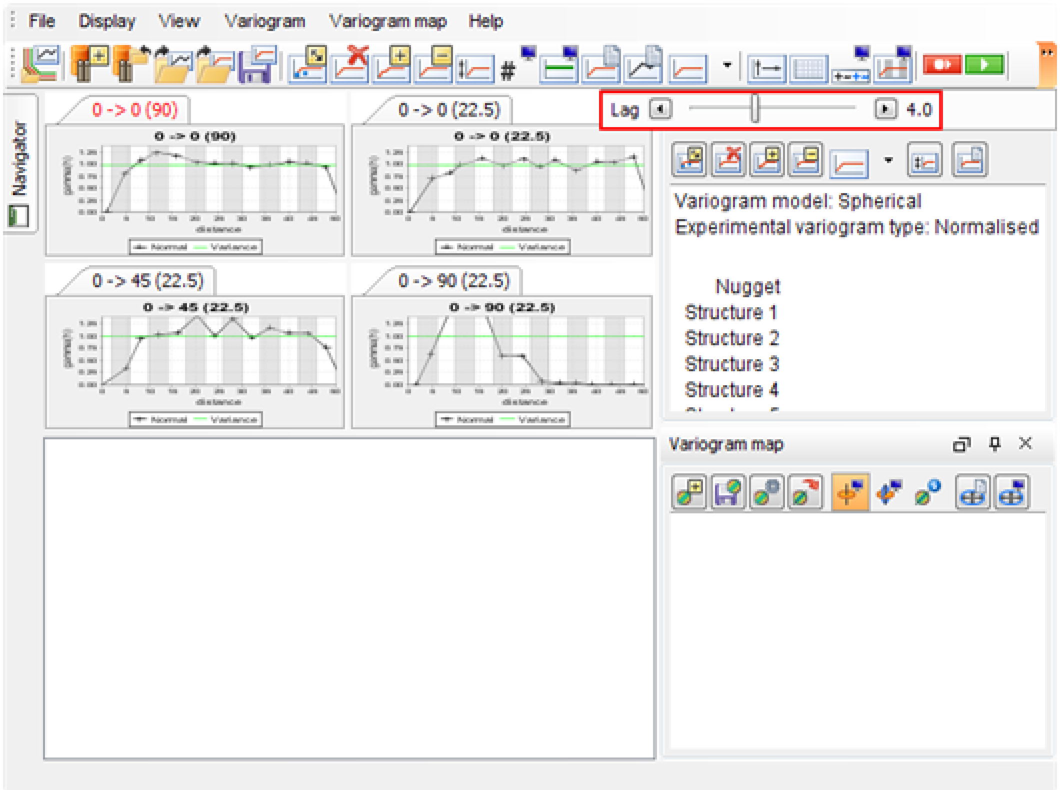


All variograms will appear tiled.



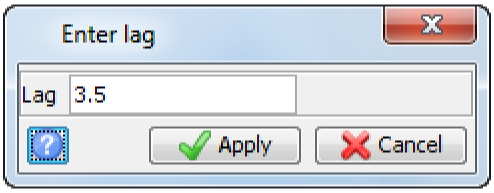
10. Change the lag by:
    - clicking and dragging the lag slider.
    - clicking the lag increment/decrement arrows on either side of the lag slider.
    - pressing the right arrow or left arrow keys on the keyboard.

    As you do any of the above, the variogram shape and the lag intervals will change.

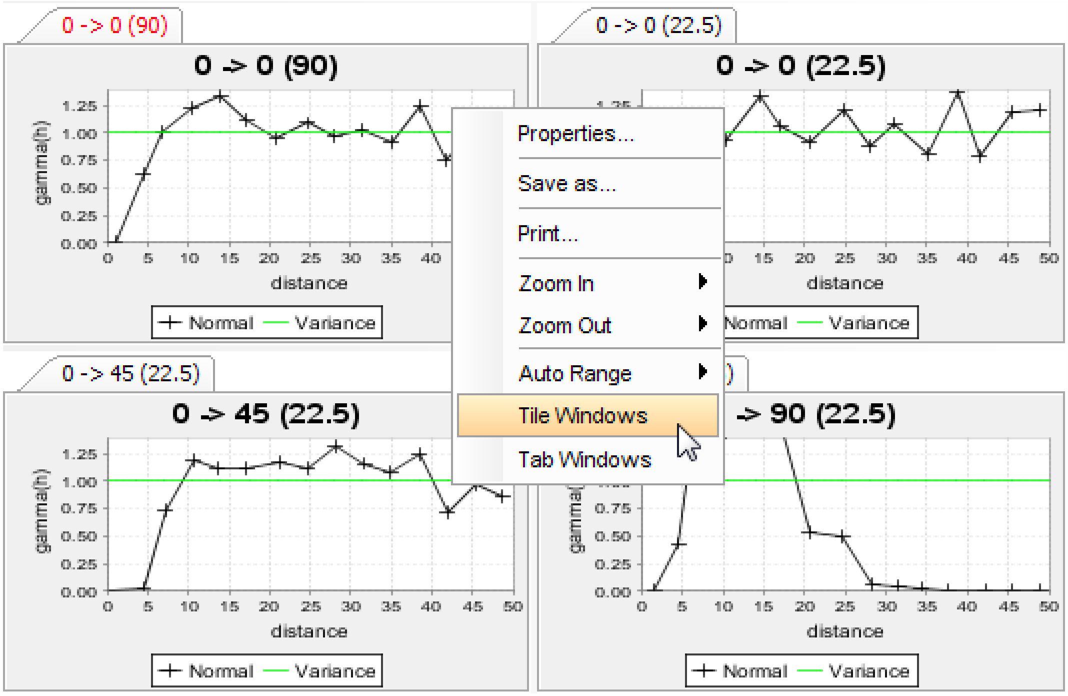


Note: Changing the lag is one of the most common ways to attempt to get a "good looking" variogram.

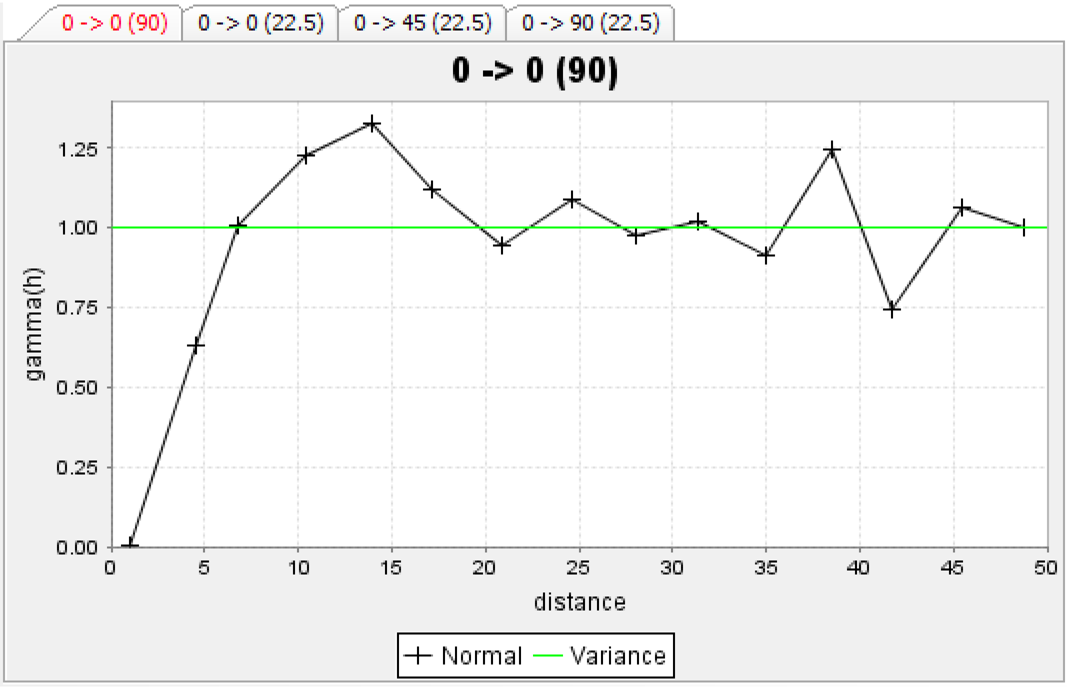
11. Choose **Variogram > Experimental variogram lag**.
12. Enter the information as shown, and click **Apply**.



13. Choose **Display > Display / Hide lag intervals** to remove the lag intervals.
14. Right click anywhere on any variogram chart, and select **Tab Windows**.

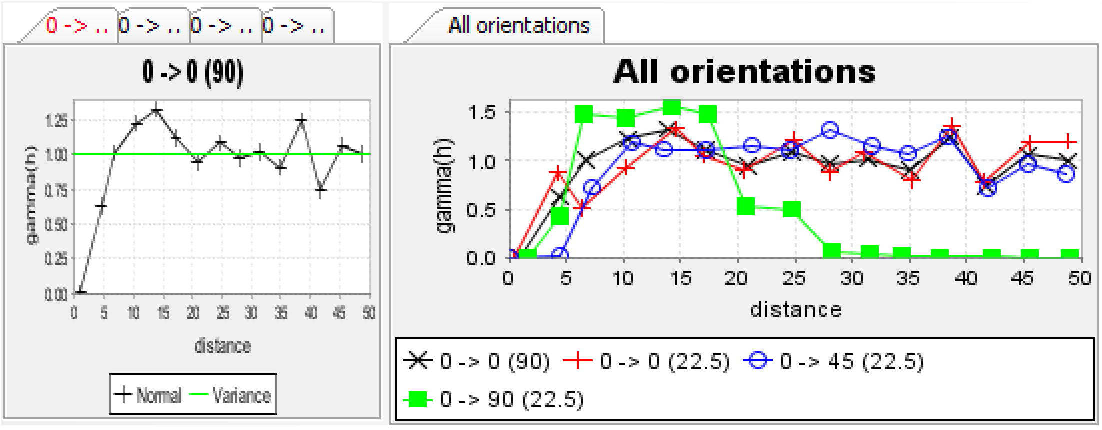


15. Select the tab labelled **0 -> 0 (90)**.
    The omnidirectional variogram is displayed.

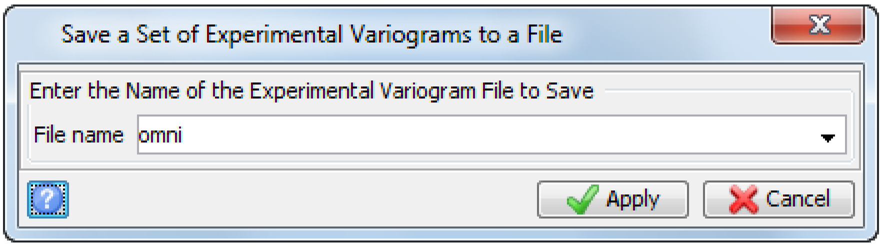


16. Select **Display > All orientations chart**

All experimental variograms are displayed together.



17. Choose **File > Save > Experimental variogram**.
18. Enter the information as shown, and click **Apply**.



19. Choose **File > Close** to exit the variogram modelling window.

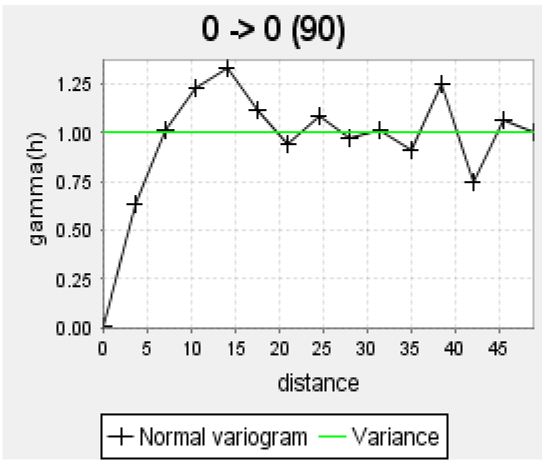
Note: To see all of the steps performed in this task. run **2d_05a_experimental_variogram.tcl**. You need to click **Apply** on any forms presented.

Types of experimental variograms

Once an experimental variogram has been calculated, it can be transformed by several different methods.

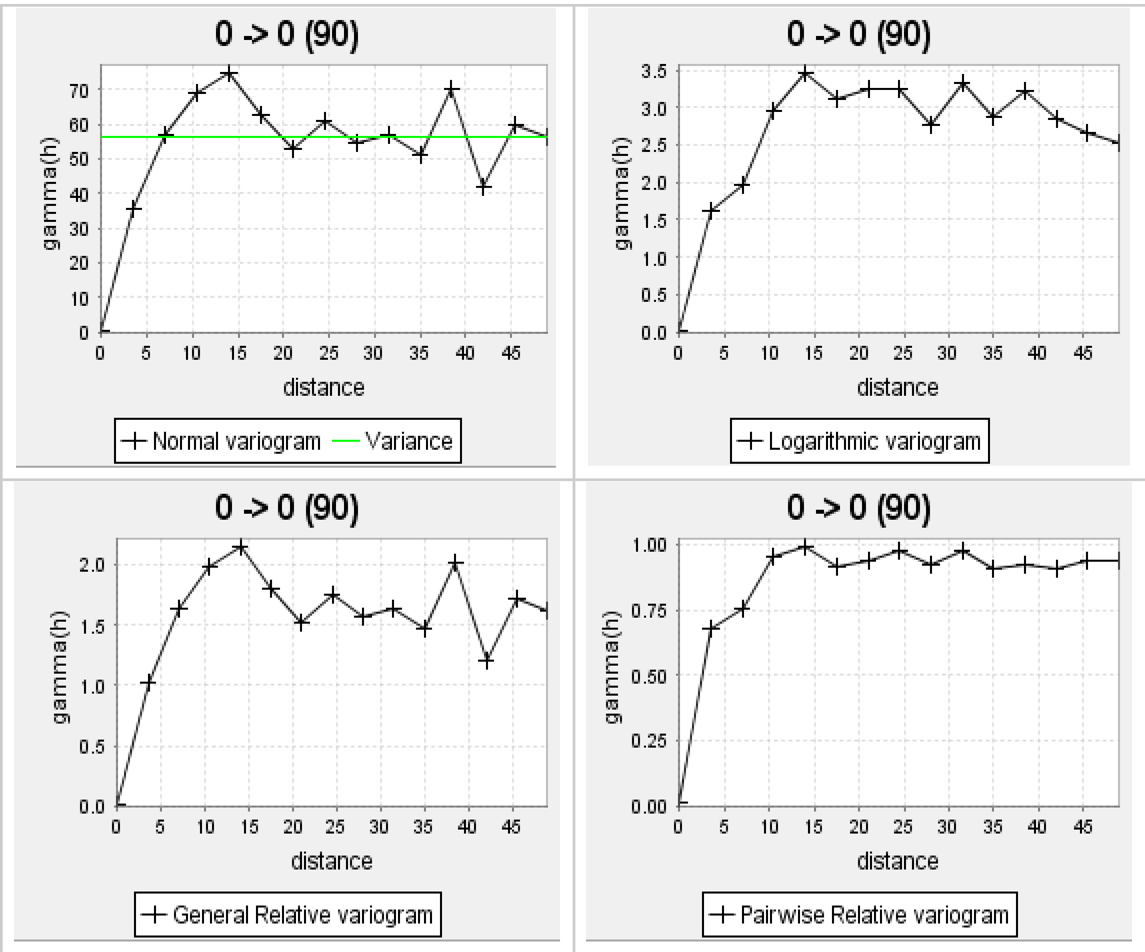
Task: Change the variogram type

1. Open **omni.evg**.
   The **Variogram Modelling** window opens, and the normalised variogram is displayed.



2. Choose **Variogram > Type**.
3. Select **Standard**, and click **Apply**.

4. Choose **Variogram > Type**.
5. Select **Logarithmic**, and click **Apply**.
   Note: Not only does the shape of the variogram change, but the gamma(h) values are also modified. If the variance of the data was displayed, it is now removed.
6. Choose **Variogram > Type**.
7. Select **General Relative**, and click **Apply**.
   Note: The shape in this case is identical to the normal variogram, but the gamma (h) values are different. They have been divided by the value of the variance of the data set.
8. Choose **Variogram > Type**.
9. Select **Pairwise Relative**, and click **Apply**.
   Note: The shape in this case is different to the normal and general relative, and the gamma(h) values are different.



Logarithmic variogram

In this type of a variogram, logarithms of the raw data are used to calculate the experimental variogram. Any negative or zero raw data values are first set to small positive values before a logarithmic transformation is applied. If the distribution of your data is logarithmic, or near logarithmic, and a reasonable fit cannot be obtained from a normal variogram, a logarithmic variogram can potentially give a usable value which can be used for the range of a normal variogram.

General Relative variogram

In this type of a variogram, each gamma(h) is divided by the squared mean of all samples used to estimate that gamma(h).

If local values within the population are affected by the local variance, a condition called a “proportional effect” is said to exist. “Relative” variograms can be more useful than “normal” variograms if a proportional effect exists.

Pairwise Relative variogram

In this type of variogram, the squared difference of each sample pair is divided by the square of the mean of each sample pair. Similarly to the logarithmic variogram, units along the Y (gamma(h)) axis have no meaning but the relative variograms may serve to identify ranges and structures

Note: The application of these types of variograms is an advanced topic. If you wish to obtain more information on this, you should obtain instruction from a qualified geostatistical consultant.

Note: To see all of the steps performed in this task, run**2d_05b_variogram_types.tcl**. You need to click **Apply** on any forms presented.

Menu commands:

Select...	to...
Geostatistics > Variogram modelling	open the Variogram Modelling Window.
From the Variogram Modelling Window:	
Variogram > New string file variogram	calculate one or more variograms.
Display > Set axis limits	set the X and Y values of the variogram graph area.
Display > Lag intervals	toggle the lag intervals on and off.
Variogram > Experimental variogram lag	set the lag exactly.
Variogram > Model	create a new model and allows editing (click and drag the blue dots).
File > Save > Experimental variogram and model	create ***.EVG** and ***.VGM** files.

Modelling a variogram

Overview

There are a number of tools to help you model a variogram in Surpac.

You will learn about:

- creating a best-fit variogram model
- saving variogram data
- modifying the lag
- types of experimental variograms
- types of variogram models
- multiple structures
- variogram modelling tips

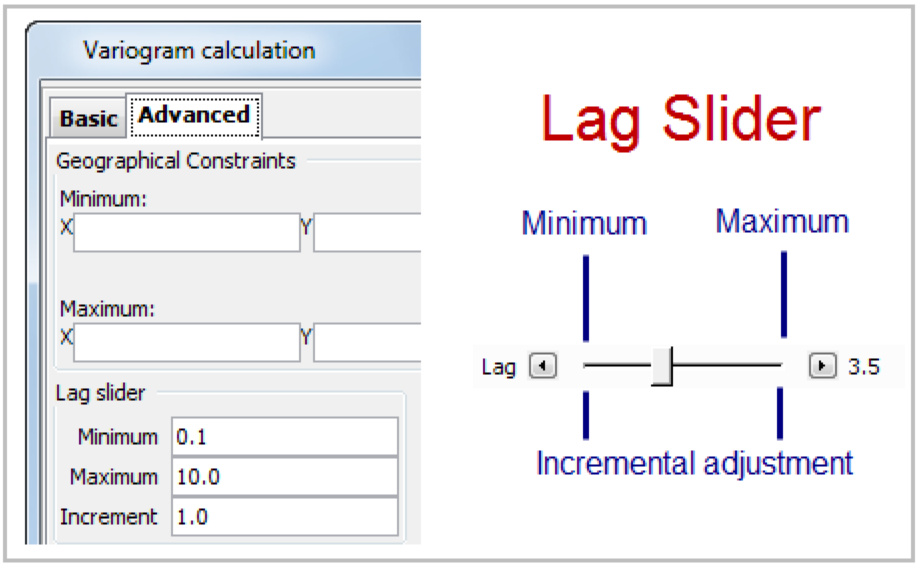
Requirements

In order to understand this information, you should:

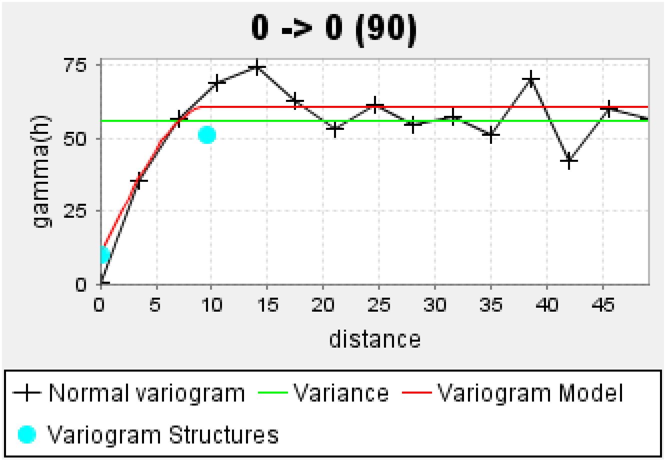
- be familiar with Surpac string files
- know how to run a Surpac macro
- understand basic variogram concepts, such as nugget, sill, lag, and multiple structures

Task: Open an experimental variogram and model

1. Open **omni.evg**.
2. Practice using the **lag slider**.
   Remember that the maximum, minimum, and incremental values are set on the **Advanced** tab, and that the right and left arrow keys on your keyboard will increase and decrease the lag by 0.1.

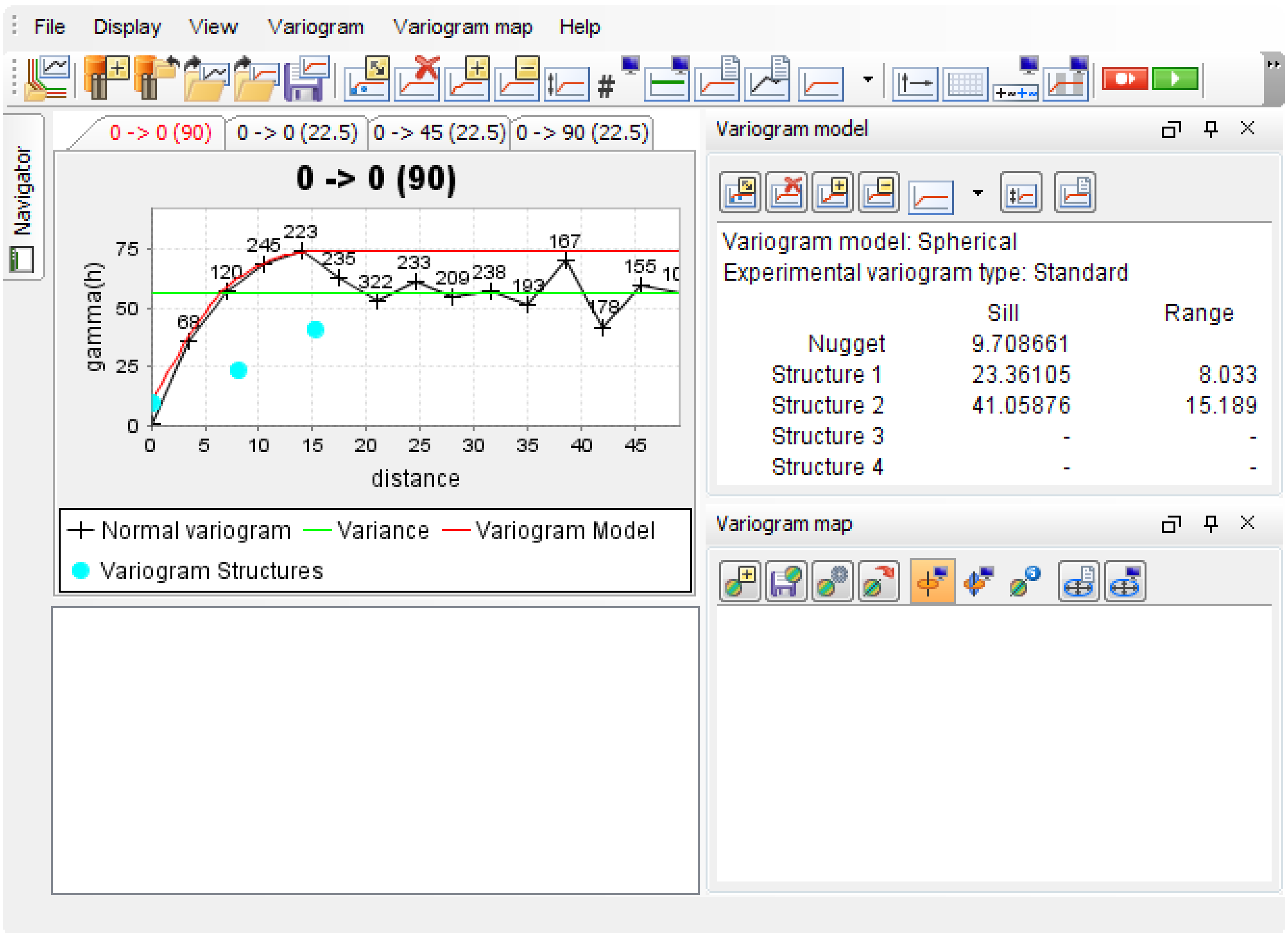


3. Choose **Variogram > Model**.
   The model is displayed.



The model displayed is a best-fit model to the experimental variogram data.

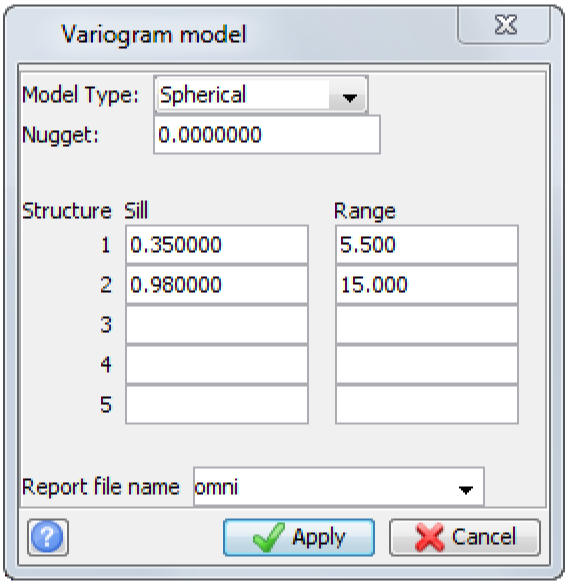
4. Click and drag either of the "variogram structures" (light blue dots) to change the shape of the model.
5. Choose **Display > Display / Hide number of pairs**.
   Note: You can ignore experimental data points with relatively low number of pairs.
6. Choose **Variogram > Add structure**.
7. Click and drag the "variogram structures" to fit the data as shown.



Note: The variogram parameters are updated as you move the structures.

8. Choose **Variogram > Report**.

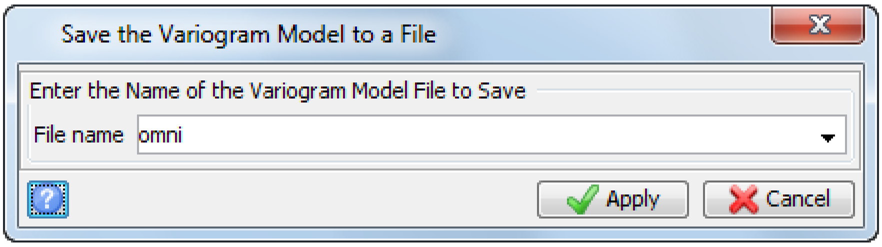
9. Enter the information as shown, and click **Apply**.



Note: The sum of the nugget and all sill values equals the "total sill".

The file **omni.not** is created in the current working directory.

10. Choose **File > Save > Variogram model**.
11. Enter the information as shown, and click **Apply**:

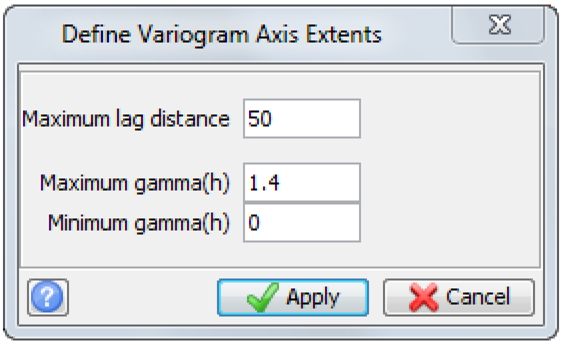


12. Choose **File > Close** to close the **Variogram Modelling** window.

To see all of the step performed in this task run **2d_06a_variogram_modelling.tcl.**

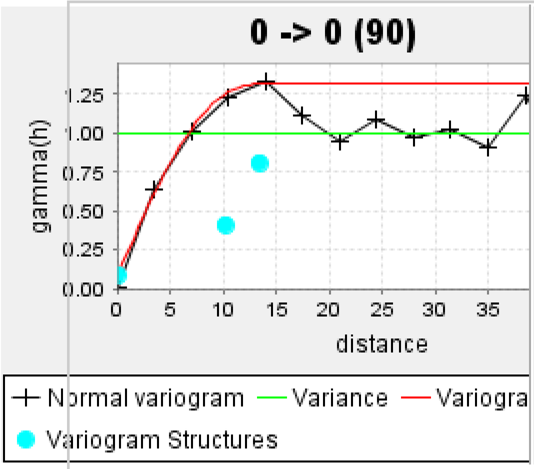
Types of variogram models

1. Open **omni.evg**.
2. Open **omni.vgm**.
3. Choose **Display > Set axis limits**.
4. Enter the information as shown, and click **Apply**.

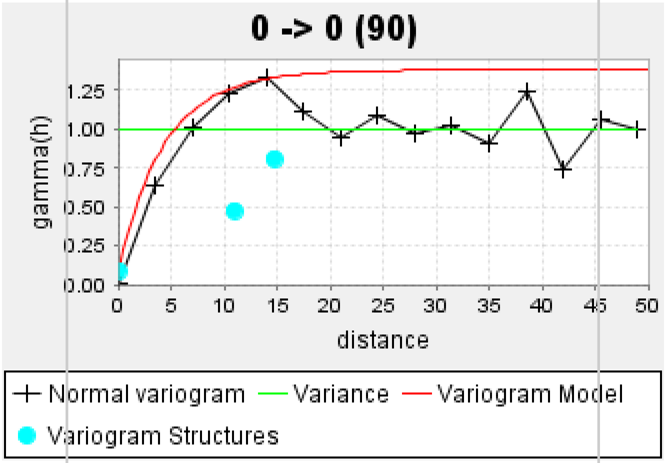


5. Choose **Variogram > Variogram model type > Exponential**.
6. Choose **Variogram > Variogram model type > Gaussian**.

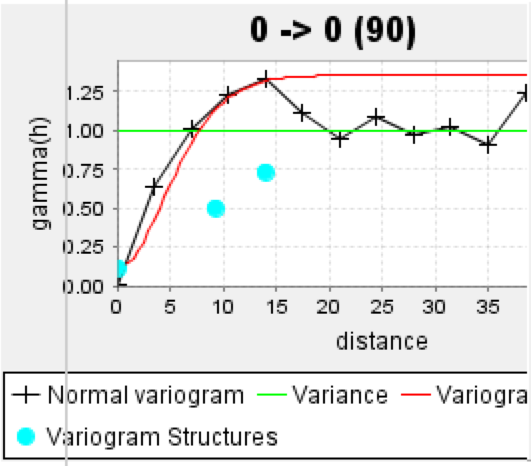
7. Choose **Variogram > Delete structure**.
8. Choose **Variogram > Variogram model type > Hole Effect**.
9. Click and drag the structures as shown.



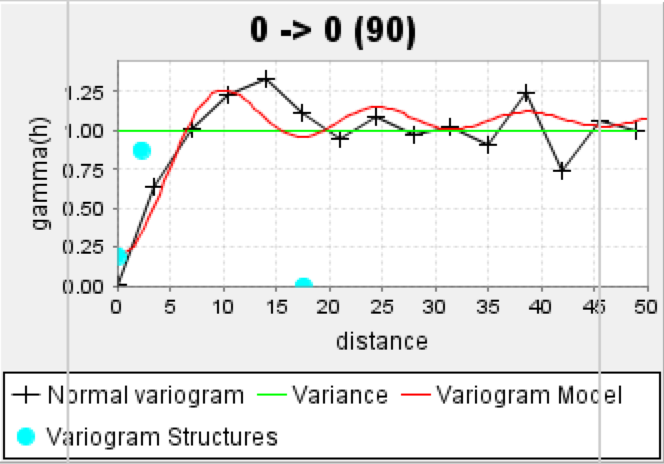
Spherical Model



Exponential Model



Gaussian Model



Hole Effect Model

10. Choose **File > Close**.

To see all of the steps in this task run **2d_06b_variogram_model_types.tcl.**

Variogram modelling tips

Modelling a variogram is not an exact science. However, the following are some tips that might help you:

- Try to find the variogram that has the longest range and the lowest variability.
- Try to model the “trend”. One way to see the “trend” of the data is to create a variogram model, then drag the lag slider back and forth. The model should fit the data reasonably well for a few different lags.
- Consider the geology of the domain. Does the model you come up with look reasonable for your data? Is the nugget effect high or low? Is the range approximately what you expected? If not, perhaps you should reconsider the data domains.
- Search the Internet. There are many online resources with explanations of variograms, variogram calculations, and results of particular data sets.
- Ask a consultant. Although they are usually not free, geostatistical consultants are perhaps the best source of geostatistical advice.

Menu commands:

Select...	to...
Geostatistics > Variogram modelling	open the **Variogram Modelling Window**.
From the Variogram Modelling Window:	
File > Open > Variogram	open an existing variogram.
Variogram > Variogram model type > Exponential	create an exponential variogram model.
Variogram > Variogram model type > Gaussian	create a gaussian variogram model.
Variogram > Delete structure	remove a variogram model.
Variogram > Variogram model type > Hole Effect	create a model that accounts for hole effect.

Variogram maps

Overview

An important aspect of performing any geostatistical evaluation is to understand the anisotropy of the data, or which direction has the longest continuity. It is also important to understand how the data values change with regard to the direction with longest continuity, as well as in relation to the two mutually perpendicular directions.

A variogram map is a tool in Surpac that allows you to visualise anisotropy in a plane, and calculate anisotropy ellipsoid parameters to use in estimation.

You will learn about the:

- primary variogram map
- secondary variogram map
- calculation of anisotropy ellipsoid parameters

Requirements

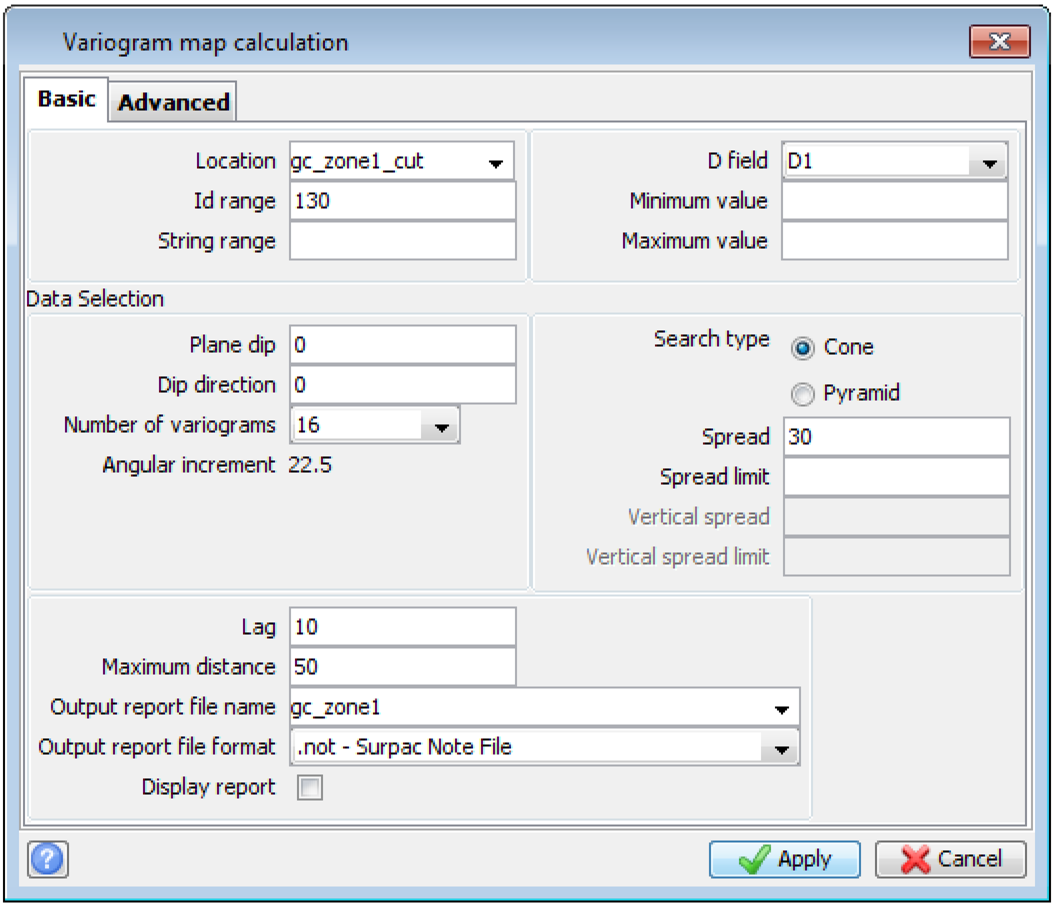
In order to understand this information, you should:

- be familiar with Surpac string files
- know how to calculate and model a variogram in Surpac
- understand the concept of an anisotropy ellipsoid
- understand the parameters that define an anisotropy ellipsoid

Primary variogram map

Task: Create a horizontal variogram map

1. Choose **Geostatistics > Variogram modelling** .
2. Choose **Variogram map > New variogram map**.
3. Enter the information as shown on the **Basic** tab.



The number of variograms selected will determine the angular increment. In our example, 16 variograms will result in a 22.5 degree angular increment (360/16=22.5). If the number of variograms was set to 36, you would get a 10 degree increment (360/36=10).

The spread and spread limit parameters are the same as in normal variogram modelling.

The relationship between the angular increment and the spread angle should be considered.

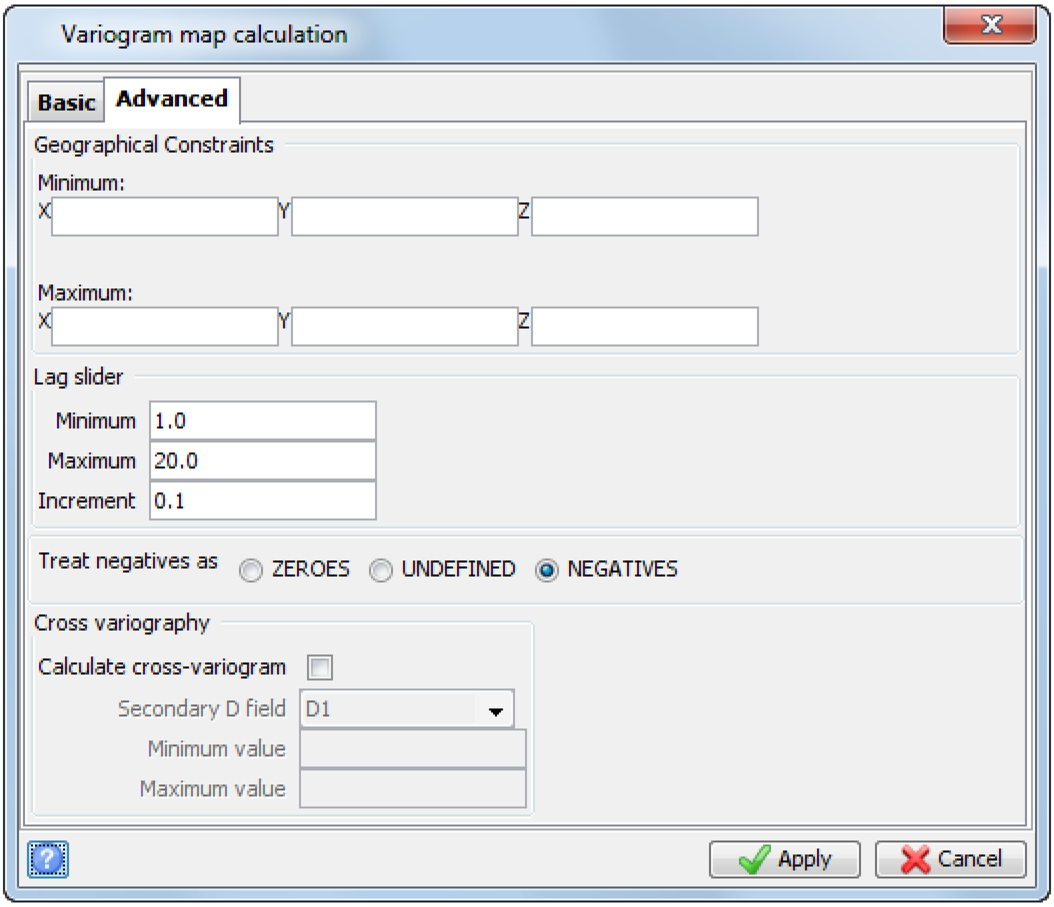
It could be considered unreasonable to define a spread tolerance anything greater than half of the angular increment. For this data set, because of the small number of pairs, if a 11.25 degree spread were used (half of the 22.5 degree angular increment between adjacent variograms), the number of data pairs would be so small that very few, if any reasonable variograms would result. A spread of 30 degrees is used for this data set to ensure that enough samples are included to produce meaningful variograms.

Given that a spread of 30 degrees is used, you could argue that the number of variograms should be reduced to minimise the “overlap” of the cones for adjacent variograms. Although this is a reasonable argument, the resulting variograms would not be suitable to use to use to visually determine anisotropy.

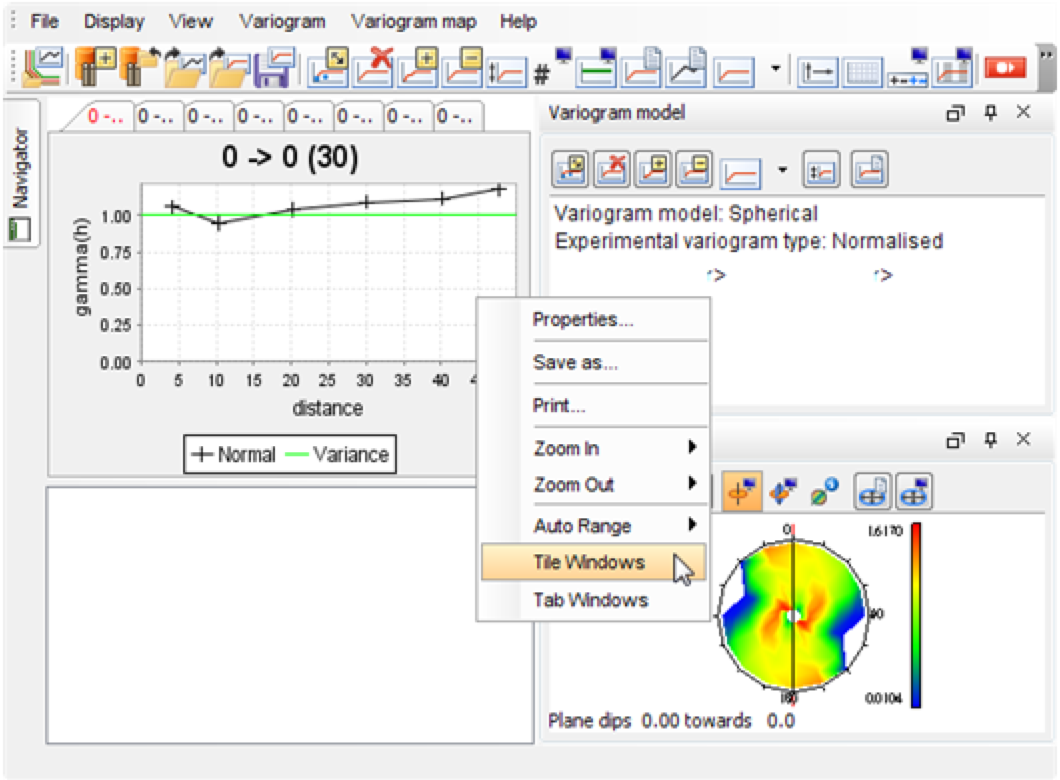
It is up to you, based the data set you are working with,to determine the values you will use to produce a usable variogram without over-smoothing your data. This is an example of how geostatistics is an inexact science. Experience with a data set will usually allow you to determine what combination of parameters will give an acceptable result.

In the bottom panel, the lag, maximum distance, and variogram report parameters are specified, exactly as they are in variogram modelling. One thing you should consider is that the maximum distance will be the radius of the variogram map. You might find that you need to try a few variations of this value to get one that gives an adequate result.

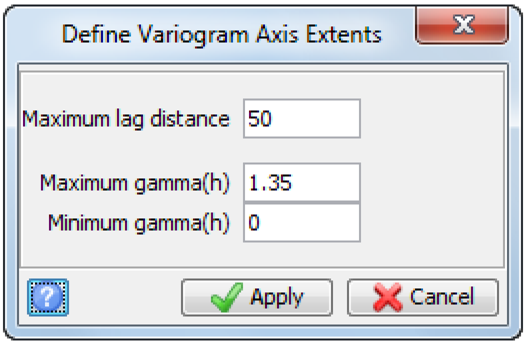
4. Click the **Advanced** tab, enter the information as shown, and click **Apply**.



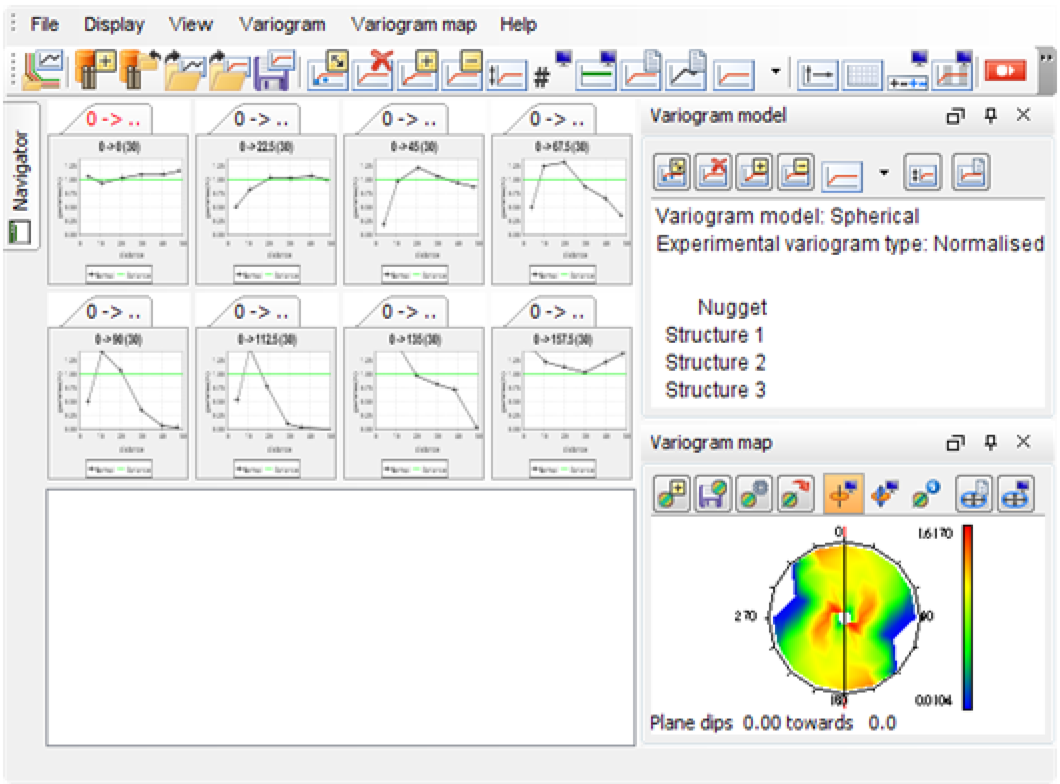
5. Right-click anywhere on the variogram, and select **Tile Windows**.



6. Choose **Display > Set axis limits.**
7. Enter the information as shown, and click **Apply**.



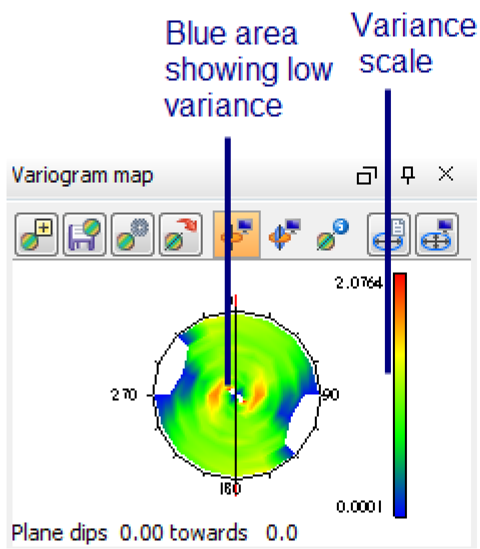
The variograms are displayed.



Task: Determine 2D anisotropy

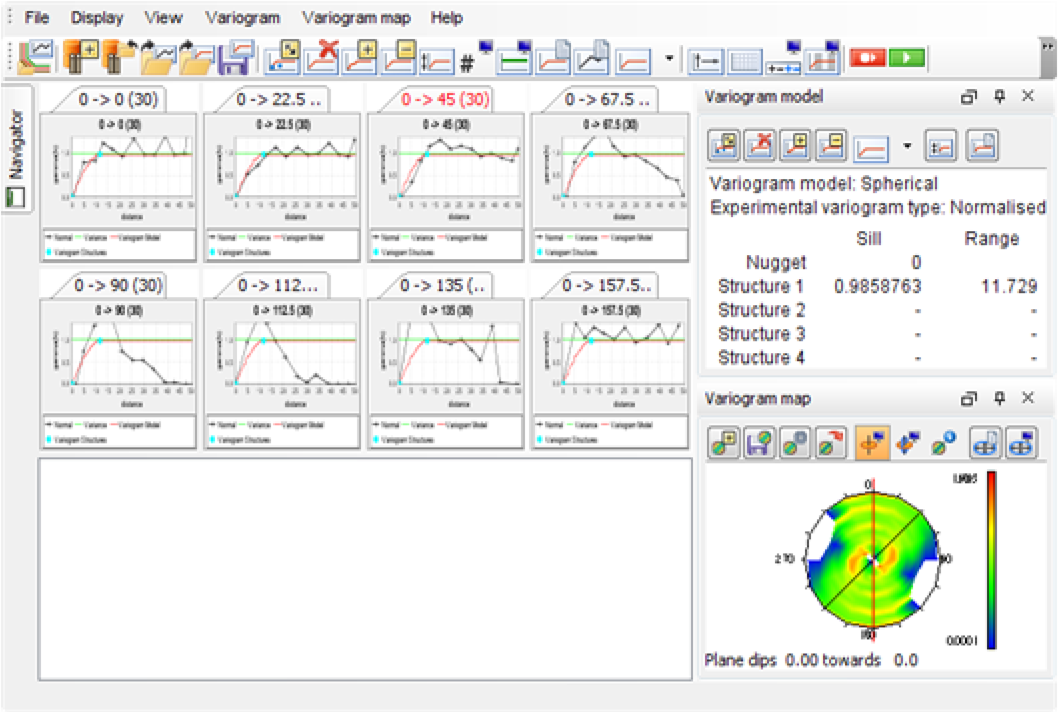
In a 2D case, both the major and semi-major axes will lie in the plane of the primary variogram map. The orientation of the major axis is chosen as the variogram which has the longest range for a given sill value.

1. Move the lag slider back and forth, changing the colours in the variogram map to show you areas of high and low variance .
   The colour bar at the side of the variogram map shows you the range of variance for your data. You will most likely see that throughout a range of lag values, there will be areas on the variogram map which will be consistently high, and others which will be consistently low. Using the example given above, the orientation of 45 degrees consistently displays colours representing low variance.

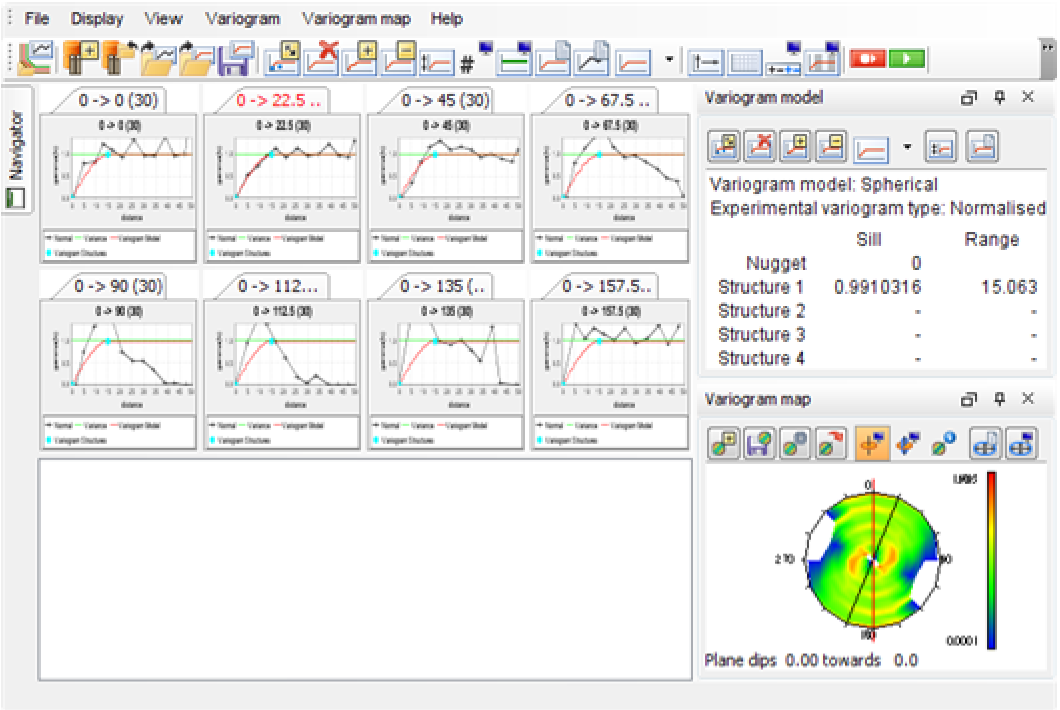


Note: You are looking for the lag that gives the lowest variance at the centre of the variogram map.

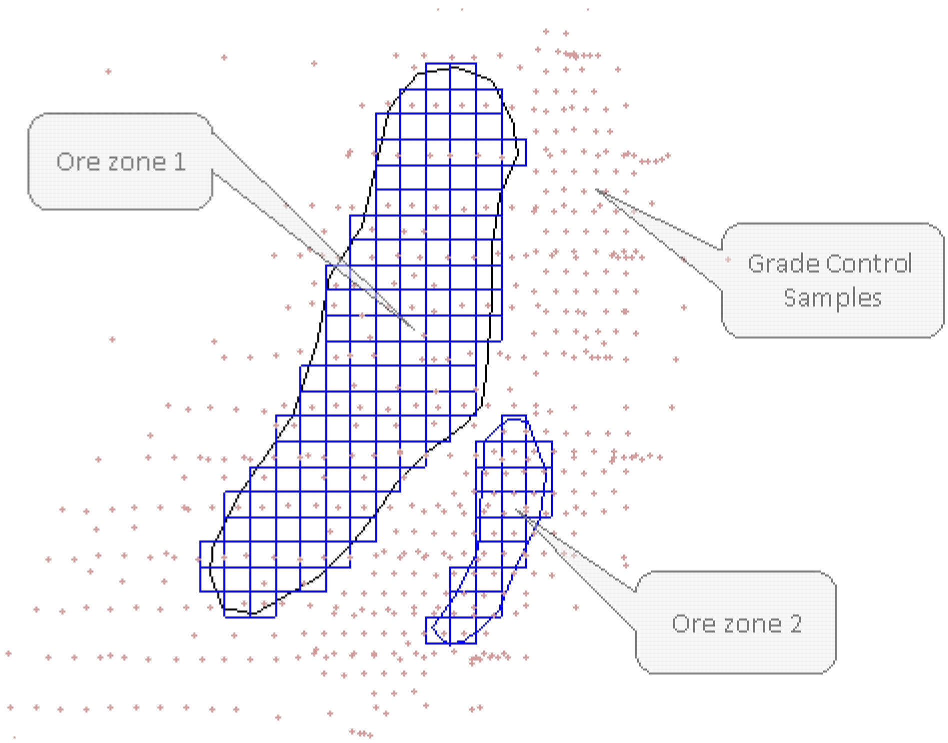
2. After you have an idea of what appears to be the orientation of the longest range, use the lag slider to improve the quality of the experimental variogram for that direction. In the previous image, a lag distance of 4.3 resulted in a good variogram for the 45 degree orientation.
   Note: You are looking for the variogram with the longest range for the lowest sill.
3. Choose **Variogram > Model**.
   This creates a variogram model for the chosen orientation.
4. Click and drag the model to fit the experimental variogram for that direction.
   As shown below, fit a model to the 45 degree orientation.



5. Check that variogram model for all other orientations.
   The major axis should be that variogram which has the lowest variance for the longest distance. In this case, the variogram at the orientation of 22.5 degrees actually has a longer range.
6. If another orientation appears to have a longer range and a lower variance, modify the model to fit that experimental variogram.
   Modifying the lag distance for that orientation might help you get a better fit.
7. Modify the variogram for the orientation of 22.5, as shown below.

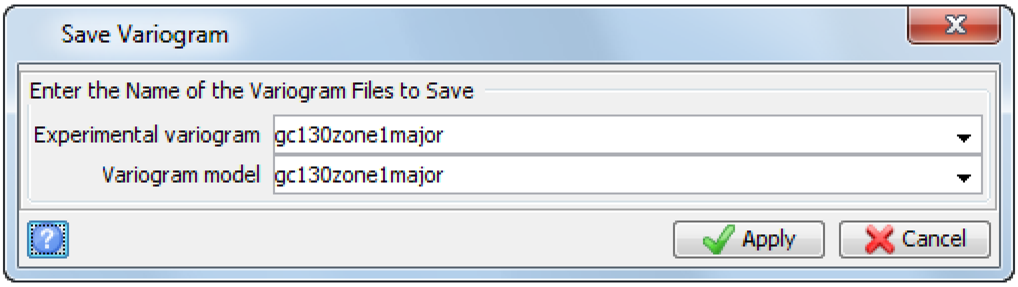


8. Repeat the previous two steps until you are satisfied that you have the orientation of the major axis.
9. After you have defined a major axis, ask yourself, and others who are familiar with the geology, if the orientation appears correct.
   In this case, the orientation of 22.5 is a good match with the orientation of the ore zone as shown below.



   For the ore zone #1, the bearing of the major axis is 22.5.

10. Choose **File > Save > Experimental variogram and model**
11. Enter the information as shown, and click **Apply**.



As you can see, not only is the subject of variogram modelling a non-scientific process, but the orientation of the major axis is also open to interpretation and debate.

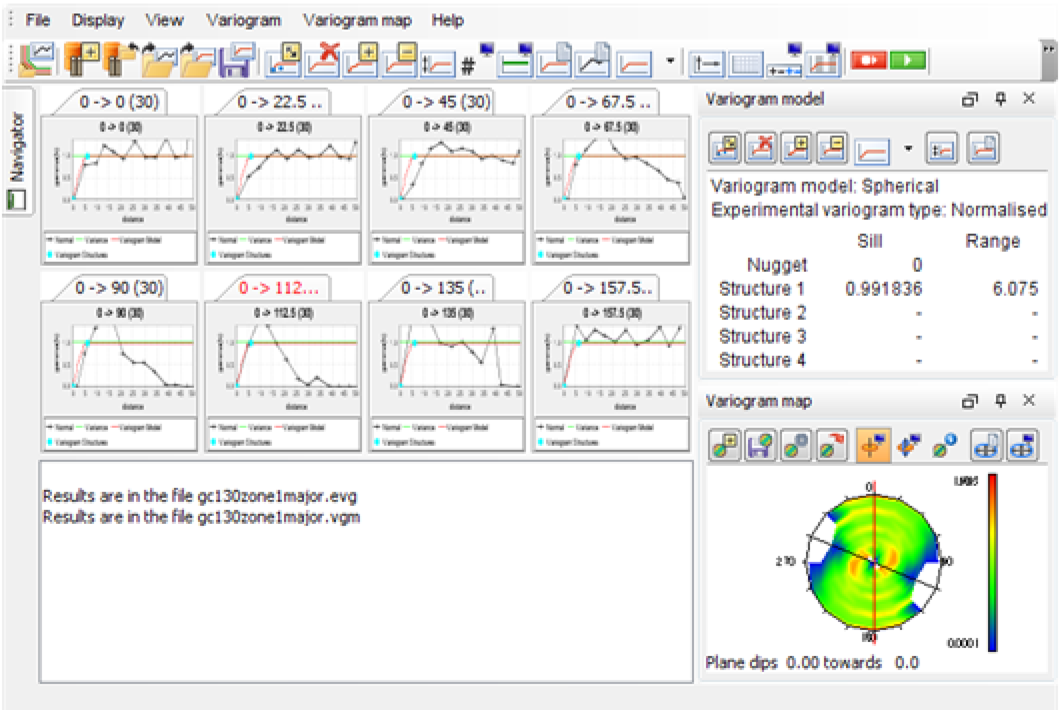
The semi-major axis is in the same plane, and is perpendicular to the major axis. Thus, the bearing of the semi-major axis for this data set is 22.5 + 90 = 112.5.

The anisotropy ratio is the range of the major axis / range of the semi-major axis for a constant sill value.

The range of the major axis is displayed as 15.1 in the upper right corner of the variogram modelling window.

You can determine the range of the semi-major axis for a variogram with only one structureby changing the range to fit the variogram for the semi-major axis the while keeping the sill the same.

12. Choose **Variogram > Model**.
13. Click and drag the variogram so that it fits the experimental variogram for bearing 112.5.



Note: The sill of the variogram is exactly the same, but the range is now 6.075.

Thus, the anisotropy ratio for zone 1 is: 15.1 / 6.1 = 2.48.

Although this is not the purpose for which these functions were designed, this is the quickest means of determining two dimensional anisotropy.

Inverse distance estimation

Overview

An important end product of a geostatistical evaluation is a “model”, or a set of points in space which contain estimated values. One of the methods for estimating values at points in a model is known as inverse distance estimation.

You will learn about:

- comparing isotropic and anisotropic inverse distance estimation
- the steps to performing inverse distance estimation
- the impact of power on inverse distance estimation
- how to implement anisotropy parameters from a primary variogram map

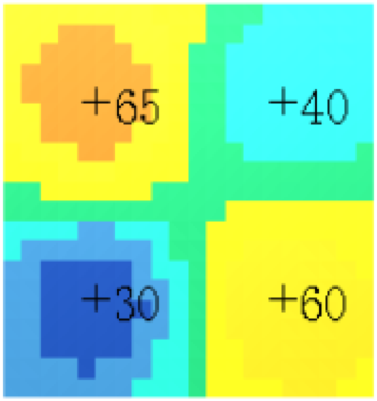
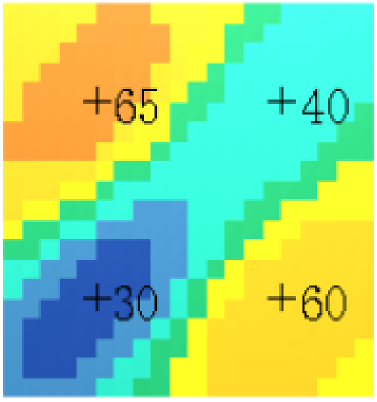
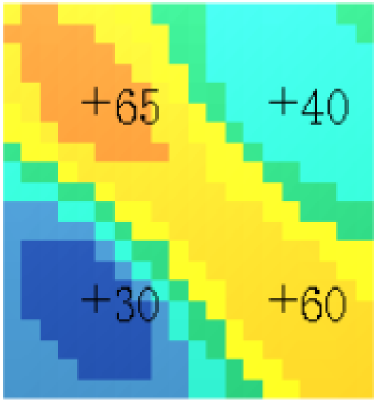
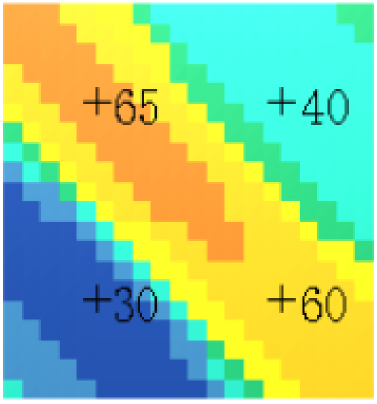
Requirements

In order to understand this information, you should:

- know how to display menu bars
- be familiar with Surpac string files
- know how to calculate and model a variogram in Surpac
- understand the concept of an anisotropy ellipsoid
- understand the parameters which define an anisotropy ellipsoid

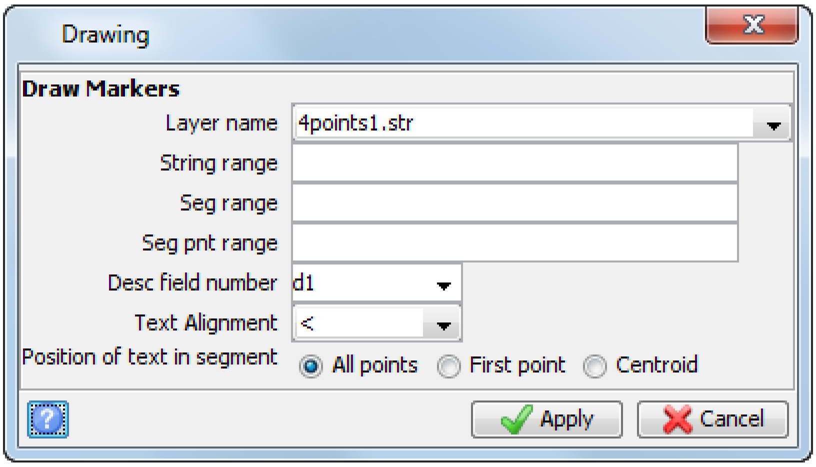
Comparing isotropic and anisotropic inverse distance estimation

When you use inverse distance weighting to estimate values in a block model, the amount and direction of anisotropy can have a significant impact on the end result. For example, the four models shown below were created from the same data set, but different amounts and orientations of anisotropy were used.

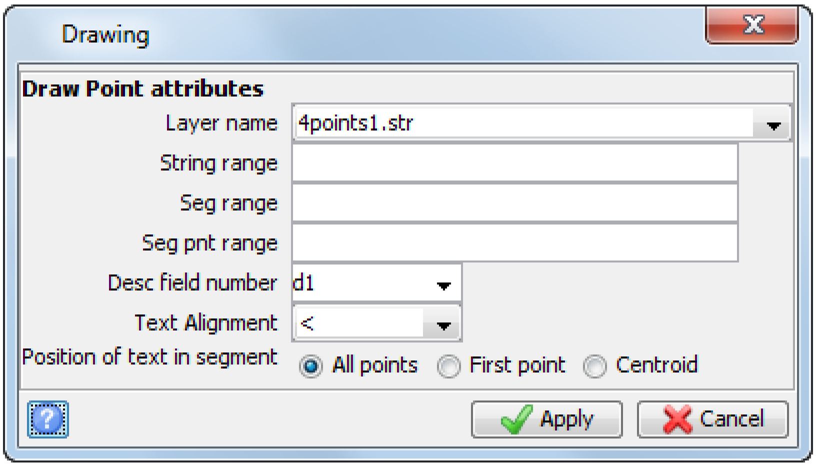
	
No Anisotropy (Isotropic)	2:1 Anisotropy Azimuth 45
	
2:1 Anisotropy Azimuth 135	5:1 Anisotropy Azimuth 135

Task: Perform inverse distance estimation using isotropy

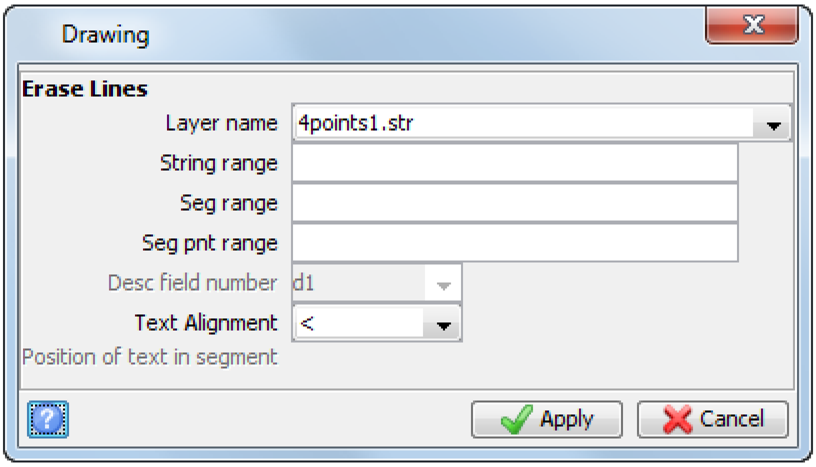
1. Open **4points1.str** in **Graphics**.
2. Choose **Display > Point > Markers**.
3. Enter the information as shown, and click **Apply**.



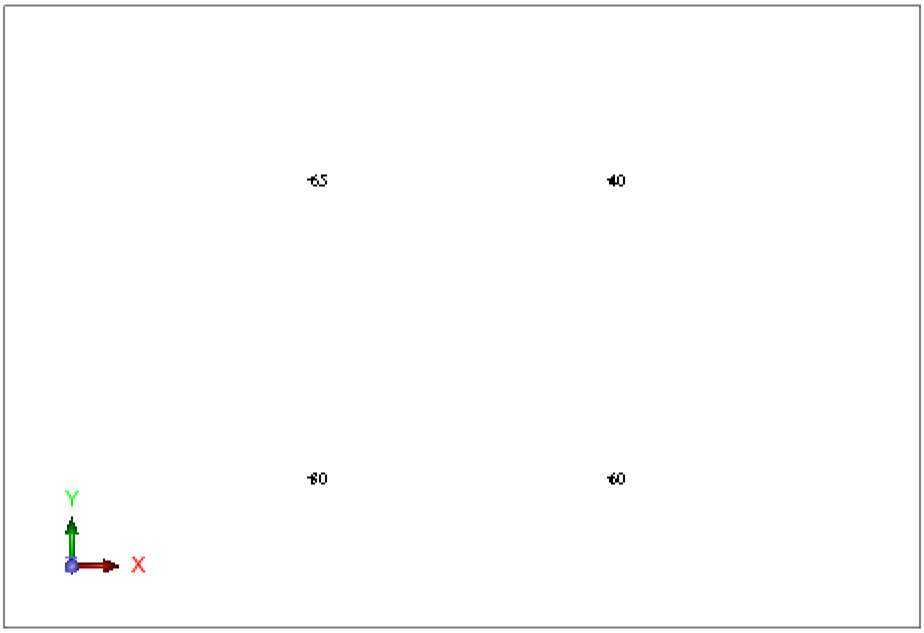
4. Choose **Display > Point > Attributes**.
5. Enter the information as shown, and click **Apply**.



6. Choose **Display > Hide strings > As lines**.
7. Enter the information as shown, and click **Apply**.



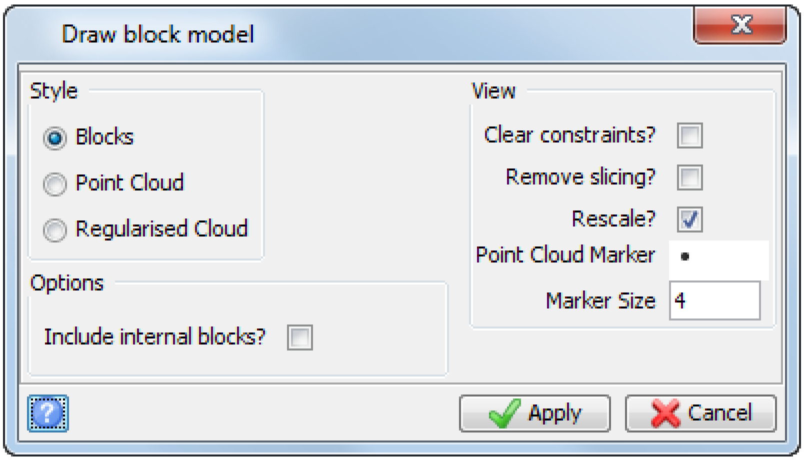
The points are displayed as follows.



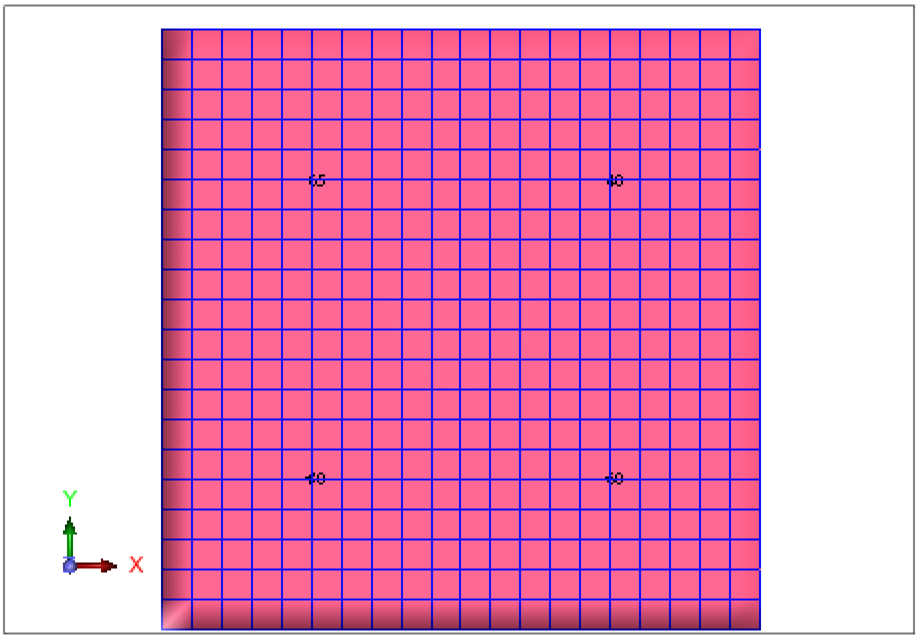
8. Right-click in the empty area to the right of the menus and choose **Menus > Block Model**.

📝 **Note**: All menu commands below here refer to the **Block Model** menu bar.

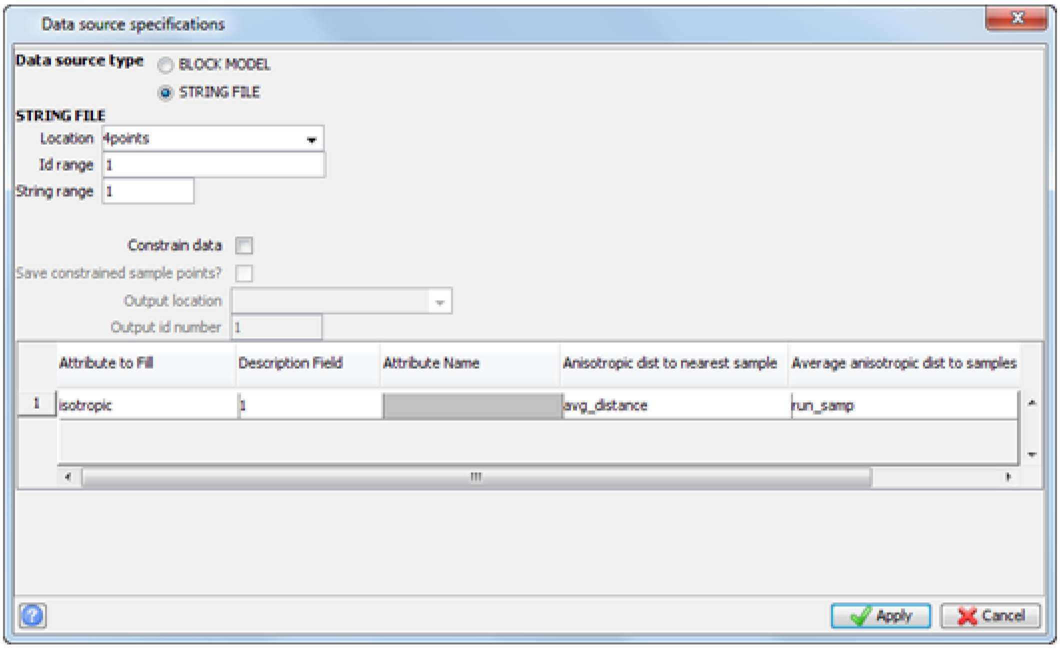
9. Open the model **20x20x1.mdl**.
10. Choose **Display > Clear model colours**.
11. Choose **Display > Display block model**.
12. Enter the information as shown, and click **Apply**.



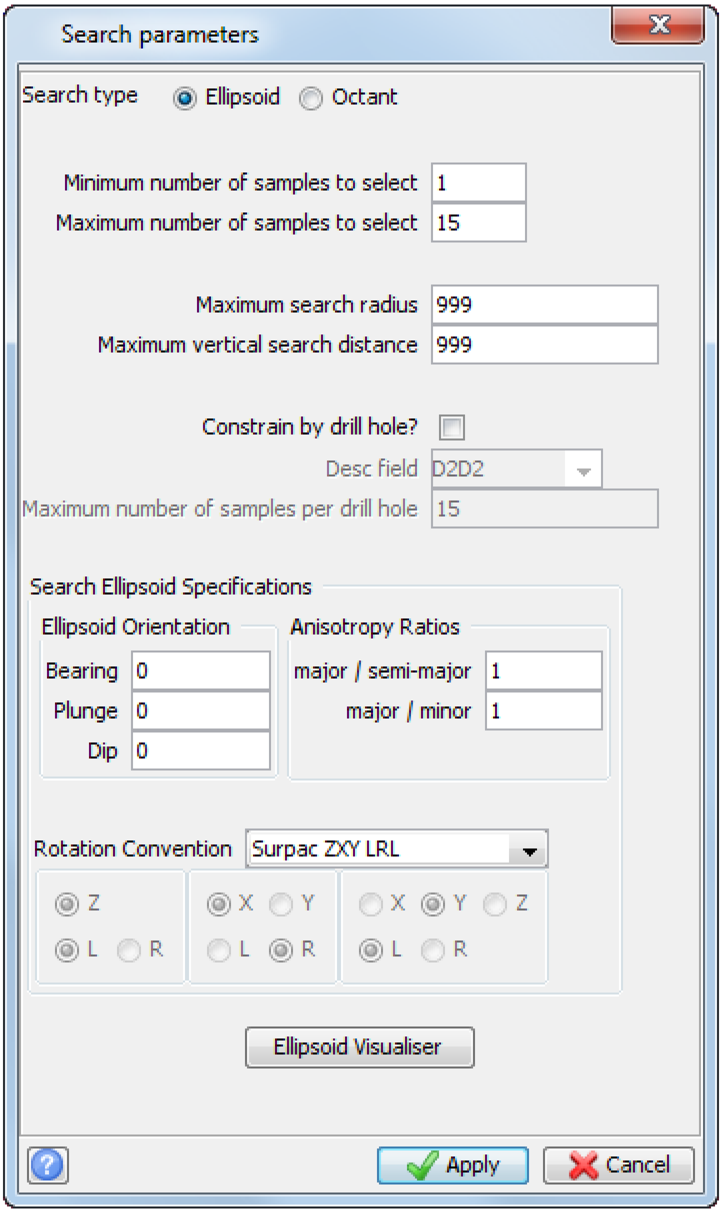
The model and data are displayed.



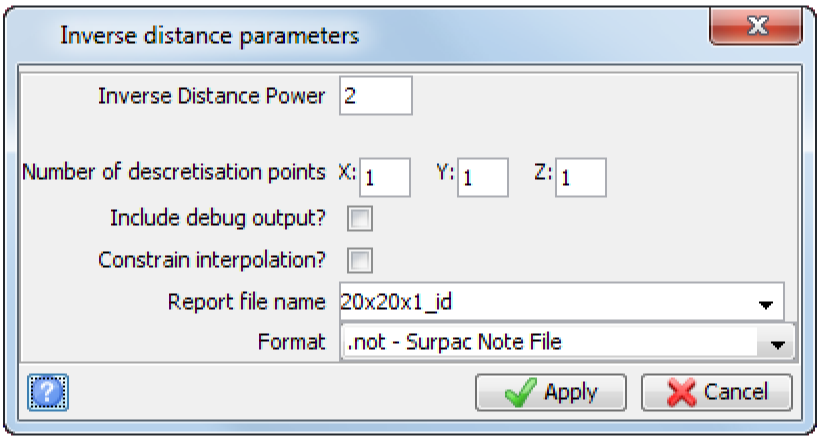
13. Choose **Estimation > Inverse distance**.
14. Enter the information as shown, and click **Apply** on the following three forms.



Note: The parameters **Anisotropic dist to nearest sample**, **Average anisotropic dist to samples**, and **Number of samples** are optional. By filling in the form this way, you specify that the data comes from string 1 of **4points1.str** and that the calculated grade will be stored in a block model attribute called isotropic.

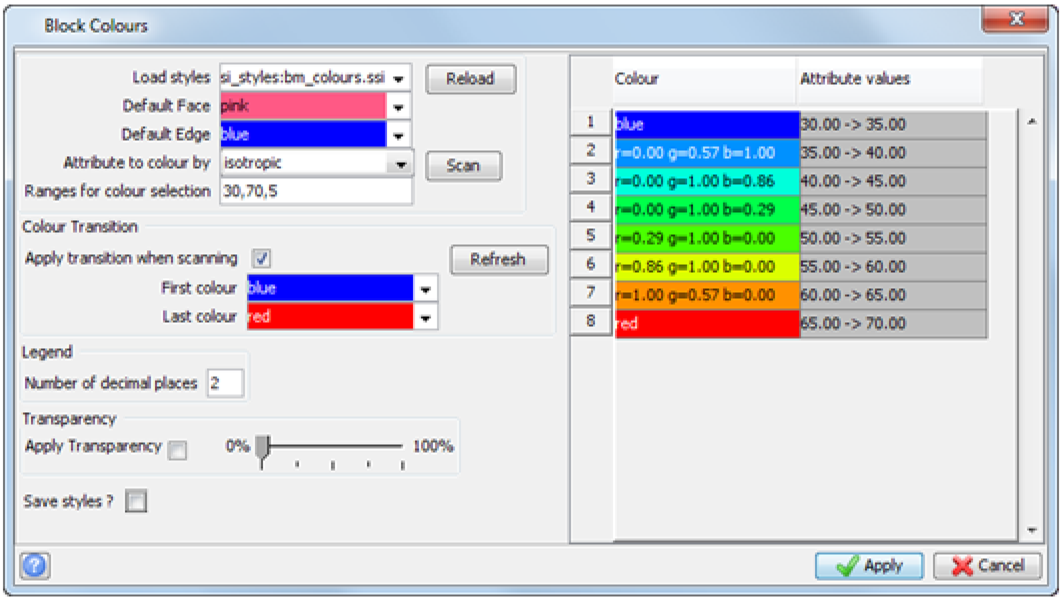


📝 **Note**: By setting both anisotropy ratios to 1, **isotropic** estimation will be performed.

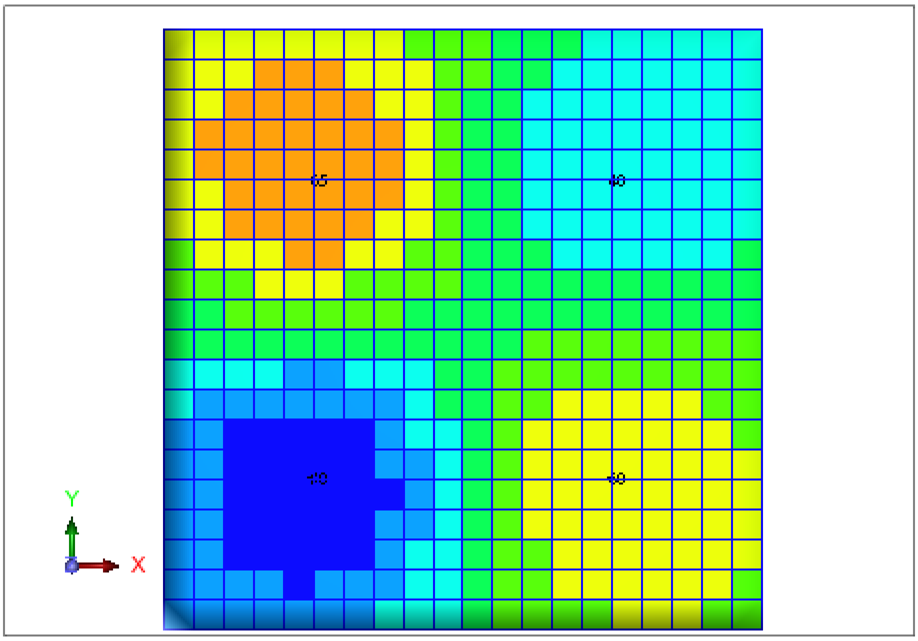


15. Choose **Display > Colour model by attribute**.
16. In the **Attribute to colour by** firld, select **isotropic**, click **Scan**, then enter values for the **Ranges for colour selection** of **30,70,5** and click **Refresh**.

17. Click **Apply**.



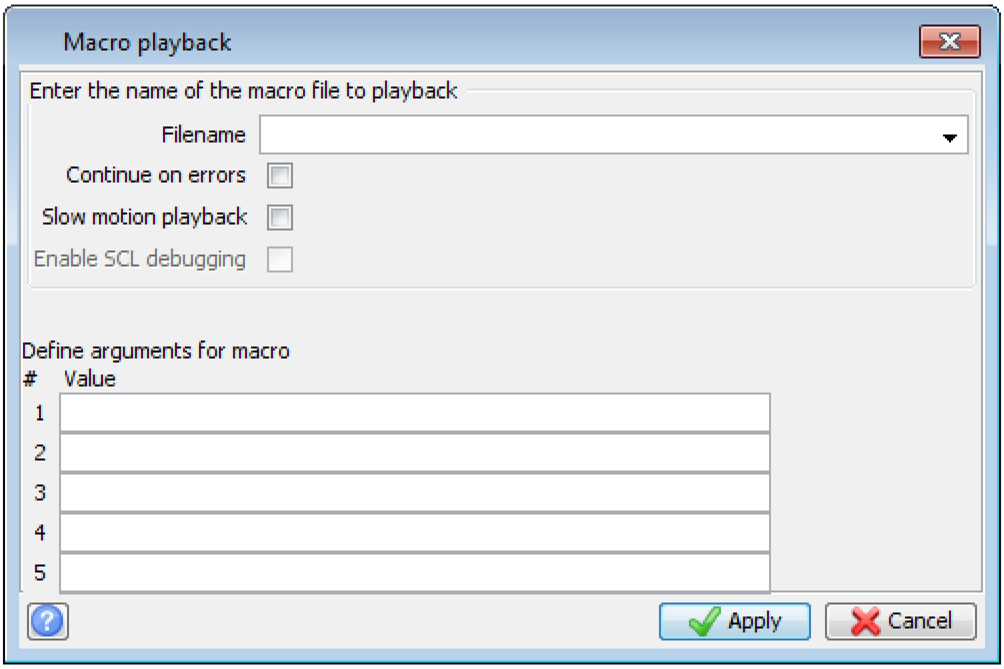
Blocks are coloured based on the inverse distance squared estimate.



18. Choose **Block Model > Close**.
19. On the *Exit block model* form, click **Save and exit**, and then click **Apply**.

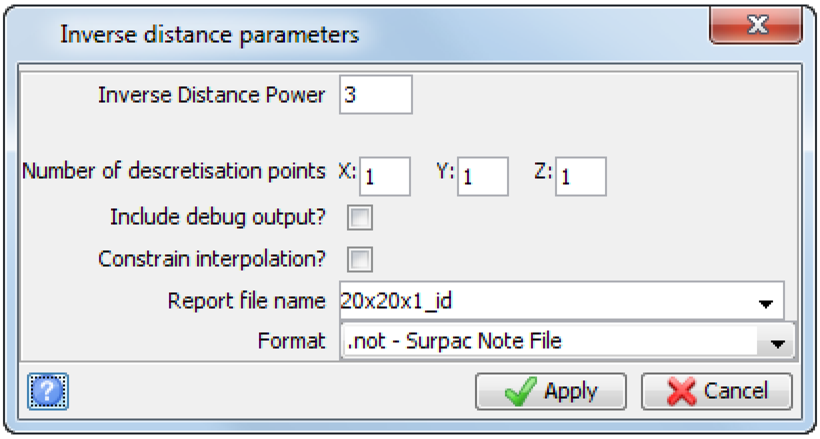
Note: To see all of the steps performed in this task:

1. Run **2d_04_anisotropy.tcl**
2. Use the **Macro playback** button and select **Slow motion playback** to display each form.

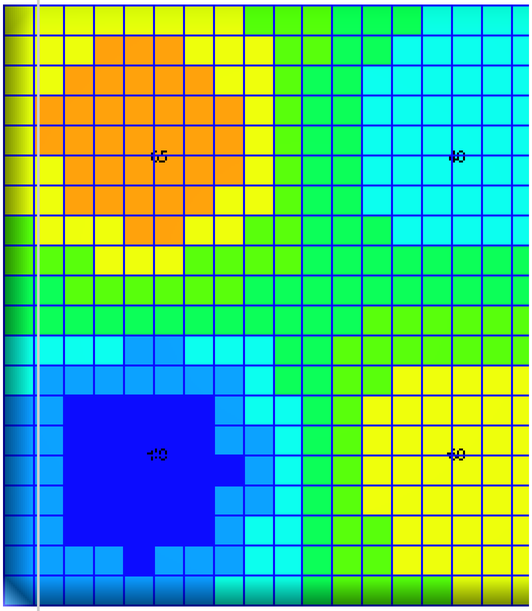


Task: View the effect of increasing inverse distance power

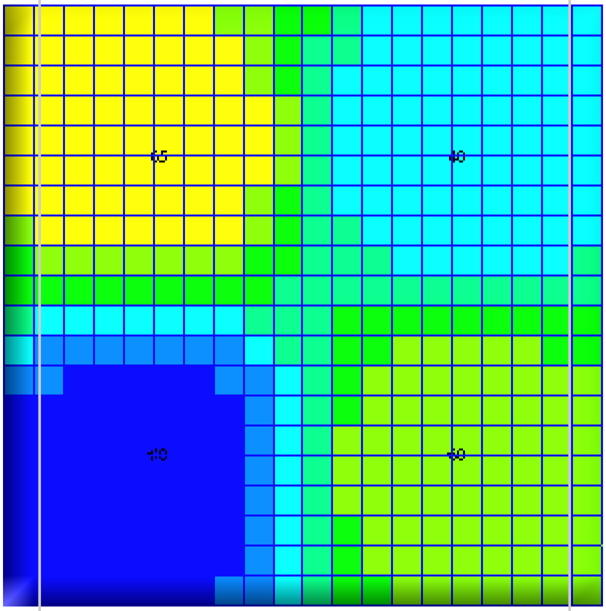
1. Open and display model **20x20x1.mdl**.
2. Choose **Estimation > Inverse distance**.
3. Enter the information on each form as in the previous task, except for the last form. Instead of an **Inverse Distance Power** of 2, enter 3, and click **Apply**.



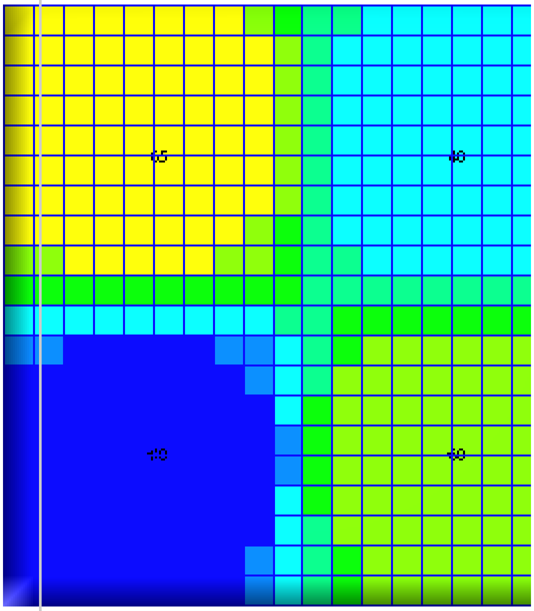
4. Display the model coloured by the **isotropic** attribute, as described in the previous task.
5. Repeat steps 2, 3, and 4 using inverse distance powers of 4 and 10.



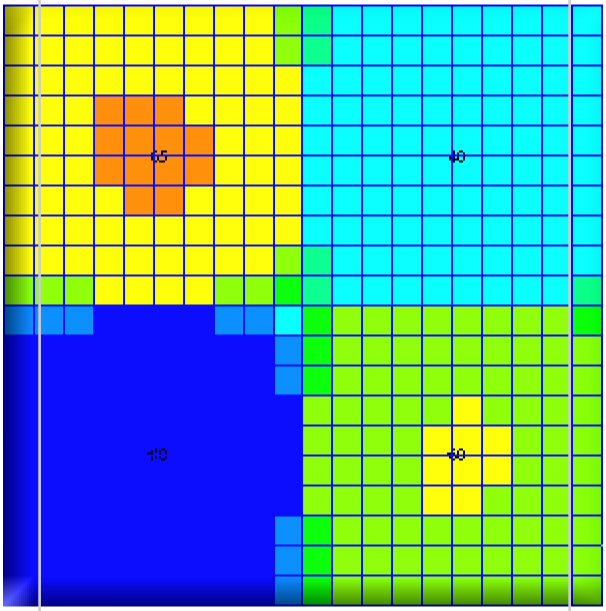
Power of 2



Power of 3



Power of 4

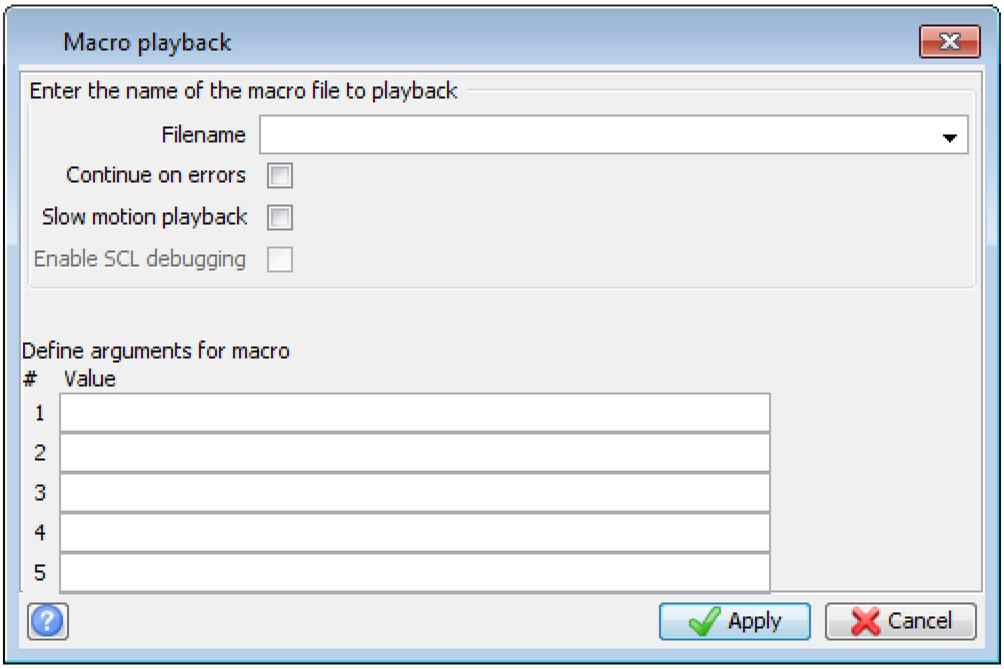


Power of 10

6. Choose **Block Model > Close**.
7. On the *Exit block model* form, click **Save and exit**, and then click **Apply**.

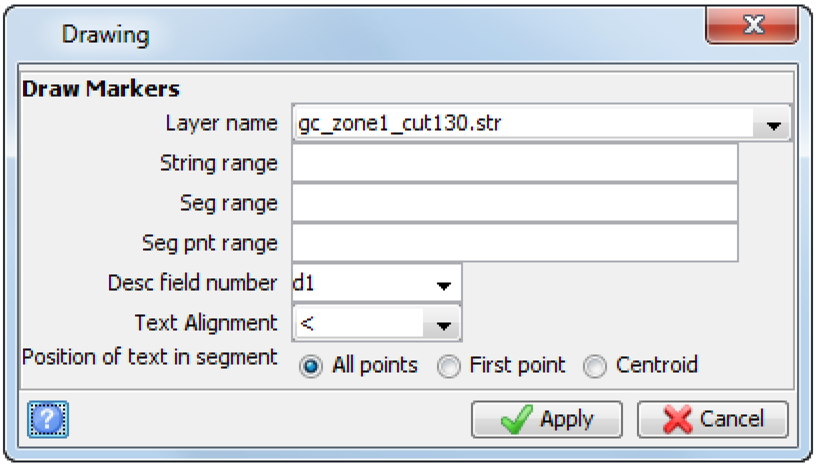
Note: To see all of the steps performed in this task:

1. Run **2d_08a_id_power.tcl**
2. Use the **Macro playback** button and select **Slow motion playback** to display each form.

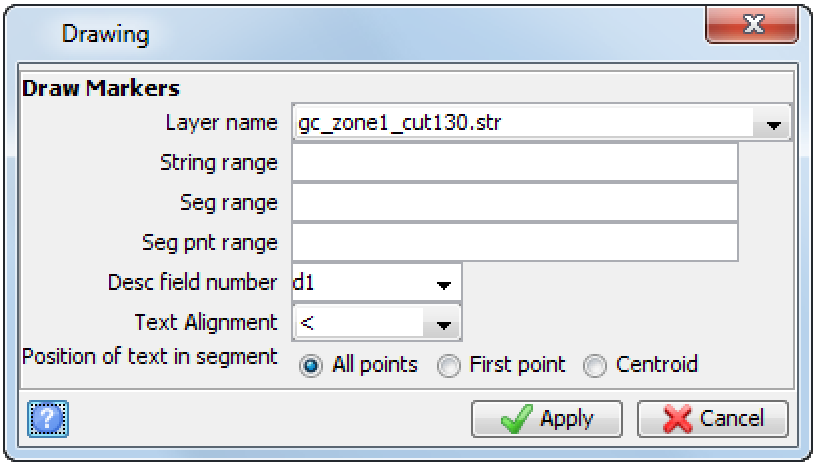


Task: Perform inverse distance estimation on grade control data

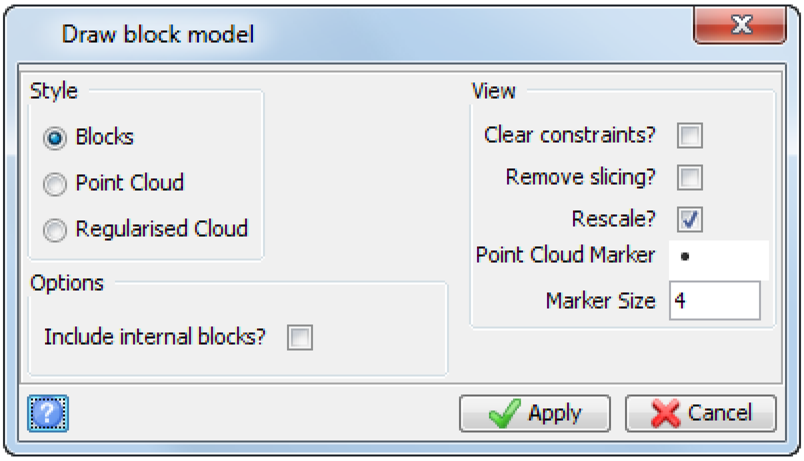
1. Click **Reset graphics** .
2. Open **gc_zone1_cut130.str** in **Graphics**.
3. Choose **Display > Point > Markers**.
4. Enter the information as shown, and click **Apply**.



5. Choose **Display > Hide strings > As lines**.
6. Enter the information as shown, and click **Apply**.

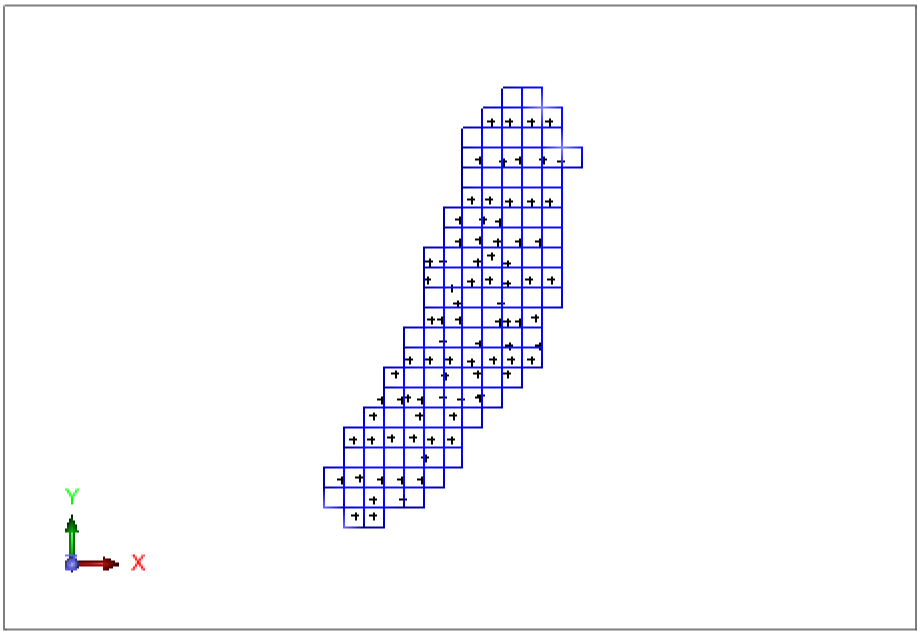


7. Open **gc130.mdl**.
8. Choose **Display > Display Block model**.
9. Enter the information as shown, and click **Apply**.

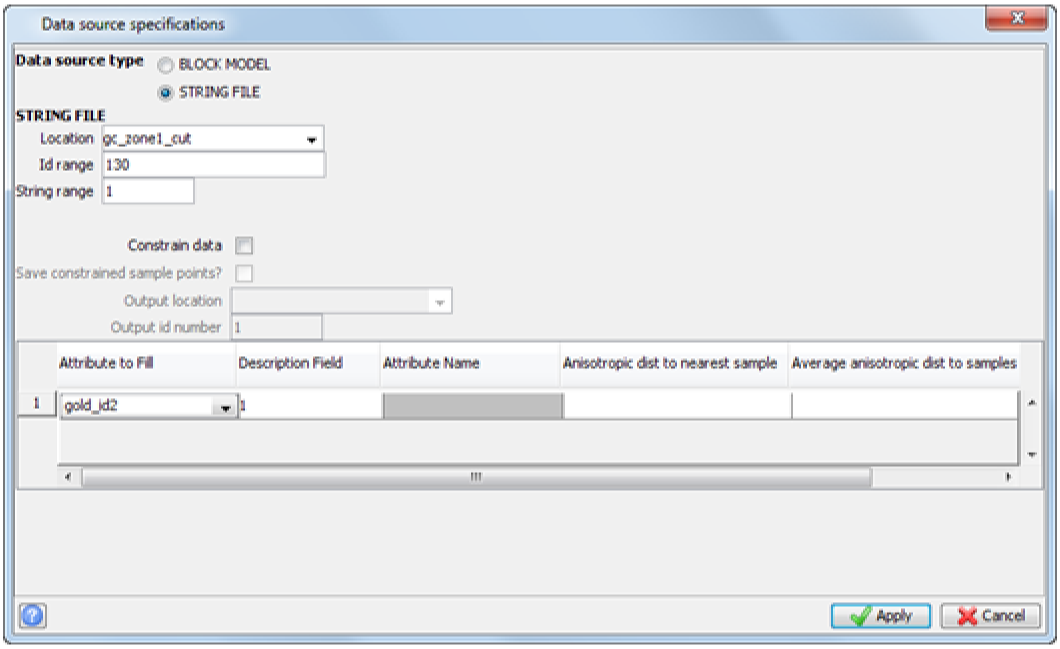


10. Open **gc_orezone1.con** in **Graphics**.
11. Click **Faces off**.

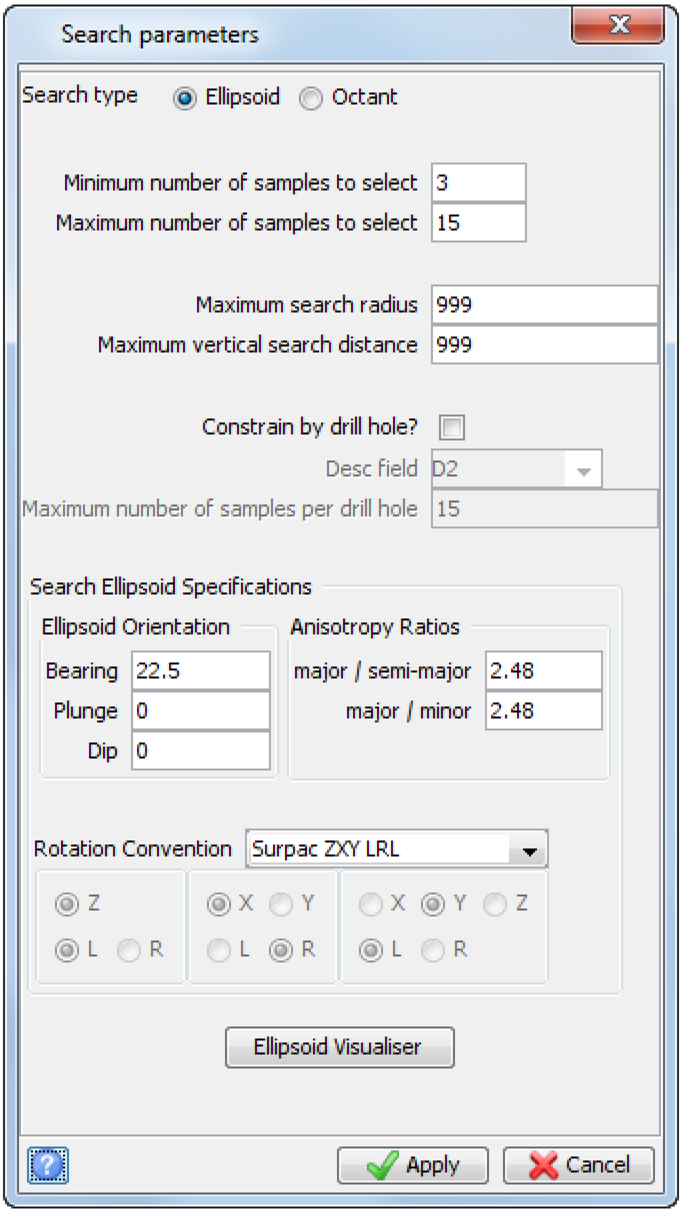
The data and model are displayed.



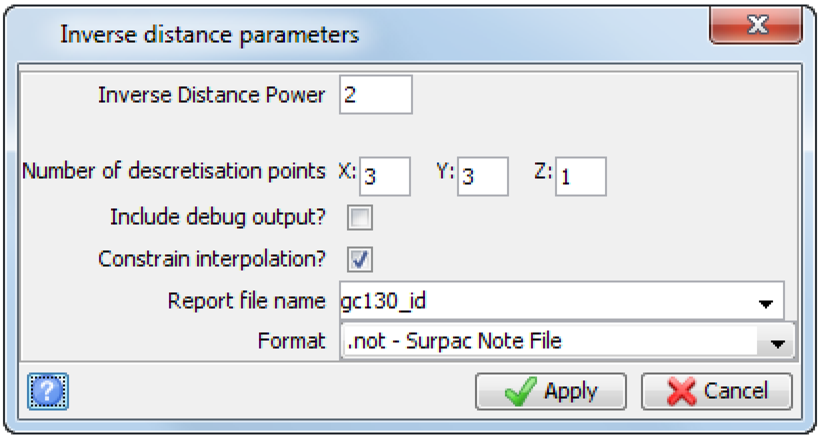
12. Choose **Estimation > Inverse distance**.
13. Enter the information as shown, and click **Apply** on the following four forms.



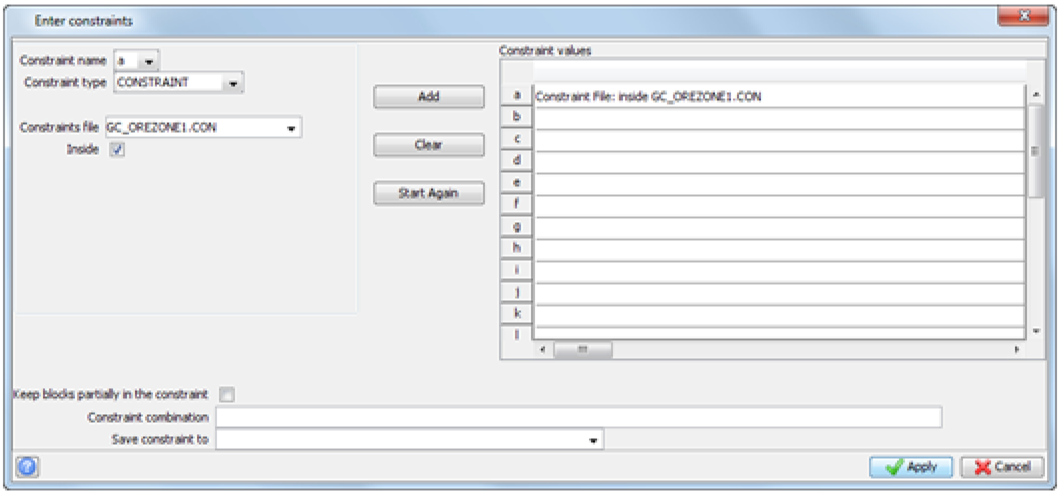
Note: The **Anisotropic distance**, **Average anisotropic distance**, and **Number of samples** fields are optional.



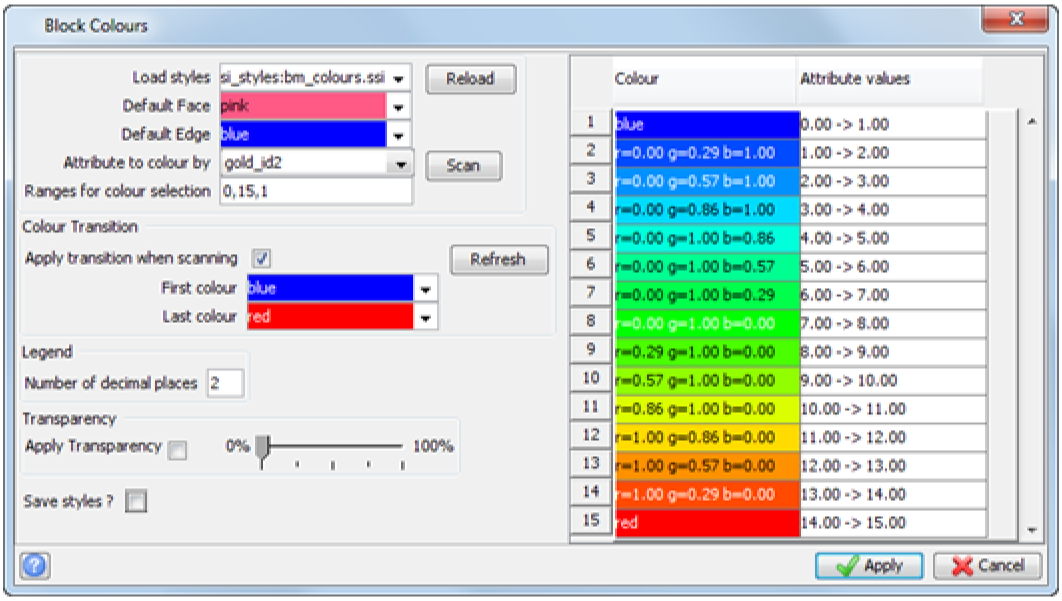
Note: The major axis and anisotropy ratios from the primary variogram map exercise are used here. The major/minor ratio must be equal to or greater than the major/semi-major ratio, even for 2D estimation.



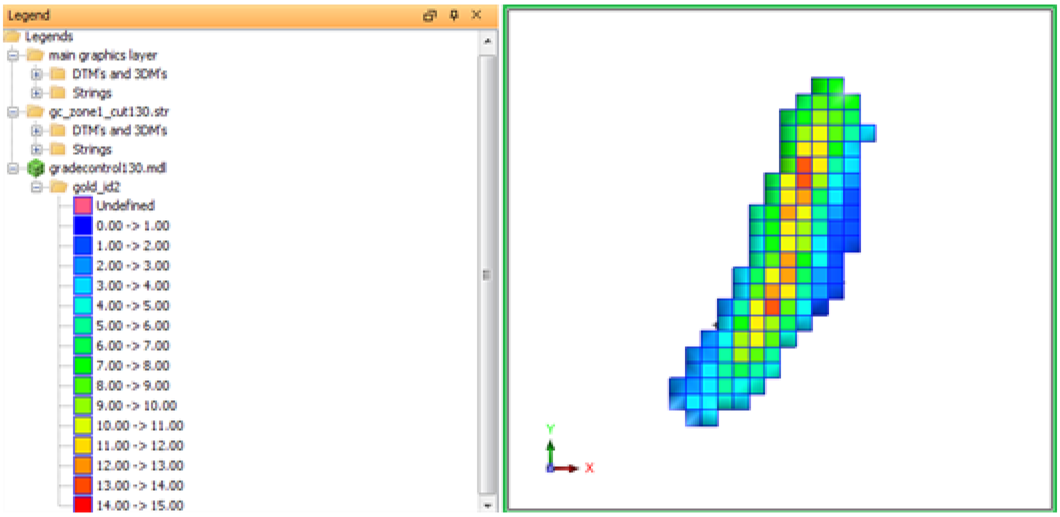
📝 **Note**: In order to restrict the blocks to the domain "Zone 1", you must select **Constrain interpolation**.



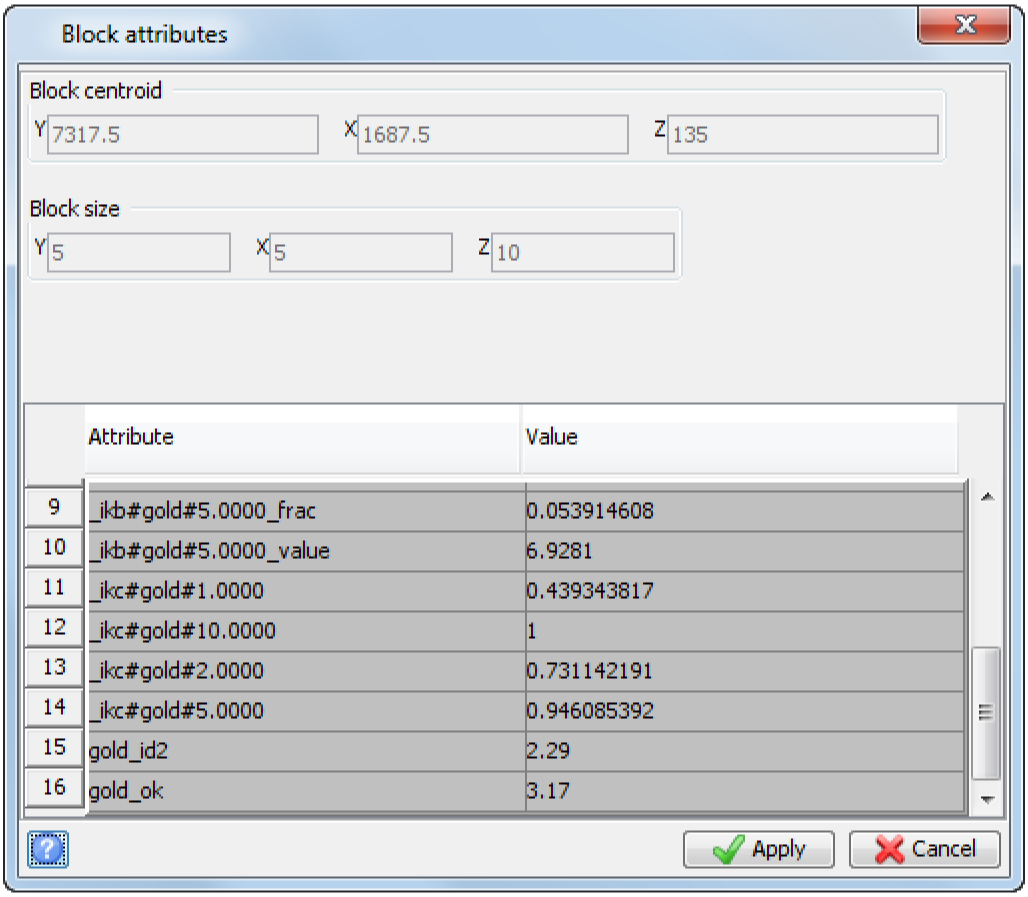
14. Choose **Display > Colour model by attribute**.
15. In the **Attribute to colour by** field, select **gold_id2**, click **Scan**, and then for the **Range for colour selection** enter **0,15,1** and click **Refresh**.
16. Click **Apply**.



17. Display the legend on the **Legend** tab.
    The data and model are displayed:



18. Choose **Attribute > View attributes for one block**.
19. Click any block.
    The value estimated for the block is displayed.



20. Click **Apply**.
21. Choose **Block Model > Close**.
22. On the *Exit block model* form, click **Save and exit**, and then click **Apply**.

Note: To see all of the steps performed in this task, run **2d_08b_inverse_distance.tcl**.

Ordinary kriging

Overview

An important end product of a geostatistical evaluation is a “model”, or a set of points in space which contain estimated values. One of the methods for estimating values at points in a model is known as ordinary kriging. The main advantage of ordinary kriging is that it uses a variogram in its estimation, where inverse distance estimation does not.

You will learn about:

- the impact of the nugget effect
- the impact of the range
- the impact of block discretisation

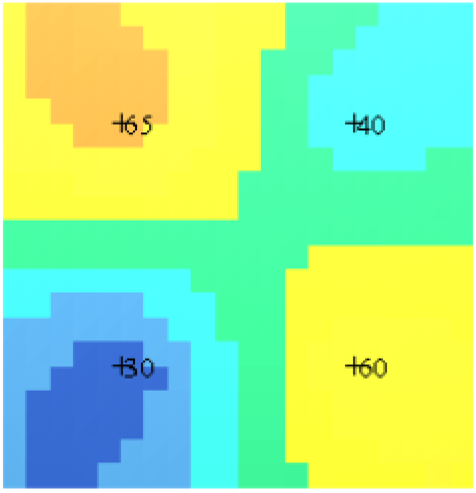
Requirements

In order to understand this information, you should understand the following concepts:

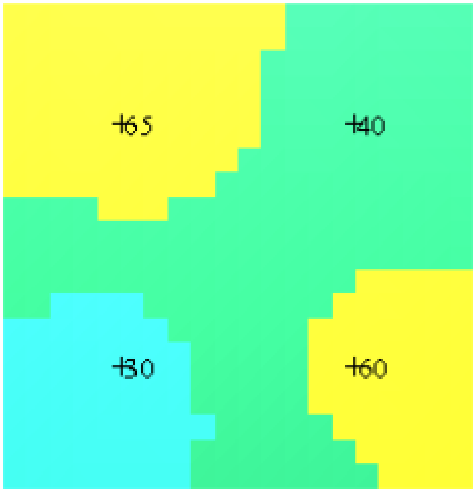
- Surpac string files
- Surpac block models
- isotropy and anisotropy
- anisotropy ellipsoid
- the parameters which define an anisotropy ellipsoid

Impact of the nugget

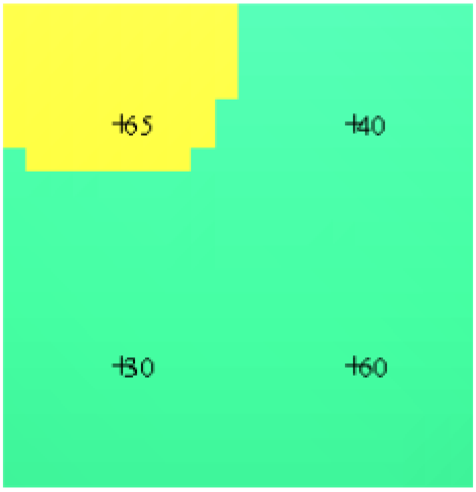
When you use ordinary kriging to estimate values in a block model, the relative percentage of the nugget can have a significant impact on the end result. For example, the four models shown below were created from the same data set, but different nugget effects were used.



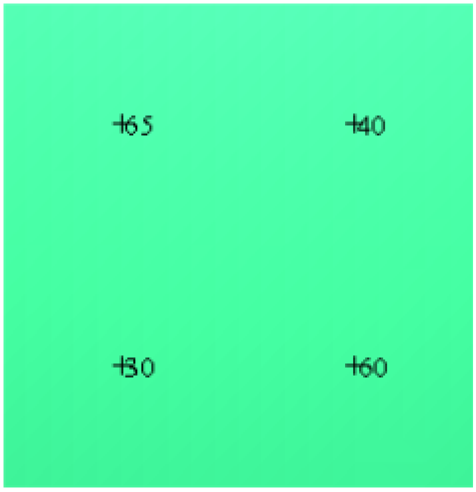
zero nugget



25% nugget



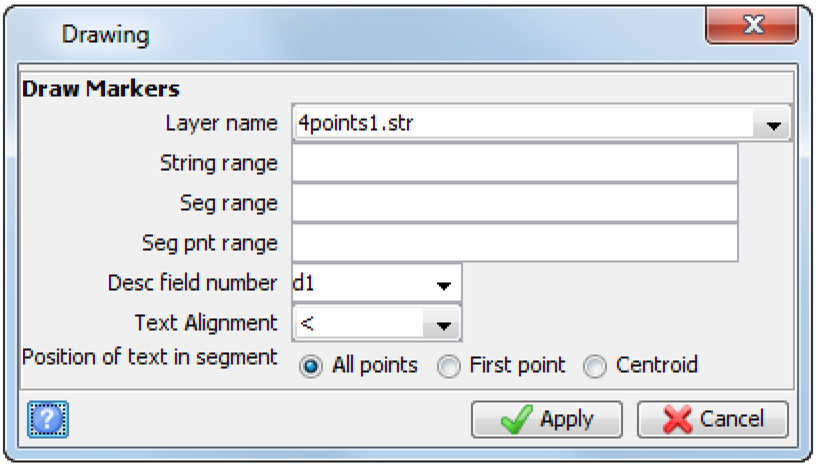
50% nugget



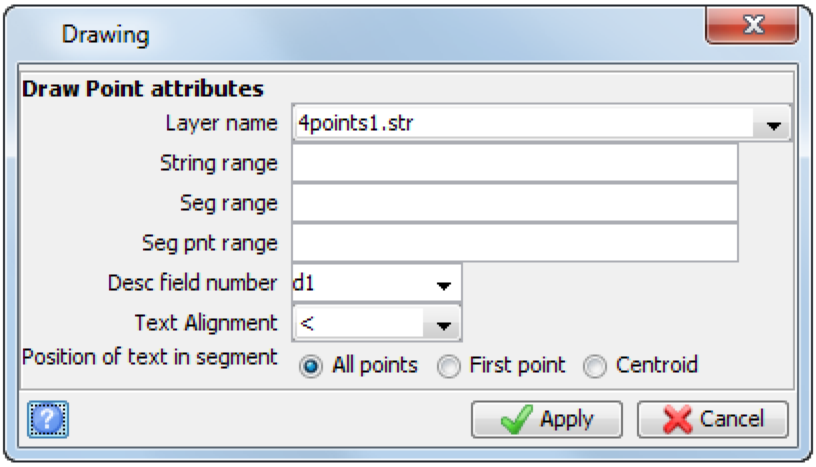
100% nugget

Task: Perform ordinary kriging estimation using a zero nugget

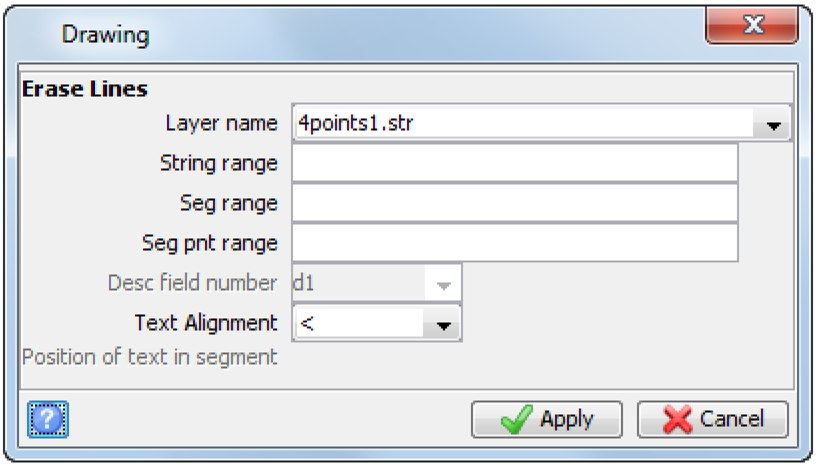
1. Open **4points1.str** in **Graphics**.
2. Choose **Display > Point > Markers**.
3. Enter the information as shown, and click **Apply**.



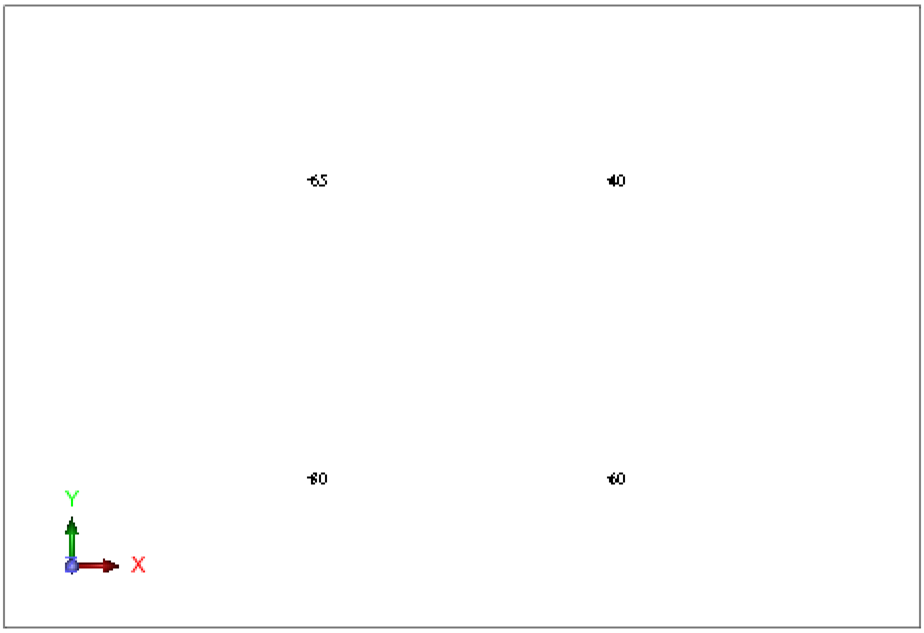
4. Choose **Display > Point > Attributes**.
5. Enter the information as shown, and click **Apply**.



6. Choose **Display > Hide strings > As lines**.
7. Enter the information as shown, and click **Apply**.



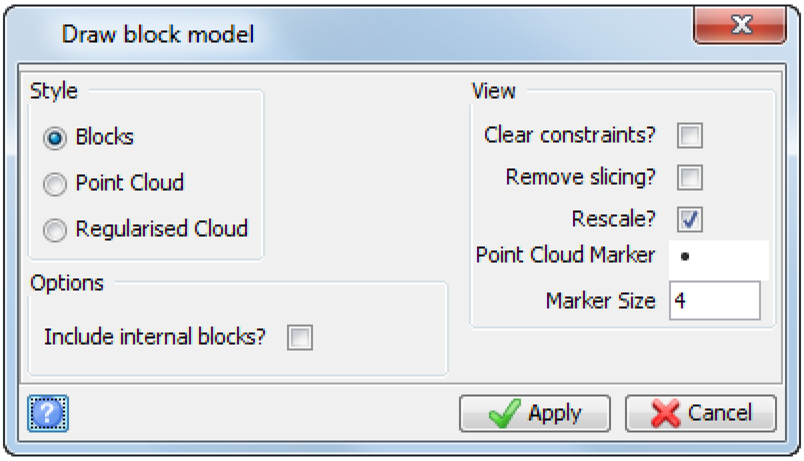
The points are displayed as follows.



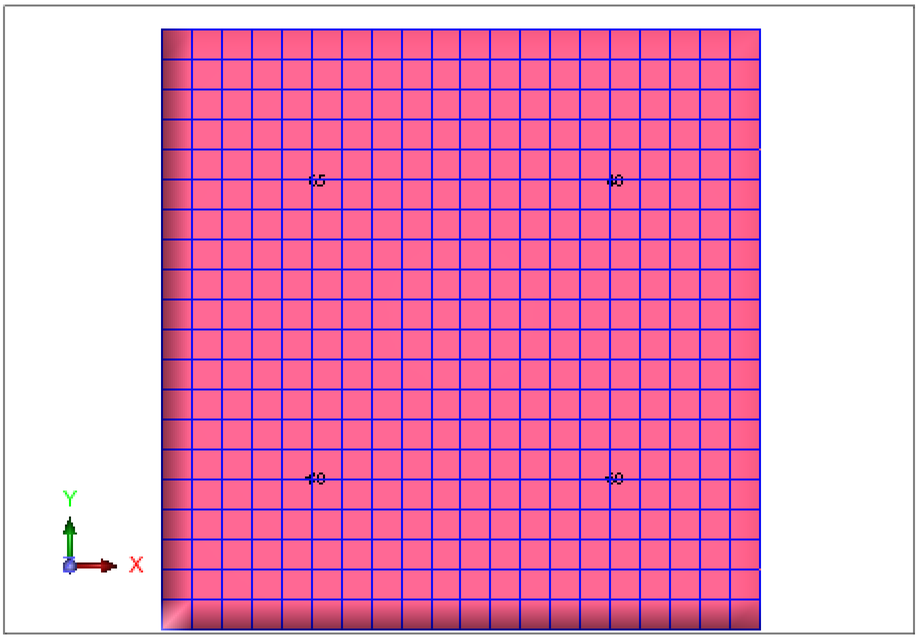
8. Right-click in the empty area to the right of the menus and choose **Menus > Block Model**.

   Note: All menu commands below here refer to the **Block Model** menu bar.

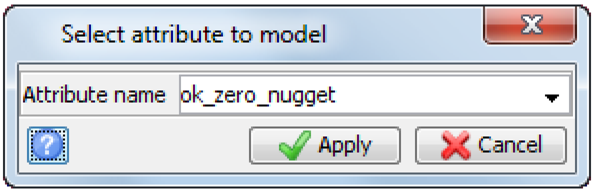
9. Open the model **20x20x1.mdl**.
10. Choose **Display > Clear model colours**.
11. Choose **Display > Display block model**.
12. Enter the information as shown, and click **Apply**.

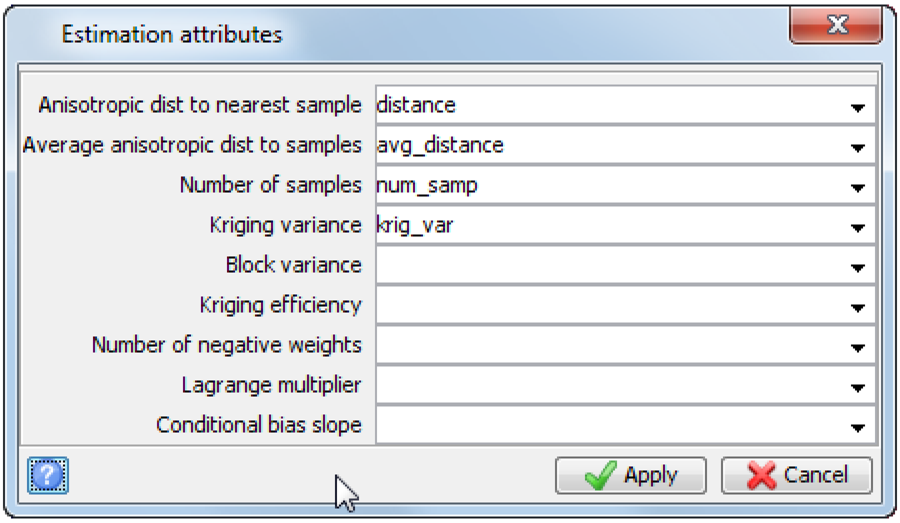


The model and data are displayed:

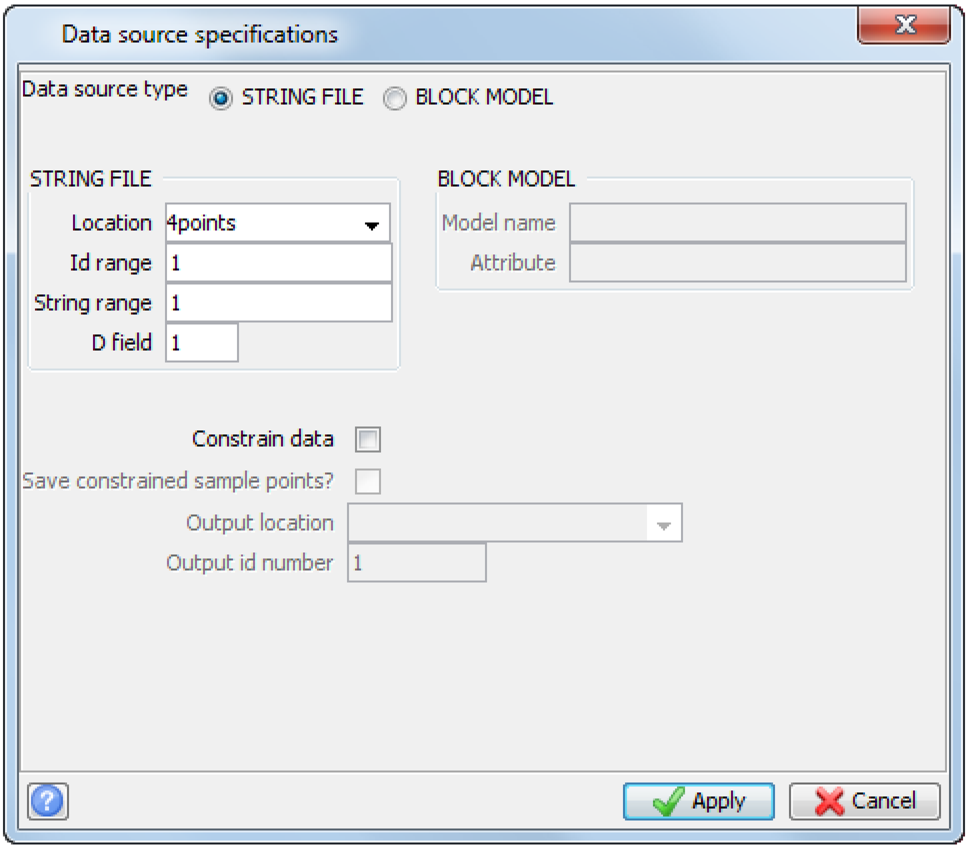


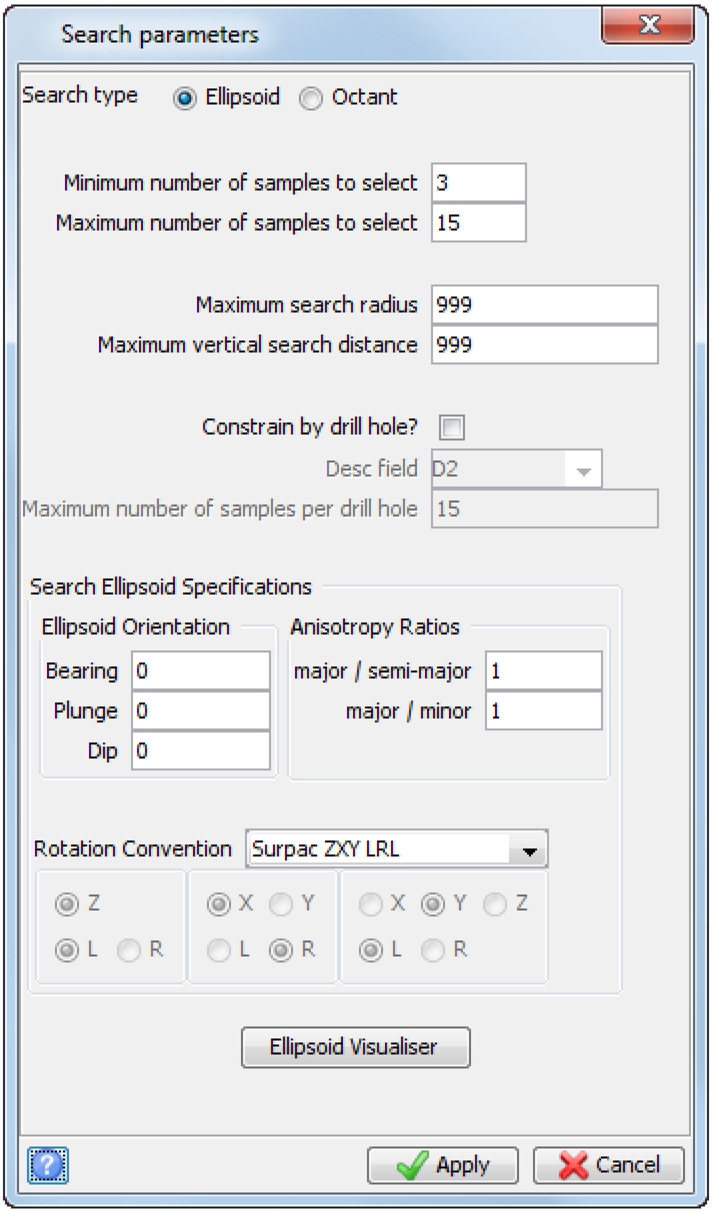
13. Choose **Estimation > Ordinary kriging**.
14. Enter the information as shown, and click **Apply**, on each of the following five forms.



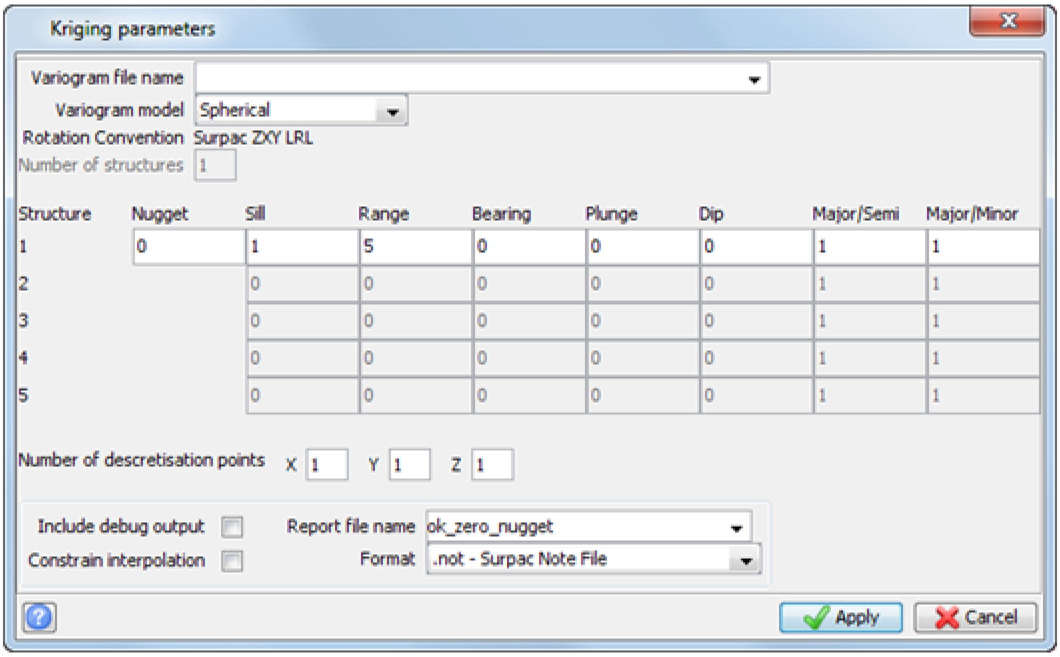


Note: All parameters on this form are optional.



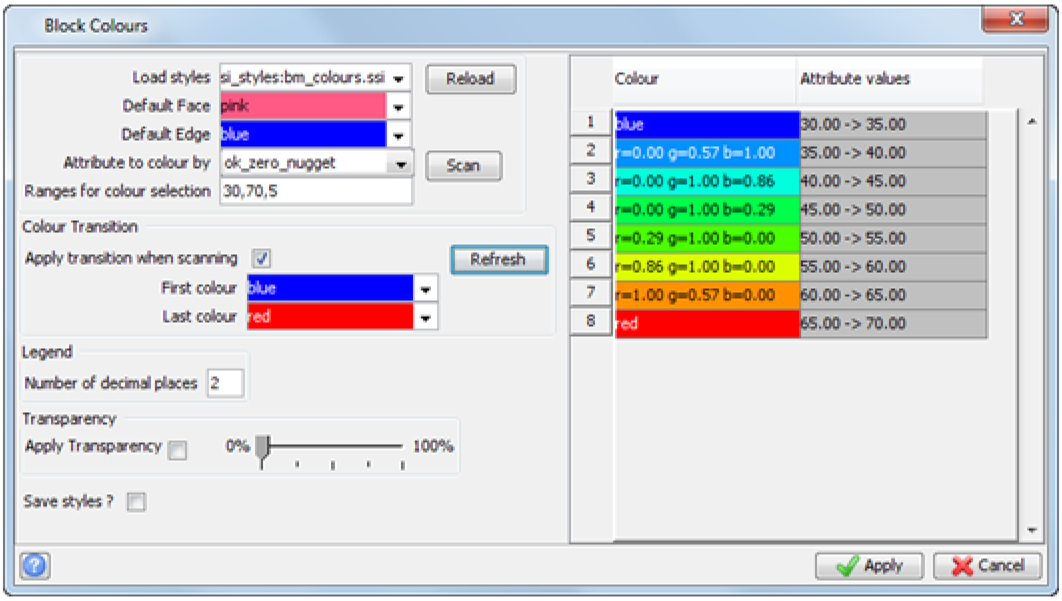


Note: By setting both anisotropy ratios to 1, an **isotropic** estimation will be performed.

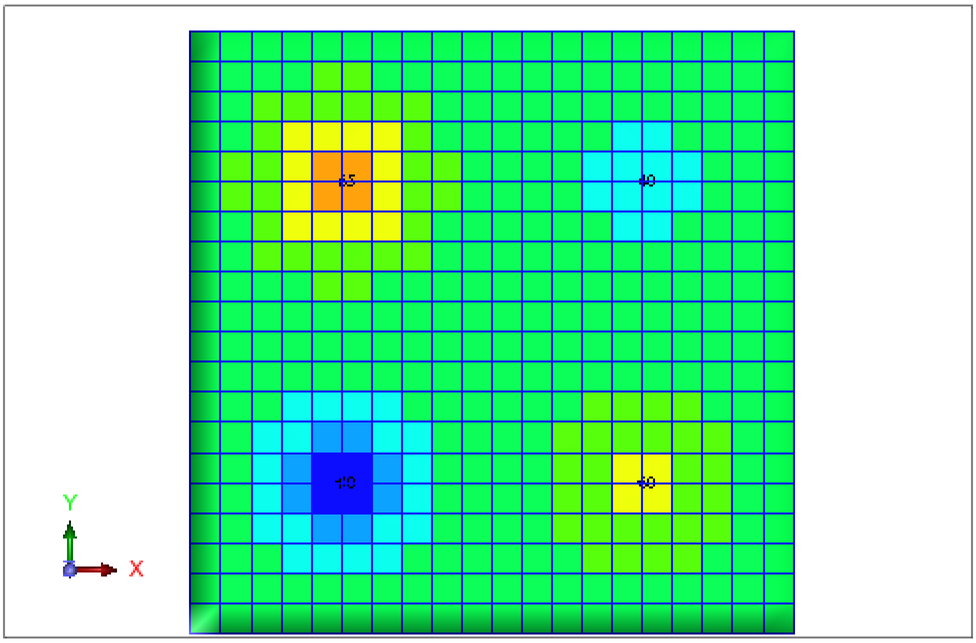


Note: The "nugget" effect is the ratio of the nugget / (total of all sill data). In this case, 0/1 = 0 nugget.

15. Choose **Display > Colour model by attribute**.
16. In the **Attribute to colour by** field, select **ok_zero_nugget** , and click **Scan**, then enter the **Ranges for colour selection** of **30,70,5** and click **Refresh**.
17. Click **Apply**.



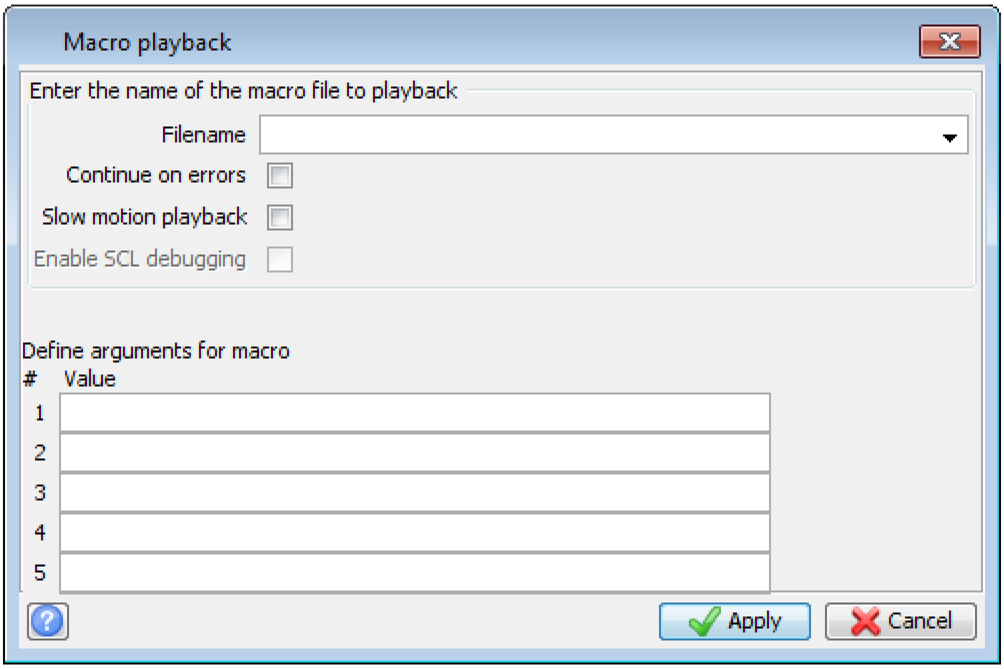
The model, as estimated by ordinary kriging using a zero nugget effect, is displayed.



18. Choose **Block Model > Close.**
19. On the Exit block model form, click **Save and exit**, and then click **Apply**.

To see all of the steps performed in this task: **Note**:

1. Run **2d_09a_ordinary_kriging_nugget.tcl**.
2. Use the **Macro playback** button and select **Slow motion playback** to display each form.

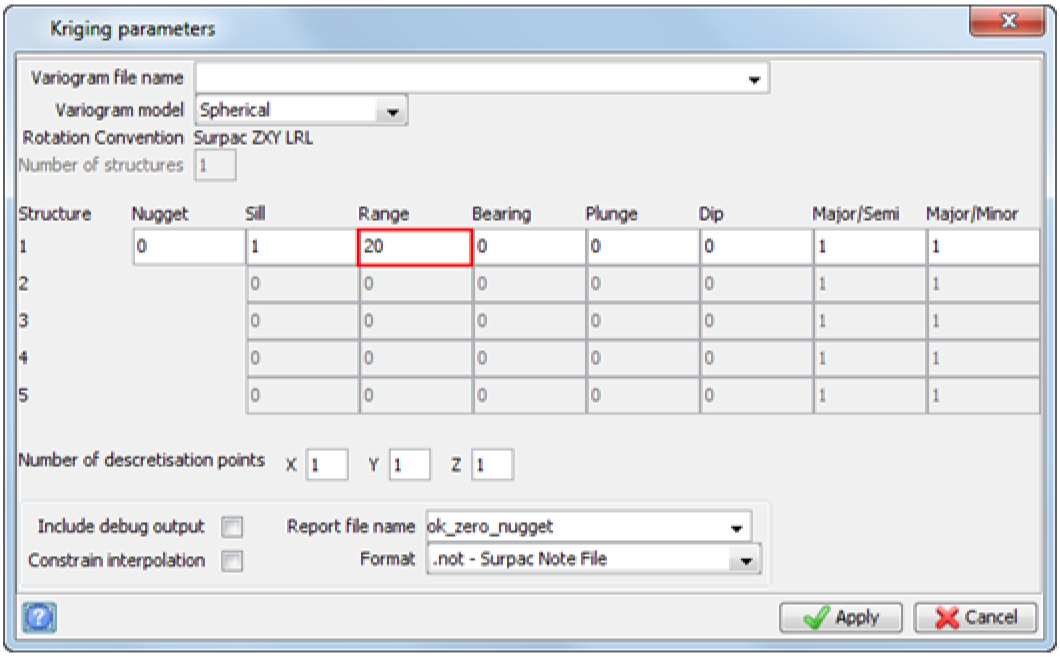


Effect of the range

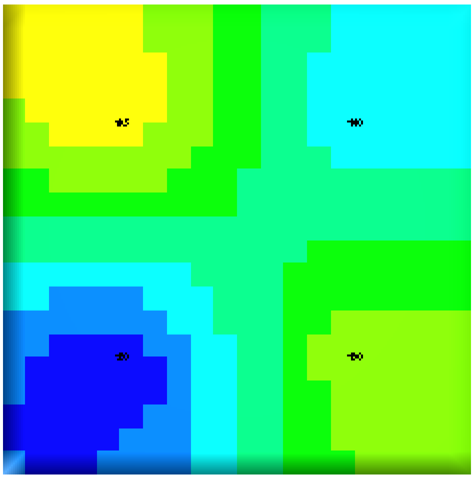
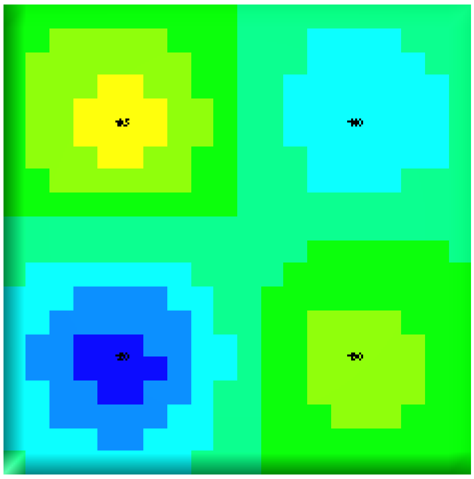
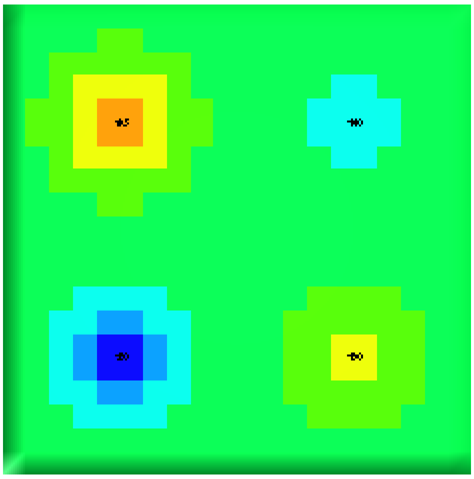
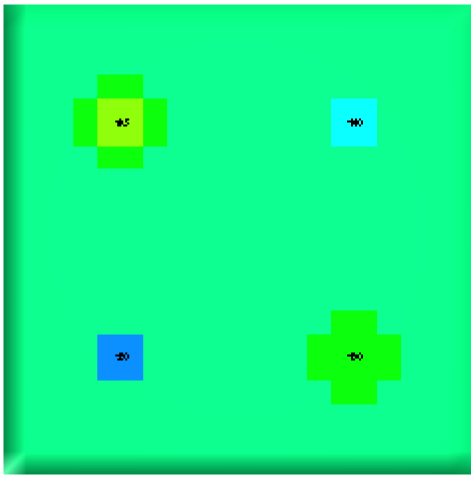
When using ordinary kriging to estimate values in a block model, the range of the variogram relative to sample spacing can have a significant impact on the end result.

Task: View the effect of the range

1. Open the model **20x20x1.mdl**.
2. Choose **Estimation > Ordinary kriging**.
3. Enter the information on each form as in step 14 of the previous task, except for the last form, where you enter a **Range** of 20, and click **Apply**.

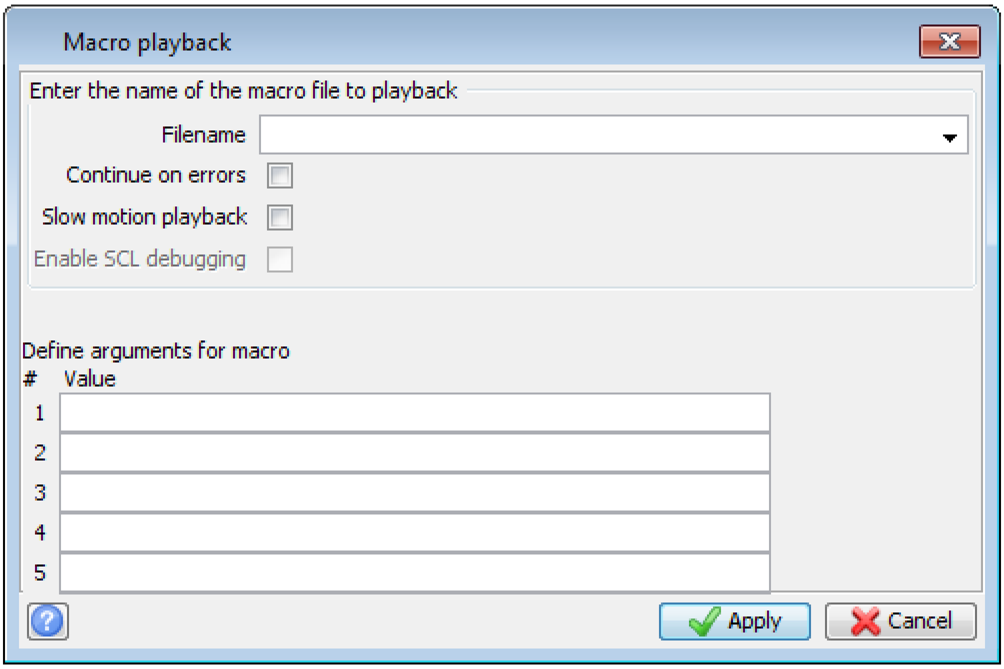


4. Display the model coloured by the **ok_zero_nugget** attribute, as described in steps 15 to 17 of the previous task
5. Repeat steps 2, 3, and 4 using ranges of 10, 5, and 2.5.

	
Range = 20 (2x sample spacing)	Range = 10 (1x sample spacing)
	
Range = 5 (0.5x sample spacing)	Range = 2.5 (0.25x sample spacing)

Note: To see all of the steps performed in this task:

1. Run **2d_09b_ordinary_kriging_range.tcl**.
2. Use the **Macro playback** button and select **Slow motion playback** to display each form.

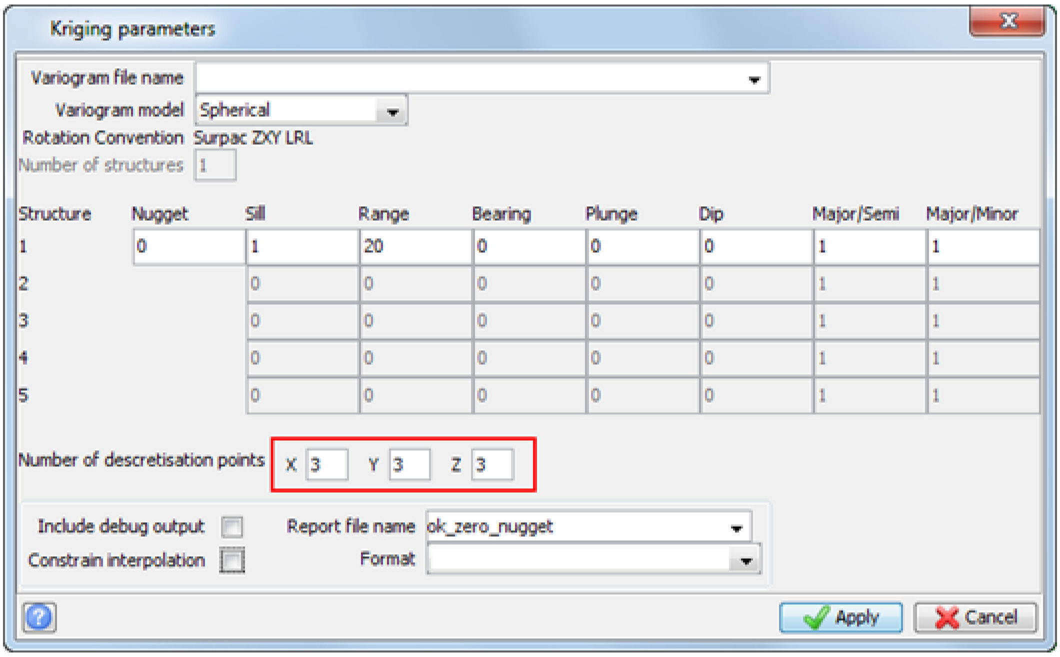


Effect of discretisation

When using ordinary kriging to estimate values in a block model, the number of discretisation points can have a significant impact on kriging variance. Kriging variance is inversely proportional to the quality of the estimate. That is, high kriging variance = low quality, and low kriging variance = higher quality.

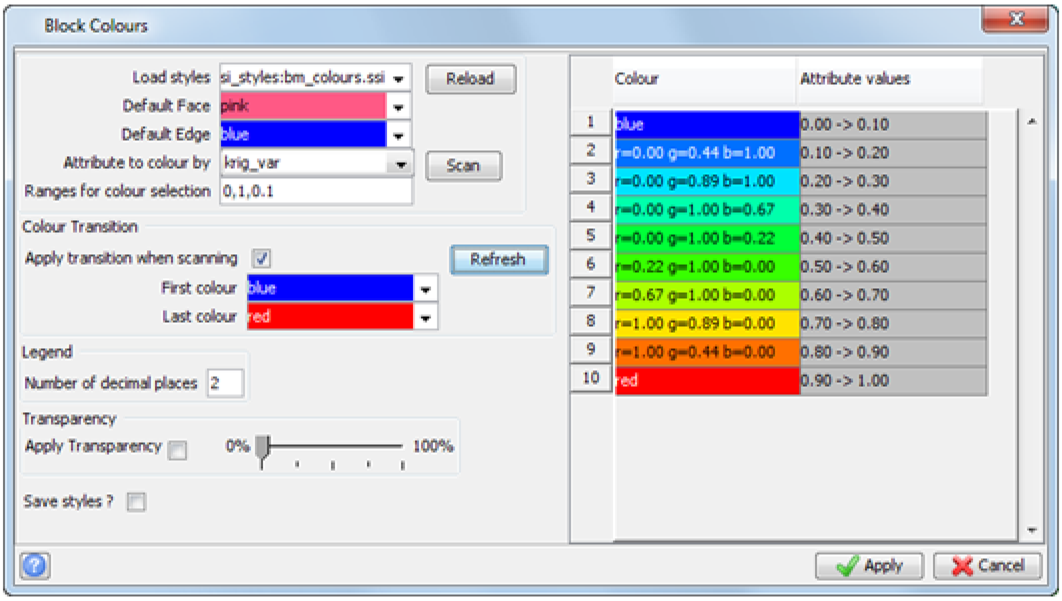
Task: View the effect of discretisation

1. Open the model **20x20x1.mdl**.
2. Choose **Estimation > Ordinary kriging**.
3. Enter the information on each form as for step 14 in the first task, except for the last form where you enter **Number of descretisation points** as X:3 Y:3 Z:3, and click **Apply**.

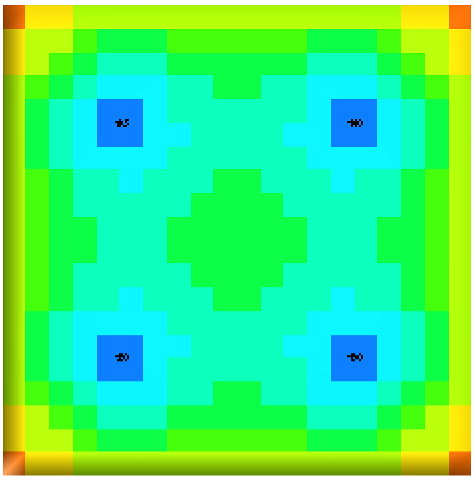


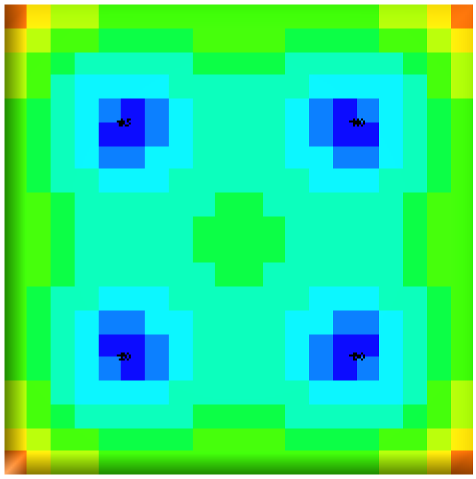
4. Choose **Display > Colour by Attribute**.

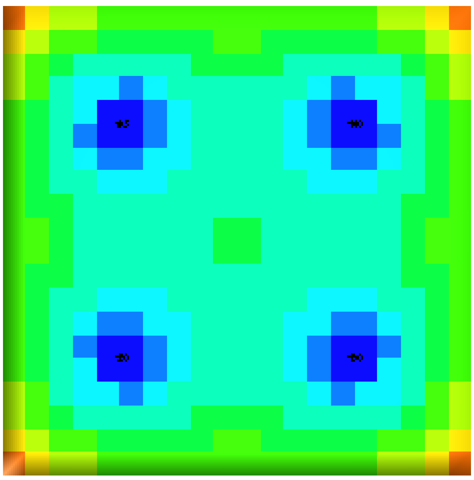
5. In the **Attribute to colour by** field, select **krig_var** , and click **Scan**, then set the **Range for colour selection** to **0,1,0.1**, and click **Refresh**.
6. Click **Apply**.

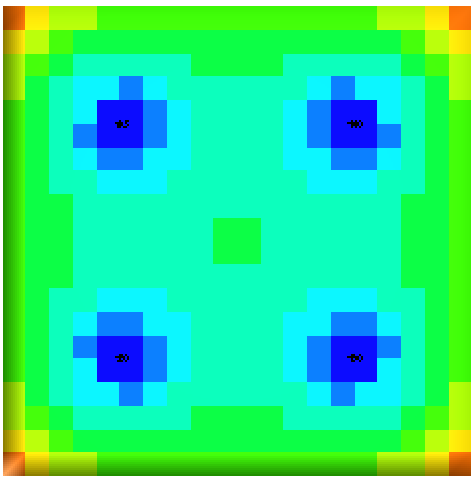


7. Repeat steps 2, 3, and 4 using discretisation of 1x1x1, 2x2x1 and 2x2x2.


1x1x1


2x2x1

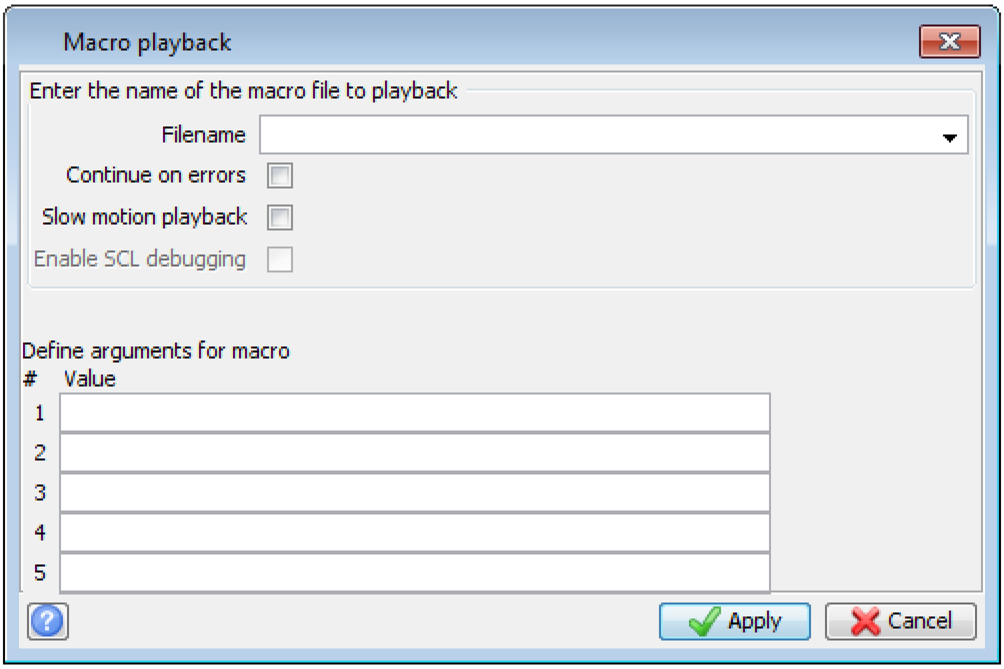

2x2x2


3x3x3

8. Choose **Block model > Close**.
9. On the *Exit block model* form, click **Exit without save**, and then click **Apply**.
10. Click **Reset graphics** .

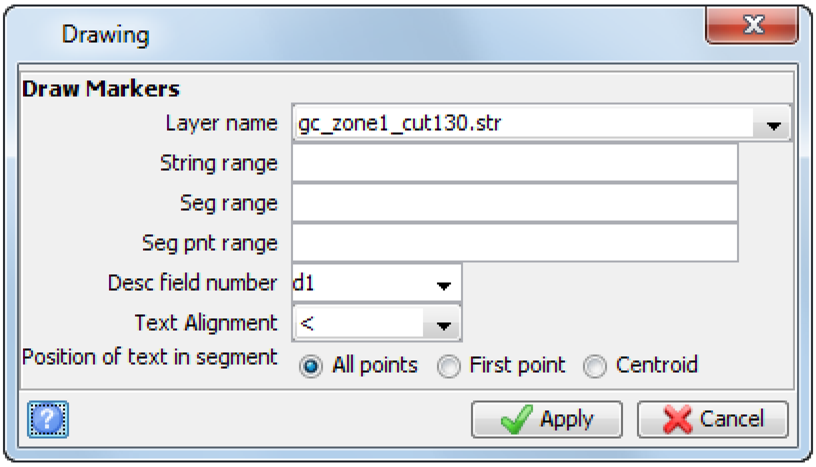
Note: To see all of the steps performed in this task:

1. Run **2d_09c_descretisation.tcl**.
2. Use the **Macro playback** button and select **Slow motion playback** to display each form.

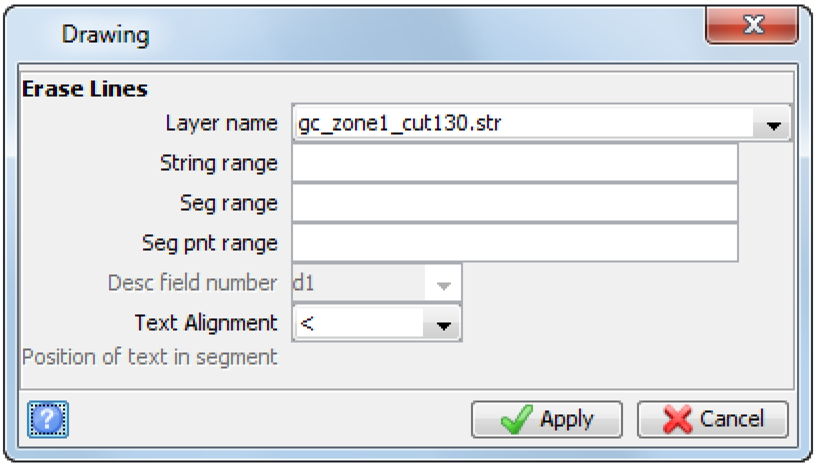


Task: Perform ordinary kriging estimation on grade control data

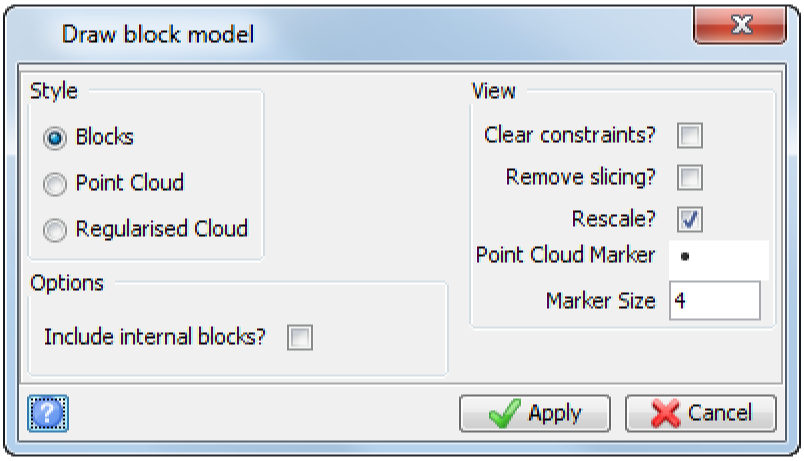
1. Open **gc_zone1_cut130.str** in **Graphics**.
2. Choose **Display > Point > Markers**.
3. Enter the information as shown, and click **Apply**.



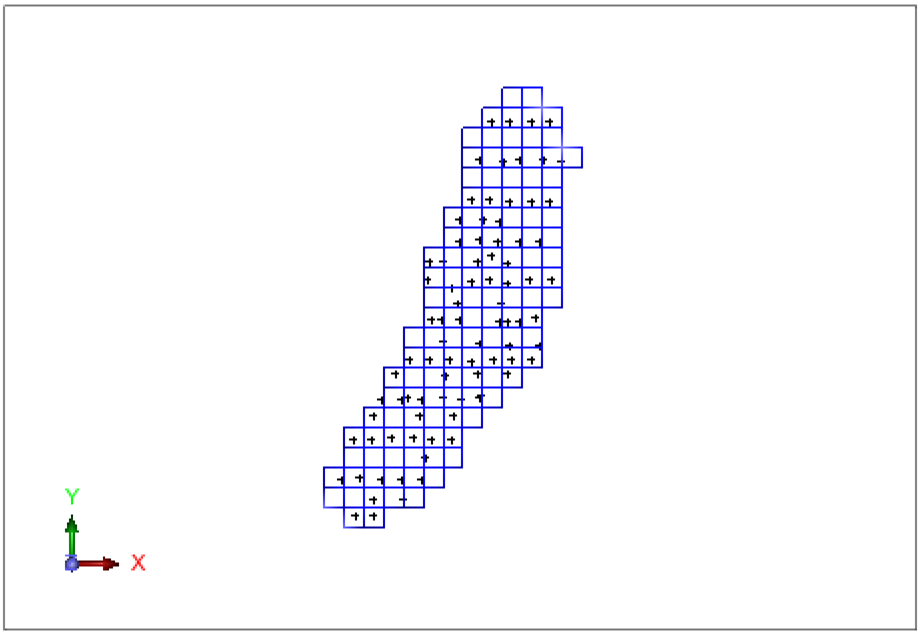
4. Choose **Display > Hide strings > As lines**.
5. Enter the information as shown, and click **Apply**.



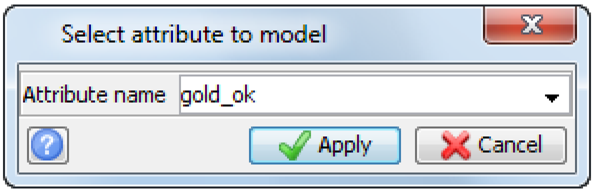
6. Open **gc130.mdl**.
7. Open **gc_orezone1.con** in **Graphics**.
8. Choose **Display > Block model**.
9. Enter the information as shown, and click **Apply**.

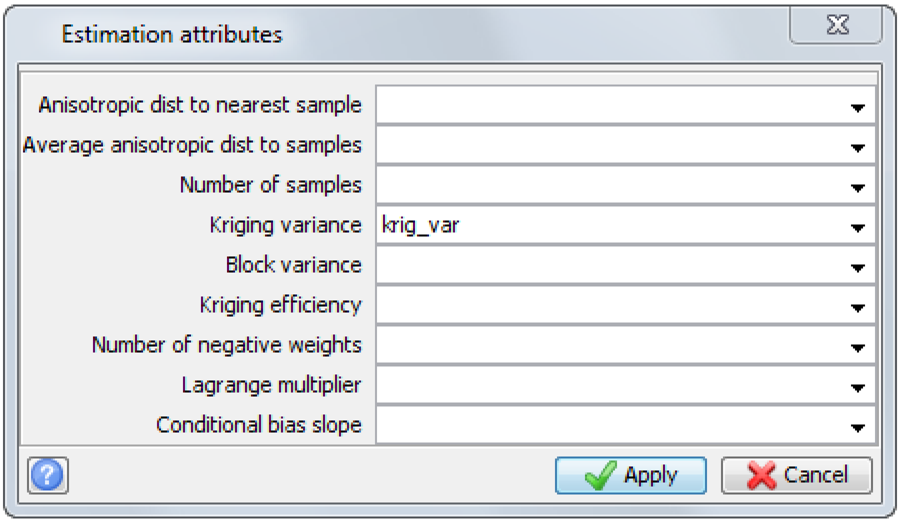


10. Click **Faces off** .
    The data and model are displayed, as shown.

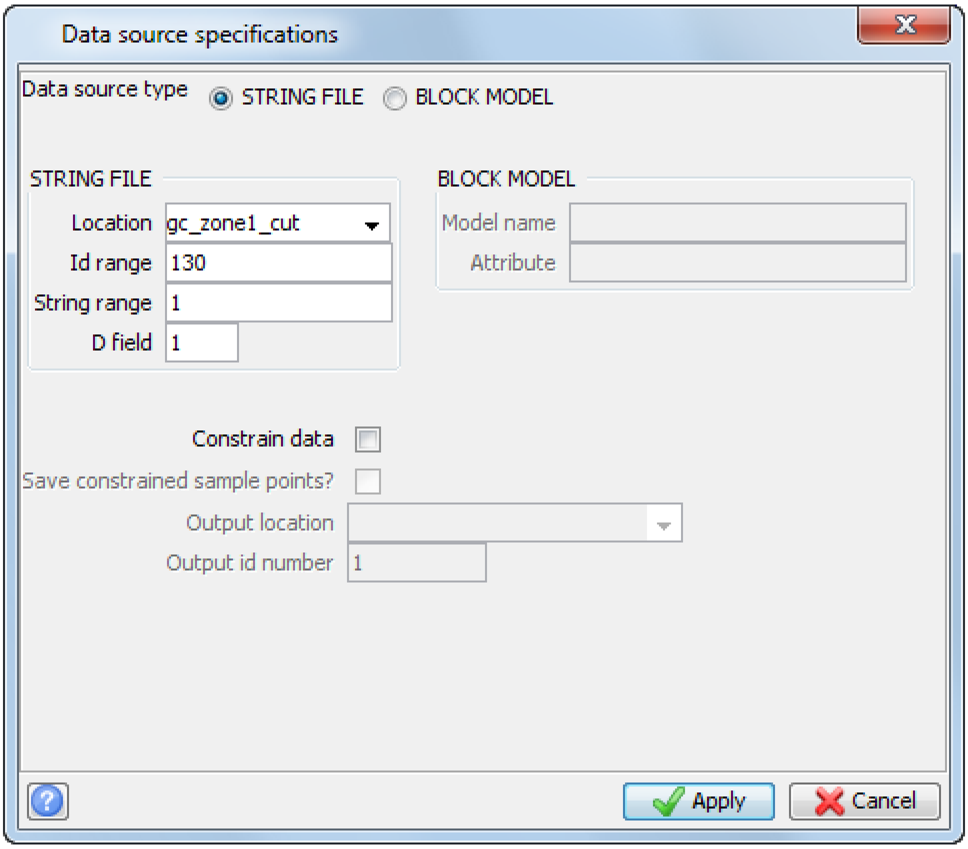


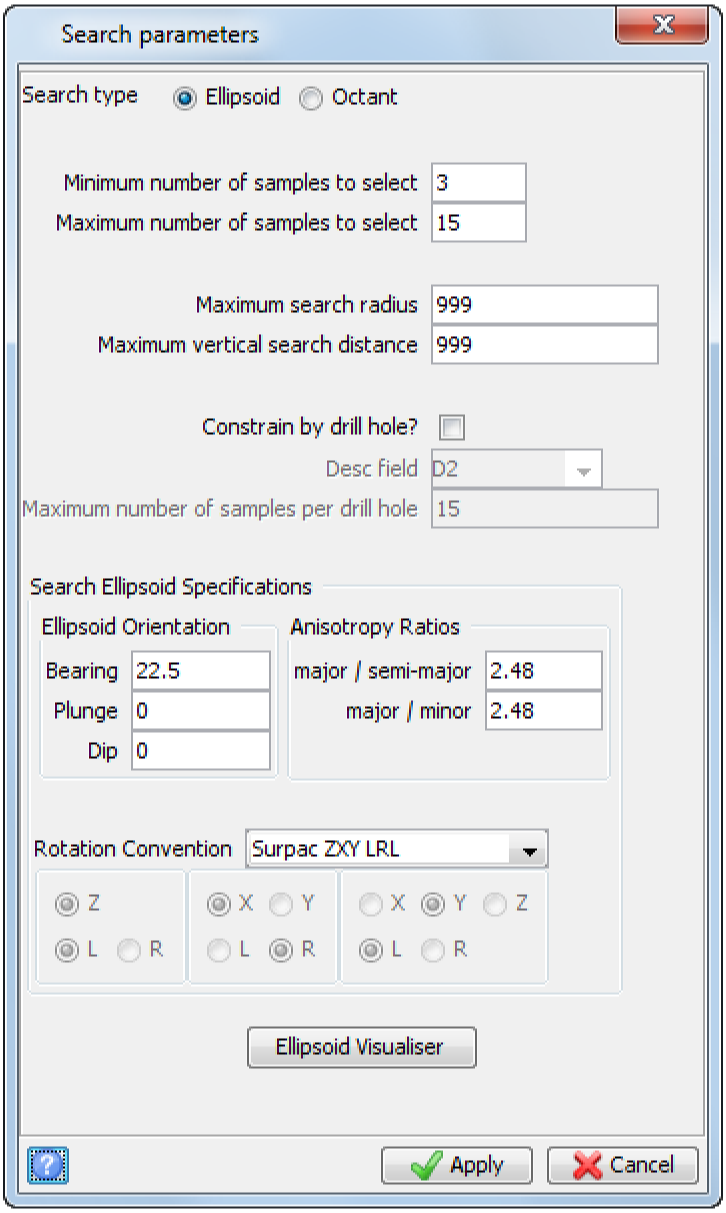
11. Choose **Estimation > Ordinary Kriging**.
12. Enter the information as shown, and click **Apply**, on each of the following six forms.



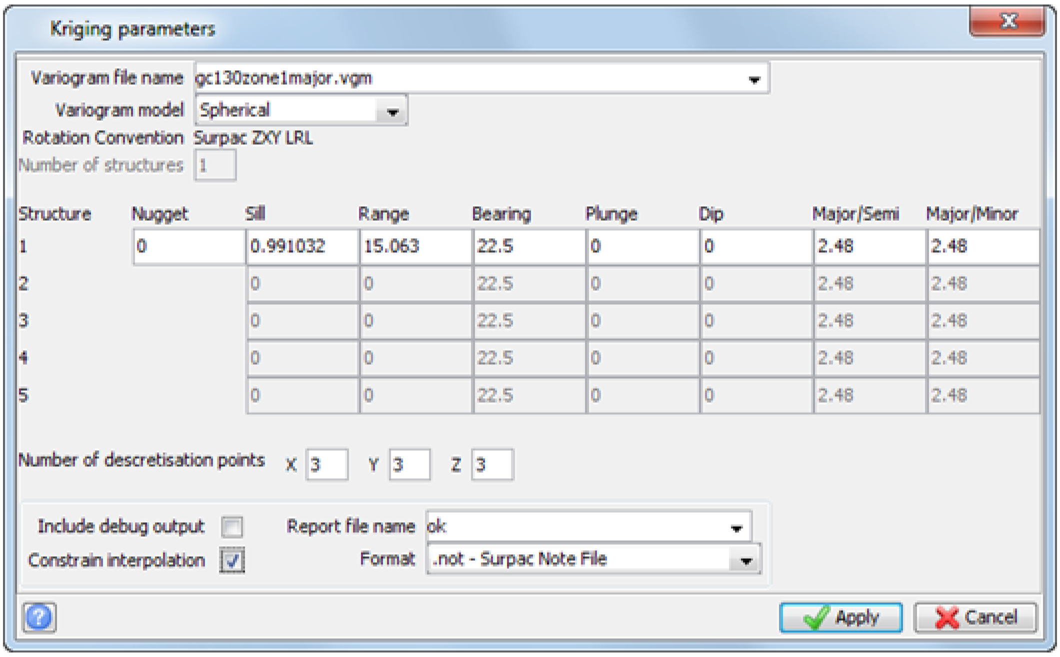


Note: All parameters on this form are optional.

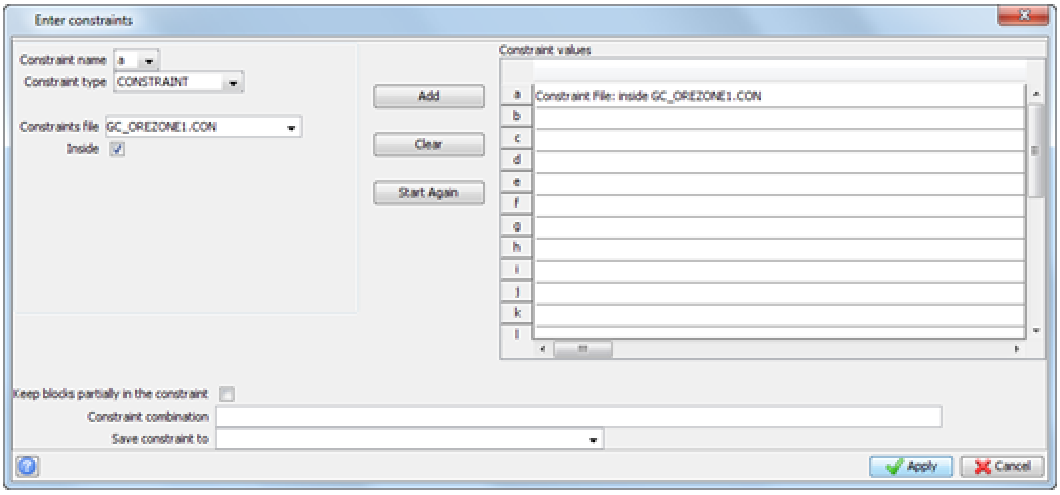




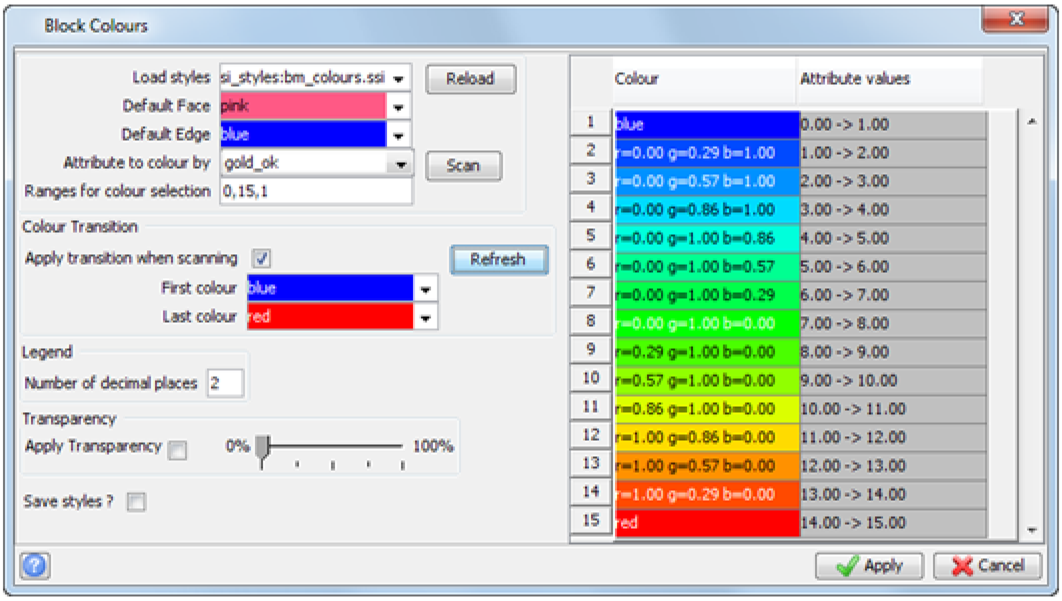
Note: The major axis and anisotropy ratios from the primary variogram map exercise are used here. The major/minor ratio must be equal to or greater than the major/semi-major ratio, even for 2D estimation.



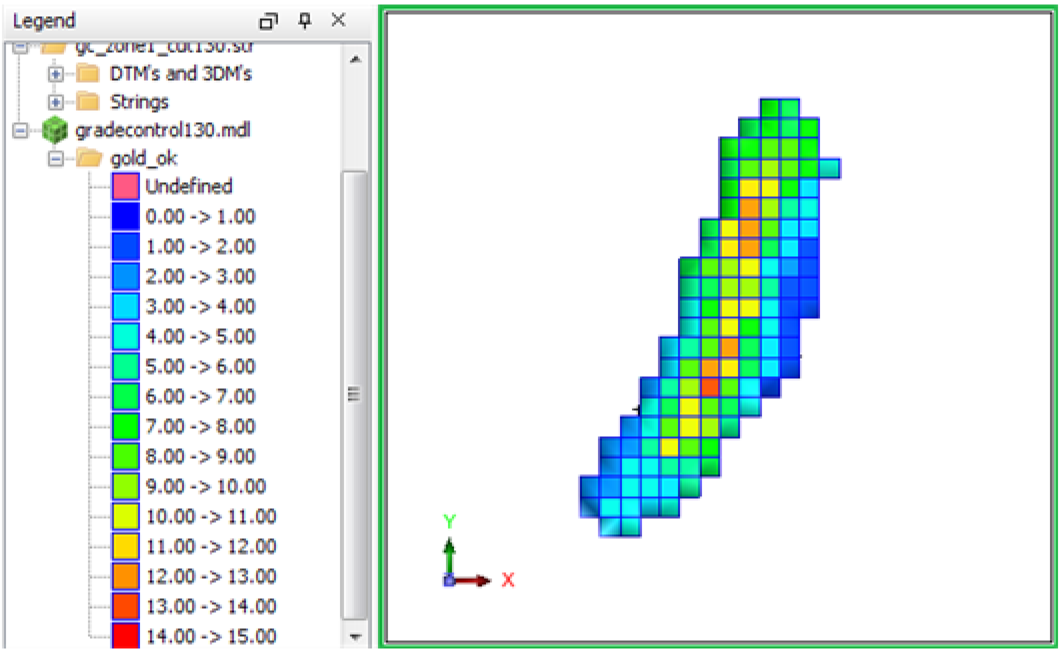
📝 **Note**: In order to restrict the blocks a domain of "Zone 1", the **Constrain interpolation** box must be selected.



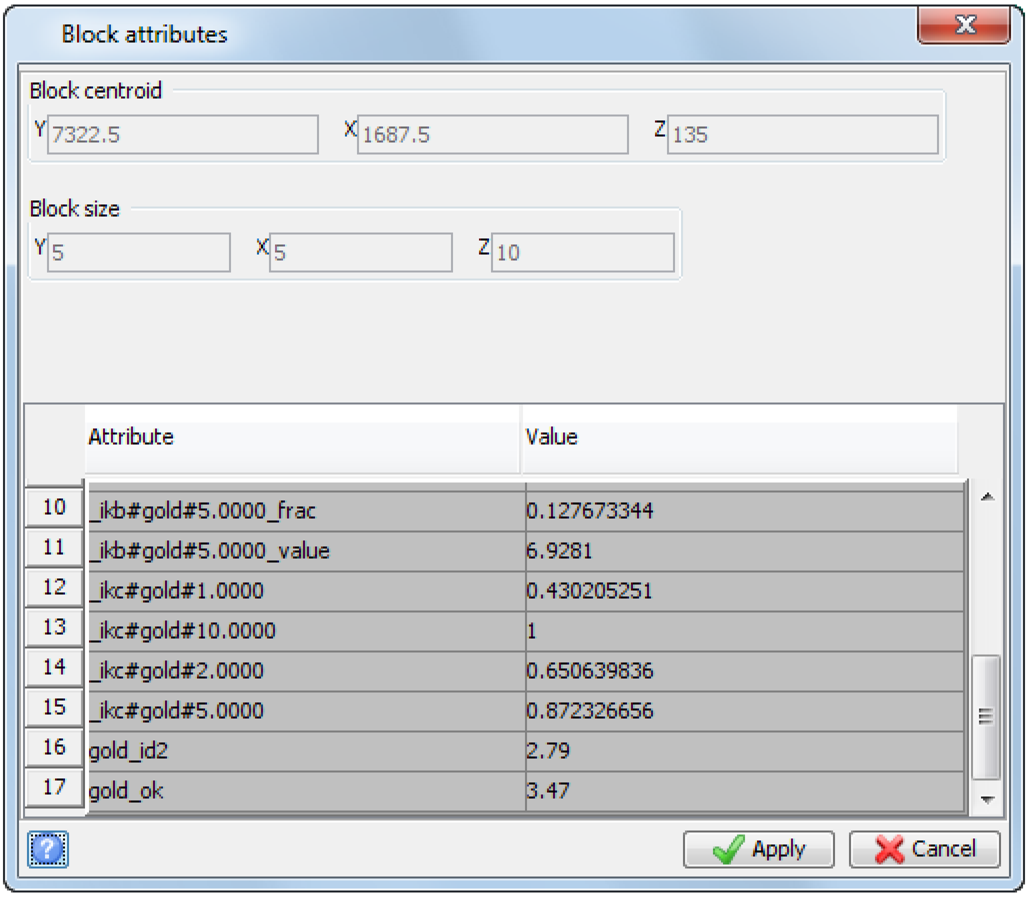
13. Choose **Display > Colour model by attribute**.
14. In the **Attribute to colour by** field, select **gold_ok**, and click **Scan**, then enter the **Range for colour selection** of **0,15,1** and click **Refresh**.
15. Click **Apply**.



16. Display the legend on the **Legend** tab.
    The data and model are displayed, as shown:



17. Choose **Attributes > View attributes for one block**.
18. Click any block.
    The value estimated for the block is displayed. Any other attributes previously estimated will also be displayed.

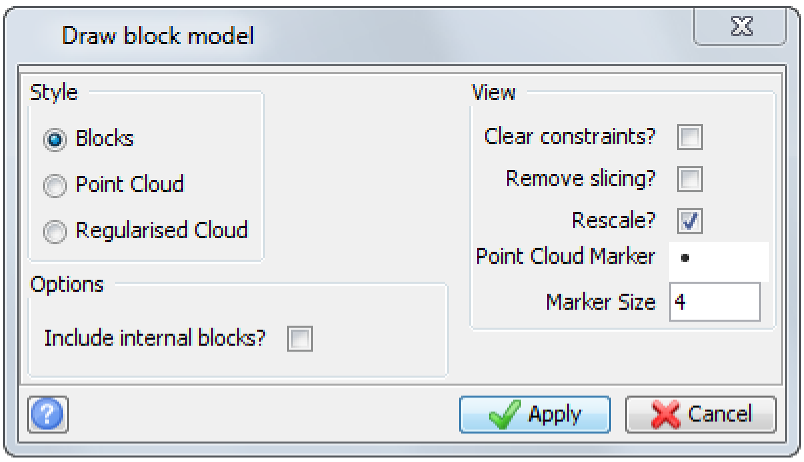


19. Click **Apply**.
20. Choose **Block Model > Close**.
21. On the *Exit block model* form, click **Save and exit**, and then click **Apply**.

Note: To see all of the steps performed in this task, run **2d_09d_ordinary_kriging.tcl**.

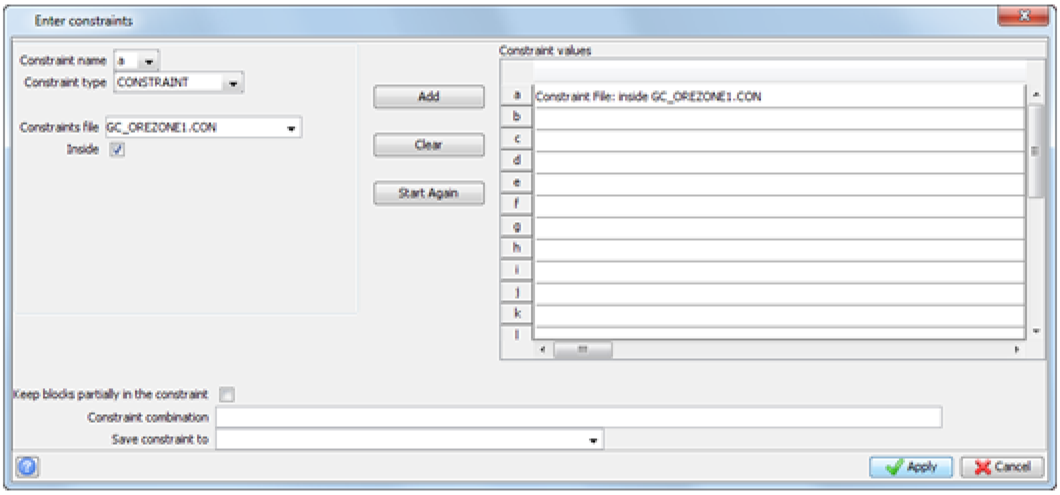
Task: Colour the block model by kriging variance to show edge effect

1. Click **Reset graphics**.
2. Open **gc130.mdl**.
3. Choose **Display > Block model**.
4. Enter the information as shown, and click **Apply**.

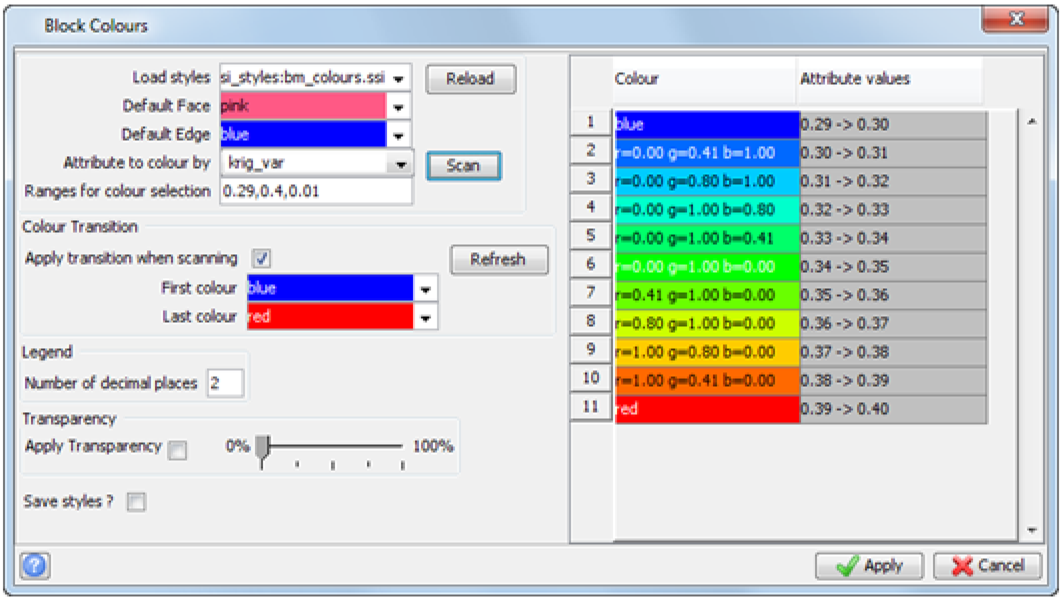


5. Choose **Constraints > New graphical constraint**.

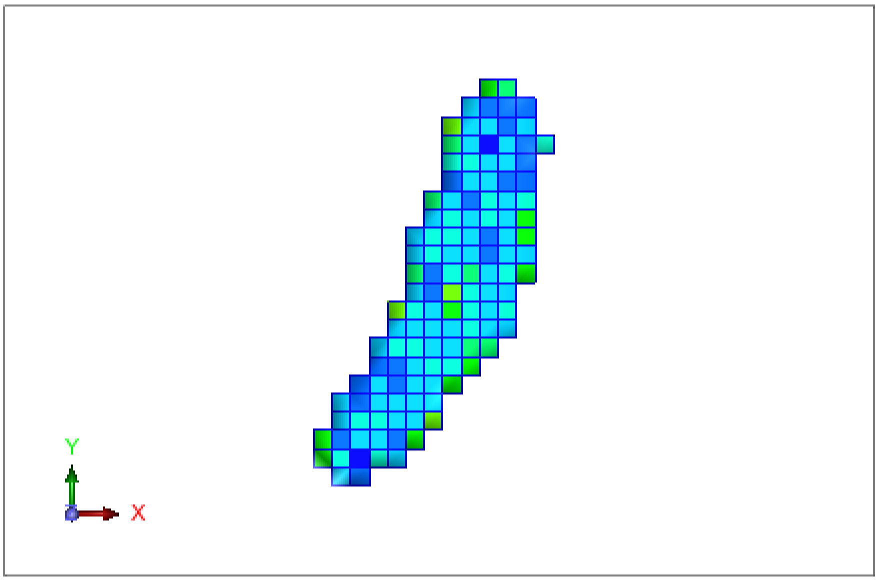
6. Enter the information as shown, and click **Apply**.



7. Choose **Display > Colour model by attribute**.
8. In the **Attribute to colour by** field, select **krig_var**, and click **Scan**, then set the **Ranges for colour selection** to **0,1,0.1**, and click **Refresh**.
9. Click **Apply**.



The model will display as follows.



10. Choose **Attribute > View attributes for one block**.
11. Select blocks at the outer edge of the model and then blocks internal to the model, to compare the values for krig_var.
12. Press ESC.
13. Choose **Block Model > Close**.

Note: To see all of the steps performed in this task run **2d_09e_edge_effect.tcl**.

Model validation

Overview

An important step in a geostatistical evaluation is to validate the model after it has been created.

You will learn about:

- comparing cross-sectional data with model values
- grade-tonnage curves from block model reports
- basic statistics of model values
- trend analysis

Requirements

In order to understand this information, you should understand the following concepts:

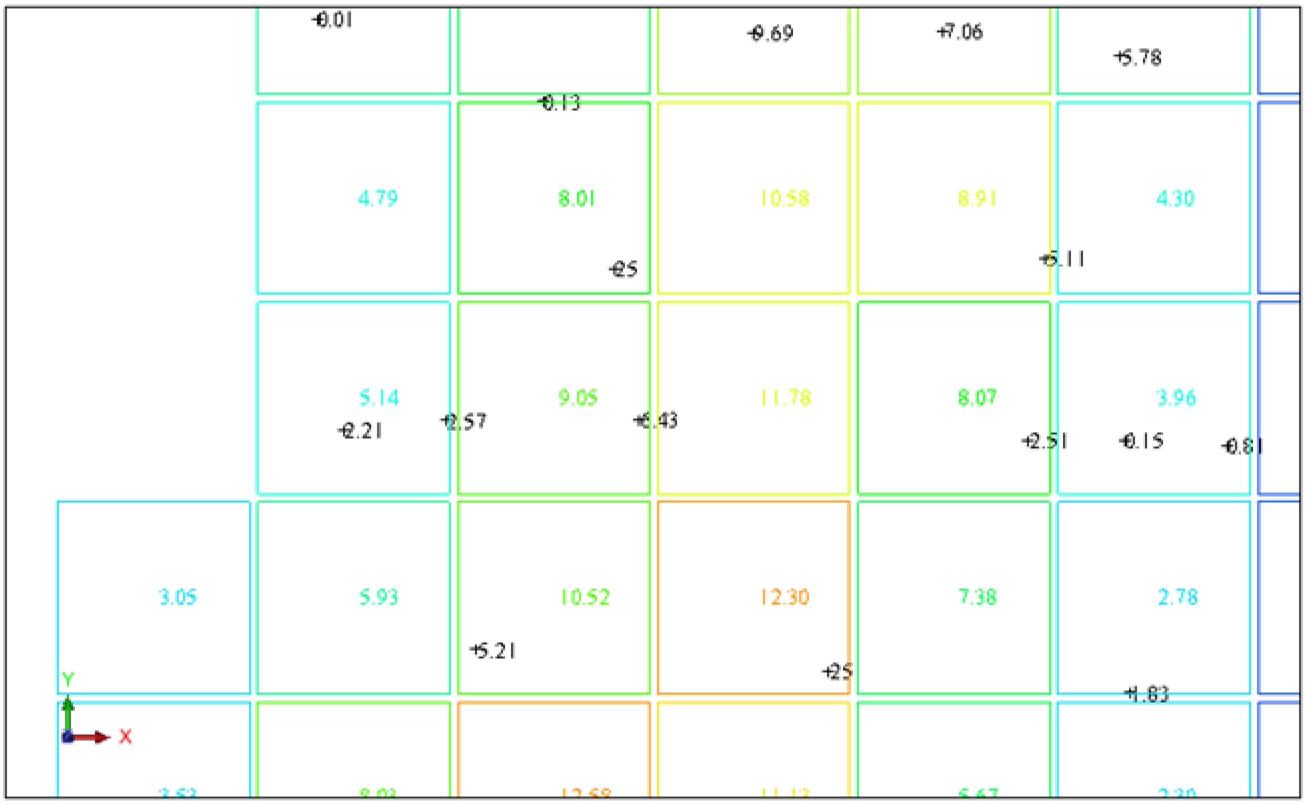
- Surpac string files
- Surpac block models
- isotropy and anisotropy
- anisotropy ellipsoid
- ordinary kriging

Comparing raw data to estimated values

One method of validating a model is to view cross-sections of it compared to other data.

Task: Comparing raw data to estimated values

1. Run **2d_10a_validation_section.tcl**.



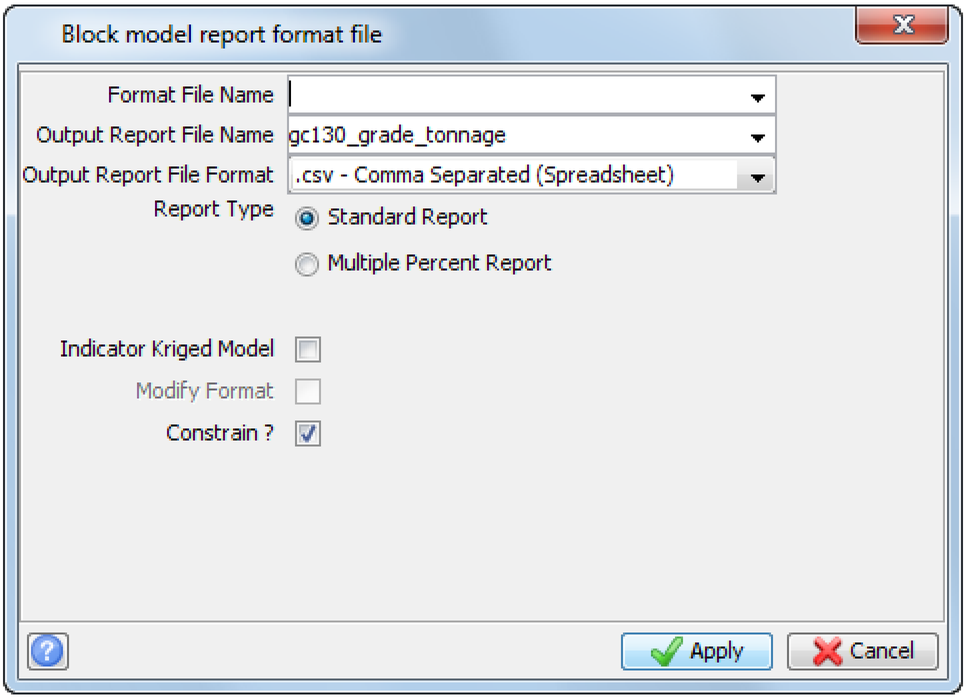
You want to ensure that the values in the model appear to be correct. In this example, this does appear to be the correct where there is significant influence from high sample values due to the low number of samples for kriging.

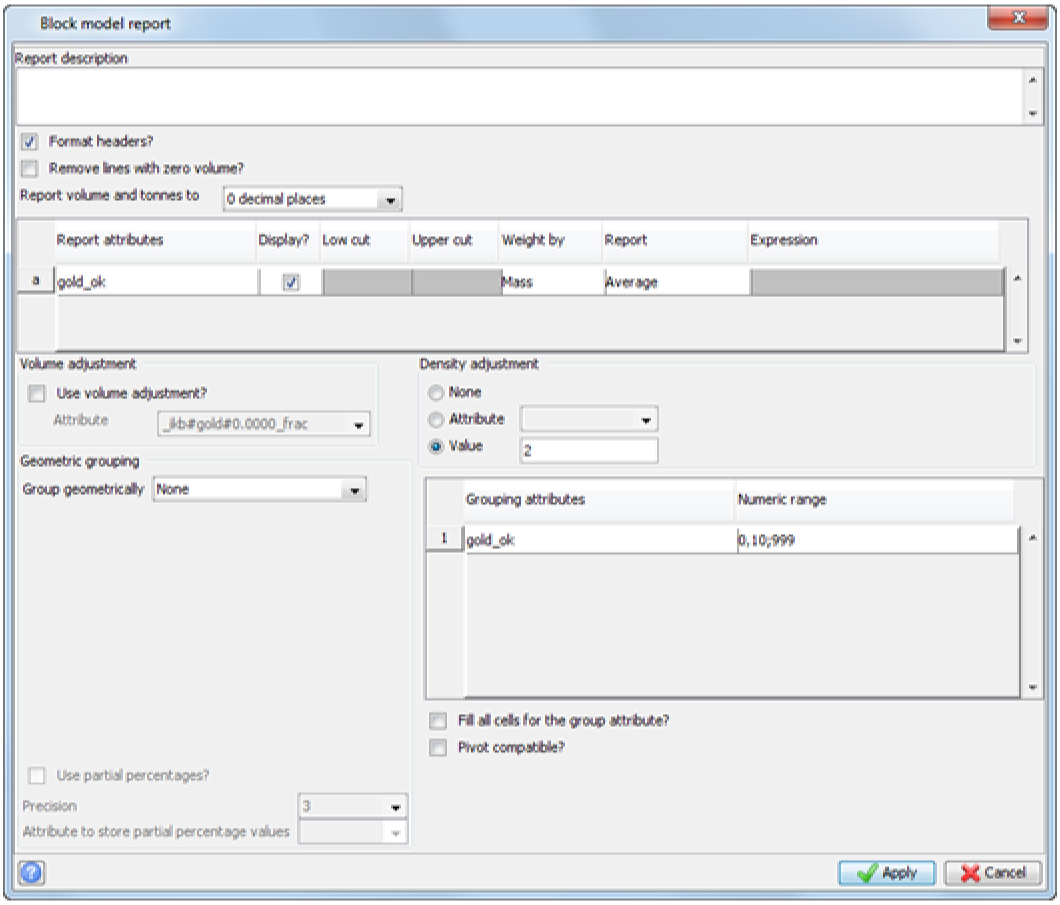
Grade-tonnage curves

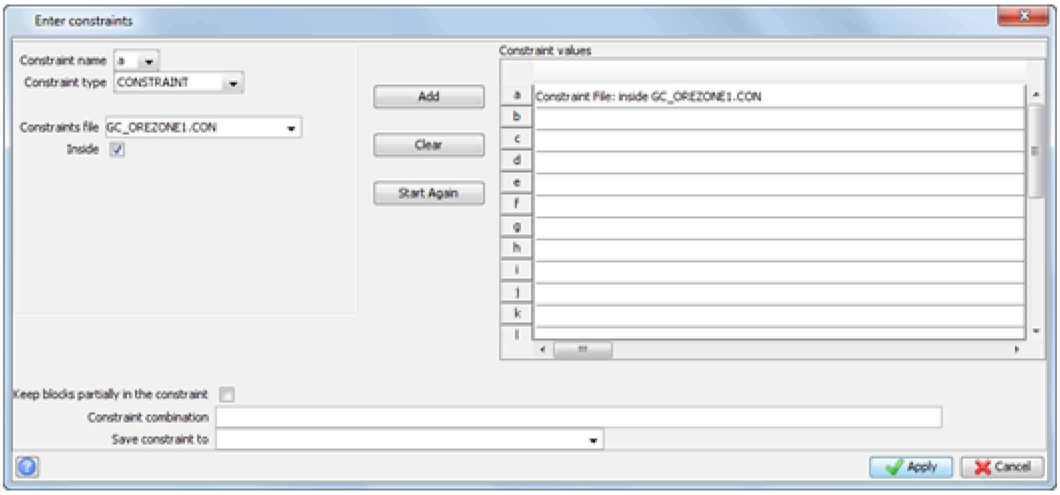
Another means of validating a model is to report tonnes and grade and construct a grade-tonnage curve.

Task: Create grade-tonnage curves

1. Run **2d_10b_grade_tonnage.tcl**.
   This macro performs block model reporting to create a ***.csv** file containing grade and tonnage. A pre-defined ***.xls** file is displayed at the end with a graph of the grade-tonnage curve.
2. Click **Apply** on each of the forms displayed.

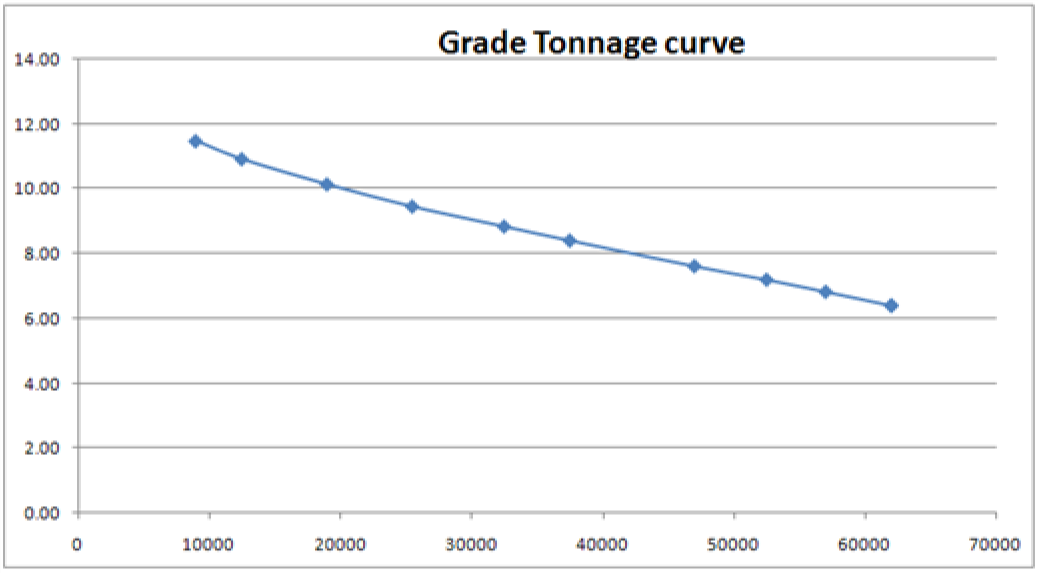






The file **gc_130_grade_tonnage.csv** is created.

The Grade-Tonnage curve is displayed.



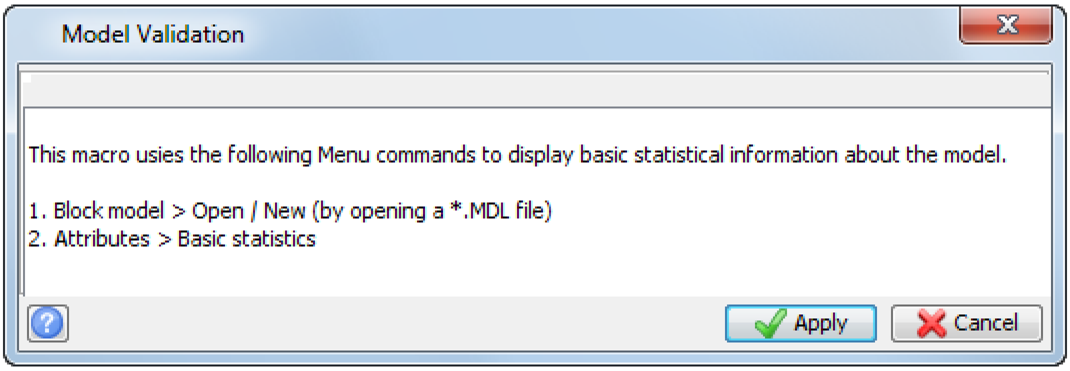
Note: **gc_130_grade_tonnage.xls** has been prepared from the output data.

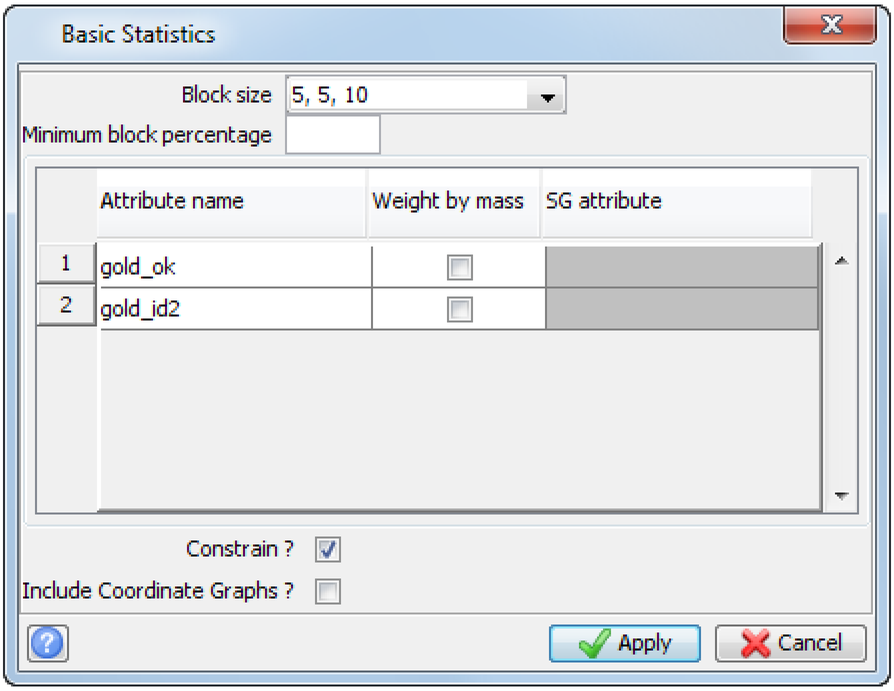
Basic statistics of model values

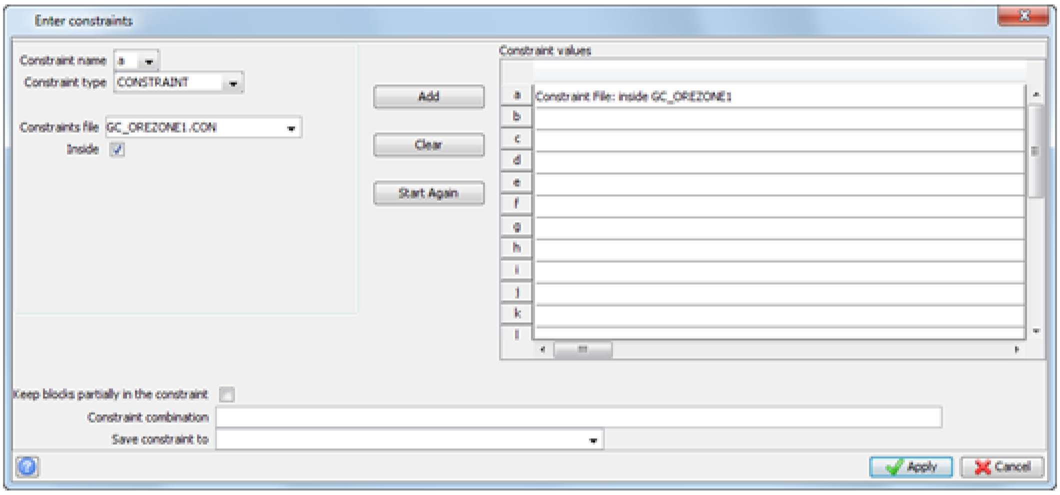
Basic statistics of the block model values is another way to validate the output from the model.

Task: Display block statistics of model values

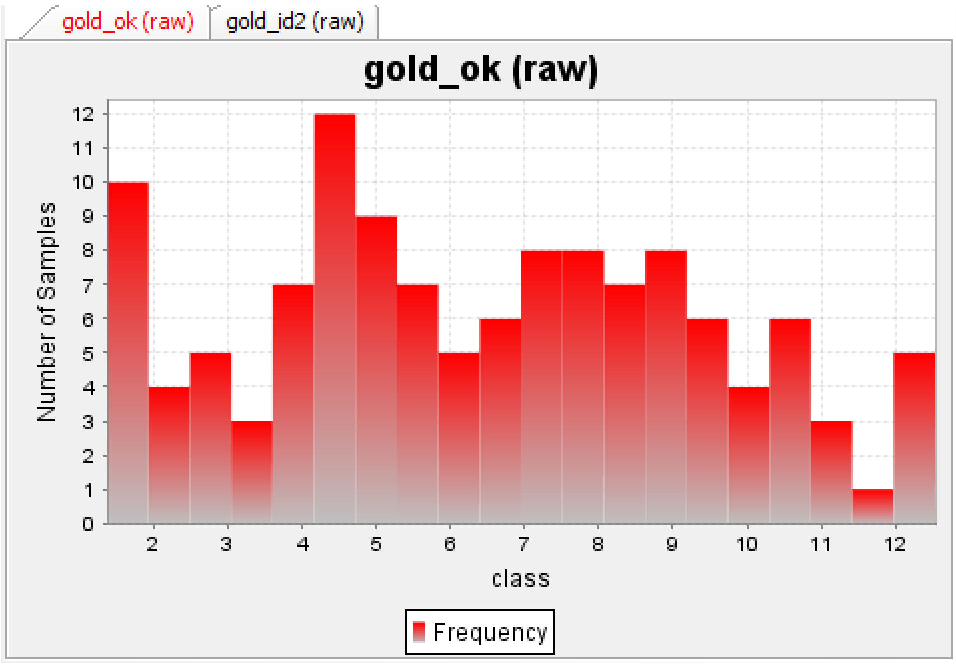
1. Run the macro **2d_10c_model_stats.tcl**.
   Note: This macro displays basic statistics on three block model parameters.
2. Click **Apply** on the three following forms.

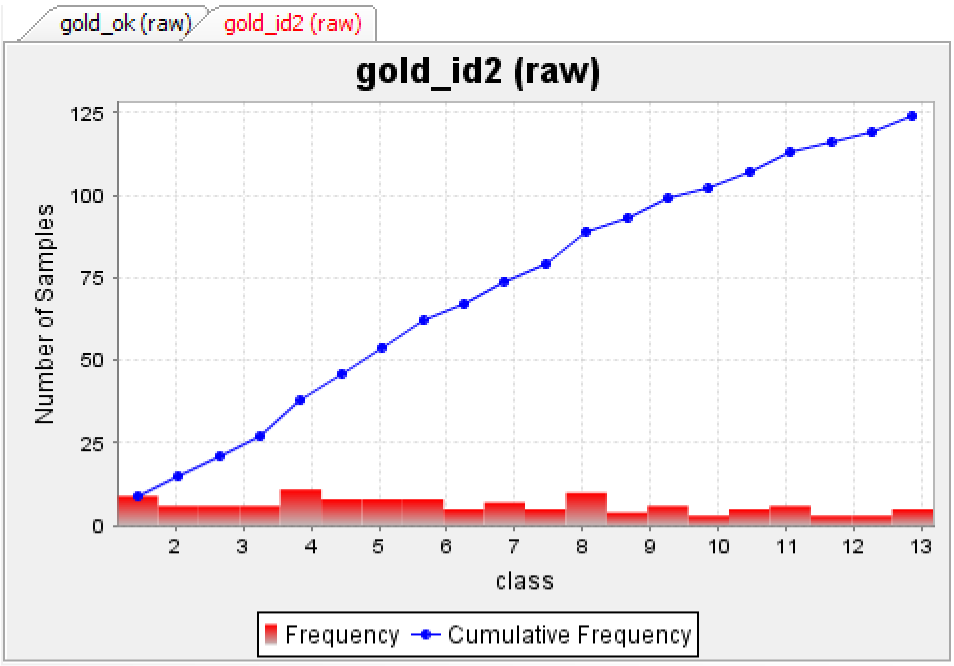




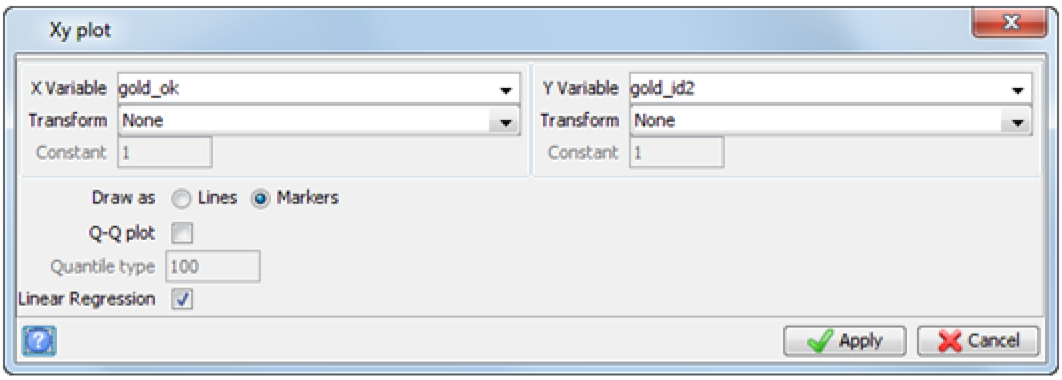


Two histograms of the data are displayed.

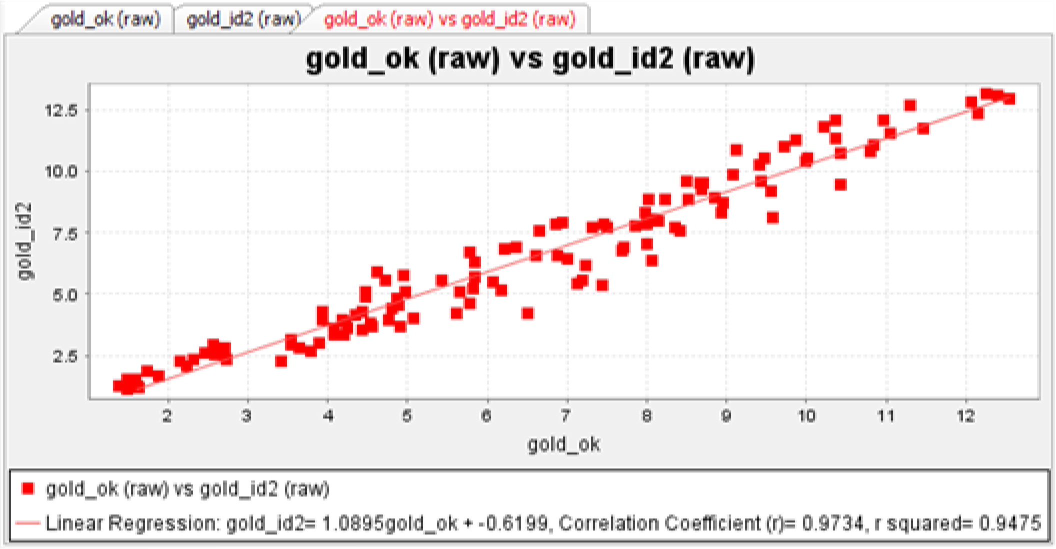




3. Click **Apply** on the following form.

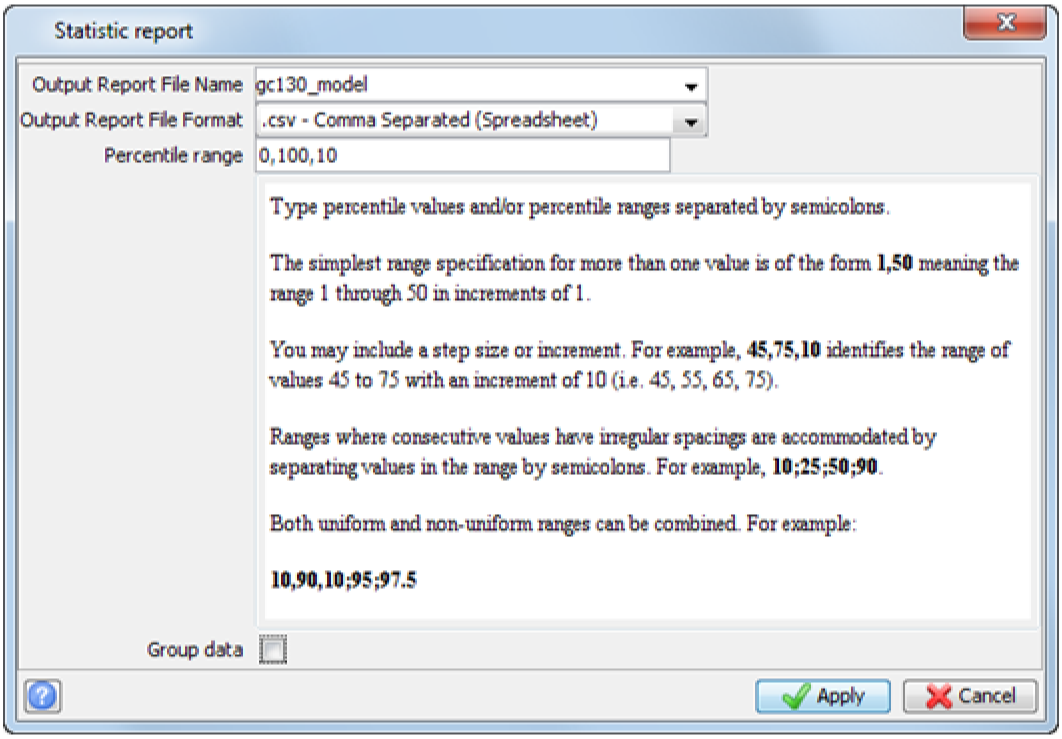


A scatter plot of the inverse distance and ordinary kriged data is plotted with a line of regression showing the correlation between the two data sets.



The validity of the result is determined by the degree of correlation between the two data sets. In this case, the correlation is close to 1, so the results are considered valid.

4. Click **Apply** on the following form.



A report of the statistics is saved as a **.csv** file.

Indicator estimation

Overview

Indicator estimation is a useful technique to use when:

- a single geological domain contains two or more populations
- estimation blocks are much larger than mining blocks
- experimental variograms are extremely difficult to model due to small sample size

Indicator estimation is commonly performed using Multiple Indicator Kriging (MIK). MIK is commonly shortened to "IK", or Indicator Kriging, despite the fact that this name is technically incorrect. In accordance with common usage MIK will be referred to as IK throughout the rest of this document.

IK produces a cumulative frequency function (CFF) for each block. After estimating the CFF, the percent of a block above/below a given cutoff can be estimated, which can also be interpreted as the percentage chance that the entire block is above or below a given cutoff.

Although there are advantages to using IK, the amount of work required before you begin estimation is significantly greater than for other estimation methods, such as inverse distance or ordinary kriging. This additional work is commonly cited as one reason not to perform IK. However, for certain situations, such as a mixed populations, IK can be the best estimator, so the extra work is accepted.

You will learn about:

- the indicator estimation process
- choosing indicator cutoffs
- indicator transformation

Requirements

In order to understand this information, you should be familiar with:

- Surpac string files
- variograms
- variogram maps
- the concept of anisotropy
- ordinary kriging

The indicator estimation process

The most common steps to produce an indicator estimation in Surpac are:

1. Choose a series of cutoff values.
2. Use indicator variogram maps to determine anisotropy ellipsoid parameters for each cutoff.
3. Create a block model.
4. Perform indicator kriging, using the cutoffs from step 1, and the anisotropy ellipsoid parameters from step 2, to create a Cumulative Frequency Function (CFF) for each block.
5. Use the CFF to calculate the overall block value, or percent of the block above or below a given cutoff.
6. Report the grade and tonnage from the IK model.

Choosing indicator cutoffs

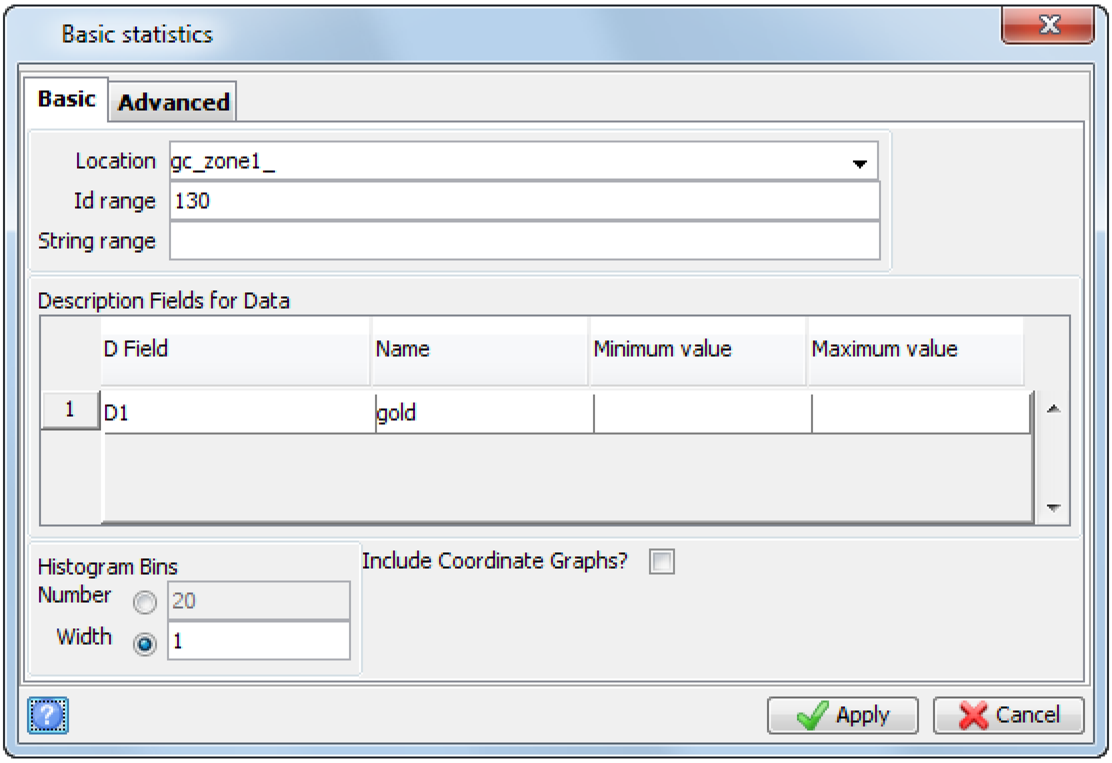
One method of selecting indicator cutoffs is to use data values which correspond to the deciles of the data (10%, 20%, 30%, ... 90%), as well as some values near the high end of the cumulative frequency to define the "upper tail" of the cumulative frequency function (95%, 97.5%, 99%). In practice, 10 to 15 cutoffs is quite common.

Alternatively, if you know what values will be used for classifying and reporting ore reserves, you can use them as indicator cutoffs. For example, if you know material will be classified into waste, low grade ore, high grade ore, you can use the cutoff values for each of those categories as indicator cutoffs.

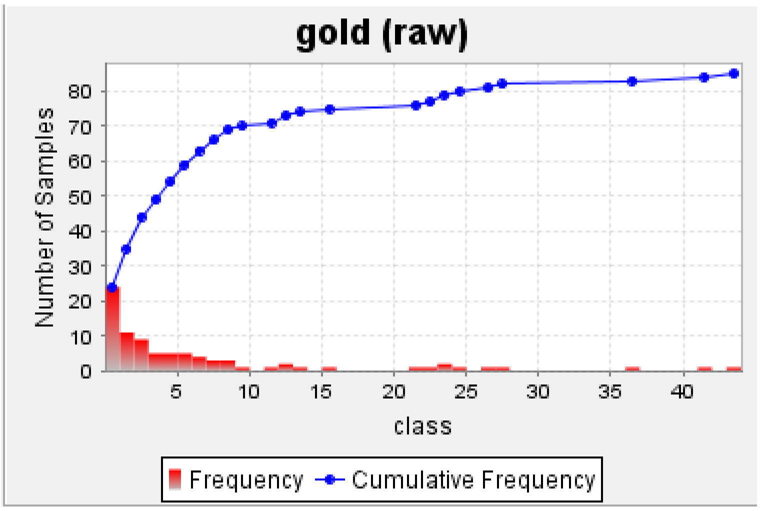
Task: Choose indicator cutoffs from percentiles

In this task, you will select cutoff values based on cumulative frequency values.

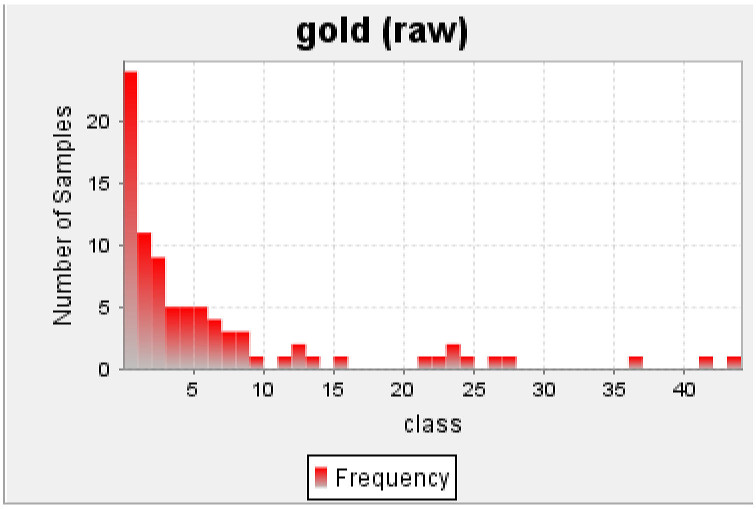
1. Choose **Geostatistics > Basic statistics**.
2. Choose **File > Load data from string files**.
3. Enter the information as shown, and click **Apply**.



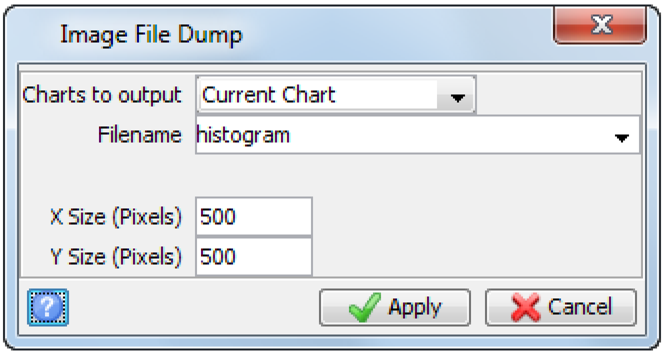
The histogram and cumulative frequency are displayed.



4. Choose **Display > Histogram**.
   The histogram is displayed

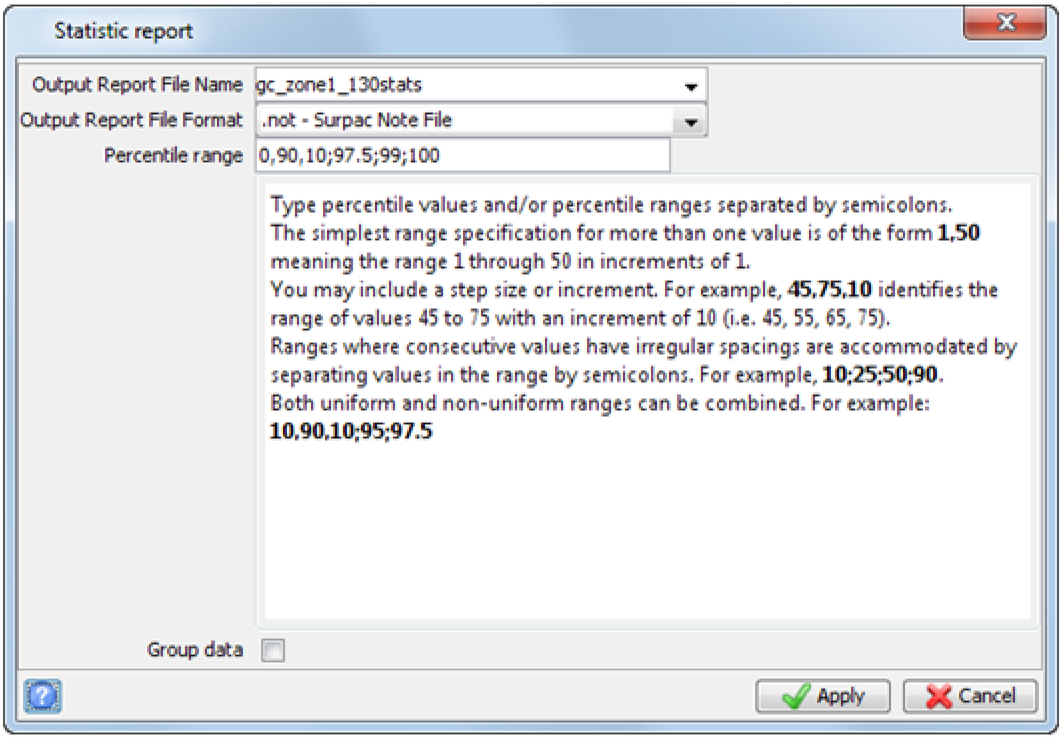


5. Choose **File > Save as > Image file**.
6. Enter the information as shown, and click **Apply**.



   The image is saved in the current working directory.

7. Choose **Statistics > Report**.
8. Enter the information as shown, and click **Apply**.



The file **gc_zone1_130stats.not** is created and displayed.

```
Output Filename: gc_zone1_130stats
                                Statistics Report


File                            Gc Zone1 130.str
-----------------------------------------------------------
String range                                 All
Variable                                    gold

Number of samples                             85
Minimum value                           0.010000
Maximum value                          43.530000

                                  Ungrouped Data
Mean                                    6.490118
Median                                  2.650000
Geometric Mean                          2.222684
Variance                               86.579051
Standard Deviation                      9.304786
Coefficient of variation                1.433685

Moment 1 About Arithmetic Mean          0.000000
Moment 2 About Arithmetic Mean         86.579051
Moment 3 About Arithmetic Mean       1808.520391
Moment 4 About Arithmetic Mean      58094.981937

Skewness                                2.244937
Kurtosis                                7.750201

Natural Log Mean                        0.798716
Log Variance                            2.947087

0.0 Percentile                          0.000000
10.0 Percentile                         0.170000
20.0 Percentile                         0.470000
30.0 Percentile                         1.160000
40.0 Percentile                         1.880000
50.0 Percentile (median)                2.650000
60.0 Percentile                         4.215000
70.0 Percentile                         5.900000
80.0 Percentile                         8.650000
90.0 Percentile                        22.500000
97.5 Percentile                        38.815000
99.0 Percentile                        42.355000
100.0 Percentile                       43.530000

Trimean                                 3.353750
Biweight                                3.071914
MAD                                     2.766914
Alpha                                   0.184082
Sichel-t                                9.311888

Normal Histogram Tabulation
gold
```

Class From	Class To	Count	Mean	Freq %	Cum Count	Cum Mean	Cum Freq %	Dec Count	Dec Mean	Dec Freq %
0.010000	1.010000	24	0.357500	0.282	24	0.357500	28.2353	85	6.490118	100.0000
1.010001	2.010000	11	1.435455	0.129	35	0.696286	41.1765	61	8.902951	71.7647
2.010000	3.010000	9	2.414444	0.106	44	1.047727	51.7647	50	10.545800	58.8235
3.010000	4.010000	5	3.512000	0.059	49	1.299184	57.6471	41	12.330732	48.2353
4.010000	5.010000	5	4.240000	0.059	54	1.571481	63.5294	36	13.555556	42.3529
5.010000	6.010000	5	5.518000	0.059	59	1.905932	69.4118	31	15.058065	36.4706
6.010000	7.010000	4	6.437500	0.047	63	2.193651	74.1176	26	16.892692	30.5882
7.010000	8.010000	3	7.446667	0.035	66	2.432424	77.6471	22	18.793636	25.8824
8.010000	9.010000	3	8.493333	0.035	69	2.695942	81.1765	19	20.585263	22.3529
9.010000	10.010000	1	9.690000	0.012	70	2.795857	82.3529	16	22.852500	18.8235
11.010000	12.010000	1	11.510000	0.012	71	2.918592	83.5294	15	23.730000	17.6471
12.010000	13.010000	2	12.430000	0.024	73	3.179178	85.8824	14	24.602857	16.4706
13.010000	14.010000	1	13.560000	0.012	74	3.319459	87.0588	12	26.631667	14.1176
15.010000	16.010000	1	15.670000	0.012	75	3.484133	88.2353	11	27.820000	12.9412
21.010000	22.010000	1	21.420000	0.012	76	3.720132	89.4118	10	29.035001	11.7647
22.010000	23.010000	1	22.500000	0.012	77	3.964026	90.5882	9	29.881111	10.5882
23.010000	24.010000	2	23.390000	0.024	79	4.455823	92.9412	8	30.803750	9.4118
24.010000	25.010000	1	24.090000	0.012	80	4.701250	94.1176	6	33.275000	7.0588
26.010000	27.010000	1	26.640000	0.012	81	4.972099	95.2941	5	35.112000	5.8824
27.010000	28.010000	1	27.760000	0.012	82	5.250000	96.4706	4	37.230000	4.7059
36.010000	37.010000	1	36.450000	0.012	83	5.625904	97.6471	3	40.386667	3.5294
41.010000	42.010000	1	41.180000	0.012	84	6.049167	98.8235	2	42.355000	2.3529
43.010000	44.010000	1	43.530000	0.012	85	6.490118	100.0000	1	43.530000	1.1765

1/1

9. Close the **Basic Statistics Window.**

📝 **Note**: To see all of the steps performed in this task, run **2d_02a_basic_statistics_histogram.tcl**.

You can use the values associated with each of the specified percentiles as the cutoff values.

Cutoff number	Cutoff value
1	0.17
2	0.47
3	1.16
4	1.88
5	2.65
6	4.22
7	5.90
8	8.65
9	22.5
10	27.2
11	38.82
12	42.36

Note: It is not necessary to select a "top cutoff" that is above all data values. When you perform indicator kriging (IK), you can specify a value which is assumed to be the mean value above the last cutoff.

Task: Choose indicator cutoffs from ore classification grades

In this task, you will assume that before you begin creating an indicator estimation, you are provided with the following information:

Ore Classification	Grade (grams/Tonne)
Waste	0.00 to 1.00
Low Grade	1.01 to 2.50
Medium Grade	2.51 to 5.00
High Grade	5.01 to 10.00
Super High Grade	above 10.00

Based on this information, you would choose four cutoffs:

Cutoff number	Cutoff value
1	1.0
2	2.5
3	5.0
4	10.00

Note: These values will be used in subsequent tasks because of the small number of cutoffs.

Indicator transformation

After you have determined the value of each of the indicator cutoffs, Surpac transforms all data to a value of one or zero for each cutoff, and then use the transformed values to perform a function. For example, calculating an indicator variogram map or performing indicator kriging. Although Surpac does this transformation for you, it is important to understand how an indicator transformation works.

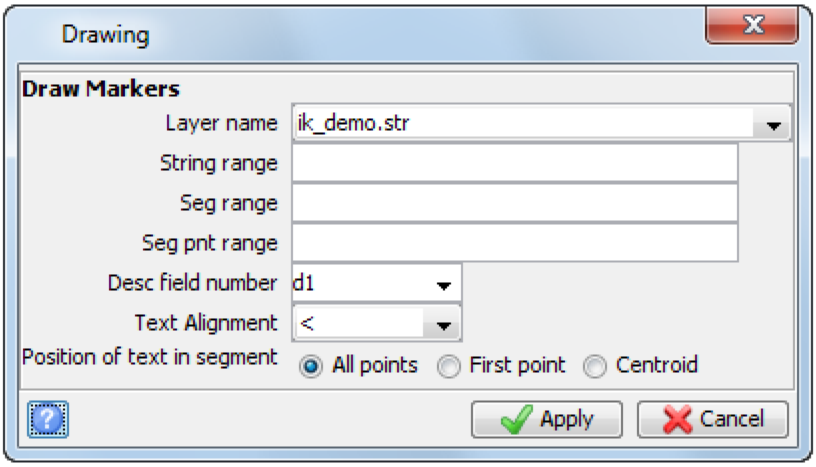
For each indicator value, a data point is transformed based on the following table:

If the data value is:	Then the transformed value is:
less than or equal to the cutoff	1
greater than the cutoff	0

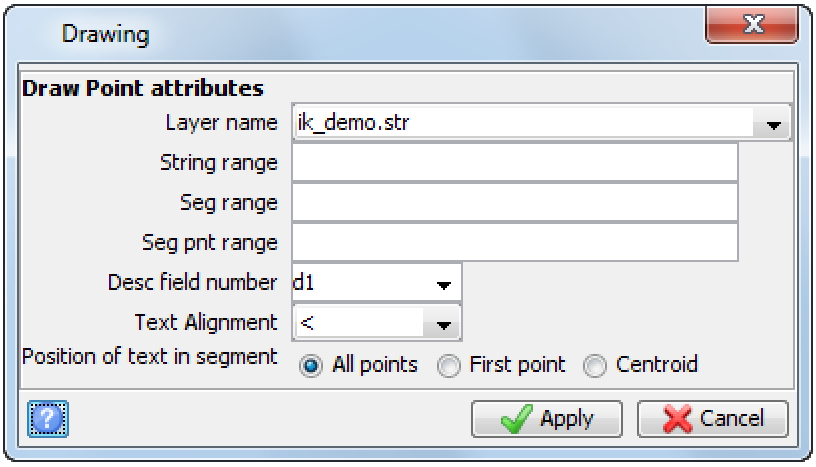
Since all data points are either transformed to a value of zero or one, there are no outliers, and the coefficient of variation is small. This means that indicator variograms can be more "well behaved" than normal variograms for data sets that contain outliers or small numbers of data.

Task: Perform indicator transformation

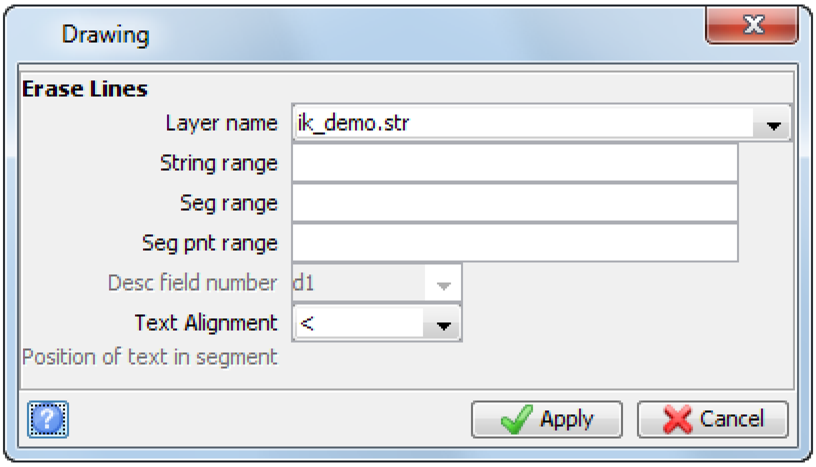
1. Open **ik_demo.str** in **Graphics**.
2. Choose **Display > Point > Markers**.
3. Enter the information as shown, and click **Apply**.

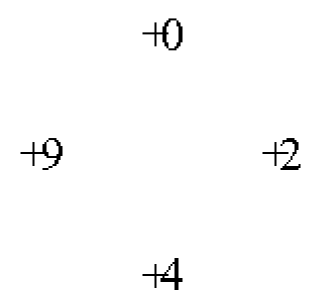


4. Choose **Display > Point > Attributes**.
5. Enter the information as shown, and click **Apply**.



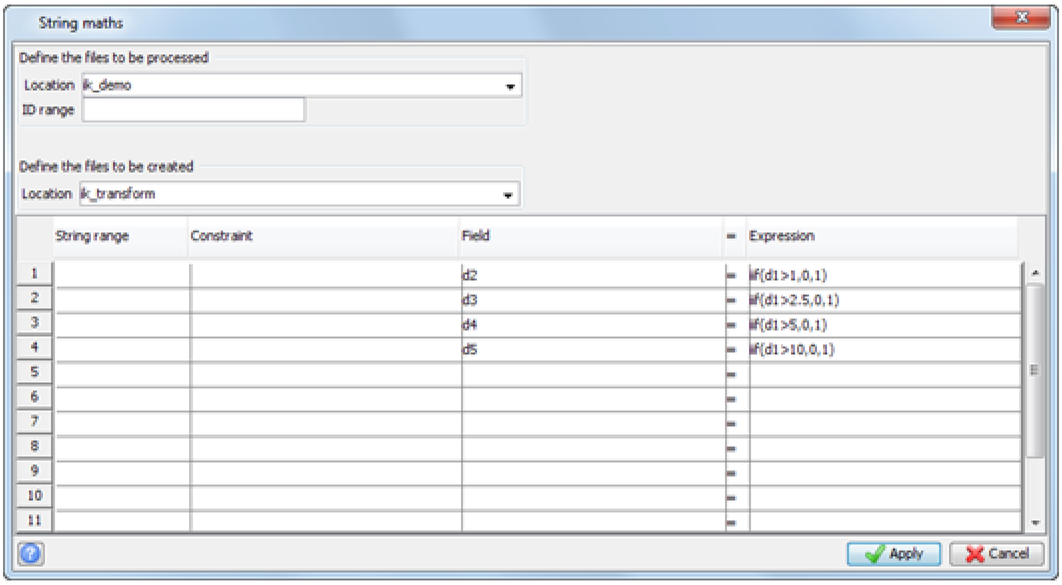
6. Choose **Display > Hide strings > As lines**.
7. Enter the information as shown, and click **Apply**.



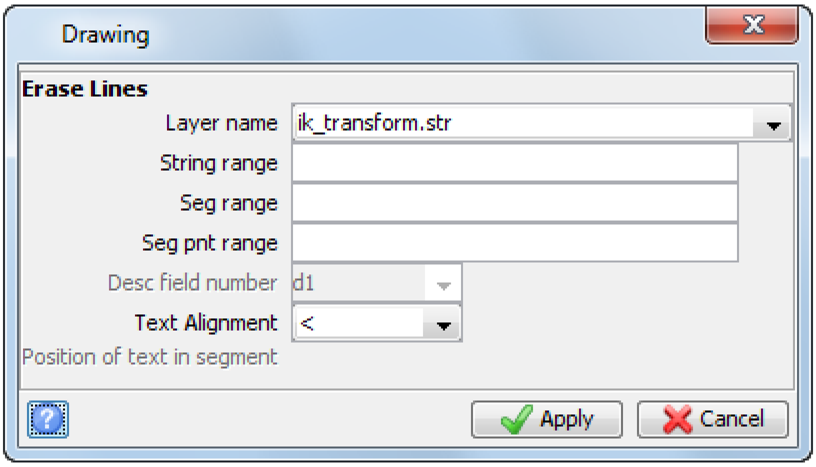


📝 **Note**: The file contains four points, with D1 values of 0, 2, 4, and 9. These will be transformed to 1 or 0 for each of the four grade classification cutoff values of 1, 2.5, 5, and 10.

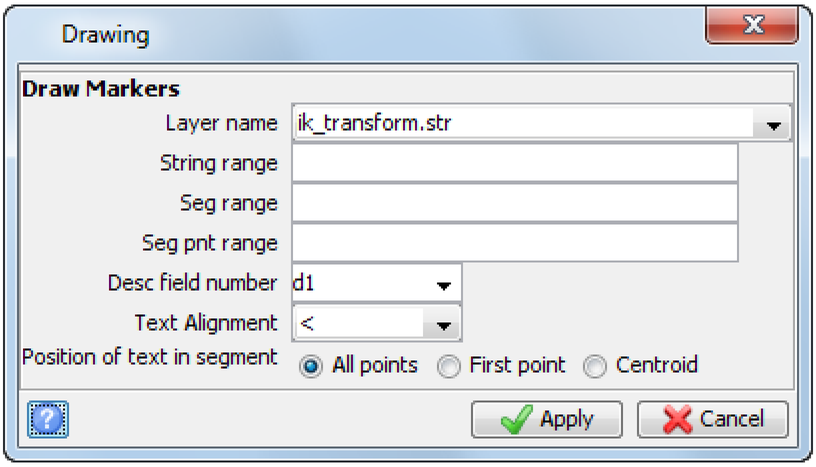
8. Choose **File tools > String maths**.
9. Enter the information as shown, and click **Apply**:



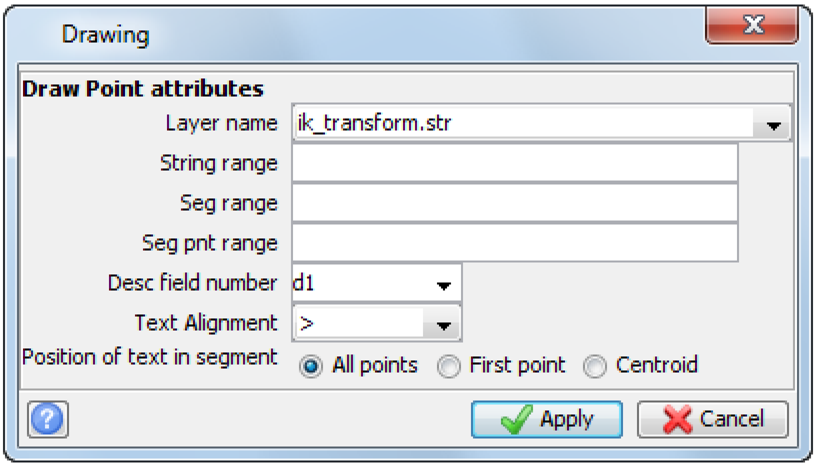
10. Click **Reset graphics**.
11. Open **ik_transform.str**.
12. Choose **Display > Hide strings > As lines**.
13. Enter the information as shown, and click **Apply**.



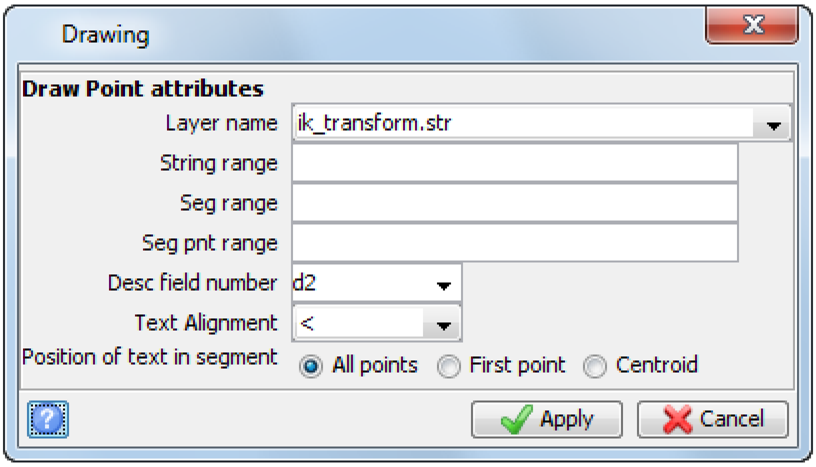
14. Choose **Display > Point > Markers**.
15. Enter the information as shown, and click **Apply**.



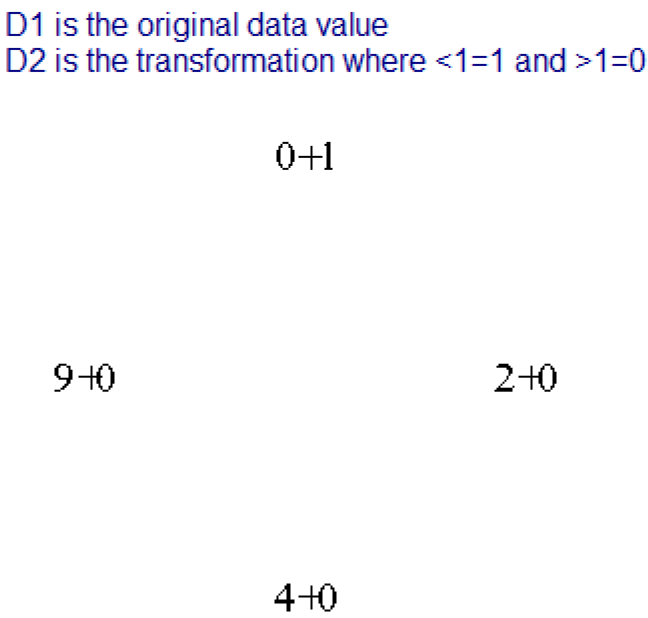
16. Choose **Display > Point > Attributes**.
17. Enter the information as shown, and click **Apply**.



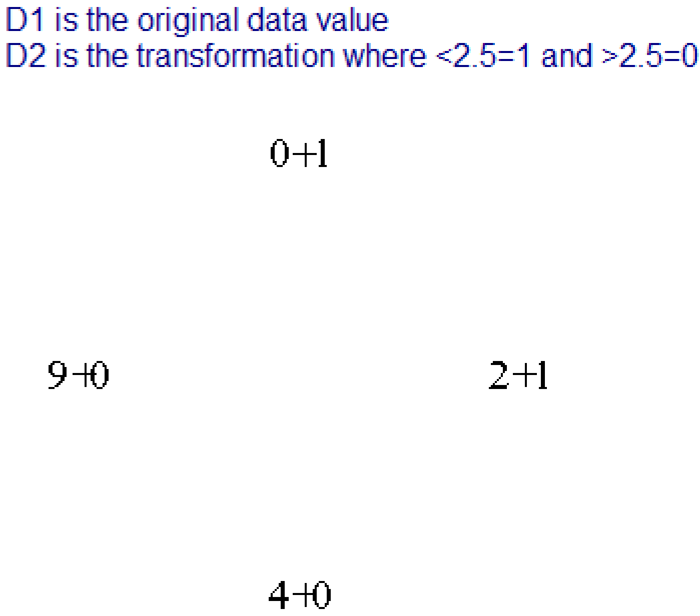
18. Choose **Display > Point > Attributes**.
19. Enter the information as shown, and click **Apply**.

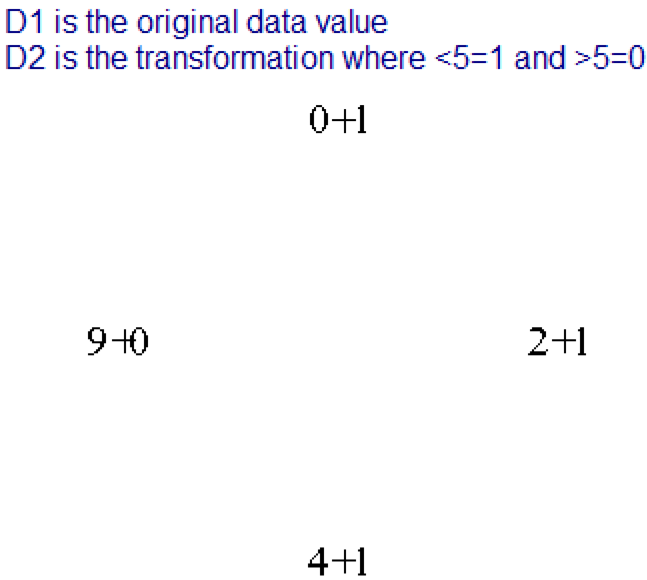


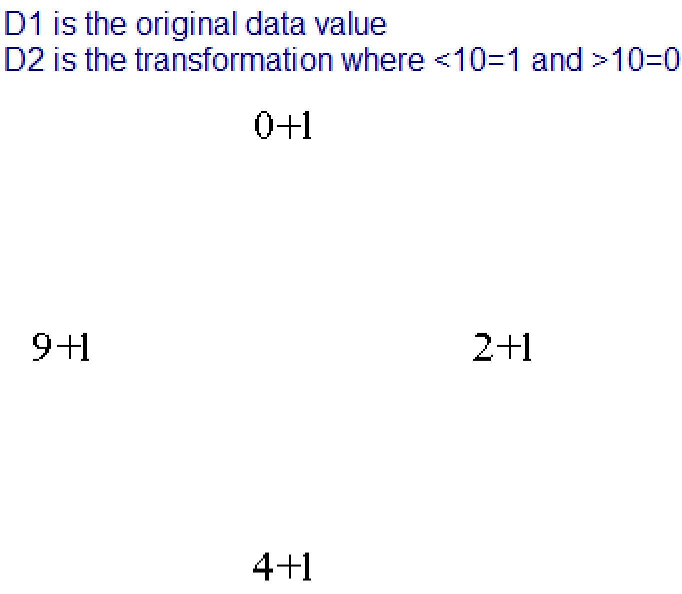
D1 values are displayed on the left of each point marker, and D2 values on the right.



10. Repeat steps 20 and 21, selecting a **Desc field number** of D3, then D4, and then D5.


D1 is the original data value
D2 is the transformation where <2.5=1 and >2.5=0
0+1
9+0
2+1
4+0

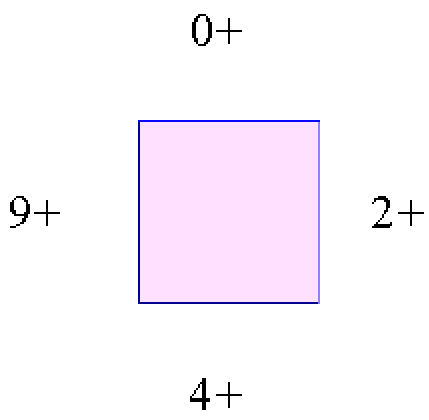

D1 is the original data value
D2 is the transformation where <5=1 and >5=0
0+1
9+0
2+1
4+1



📝 **Note**: To see all of the steps performed in this task, run **2d_11a_ik_transform.tcl**.

Indicator estimation

Indicator kriging is used to estimate a cumulative frequency function and block value for a single block from four samples, all equally spaced from the block centroid.



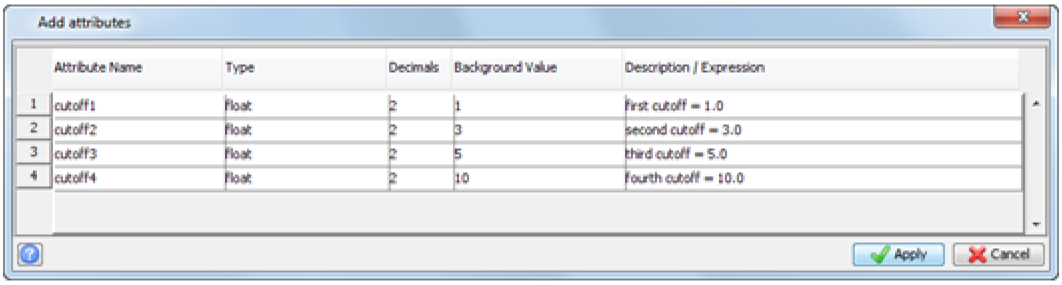
Four cutoff values are chosen from ore classification grades.

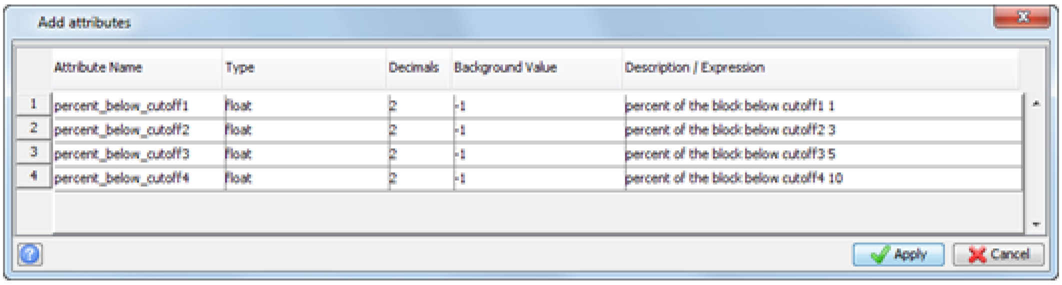
Cutoff number	Cutoff value
1	1.0
2	2.5
3	5.0
4	10.00

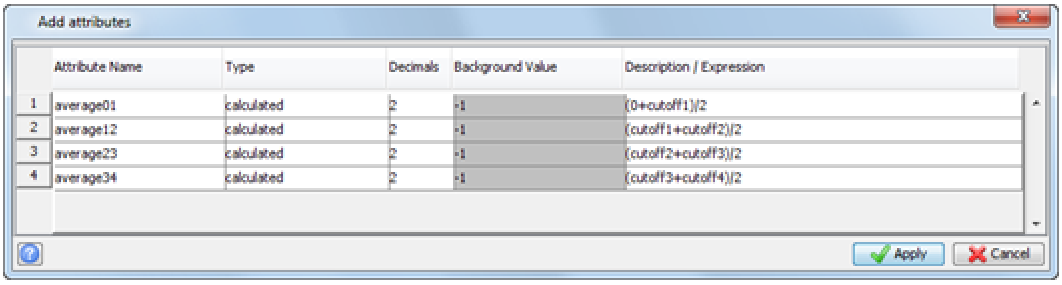
Isotropy is assumed for all cutoffs.

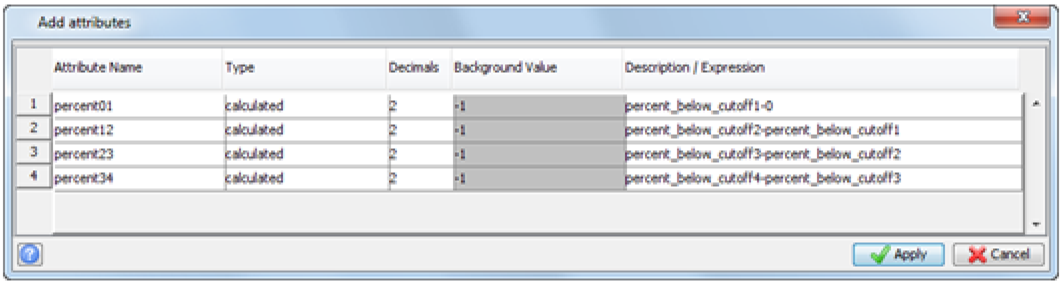
Task: Perform indicator estimation

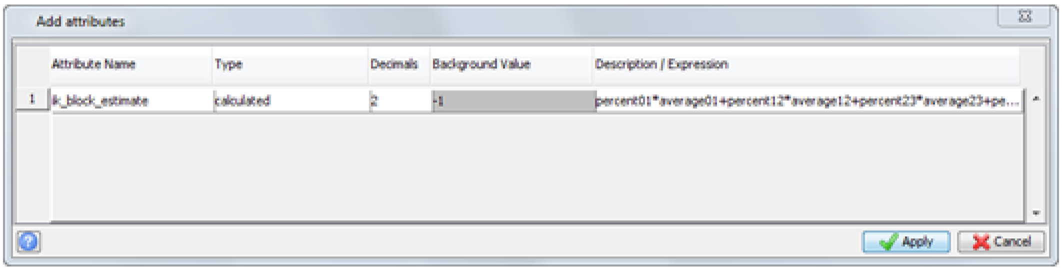
1. Run **2d_11b_indicator_estimation.tcl**.
2. Click **Apply** on each form presented.

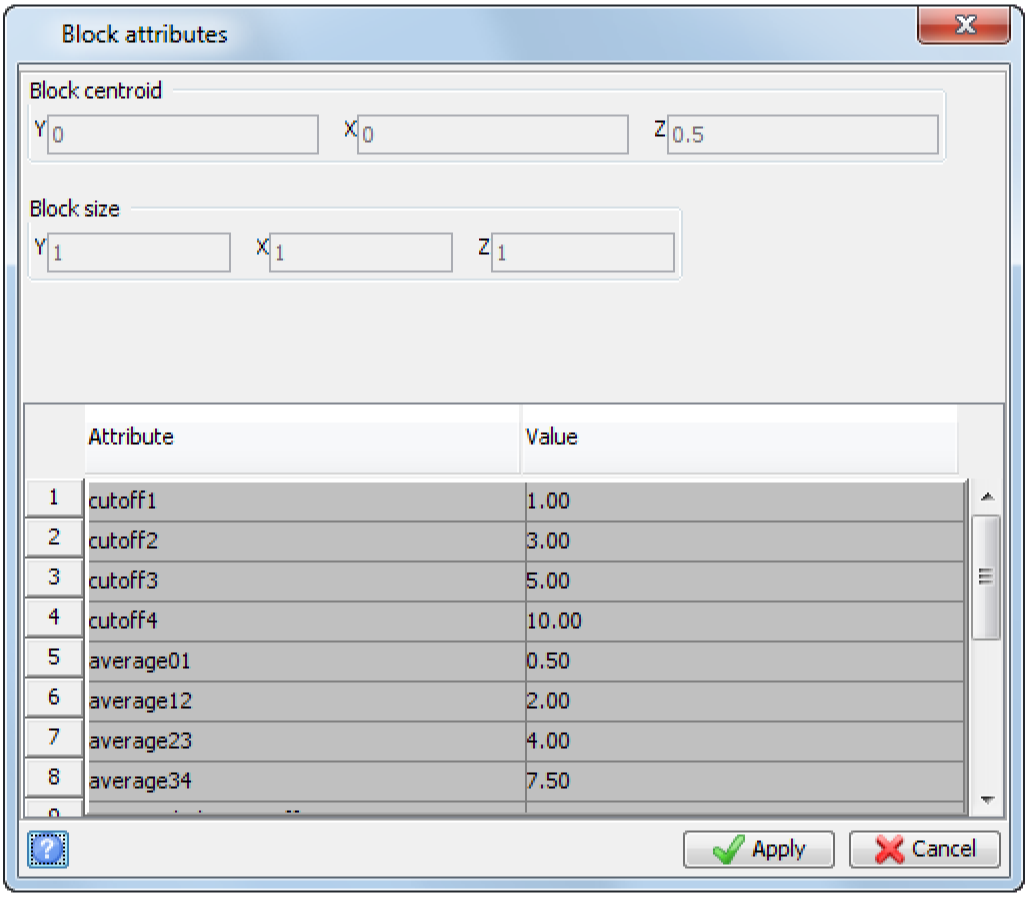

Add attributes
Attribute Name | Type | Decimals | Background Value | Description / Expression
1 | cutoff1 | float | 2 | 1 | first cutoff = 1.0
2 | cutoff2 | float | 2 | 3 | second cutoff = 3.0
3 | cutoff3 | float | 2 | 5 | third cutoff = 5.0
4 | cutoff4 | float | 2 | 10 | fourth cutoff = 10.0
Apply
Cancel


Add attributes
Attribute Name | Type | Decimals | Background Value | Description / Expression
1 | percent_below_cutoff1 | float | 2 | -1 | percent of the block below cutoff1 1
2 | percent_below_cutoff2 | float | 2 | -1 | percent of the block below cutoff2 3
3 | percent_below_cutoff3 | float | 2 | -1 | percent of the block below cutoff3 5
4 | percent_below_cutoff4 | float | 2 | -1 | percent of the block below cutoff4 10
Apply
Cancel


Add attributes
Attribute Name | Type | Decimals | Background Value | Description / Expression
1 | average01 | calculated | 2 | -1 | (0+cutoff1)/2
2 | average12 | calculated | 2 | -1 | (cutoff1+cutoff2)/2
3 | average23 | calculated | 2 | -1 | (cutoff2+cutoff3)/2
4 | average34 | calculated | 2 | -1 | (cutoff3+cutoff4)/2
Apply
Cancel


Add attributes
Attribute Name | Type | Decimals | Background Value | Description / Expression
1 | percent01 | calculated | 2 | -1 | percent_below_cutoff1-0
2 | percent12 | calculated | 2 | -1 | percent_below_cutoff2-percent_below_cutoff1
3 | percent23 | calculated | 2 | -1 | percent_below_cutoff3-percent_below_cutoff2
4 | percent34 | calculated | 2 | -1 | percent_below_cutoff4-percent_below_cutoff3
Apply
Cancel


Add attributes
Attribute Name | Type | Decimals | Background Value | Description / Expression
1 | ik_block_estimate | calculated | 2 | -1 | percent01*average01+percent12*average12+percent23*average23+pe...
Apply
Cancel


Block attributes
Block centroid
Y 0
X 0
Z 0.5
Block size
Y 1
X 1
Z 1
Attribute
Value
1 cutoff1 1.00
2 cutoff2 3.00
3 cutoff3 5.00
4 cutoff4 10.00
5 average01 0.50
6 average12 2.00
7 average23 4.00
8 average34 7.50
Apply
Cancel

Indicator variogram maps

Overview

Indicator variogram maps are used in the same way as ordinary variogram maps to obtain anisotropy ellipsoid parameters. When you create an indicator variogram map, the data is transformed to indicator values based on the value of each cutoff. The entire process of determining anisotropy ellipsoid parameters is repeated for each cutoff.

You will learn about using indicator variogram maps to determine anisotropy ellipsoid parameters for a series of cutoffs

Requirements

In order to understand this information, you should:

- be familiar with Surpac string files
- know how to create and use variogram maps to obtain anisotropy ellipsoid parameters
- understand the concepts of anisotropy and ordinary kriging

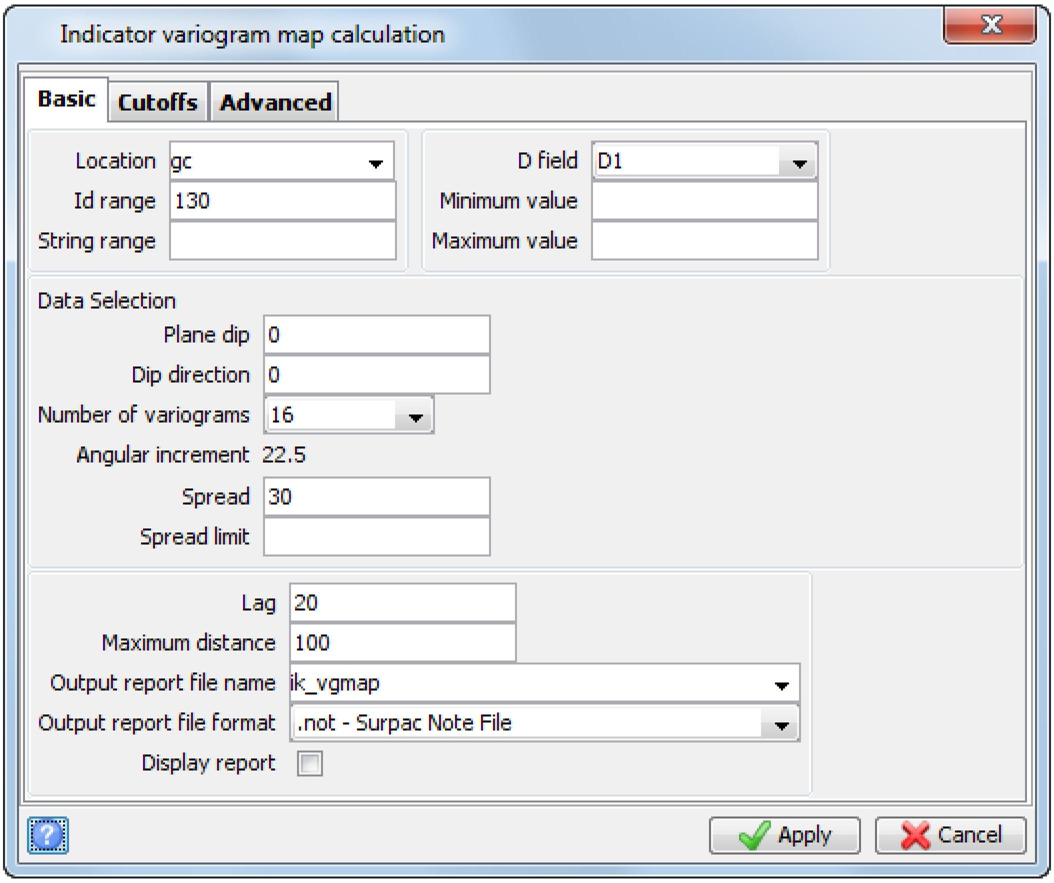
Using indicator variogram maps

In order to create indicator variogram maps, you must have defined a set of cutoff values. To keep the procedure simple, only four cutoffs are used in this exercise.

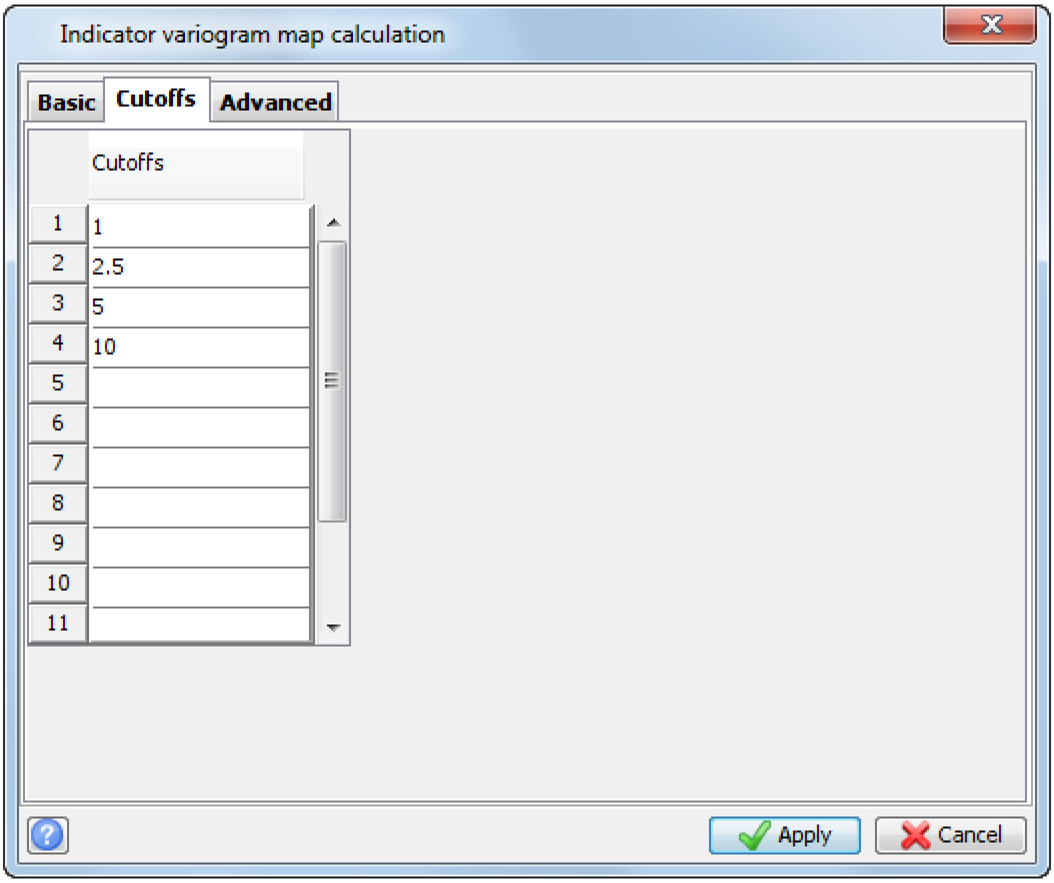
The end product of the process of using indicator variogram maps is to get anisotropy ellipsoid parameters for indicator kriging. These parameters need to be documented for each cutoff.

Task: Calculate anisotropy parameters for each cutoff

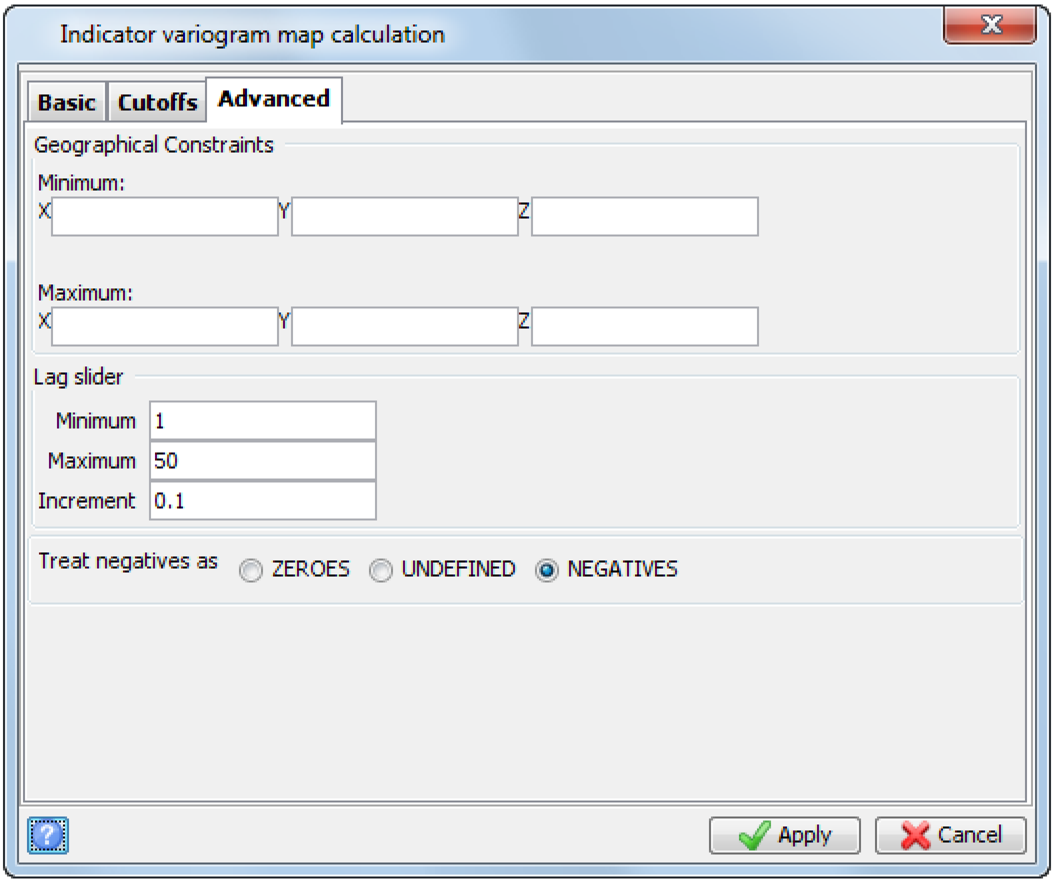
1. Choose **Block model > Geostatistics > Indicator variogram modelling**.
2. Choose **Variogram Map > New variogram map**.
3. On the **Basic** tab, enter the information as shown.



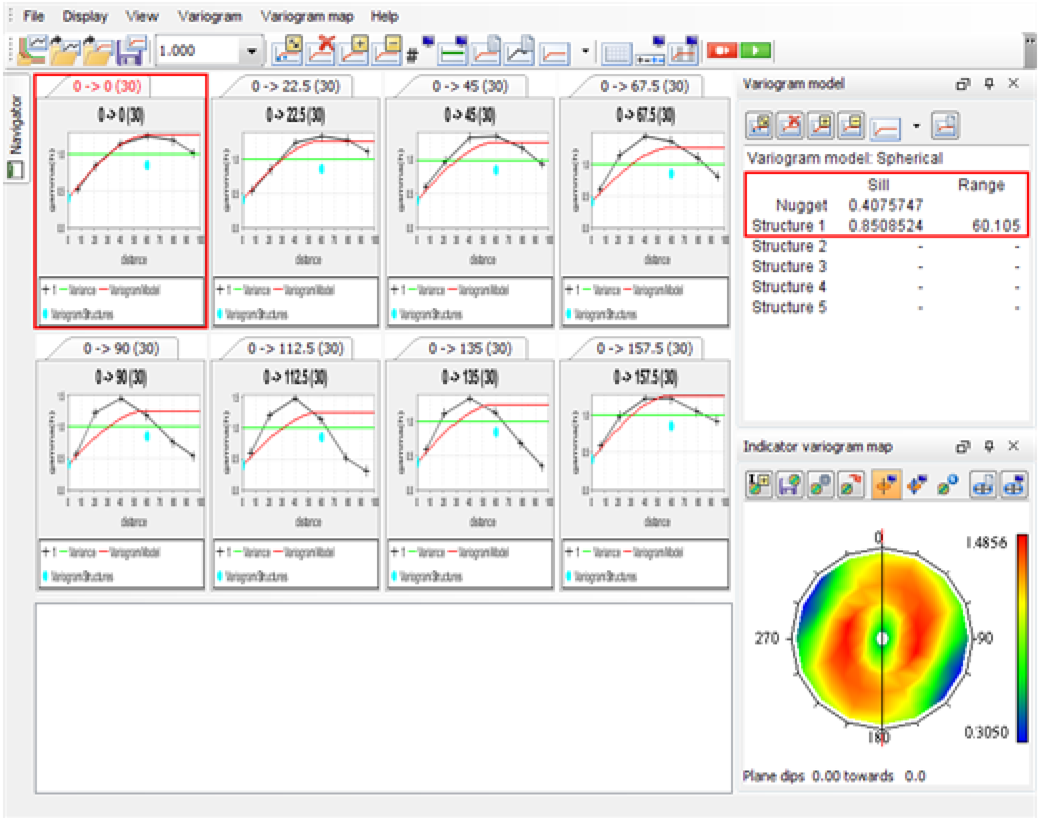
4. Click the **Cutoffs** tab, and enter the information as shown.



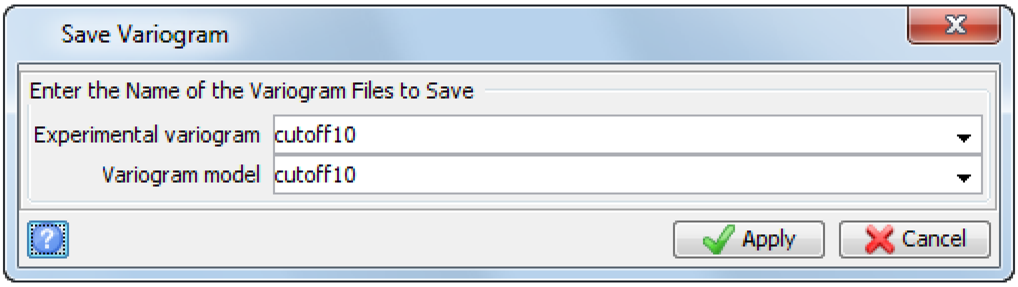
5. Click the **Advanced** tab, enter the information as shown, and click **Apply**.



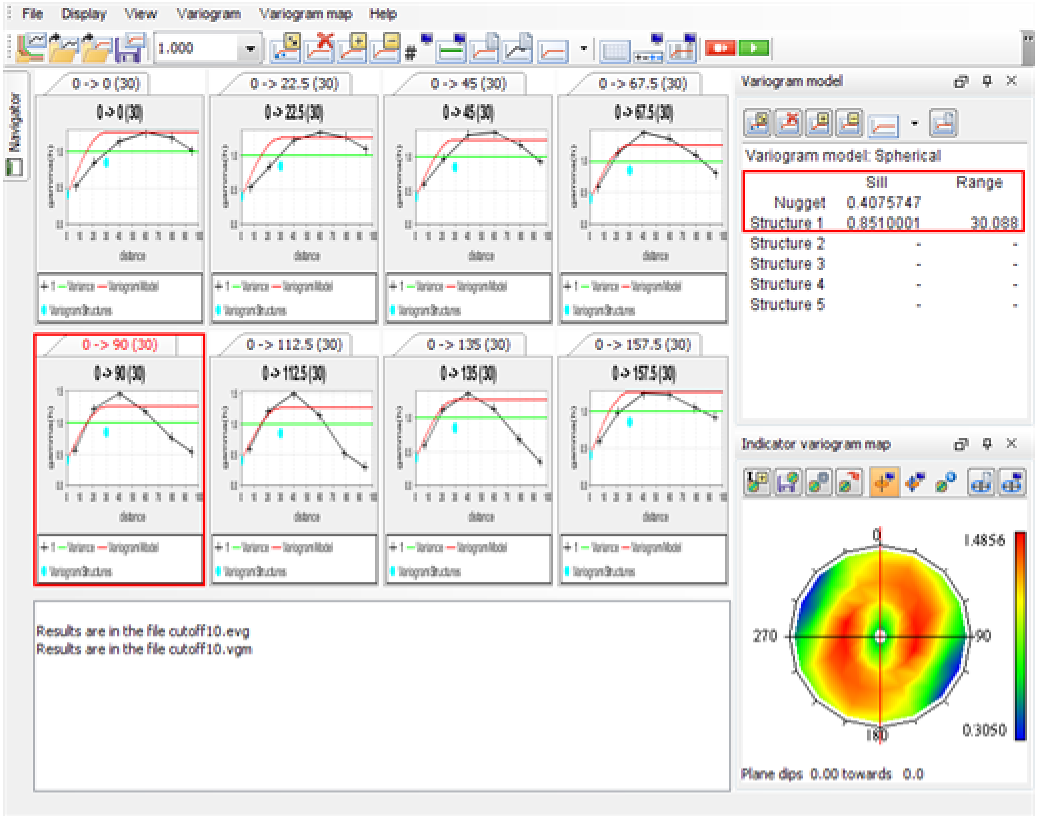
6. Right-click and choose **Tile Windows**.
7. Use the variogram map to identify the major axis for the first cutoff (1.000), as shown.
8. Use **Variogram > Model** to create a variogram for that orientation, and note the **Range**.



9. Choose **File > Save > Experimental variogram and model**.
10. Enter the information as shown, and click **Apply**.



11. Modify the variogram to best-fit the semi-major axis (keep the nugget and sill the same), and note the range.



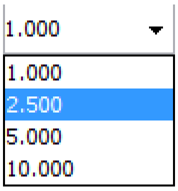
12. Calculate the anisotropy ratio (range of the major axis divided by the range of the semi-major axis) for the first cutoff:

major/semi-major anisotropy ratio = 60 / 30 = 2

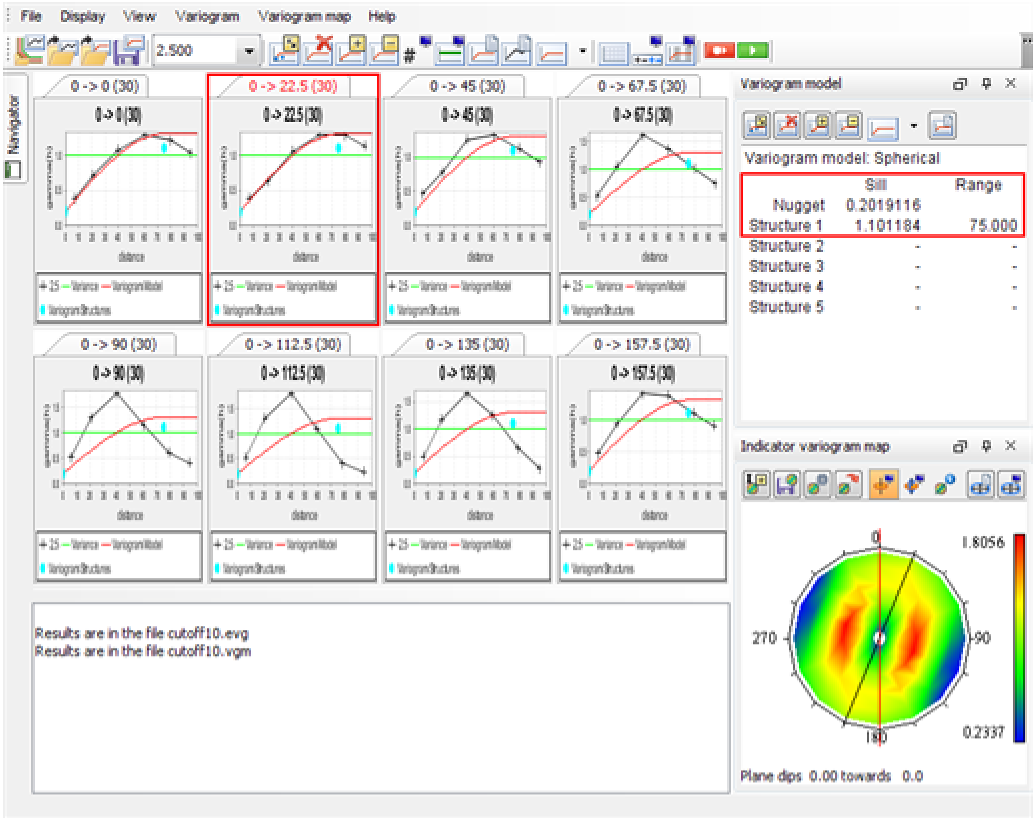
13. Document the values as shown.

Cutoff	Variogram	Bearing	Major/Semi-Major Anisotropy Ratio
1	cutoff10.vgm	0	2.0
2.5			
5			
10			

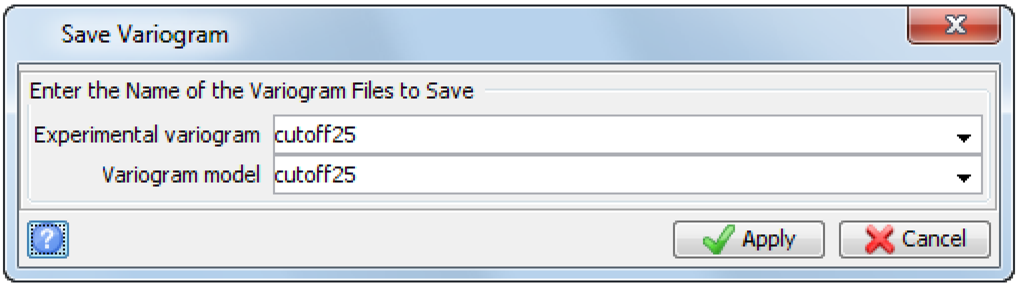
14. Use the **cutoff selector**to display the variogram map for the next cutoff (2.5).



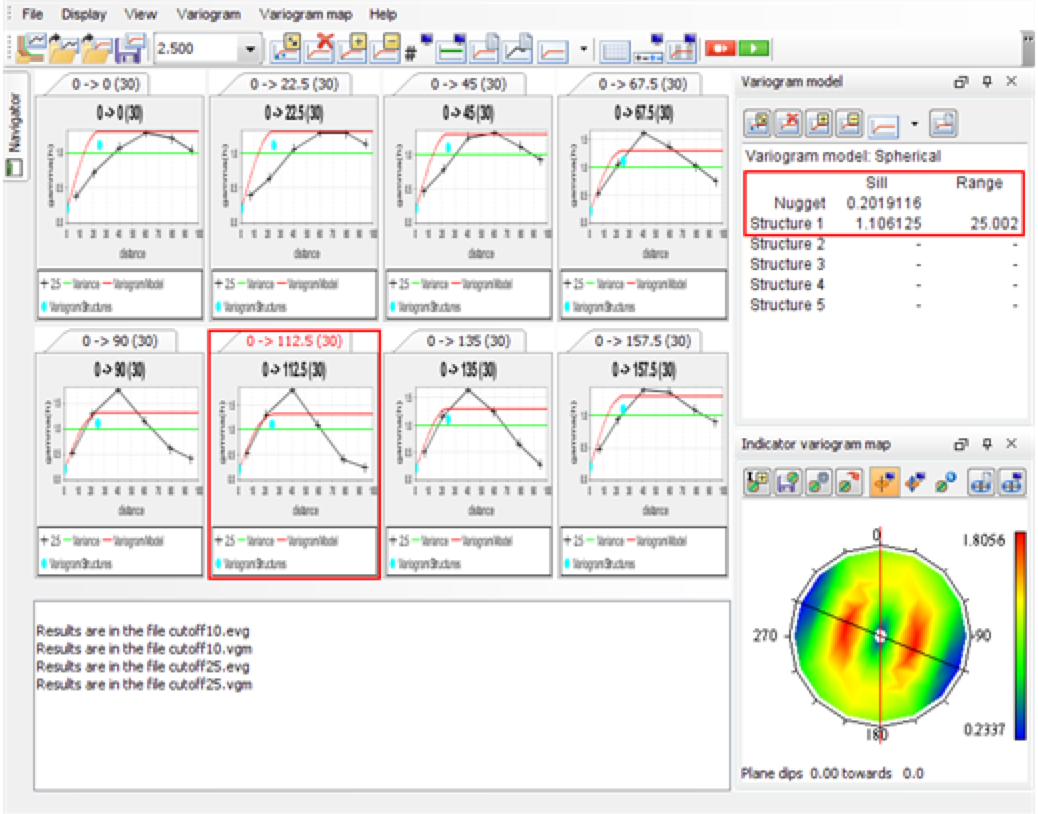
15. Use the variogram map to identify the major axis for the 2.5 cutoff, as shown.
16. Create a variogram for that orientation, and note the **Range**.



17. Choose **File > Save > Experimental variogram and model**.
18. Enter the information as shown, and click **Apply**.



19. Modify the variogram to best-fit the semi-major axis (keep the nugget and sill the same), and note the range.



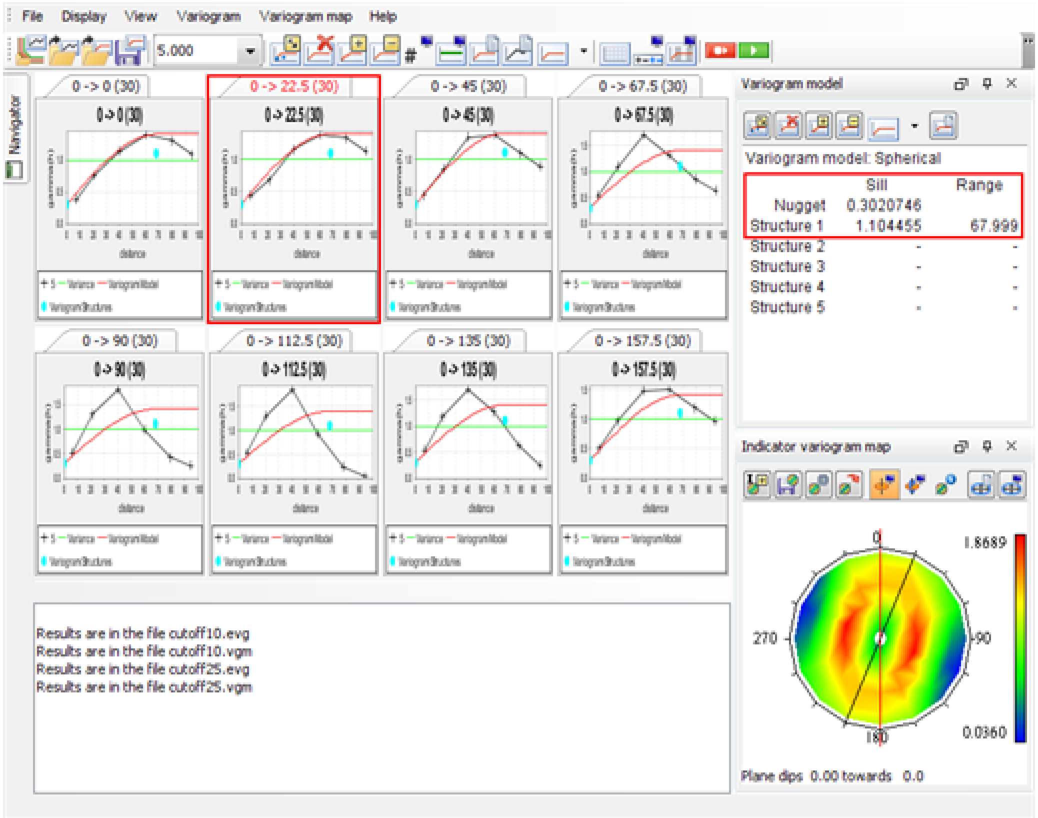
20. Calculate the anisotropy ratio (range of the major axis divided by the range of the semi-major axis) for the first cutoff:

major/semi-major anisotropy ratio = 75 / 25 = 3

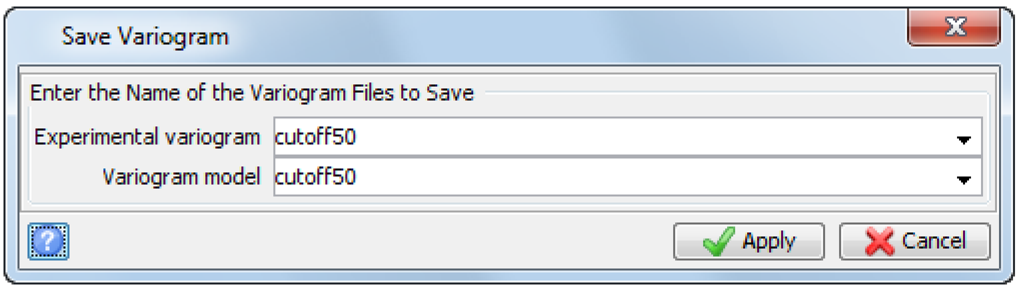
21. Document the values as shown.

Cutoff	Variogram	Bearing	Major/Semi-Major Anisotropy Ratio
1	cutoff10.vgm	0	2.0
2.5	cutoff25.vgm	22.5	3.0
5			
10			

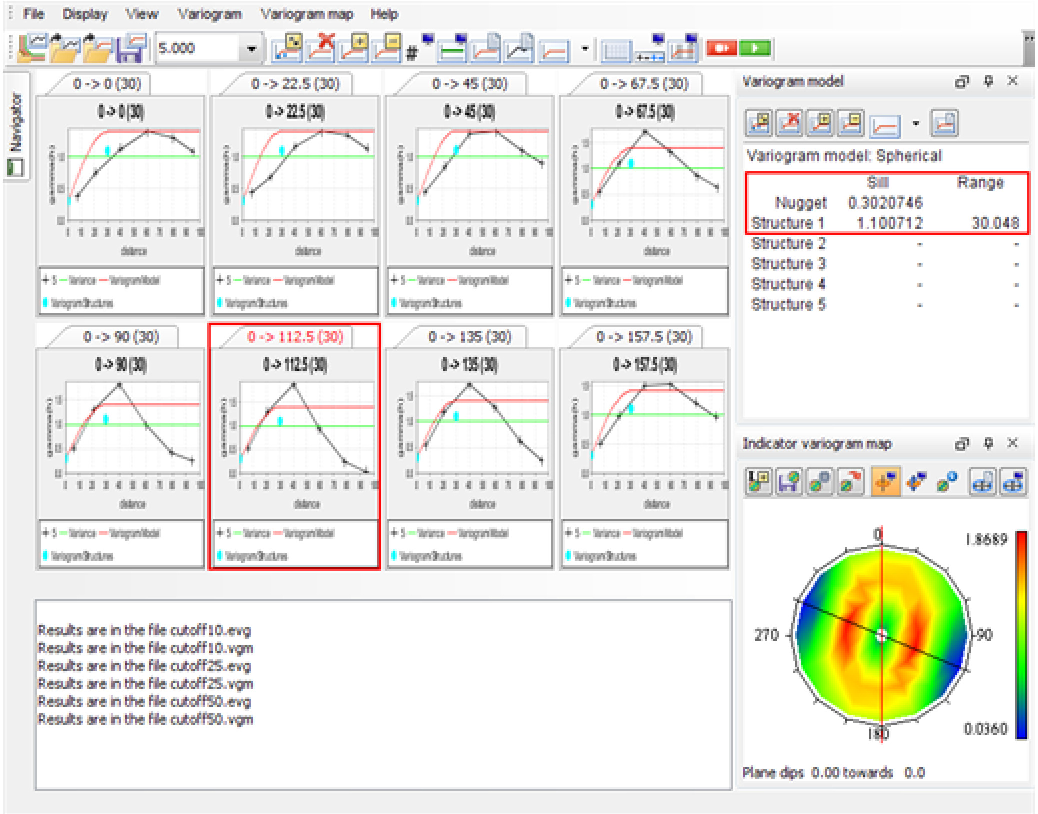
22. Use the **cutoff selector** to display the variogram map for the next cutoff (5.0).
23. Use the variogram map to identify the major axis for the 5.0 cutoff, as shown.
24. Create a variogram for that orientation, and note the **Range**.



25. Choose **File > Save > Experimental variogram and model**.
26. Enter the information as shown, and click **Apply**.



27. Modify the variogram to best-fit the semi-major axis (keep the nugget and sill the same), and note the range.



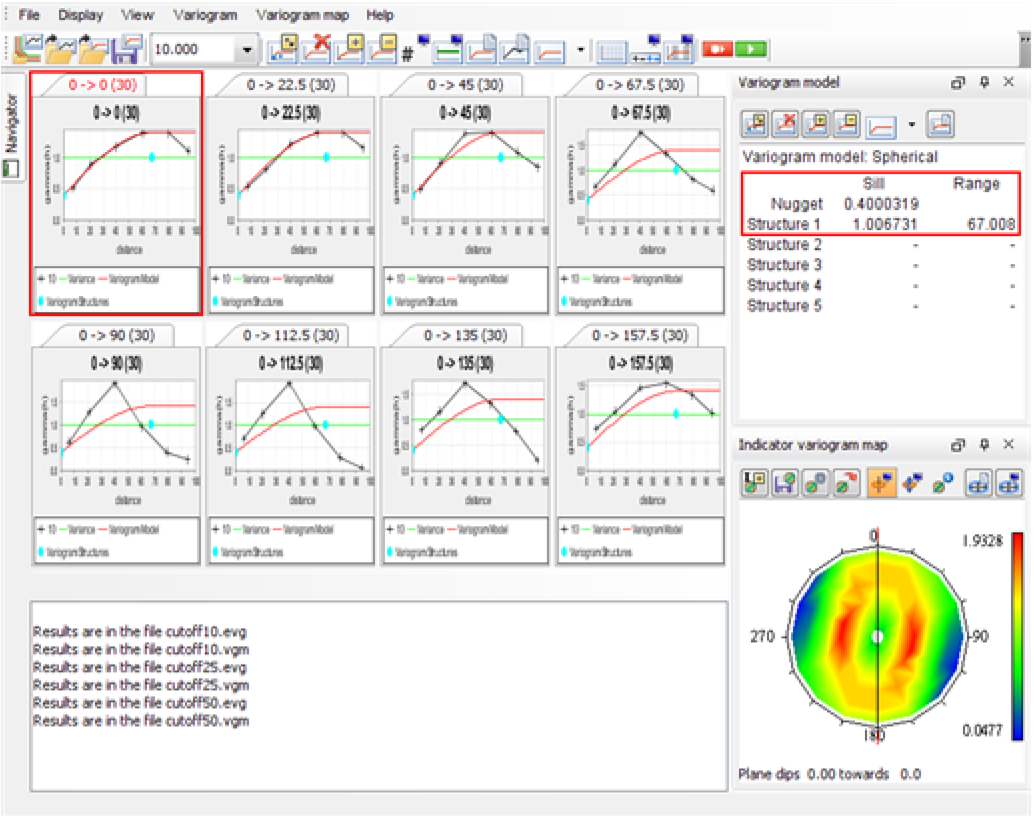
28. Calculate the anisotropy ratio (range of the major axis divided by the range of the semi-major axis) for the first cutoff:

    major/semi-major anisotropy ratio = 68 / 30 = 2.3

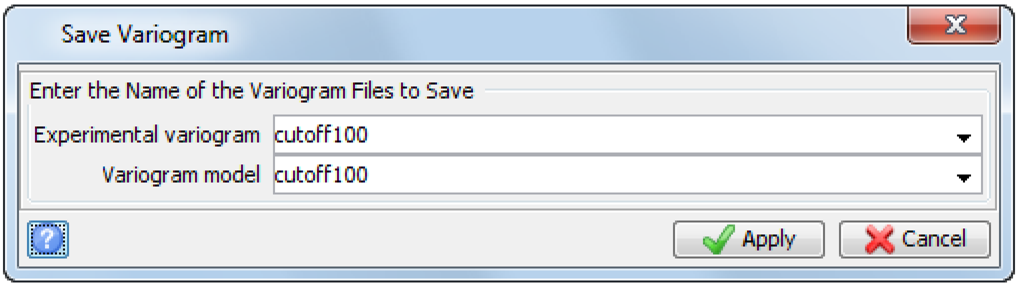
29. Document the values as shown:.

Cutoff	Variogram	Bearing	Major/Semi-Major Anisotropy Ratio
1	cutoff10.vgm	0	2.0
2.5	cutoff25.vgm	22.5	3.0
5	cutoff50.vgm	22.5	2.3
10			

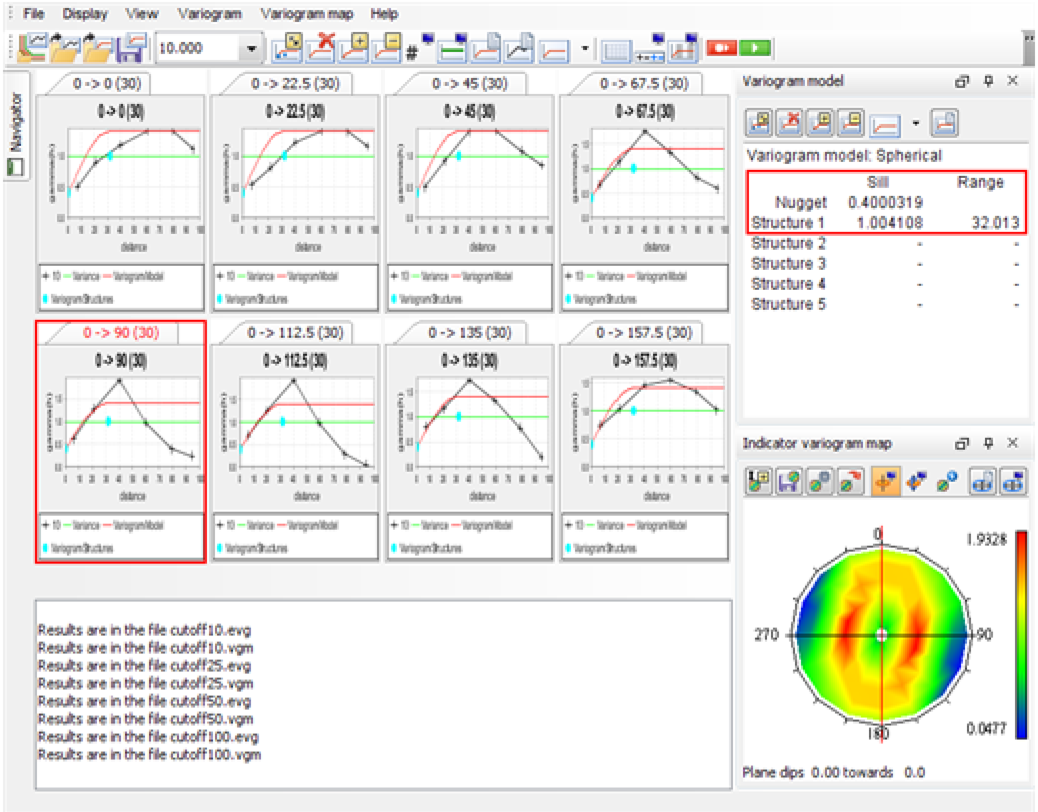
30. Use the **cutoff selector** to display the variogram map for the next cutoff (10.0).
31. Use the variogram map to identify the major axis for the 10.0 cutoff, as shown.
32. Create a variogram for that orientation, and note the **Range**.



33. Choose **File > Save > Experimental variogram and model**.
34. Enter the information as shown, and click **Apply**.



35. Modify the variogram to best-fit the semi-major axis (keep the nugget and sill the same), and note the range.



36. Calculate the anisotropy ratio (range of the major axis divided by the range of the semi-major axis) for the first cutoff:

major/semi-major anisotropy ratio = 67 / 32 = 2.1

37. Document the values, as shown.

Cutoff	Variogram	Bearing	Major/Semi-Major Anisotropy Ratio
1	cutoff10.vgm	0	2.0
2.5	cutoff25.vgm	22.5	3.0
5	cutoff50.vgm	22.5	2.3
10	cutoff100.vgm	0	2.1

Note: This exercise, with four cutoffs, demonstrates that the amount of work to obtain the parameters necessary for performing indicator kriging of one attribute (gold, in this case) is equal to four times the amount of work required to obtain the anisotropy parameters for ordinary kriging. Normally, ten or more cutoffs are used. This means it requires ten or more times the amount of work per attribute. Multiply this times the number of attributes per model, and can see that considerable effort is required to derive all of the anisotropy ellipsoid parameters for all attributes in a model. This extra work is a main reason why indicator kriging is not used for the majority of resource estimations. If a data set contains multiple populations (as evidenced by a bimodal distribution), which cannot be geographically separated, then indicator kriging is used because it is seen as a viable alternative, despite the work involved.

Indicator kriging

Indicator kriging is ordinary kriging of indicator-transformed data values for each of several cutoffs. The result of performing indicator kriging is a Cumulative Frequency Function (CFF), stored as attributes in the block model. In this way, indicator kriging is not creating a single value for the entire block, but rather describing the amount of material in the block above or below a given cutoff.

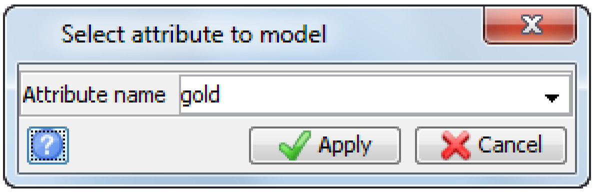
You must have previously created and documented variogram models and anisotropy parameters, such as as shown in the following table for this two-dimensional example.

Cutoff	Variogram	Bearing	Major/Semi-Major Anisotropy Ratio
1	cutoff10.vgm	0	2.0
2.5	cutoff25.vgm	22.5	3.0
5	cutoff50.vgm	22.5	2.3
10	cutoff100.vgm	0	2.1

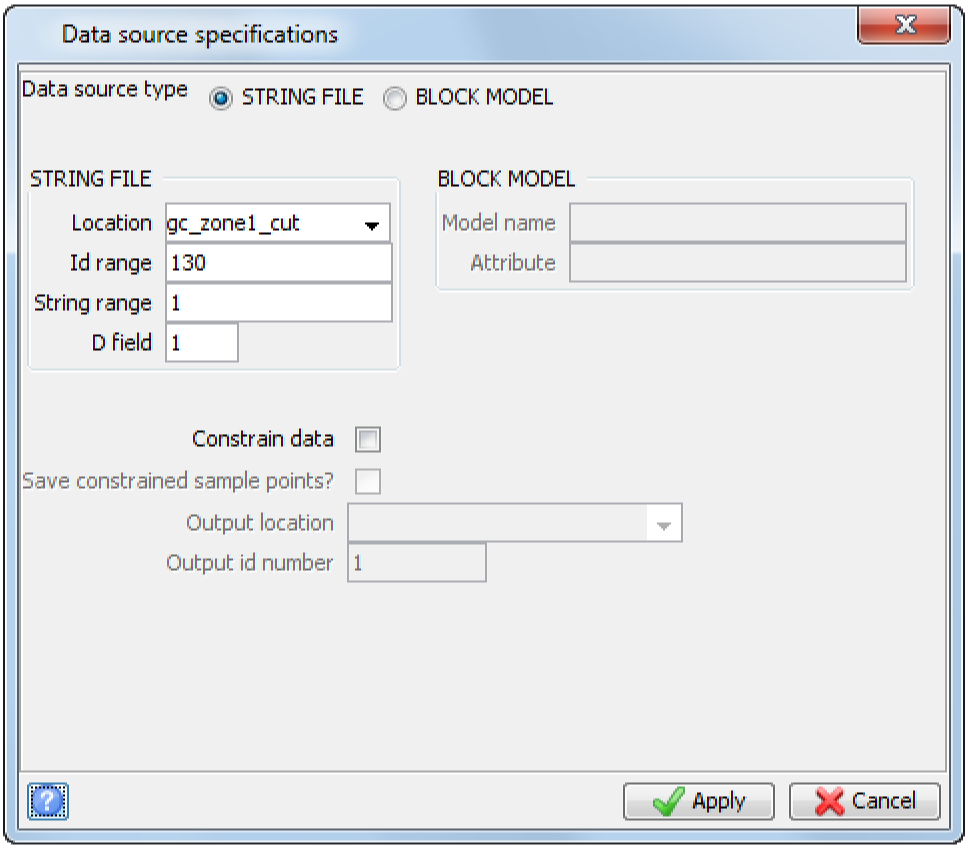
For a three-dimensional example, you would have one additional column for major/minor anisotropy ratio.

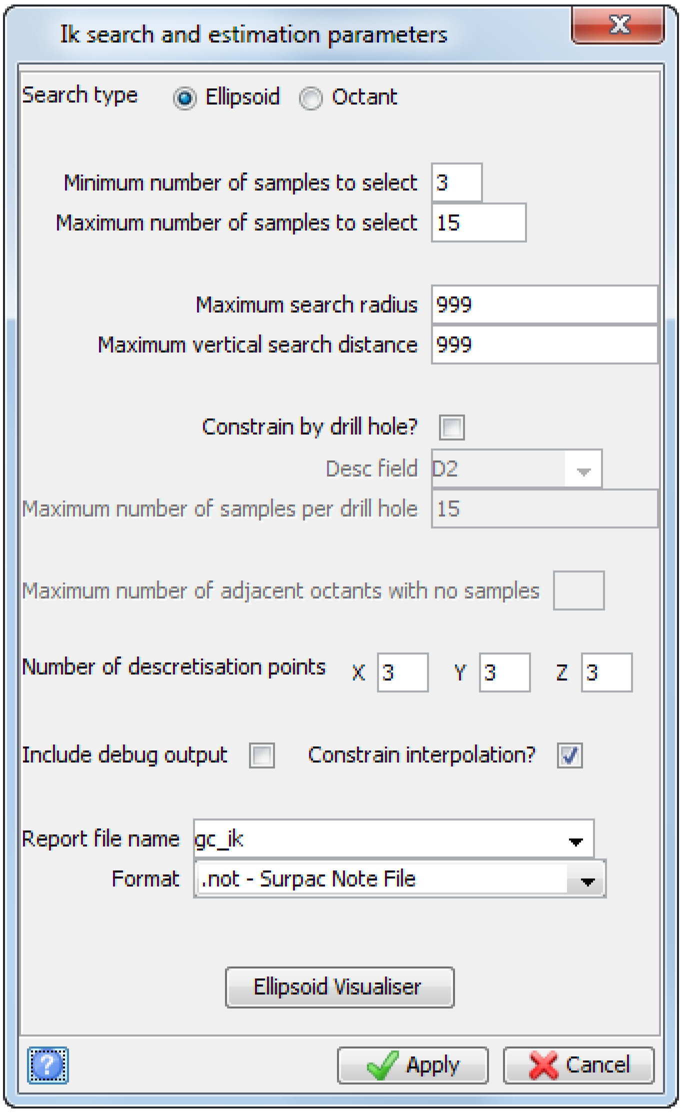
Task: Perform indicator kriging

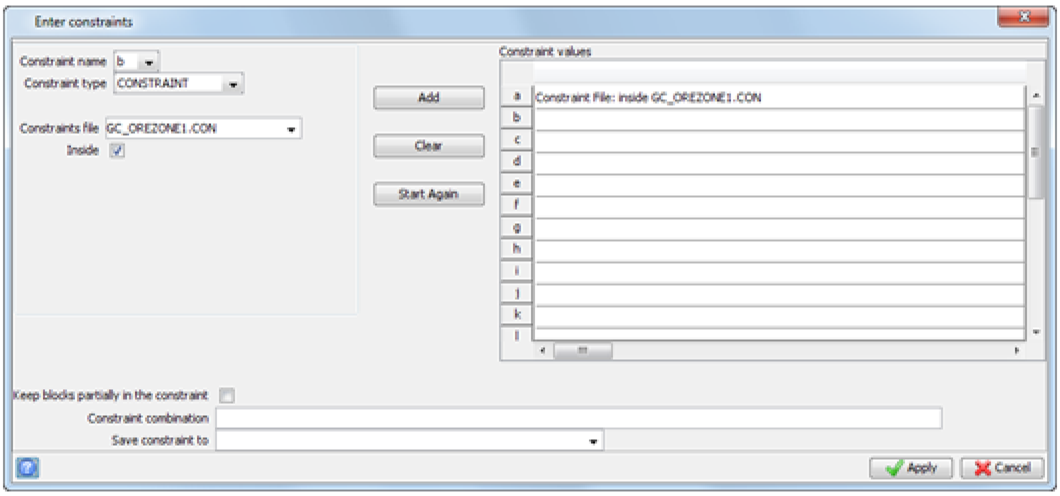
1. Choose **Indicator kriging > Indicator kriging attribute ()**.
2. Enter the information as shown, and click **Apply**.

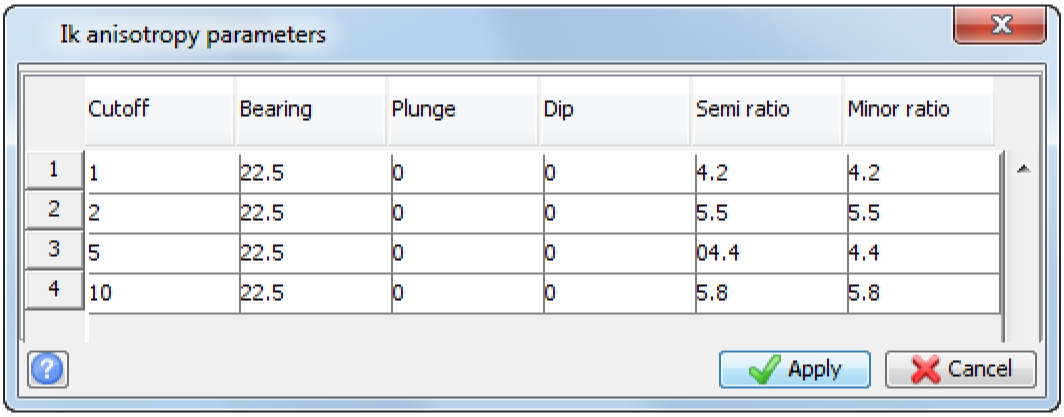


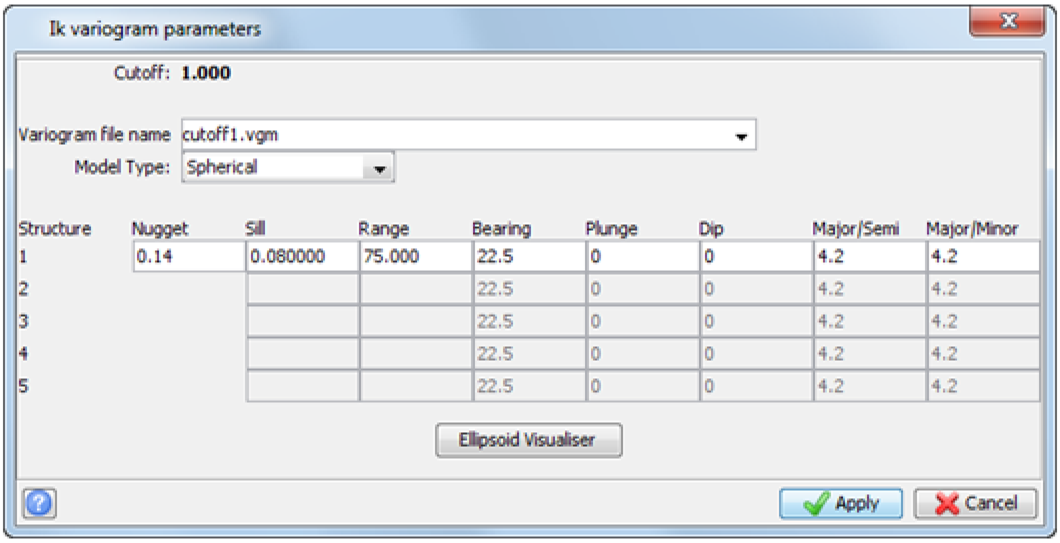
3. Choose **Indicator kriging > Indicator kriging**.
4. Enter the information as shown on each of the six following forms, and click **Apply**.

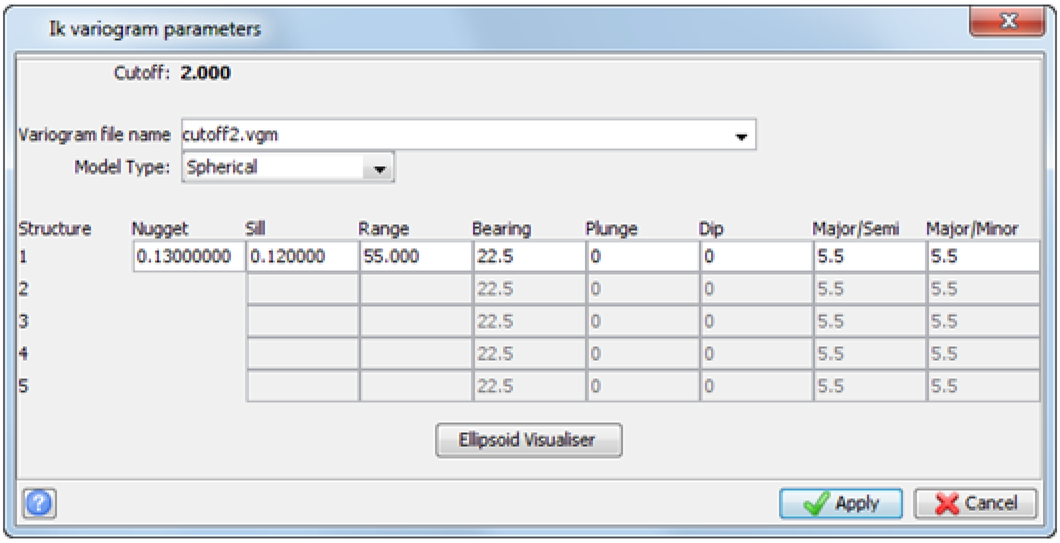


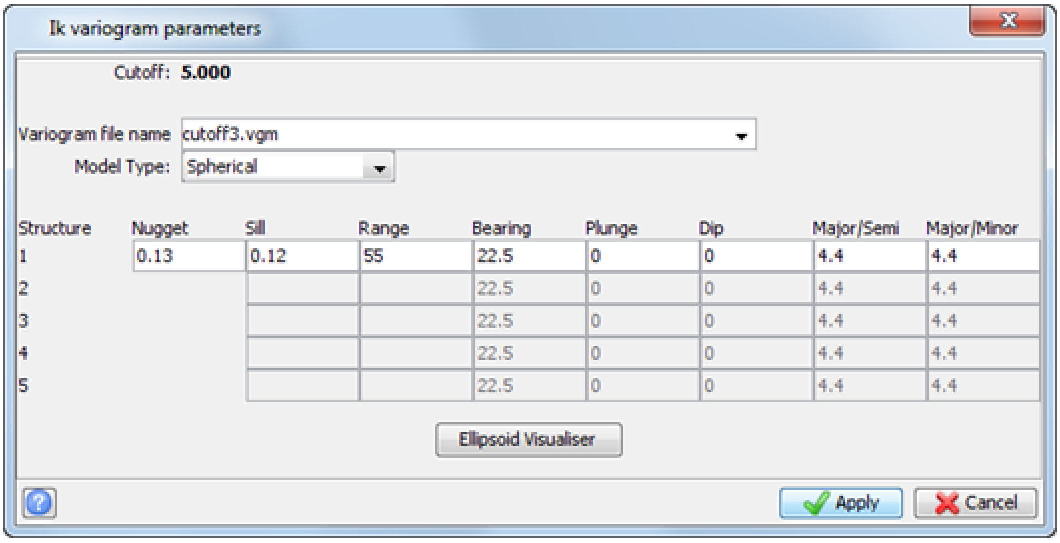

Ik search and estimation parameters
Search type
Ellipsoid
Octant
Minimum number of samples to select
3
Maximum number of samples to select
15
Maximum search radius
999
Maximum vertical search distance
999
Constrain by drill hole?
Desc field
D2
Maximum number of samples per drill hole
15
Maximum number of adjacent octants with no samples
Number of descretisation points
X
3
Y
3
Z
3
Include debug output
Constrain interpolation?
Report file name
gc_ik
Format
.not - Surpac Note File
Ellipsoid Visualiser
Apply
Cancel

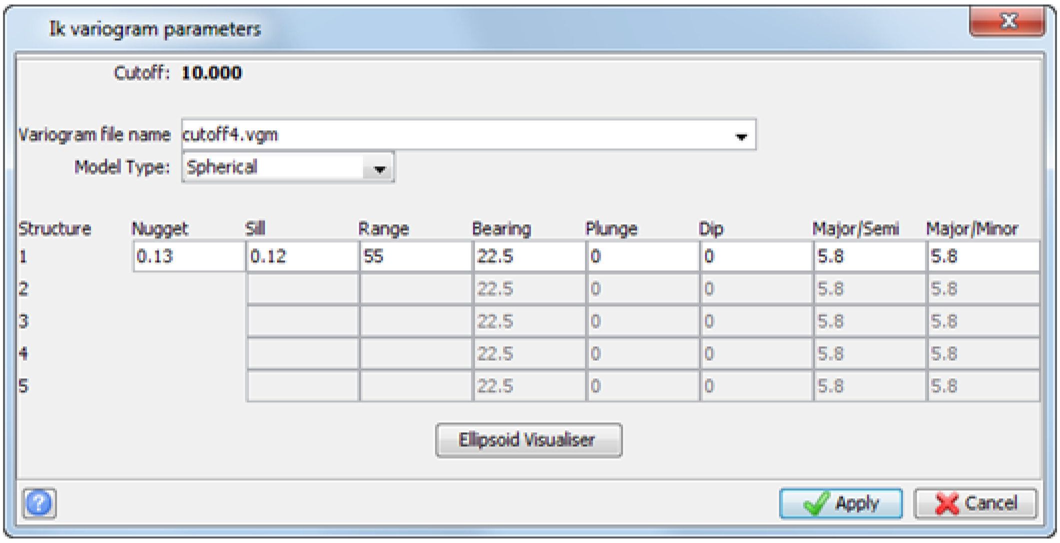

Enter constraints
Constraint name
b
Constraint type
CONSTRAINT
Constraints file
GC_OREZONE1.CON
Inside
Add
Clear
Start Again
Constraint values
Constraint File: inside GC_OREZONE1.CON
Keep blocks partially in the constraint
Constraint combination
Save constraint to
Apply
Cancel


Ik anisotropy parameters
Cutoff
Bearing
Plunge
Dip
Semi ratio
Minor ratio
1 1 22.5 0 0 4.2 4.2
2 2 22.5 0 0 5.5 5.5
3 5 22.5 0 0 04.4 4.4
4 10 22.5 0 0 5.8 5.8
Apply
Cancel

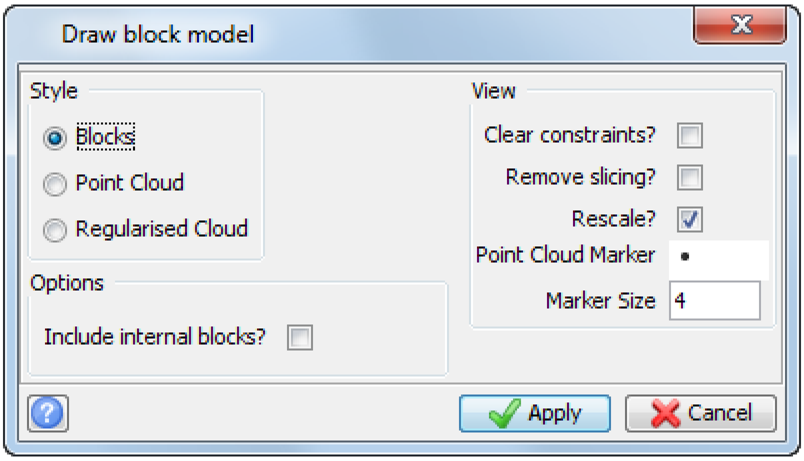

Ik variogram parameters
Cutoff: 1.000
Variogram file name cutoff1.vgm
Model Type: Spherical
Structure Nugget Sill Range Bearing Plunge Dip Major/Semi Major/Minor
1 0.14 0.080000 75.000 22.5 0 0 4.2 4.2
2 22.5 0 0 4.2 4.2
3 22.5 0 0 4.2 4.2
4 22.5 0 0 4.2 4.2
5 22.5 0 0 4.2 4.2
Ellipsoid Visualiser
Apply
Cancel


Ik variogram parameters
Cutoff: 2.000
Variogram file name cutoff2.vgm
Model Type: Spherical
Structure Nugget Sill Range Bearing Plunge Dip Major/Semi Major/Minor
1 0.13000000 0.120000 55.000 22.5 0 0 5.5 5.5
2 22.5 0 0 5.5 5.5
3 22.5 0 0 5.5 5.5
4 22.5 0 0 5.5 5.5
5 22.5 0 0 5.5 5.5
Ellipsoid Visualiser
Apply
Cancel

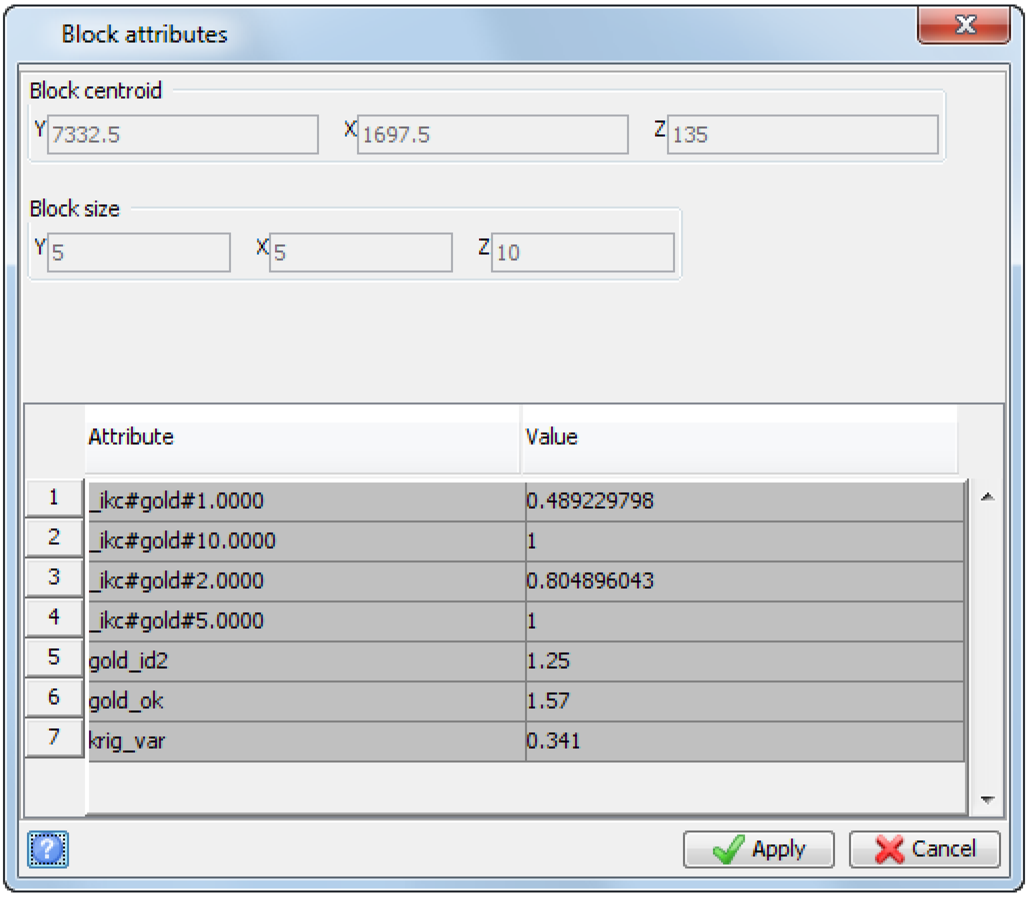




5. Choose **Display > Display block model**.
6. Enter the information as shown, and click **Apply**.



7. Open **gc_orezone1.con** in **Graphics**.
8. Choose **Attributes > View attributes for one block**.
9. Select a block, to see its attributes.



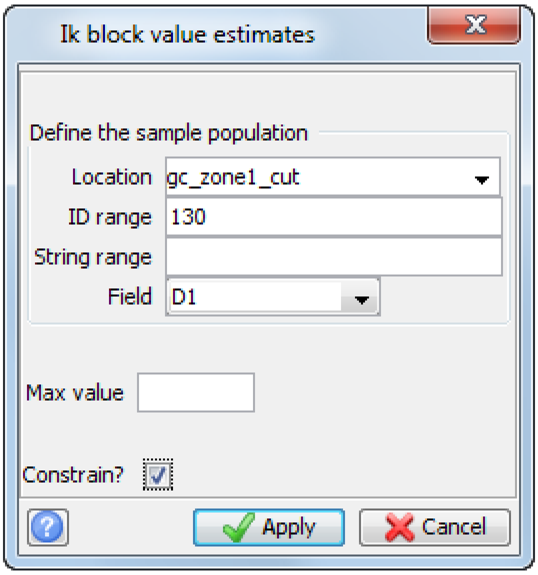
	Attribute	Value
1	_ikc#gold#1.0000	0.489229798
2	_ikc#gold#10.0000	1
3	_ikc#gold#2.0000	0.804896043
4	_ikc#gold#5.0000	1
5	gold_id2	1.25
6	gold_ok	1.57
7	krig_var	0.341

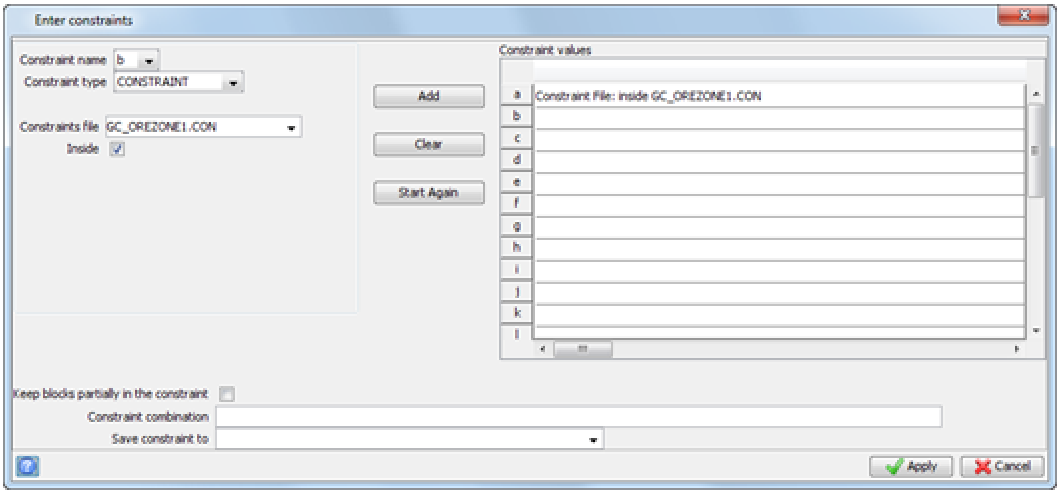
The Cumulative Frequency Function (CFF) values have been estimated. New attributes have been created to store the CFF values, and are named _ikc#IKattribute#cutoff. In the image above, the value of 0.14 for the attribute **_ikc#gold#5.0000** indicates that 14% of the block is estimated to fall below the value of 5.0.

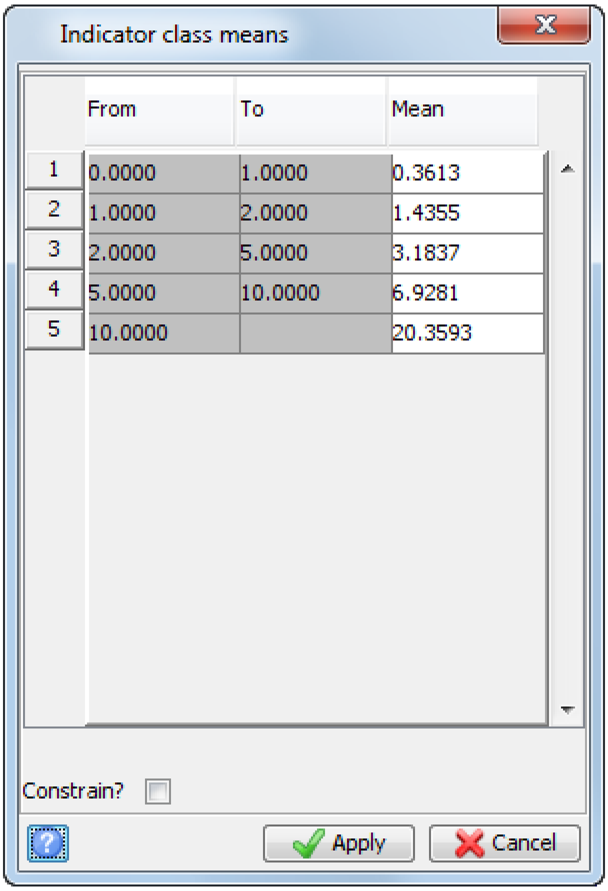
Note: To see all of the steps performed in this task, run **2d_11e_ik_cff.tcl**

Task: Calculate block values

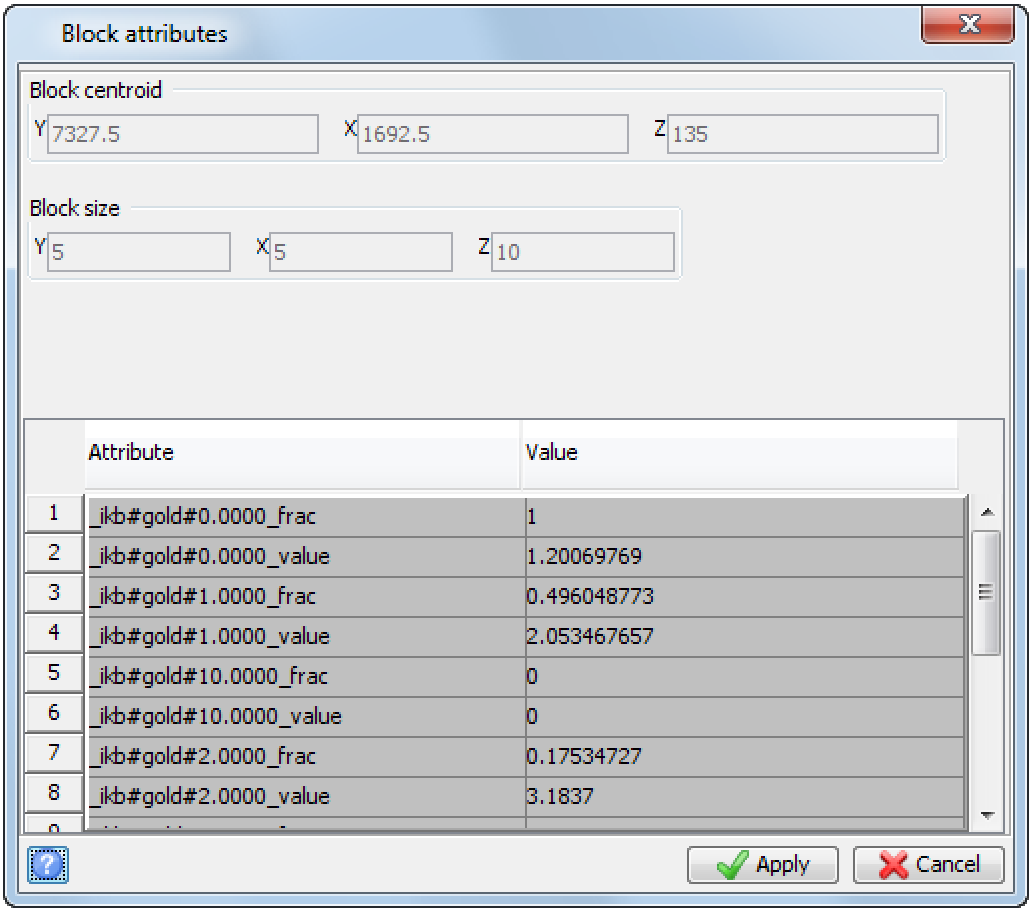
1. Choose **Indicator kriging > Block value estimates**
2. Enter the information as shown on each of the four following forms, and click **Apply**.

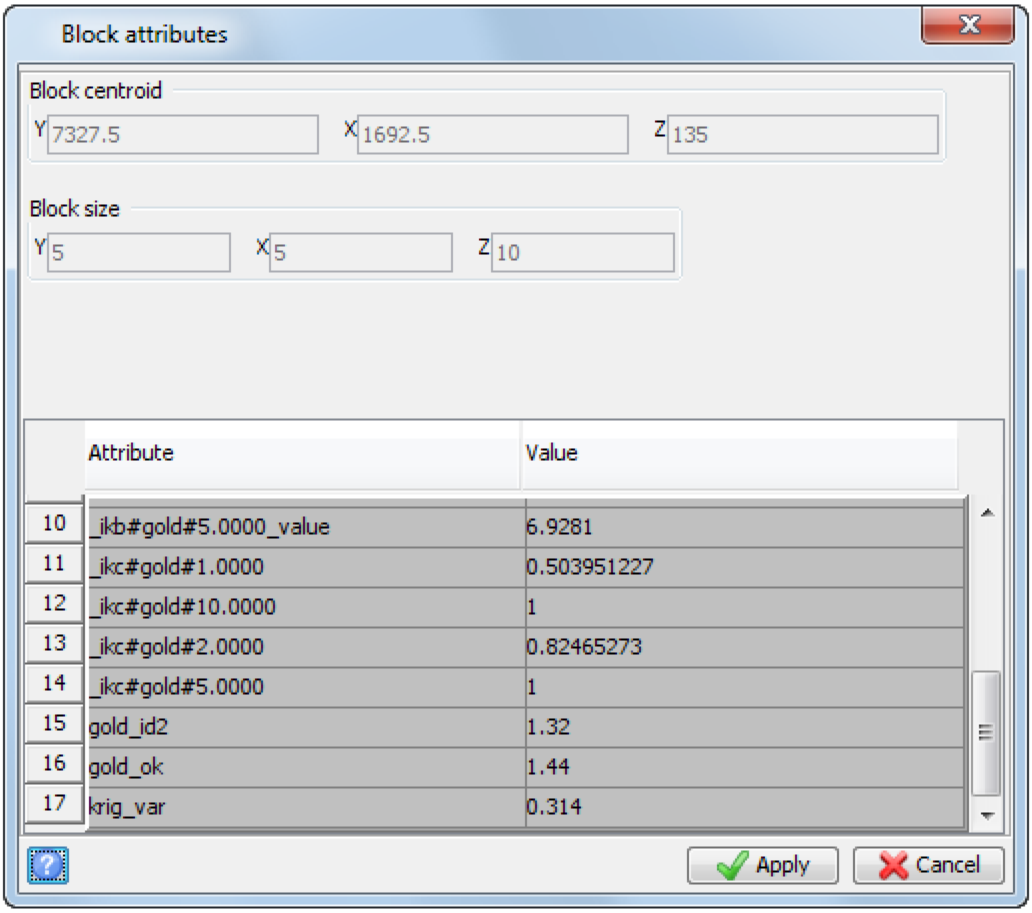

Ik block value estimates
Define the sample population
Location
gc_zone1_cut
ID range
130
String range
Field
D1
Max value
Constrain?
Apply
Cancel


Enter constraints
Constraint name
b
Constraint type
CONSTRAINT
Constraints file
GC_OREZONE1.CON
Inside
Add
Clear
Start Again
Constraint values
Constraint File: inside GC_OREZONE1.CON
Keep blocks partially in the constraint
Constraint combination
Save constraint to
Apply
Cancel



3. On the *Verify creation of file* form, click **Yes**.
4. Choose **Attributes View attributes for one block**.
5. Select a block.


Block attributes
Block centroid
Y 7327.5
X 1692.5
Z 135
Block size
Y 5
X 5
Z 10
Attribute
Value
1 _ikb#gold#0.0000_frac 1
2 _ikb#gold#0.0000_value 1.20069769
3 _ikb#gold#1.0000_frac 0.496048773
4 _ikb#gold#1.0000_value 2.053467657
5 _ikb#gold#10.0000_frac 0
6 _ikb#gold#10.0000_value 0
7 _ikb#gold#2.0000_frac 0.17534727
8 _ikb#gold#2.0000_value 3.1837
Apply
Cancel

6. 
Block attributes
Block centroid
Y 7327.5
X 1692.5
Z 135
Block size
Y 5
X 5
Z 10
Attribute
Value
10 _ikb#gold#5.0000_value 6.9281
11 _ikc#gold#1.0000 0.503951227
12 _ikc#gold#10.0000 1
13 _ikc#gold#2.0000 0.82465273
14 _ikc#gold#5.0000 1
15 gold_id2 1.32
16 gold_ok 1.44
17 krig_var 0.314
Apply
Cancel

The block values have been calculated. Two new attributes have been created for each cutoff.

_ikb#IKattribute#cutoff_frac - the fraction of the block above the cutoff

_ikb#IKattribute#cutoff_value - the average grade of the block above that cutoff.

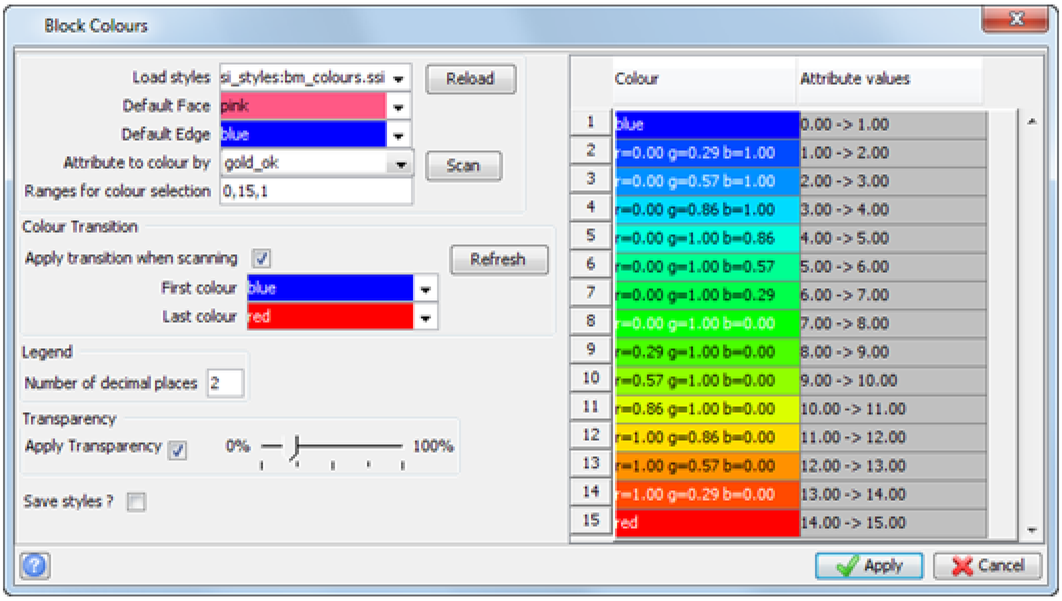
In addition, two other attributes are created.

_ikb#IKattribute#0.0000_frac - this will always be 1.00 = 100% of the block

_ikb#IKattribute#0.0000_value - the average grade of the entire block.

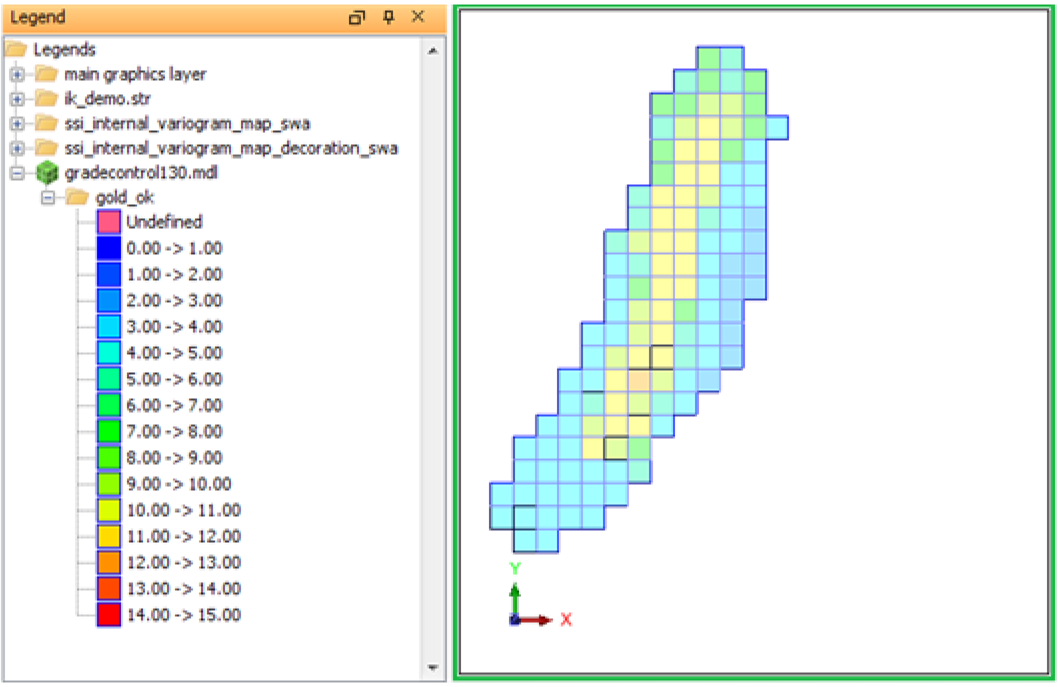
In the image above, the value of 13.45 for the attribute **_ikb#gold#0.0000** indicates that the average grade of the entire block is 13.45.

7. Click **Cancel**.
8. Choose **Display > Colour model by attribute**.
9. In the **Attribute to colour by** field, select **gold_ok**, click **Scan**, for the **Ranges for colour selection**type **0,15,1** and click **Refresh**.
10. Click **Apply**.



11. Display the legend on the **Legend** tab.

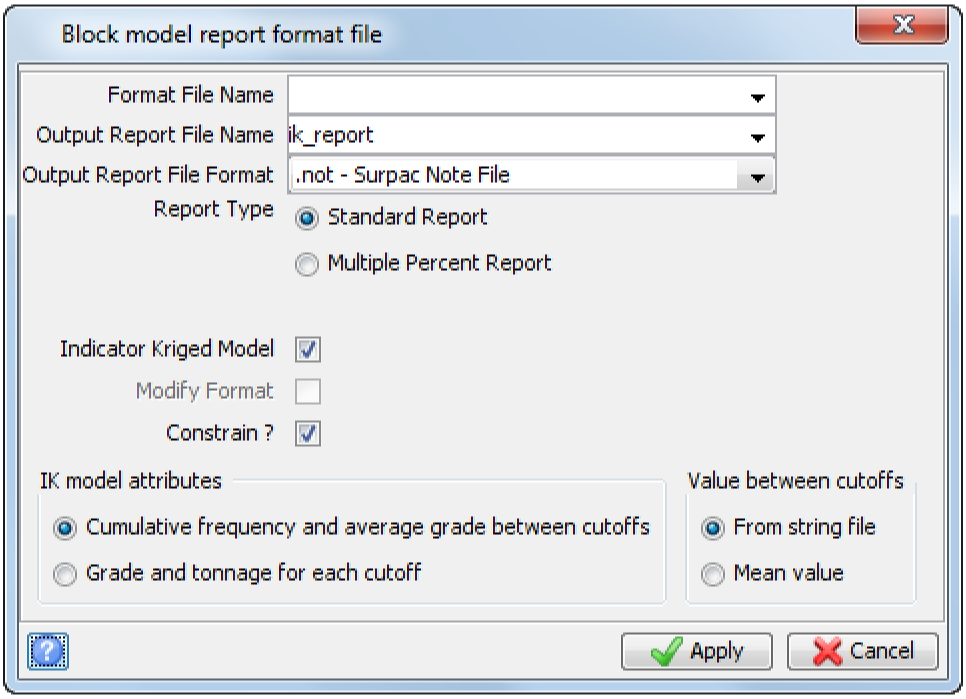
    The data and model are displayed, as shown.

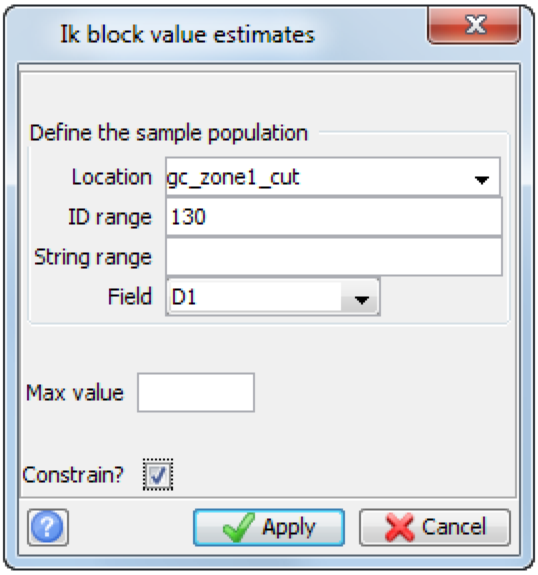


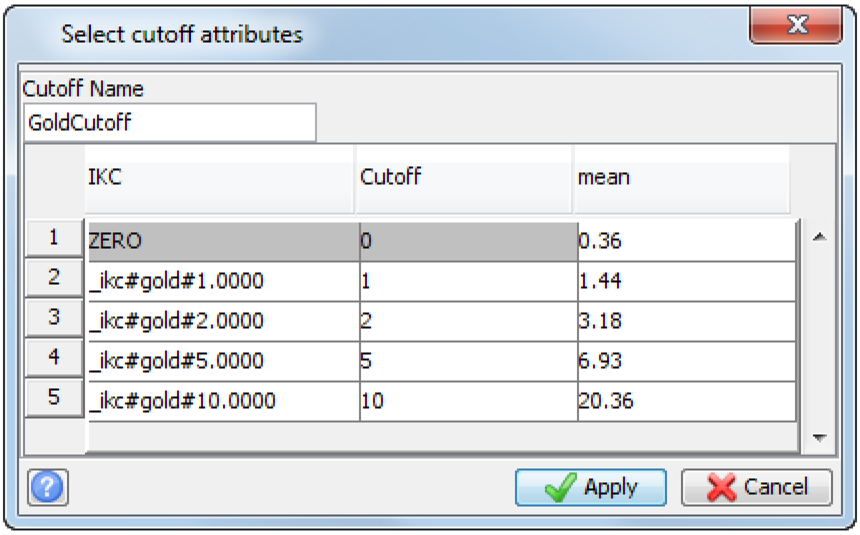
12. Choose **Block Model > Close**, and click **Yes**.

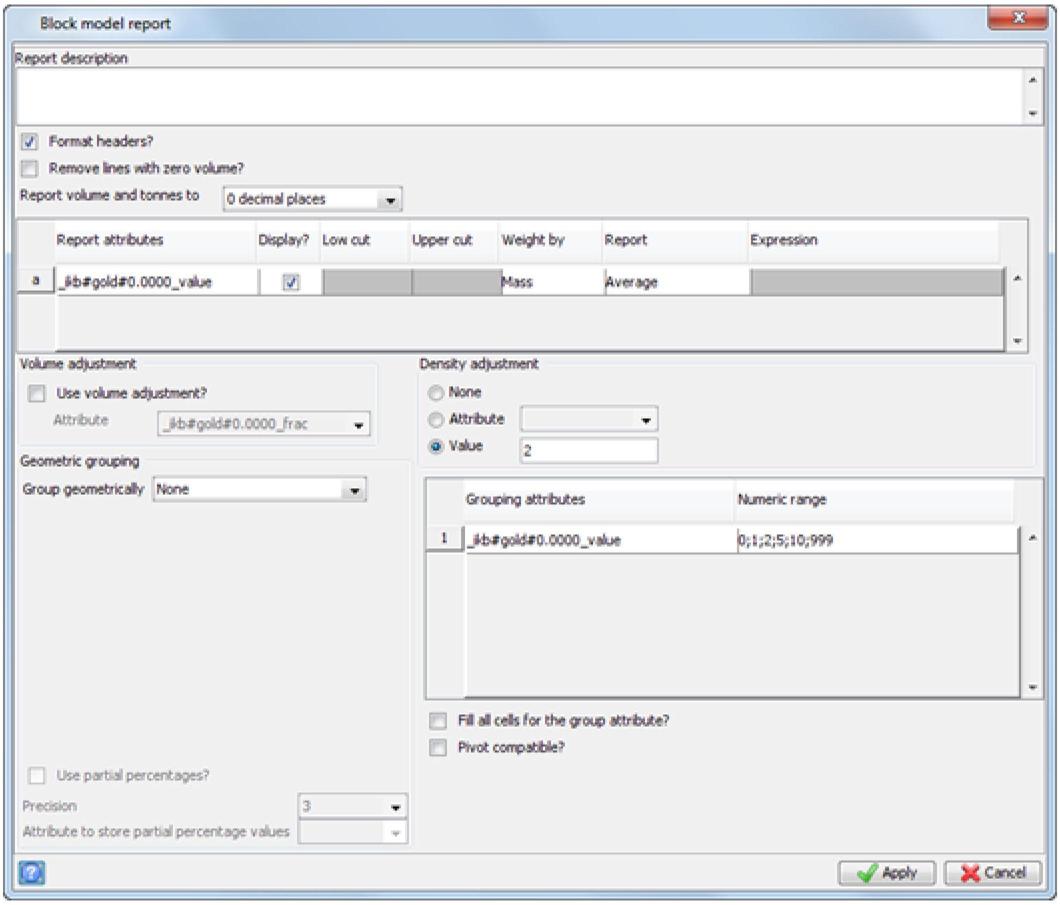
Task: Report tonnes and grade for an indicator kriged (IK) model

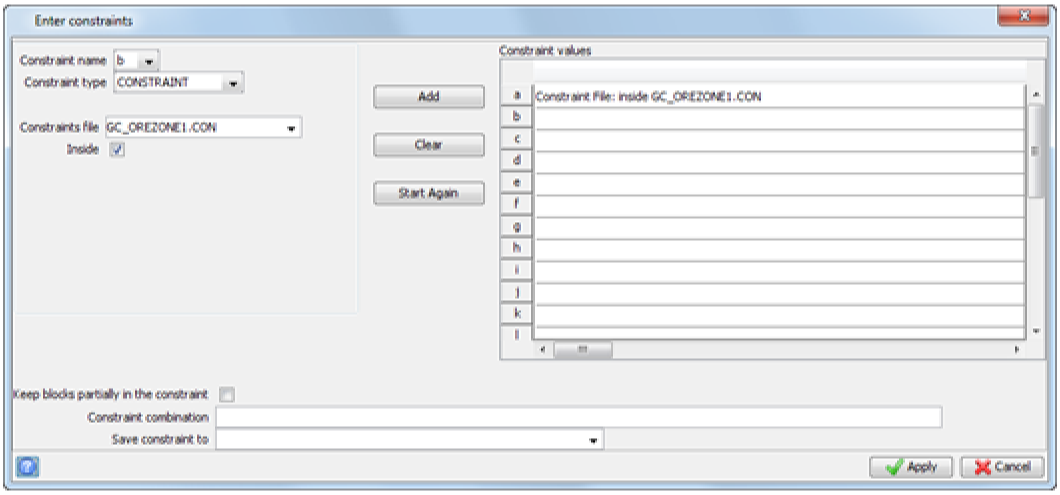
1. Choose **Block model > Report.**
2. Enter the information as shown on each of the five following forms, and click **Apply**.




Ik block value estimates
Define the sample population
Location gc_zone1_cut
ID range 130
String range
Field D1
Max value
Constrain?
Apply
Cancel


Select cutoff attributes
Cutoff Name
GoldCutoff
IKC
Cutoff
mean
1 ZERO 0 0.36
2 _ikc#gold#1.0000 1 1.44
3 _ikc#gold#2.0000 2 3.18
4 _ikc#gold#5.0000 5 6.93
5 _ikc#gold#10.0000 10 20.36
Apply
Cancel





The block model report opens in your default text editor.

```
                                Block model report

Constraints used
  a.  INSIDE CONSTRAINT GC_OREZONE1

  Keep blocks partially in the constraint : False


Ikb#gold#0.0000 Value              Attribute  Volume  Tonnes  Average Grade
---------------------------------------------------------------------------
          0.0 -> 1.0  _ikb#gold#0.0000_value       0       0          0.000

          1.0 -> 2.0  _ikb#gold#0.0000_value    3250    6500          1.497

          2.0 -> 5.0  _ikb#gold#0.0000_value   10250   20500          3.238

         5.0 -> 10.0  _ikb#gold#0.0000_value   12500   25000          7.101

       10.0 -> 999.0  _ikb#gold#0.0000_value    5000   10000         11.438

---------------------------------------------------------------------------
         Grand Total  _ikb#gold#0.0000_value   31000   62000          5.936
---------------------------------------------------------------------------
```

Note: To see all of the steps performed in this task, run **2d_11g_ik_report.tcl**. You need to click **Apply** on any forms presented.

Conditional simulation

Overview

Conditional Simulation is an advanced geostatistical technique. It is useful for assessing risk associated with an estimate. Other estimation methods, such as inverse distance weighting and ordinary kriging have a tendency to "smooth" data values. In general, the standard deviation and coefficient of variation of the block values estimated with these techniques will be less than for the data set that was used to perform the estimate. The histogram of the estimated blocks will have a higher minimum value and a lower maximum value than the histogram of the data.

Conditional simulation theory attempts to create a set of block estimates which is conditioned to simulate the histogram and other basic statistical parameters of the input data.

You will learn about:

- normal scores transformation
- conditional simulation estimation

Requirements

In order to understand this information, you should:

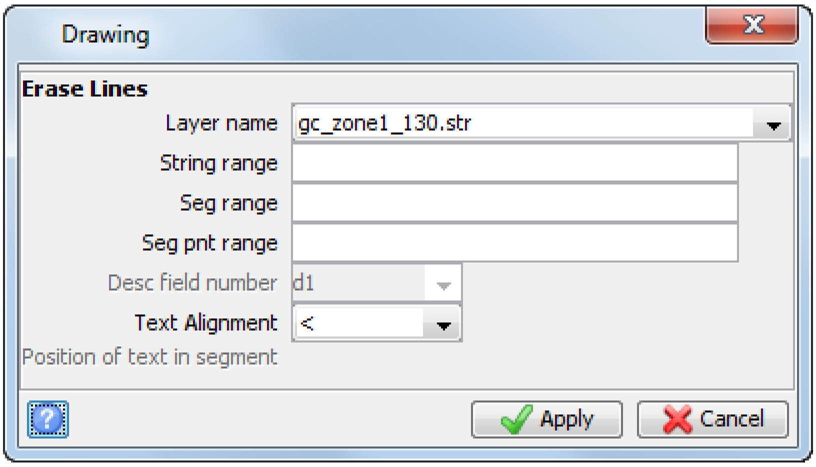
- be familiar with Surpac string files and block models
- know how to create and use variogram maps
- understand the concepts of anisotropy and kriging

Normal scores transformation

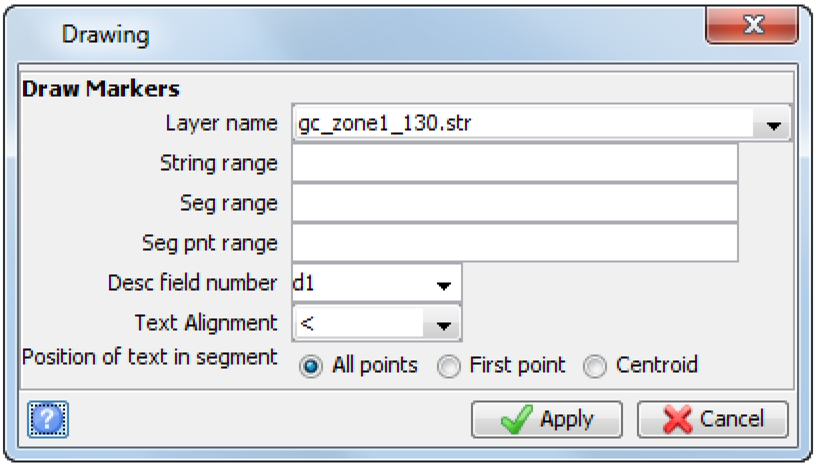
Conditional simulation requires the maximum sill of the variogram to be 1.0. This is achievable by first performing a normal scores transformation of the data.

Task: Perform a normal scores transformation

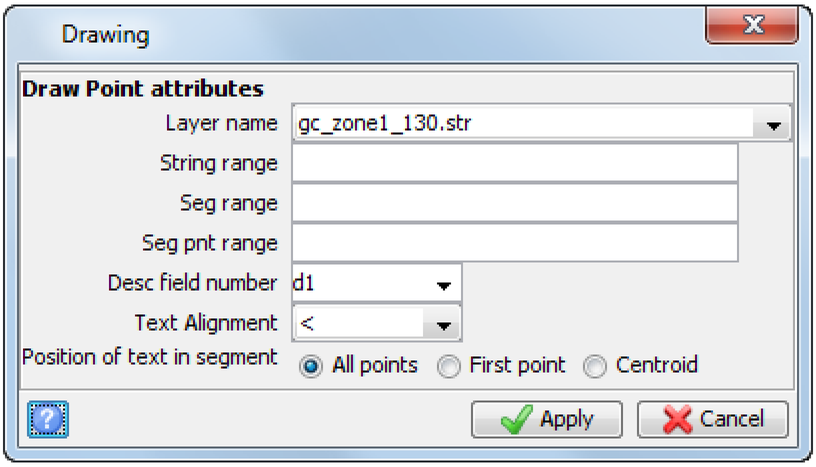
1. Open **gc_zone1_130.str** in **Graphics**.
2. Choose **Display > Hide strings > As lines**.
3. Enter the information as shown, and click **Apply**.



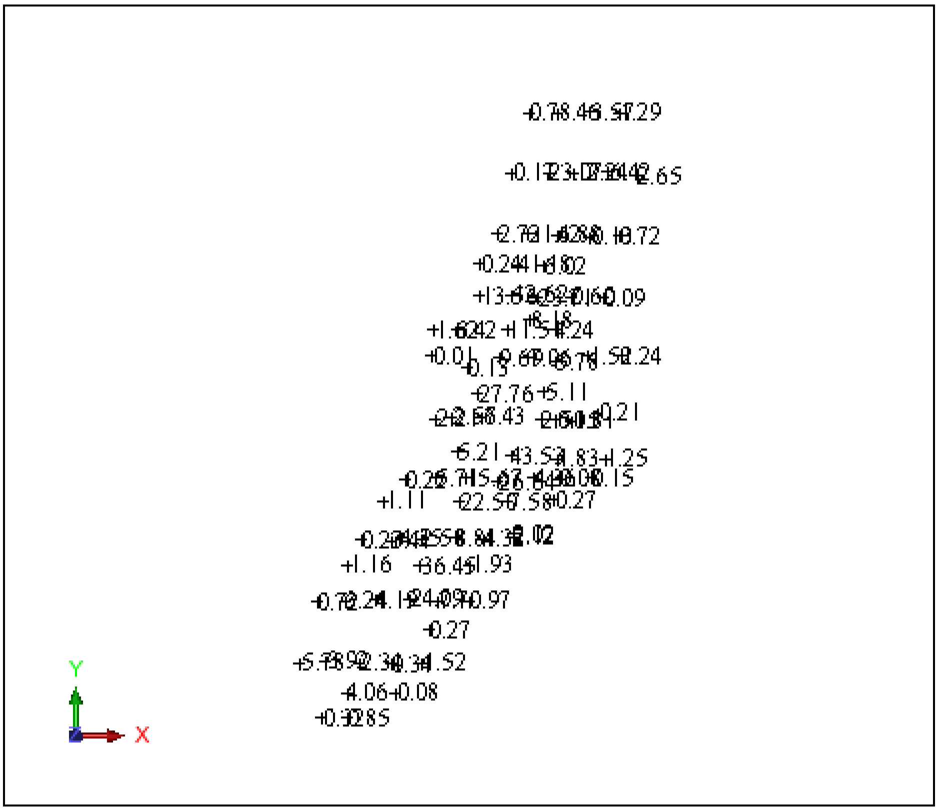
4. Choose **Display > Point > Markers**.
5. Enter the information as shown, and click **Apply**.



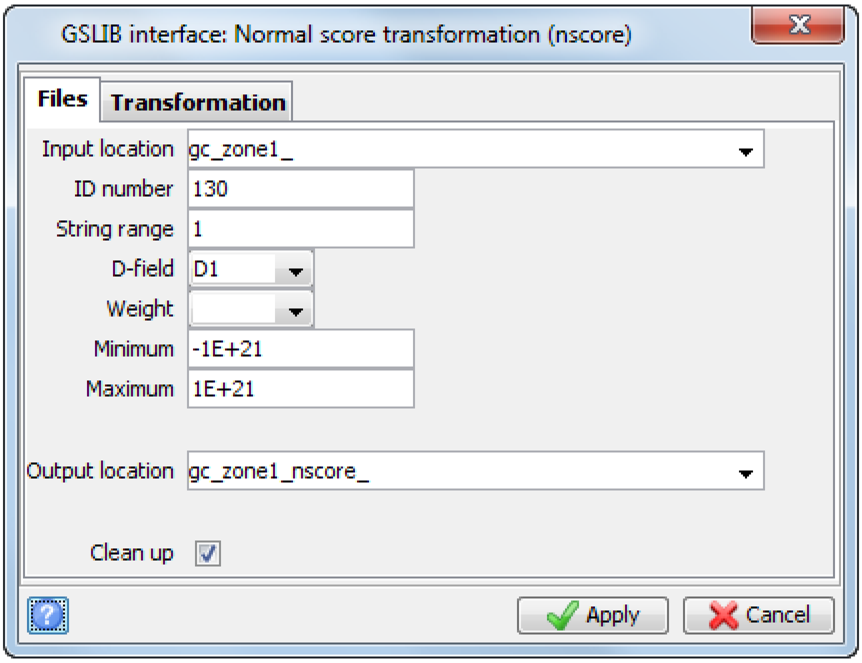
6. Choose **Display > Point > Attributes**.
7. Enter the information as shown, and click **Apply**.

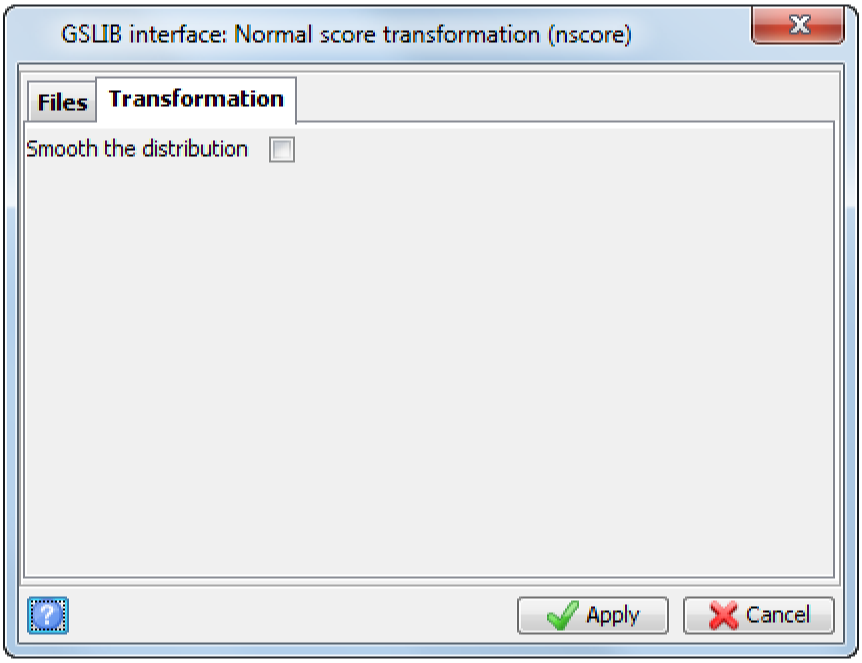


8. The D1 values are displayed.

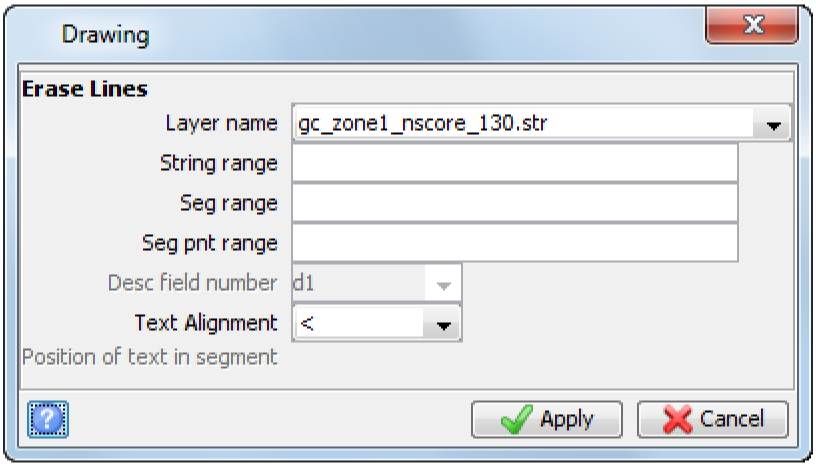


9. Choose **Estimation > GSLIB > Normal score transformation (nscore)**.
10. Enter the information as shown on the two tabs of the following form, and click **Apply**.

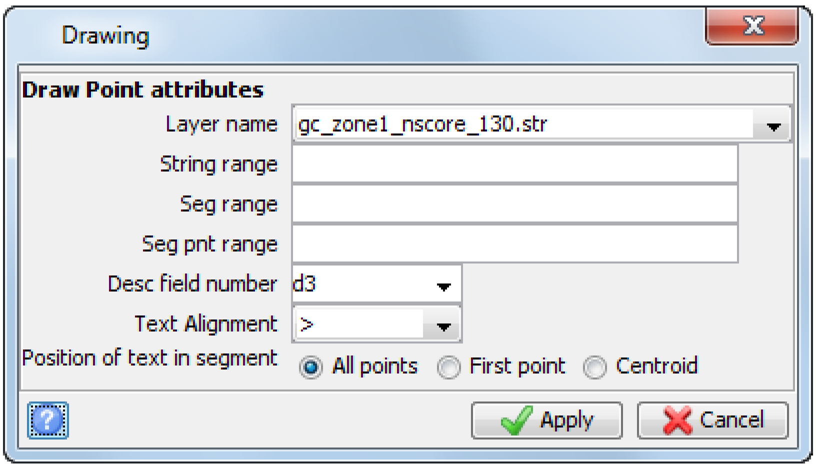




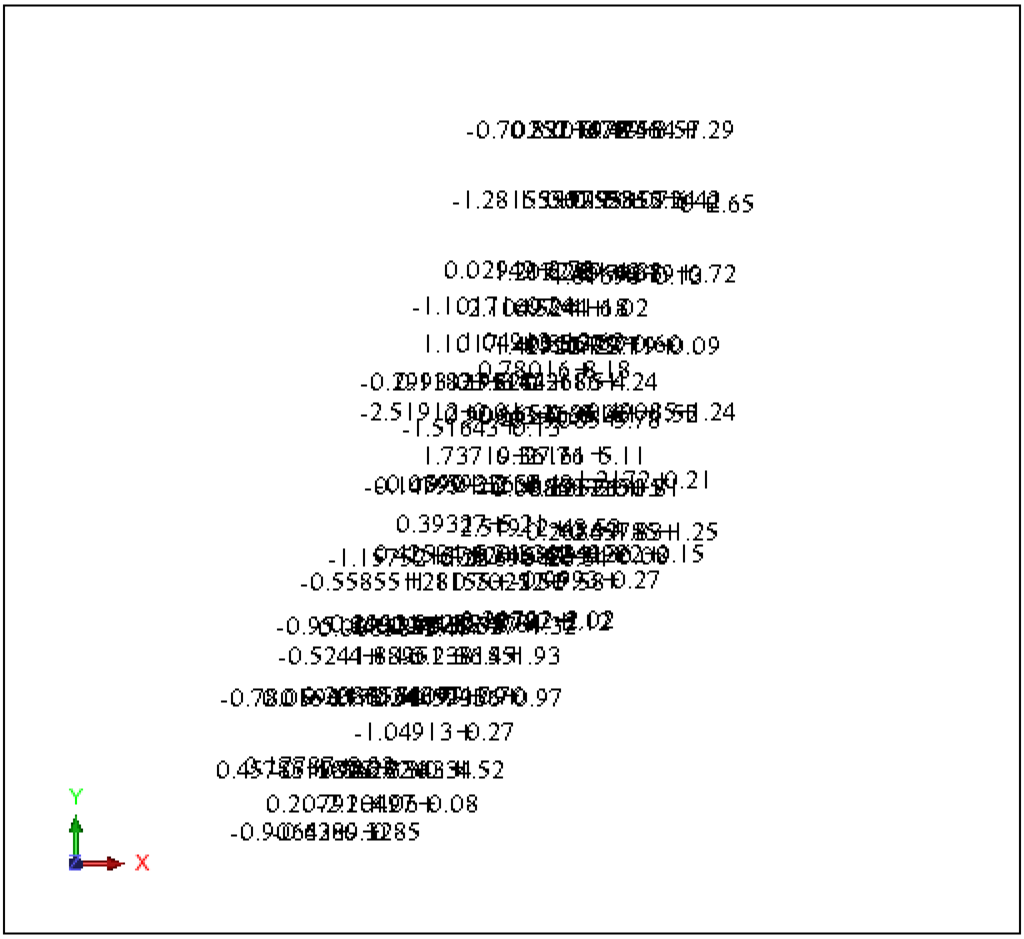
11. Open **gc_zone1_nscore_130.str** in **Graphics**.
12. Choose **Display > Hide strings > As lines**.
13. Enter the information as shown, and click **Apply**.



14. Choose **Display > Point > Attributes**.
15. Enter the information as shown, and click **Apply**.

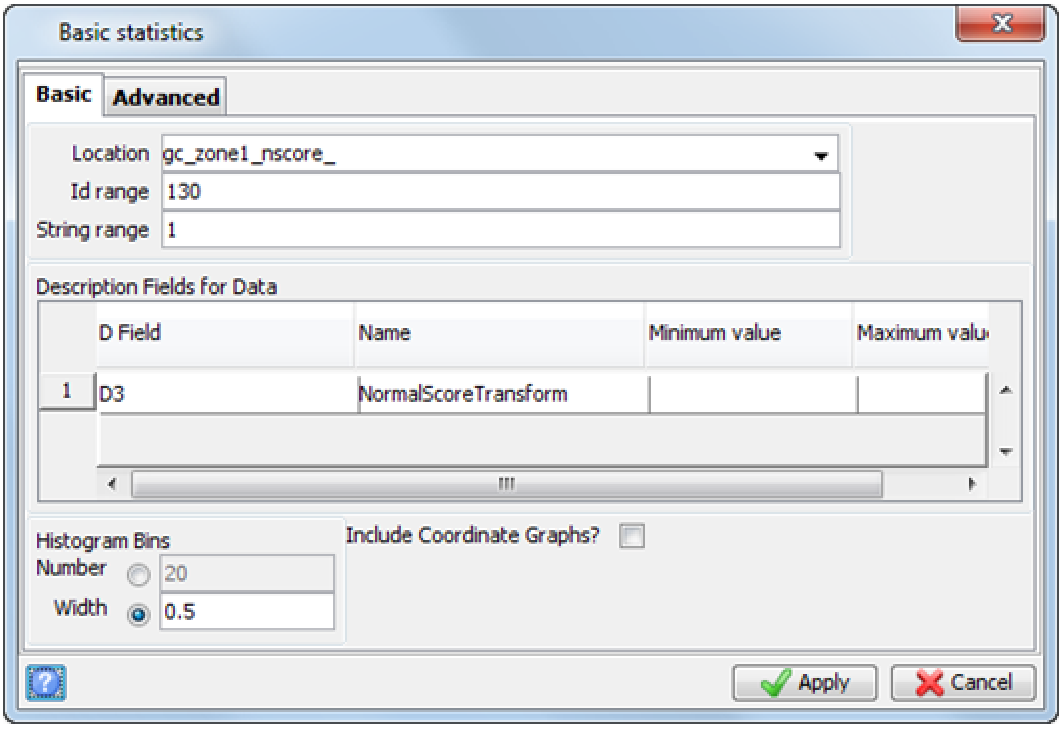


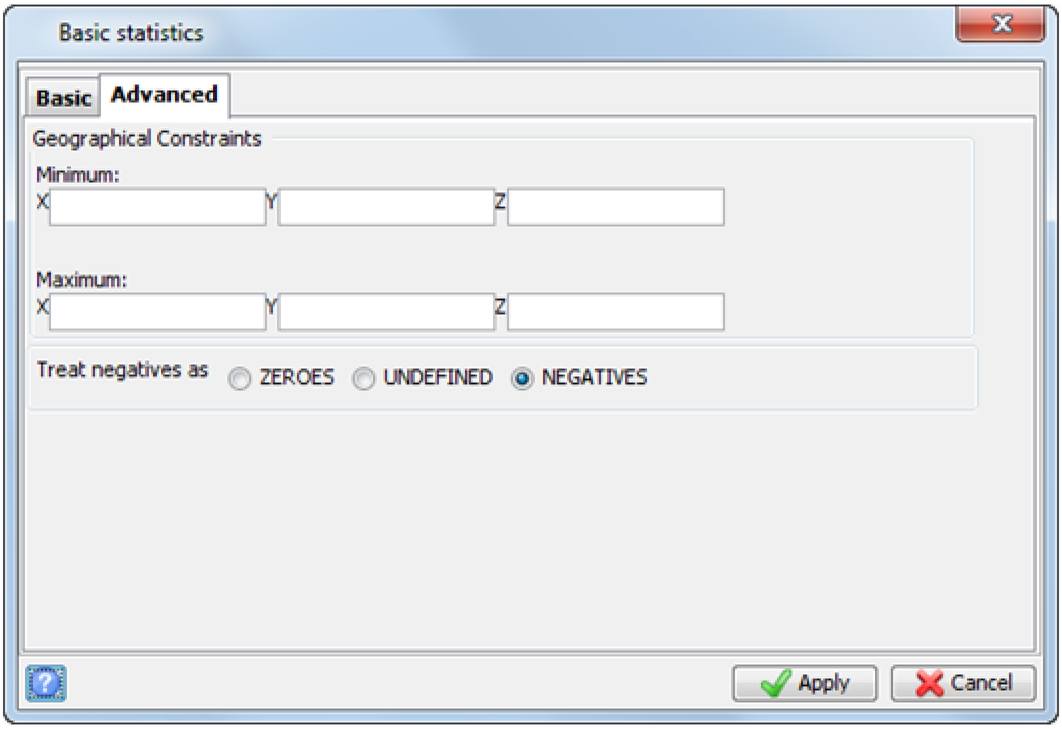
The D3 values are displayed.



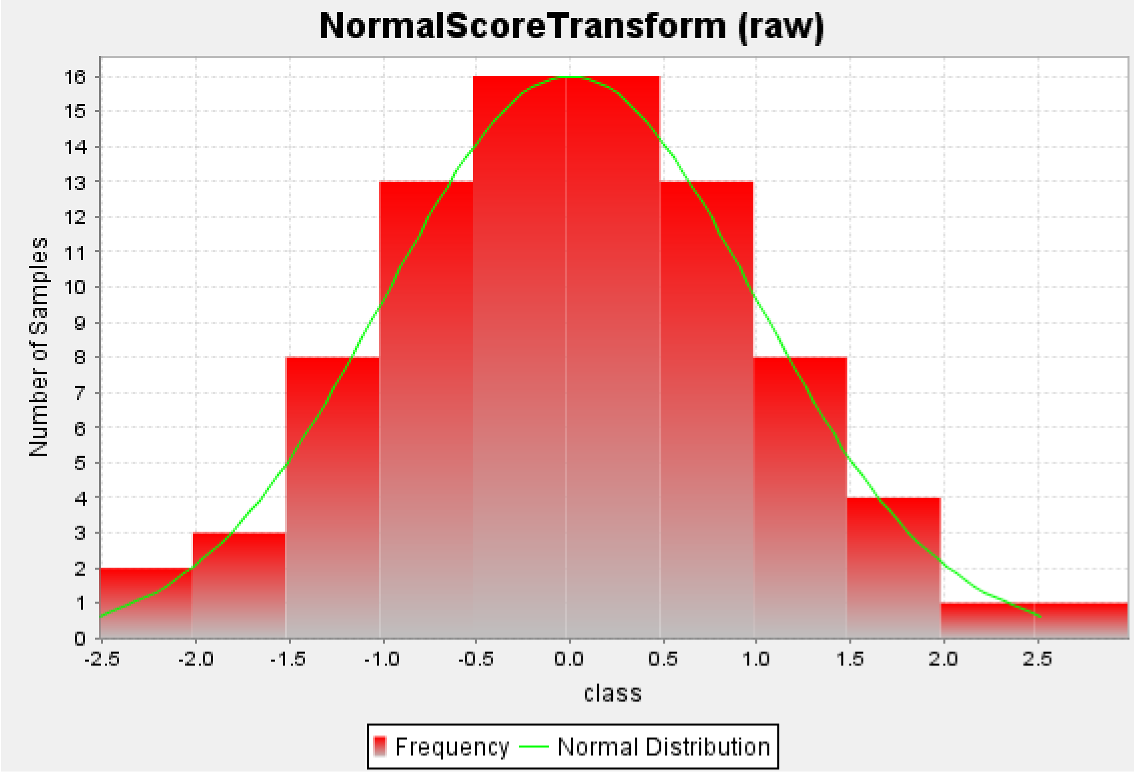
The D1 values in the output file are the same as the input data, and the D3 field contains the normal score transformed data.

16. Choose **Geostatistics > Basic statistics**.
17. Choose **File > Load data from string files**.
18. Enter the information as shown on each tab of the following form, and click **Apply**.



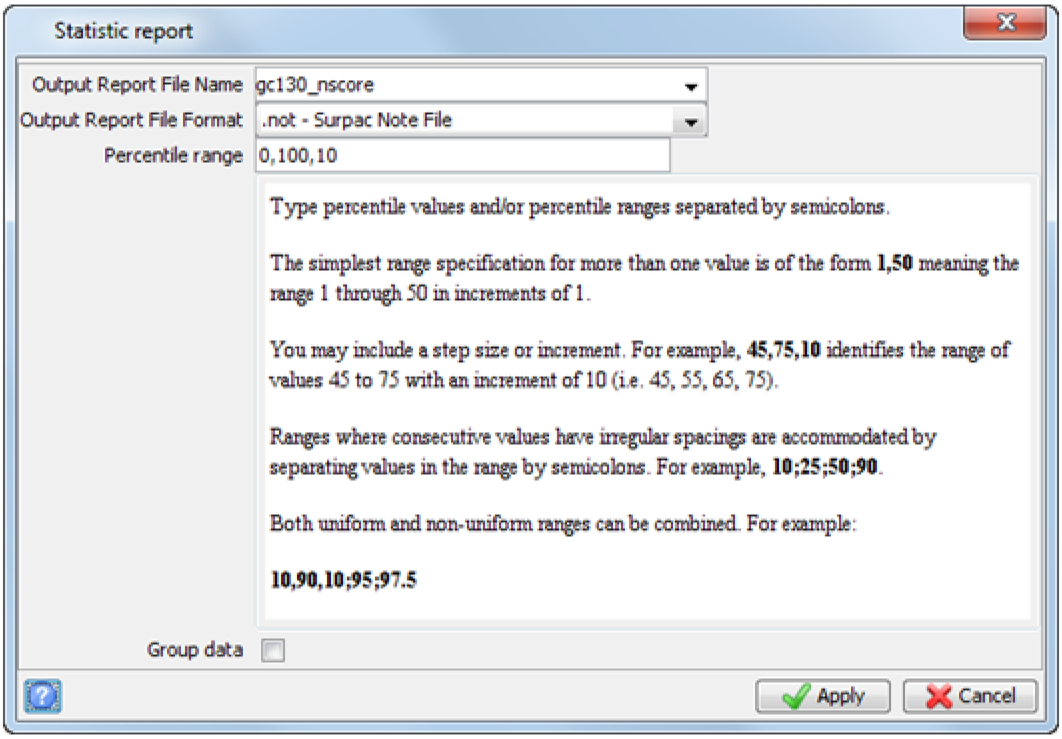


19. Choose **Display > Histogram**.
20. Choose **Display > Normal distribution curve**.



The histogram of the normal scores transformed data is very close to a normal distribution.

21. Choose **Statistics > Report**.
22. Enter the information as shown, and click **Apply**.

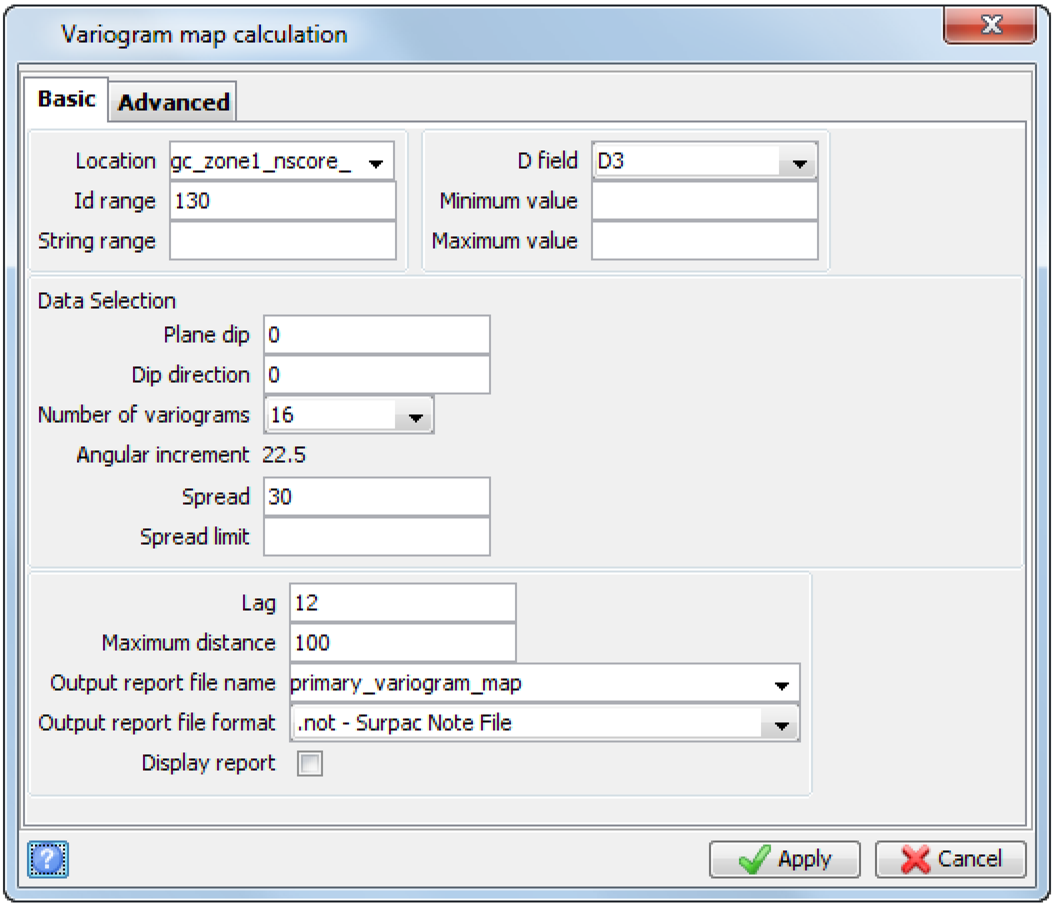


23. Choose **File > Close.**

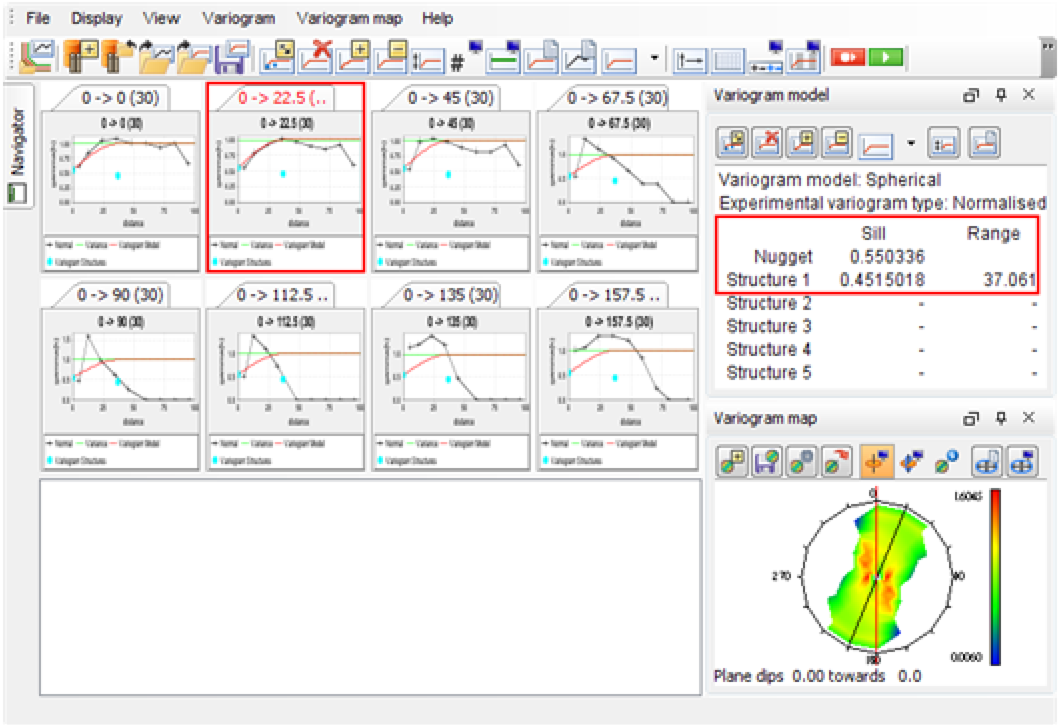
Note: To see all of the steps in this task, run **2d_12a_nscore.tcl**. You need to click **Apply** on any forms presented.

Task: Calculate anisotropy parameters for normal score transformed data

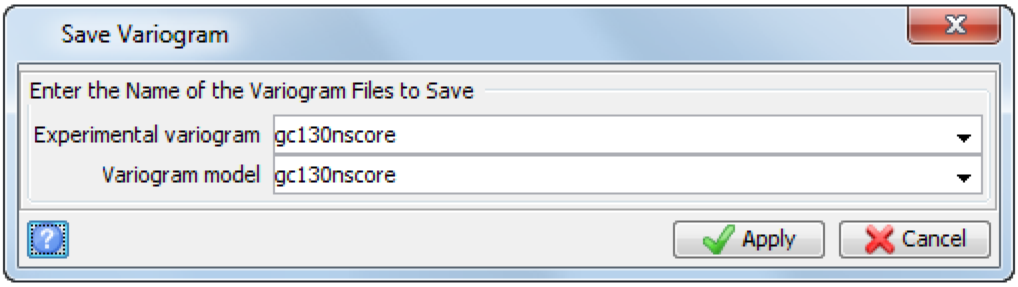
1. Choose **Geostatistics > Variogram modelling**.
2. Choose **Variogram Map > New variogram map**.
3. Enter the information as shown and click **Apply**.



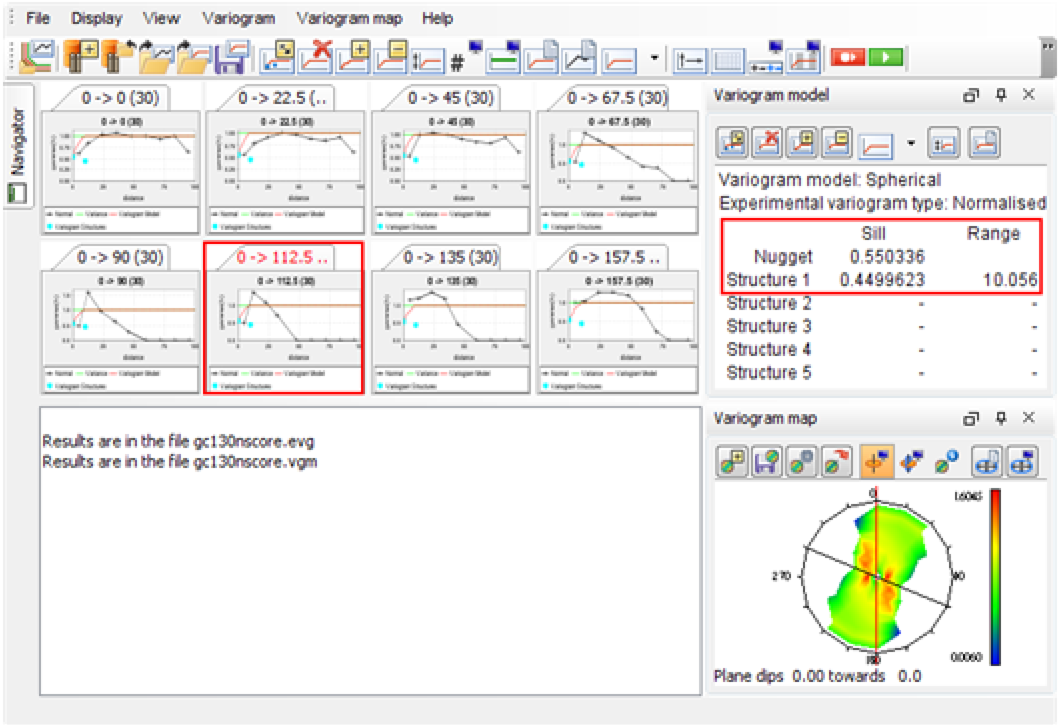
4. Right-click and choose **Tile Windows**.
5. Use the variogram map to identify the major axis, as shown.



6. Choose **File > Save > Experimental variogram and model**
7. Enter the information as shown, and click **Apply**.



8. Modify the variogram to fit it to the variogram for the semi-major axis (keep the nugget and sill the same), and note the range.

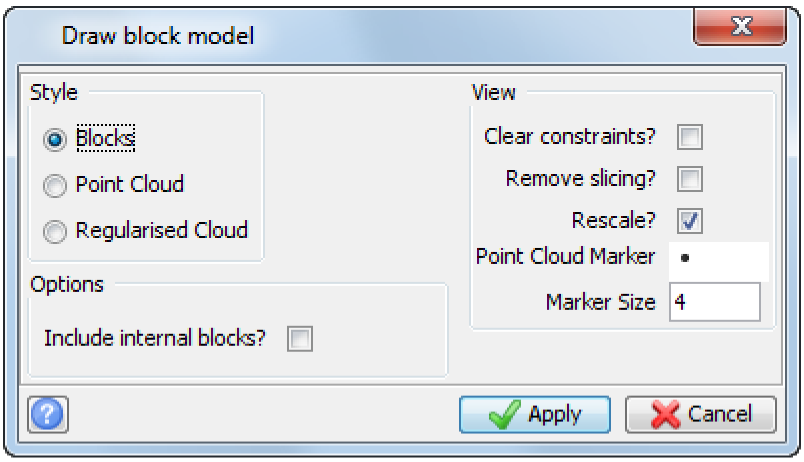


9. You must document the following information for use in the conditional simulation function (SGSIM).

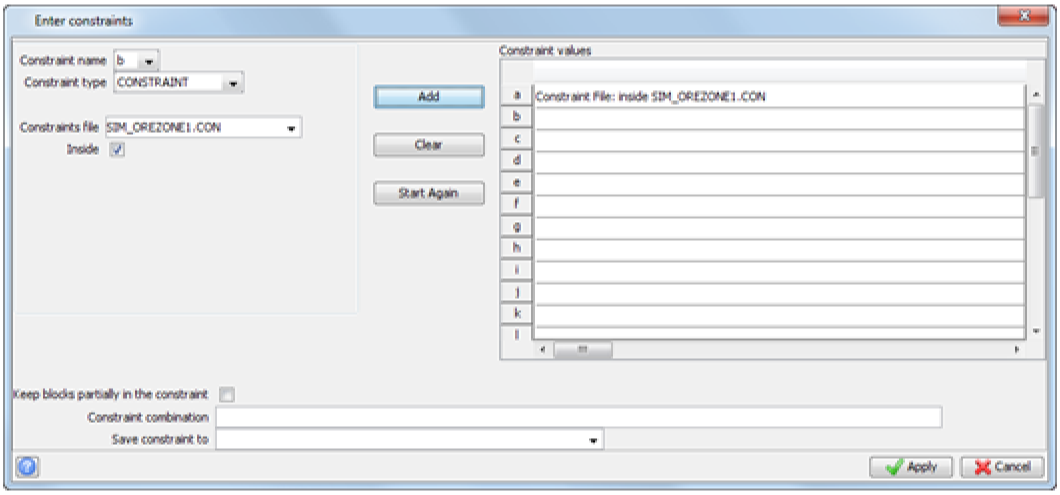
SGSIM Parameter	Description	Value
Angle1	Bearing of major axis	22.5
Nugget	Nugget of major axis variogram	0.45
Cc	Sill of major axis variogram	0.55
hMax	range of major axis variogram	37
hMin	range of semi-major axis variogram	10
Vert	range of minor axis variogram	10(=hMin)

Task: Perform conditional simulation using SGSIM

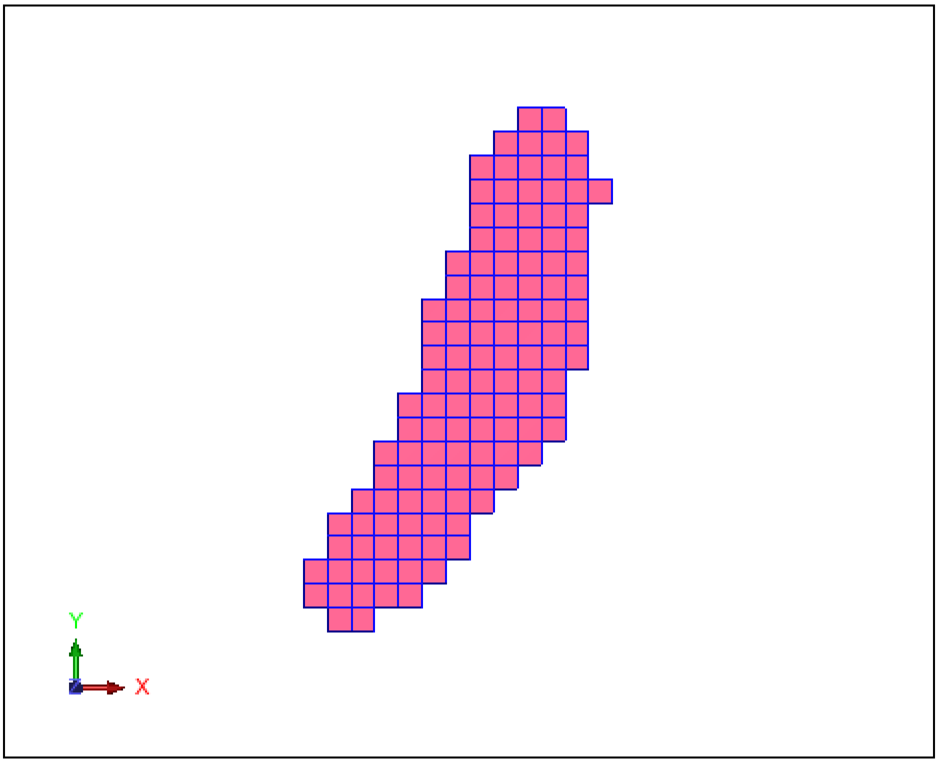
1. Run **2d_12c_create_sim_model.tcl** to create (or recreate) the model **gc_130simulation.mdl** and constraints **sim_orezone1.con** and **sim_orezone2.con**.
2. Open **gc_130simulation.mdl**.
3. Choose **Display > Display block model**.
4. Enter the information as shown, and click **Apply**.



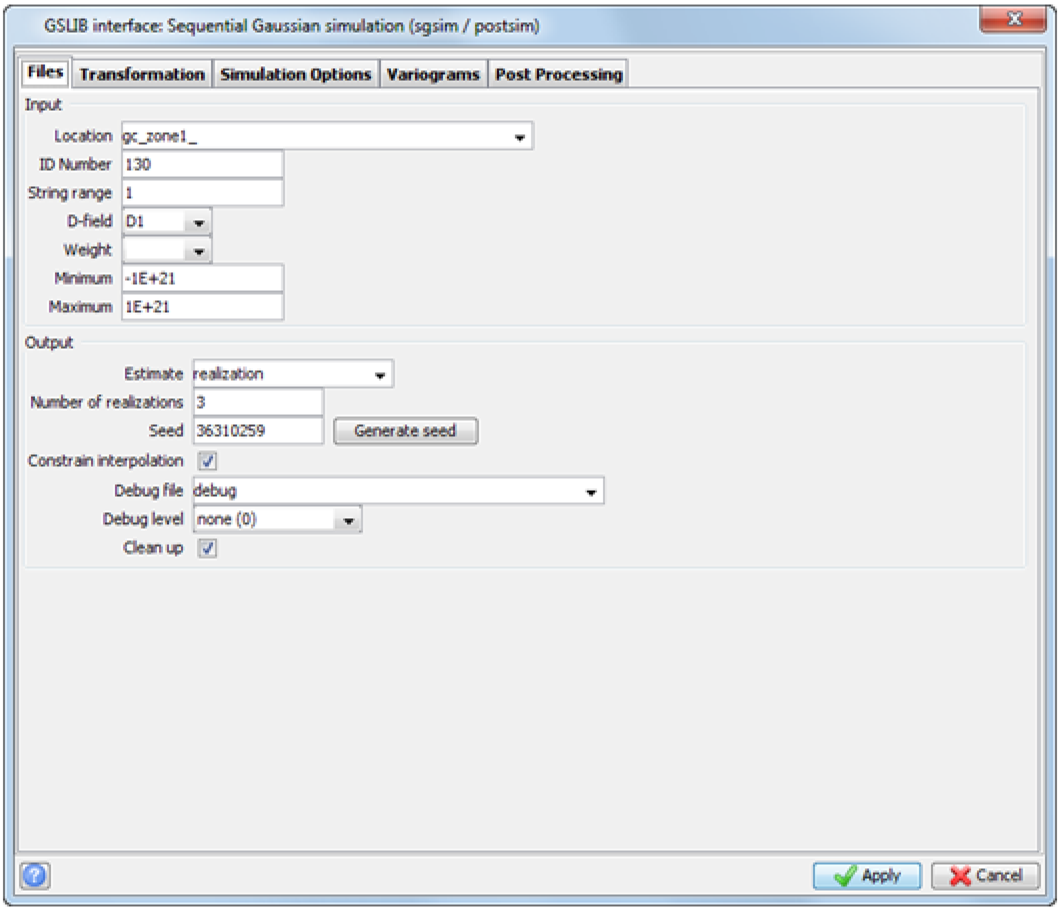
5. Choose **Constraints > New graphical constraint**.
6. Enter the information as shown, and click **Apply**.

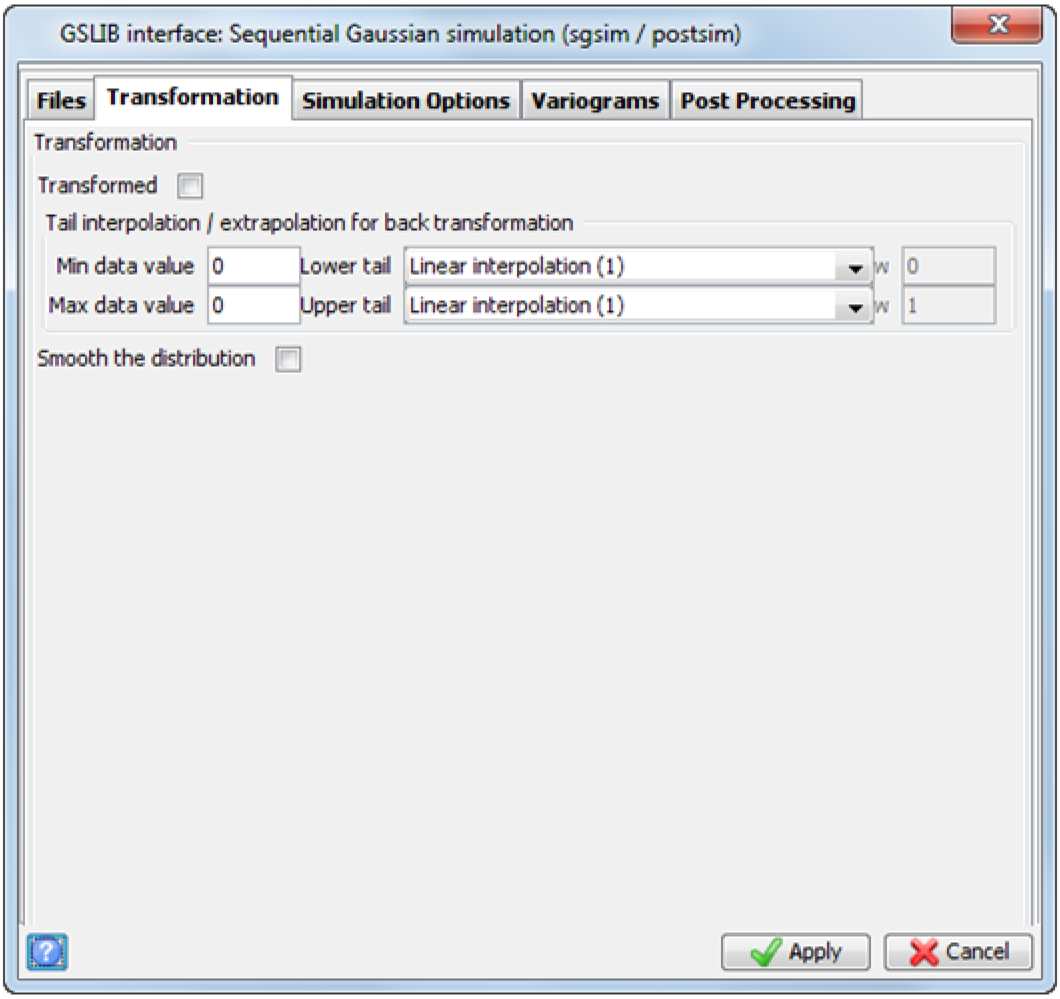


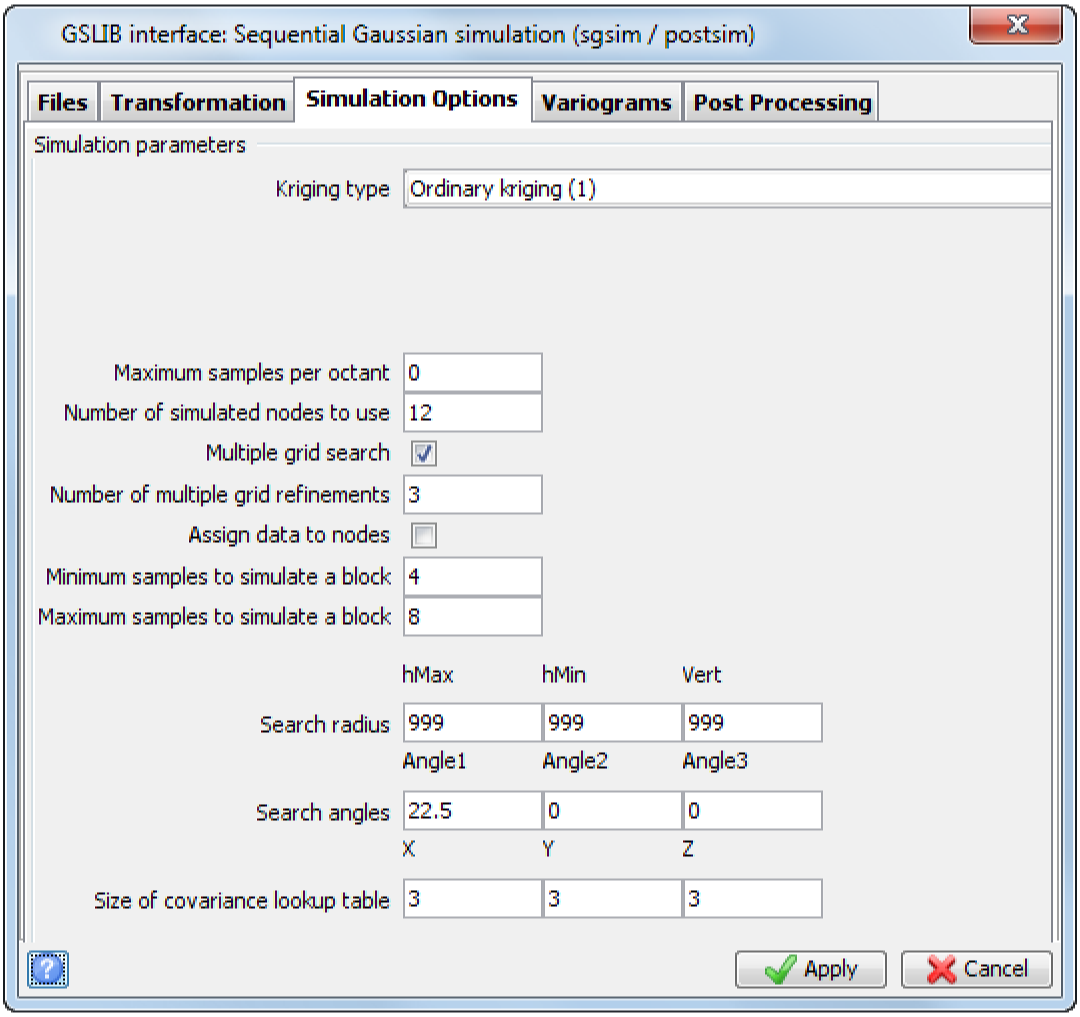
The constrained model is displayed.

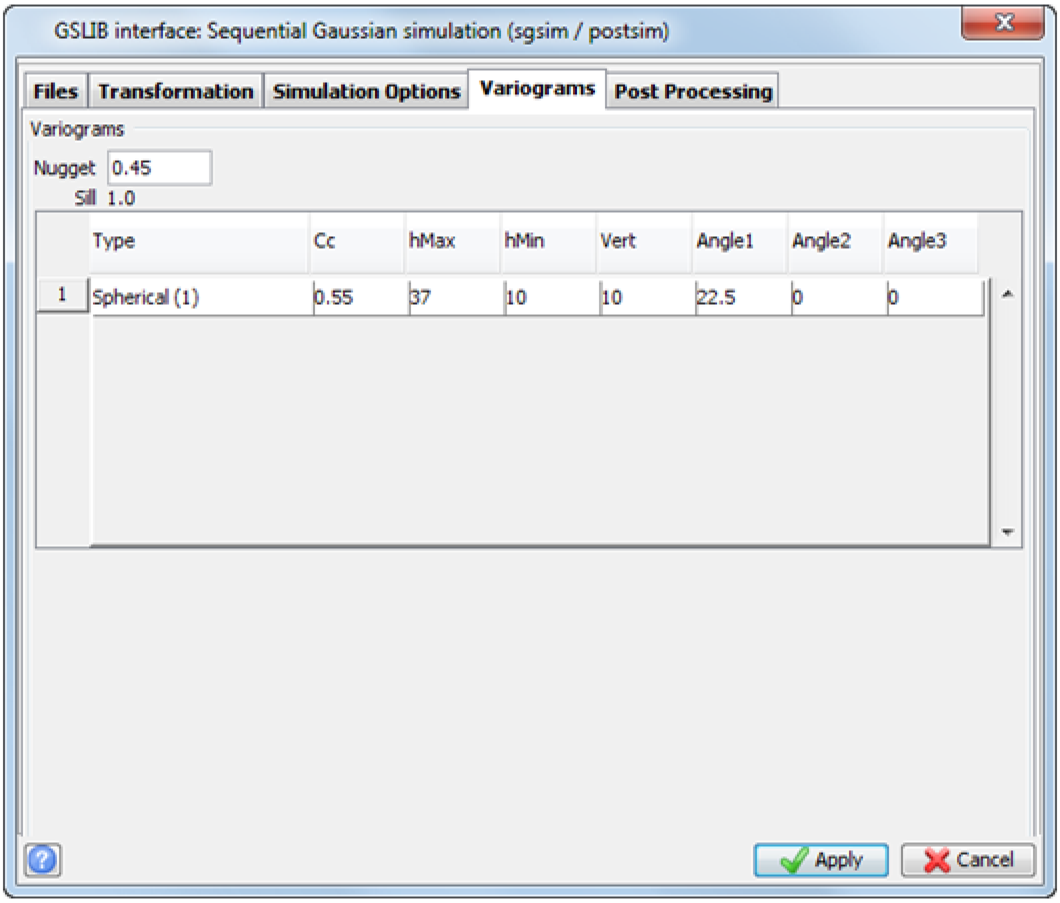


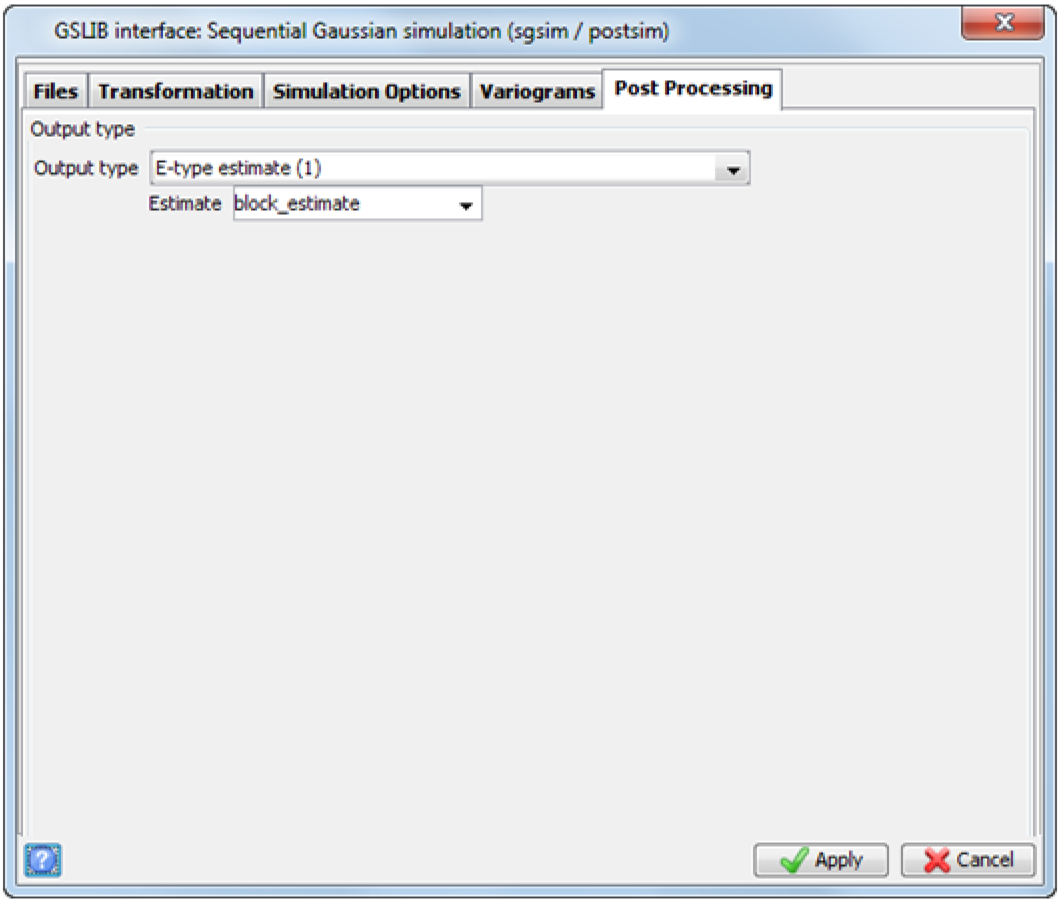
7. Choose **Estimation > GSLIB > Sequential Gaussian simulation (sgsim / postsim)**.
8. Enter the information as shown on the five tabs of this form, and the *Enter constraints* form, and click **Apply**.

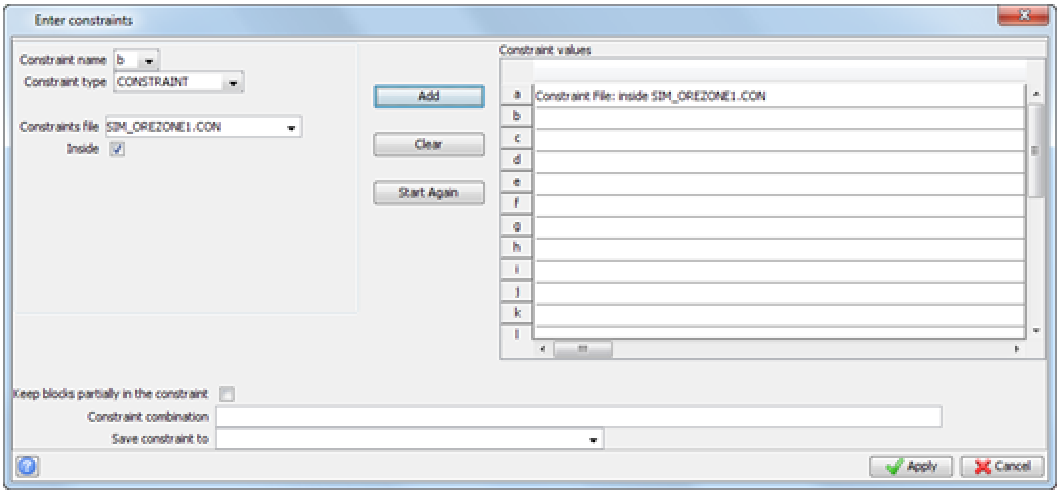

GSLIB interface: Sequential Gaussian simulation (sgsim / postsim)
Files
Transformation
Simulation Options
Variograms
Post Processing
Input
Location gc_zone1_
ID Number 130
String range 1
D-field D1
Weight
Minimum -1E+21
Maximum 1E+21
Output
Estimate realization
Number of realizations 3
Seed 36310259
Generate seed
Constrain interpolation
Debug file debug
Debug level none (0)
Clean up
Apply
Cancel


GSLIB interface: Sequential Gaussian simulation (sgsim / postsim)
Files
Transformation
Simulation Options
Variograms
Post Processing
Transformation
Transformed
Tail interpolation / extrapolation for back transformation
Min data value
0
Lower tail
Linear interpolation (1)
w
0
Max data value
0
Upper tail
Linear interpolation (1)
w
1
Smooth the distribution
Apply
Cancel

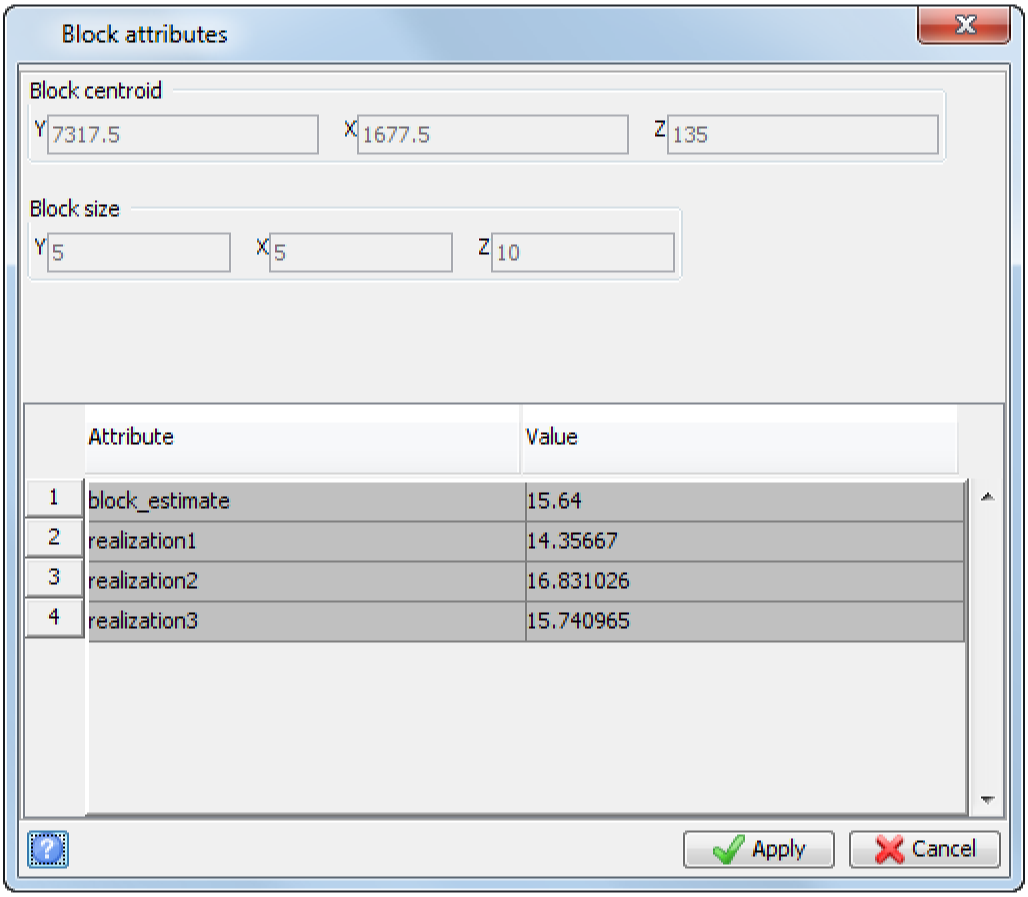

GSLIB interface: Sequential Gaussian simulation (sgsim / postsim)
Files
Transformation
Simulation Options
Variograms
Post Processing
Simulation parameters
Kriging type
Ordinary kriging (1)
Maximum samples per octant
0
Number of simulated nodes to use
12
Multiple grid search
Number of multiple grid refinements
3
Assign data to nodes
Minimum samples to simulate a block
4
Maximum samples to simulate a block
8
hMax
hMin
Vert
Search radius
999
999
999
Angle1
Angle2
Angle3
Search angles
22.5
0
0
X
Y
Z
Size of covariance lookup table
3
3
3
Apply
Cancel


GSLIB interface: Sequential Gaussian simulation (sgsim / postsim)
Files
Transformation
Simulation Options
Variograms
Post Processing
Variograms
Nugget 0.45
Sill 1.0
Type Cc hMax hMin Vert Angle1 Angle2 Angle3
1 Spherical (1) 0.55 37 10 10 22.5 0 0
Apply
Cancel


GSLIB interface: Sequential Gaussian simulation (sgsim / postsim)
Files
Transformation
Simulation Options
Variograms
Post Processing
Output type
Output type E-type estimate (1)
Estimate block_estimate
Apply
Cancel



9. On the *Verify creating of file* form, click **Yes**.
10. Choose **Attributes > View attributes for one block**.
11. Select a block.



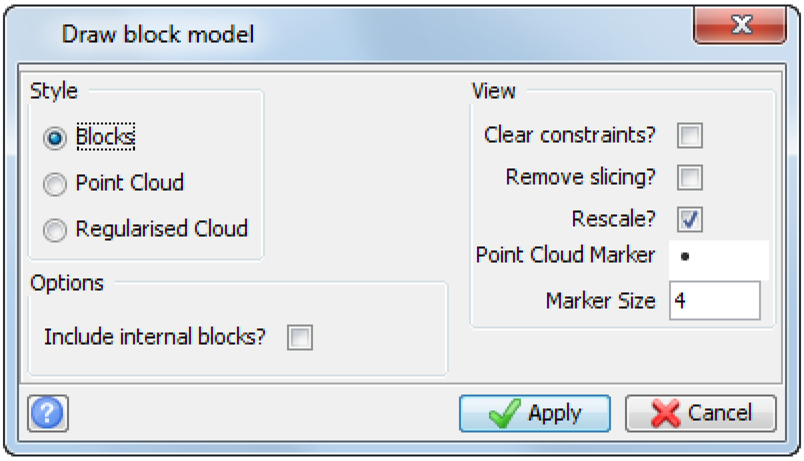
Three new attributes have been created to store each of the simulation realizations, using the name specified on the **Files** tab (Output - Estimation). In this example, the name "realization" was used. In addition, a block value estimate (E-type estimate) has been calculated and is stored in the attribute **block_estimate** . The attribute must exist prior to running SGSIM. The E-type estimate is the average of all realizations.

12. Click **Apply**.
13. Choose **Block model > Save.**
14. Choose **Block model > Close.**

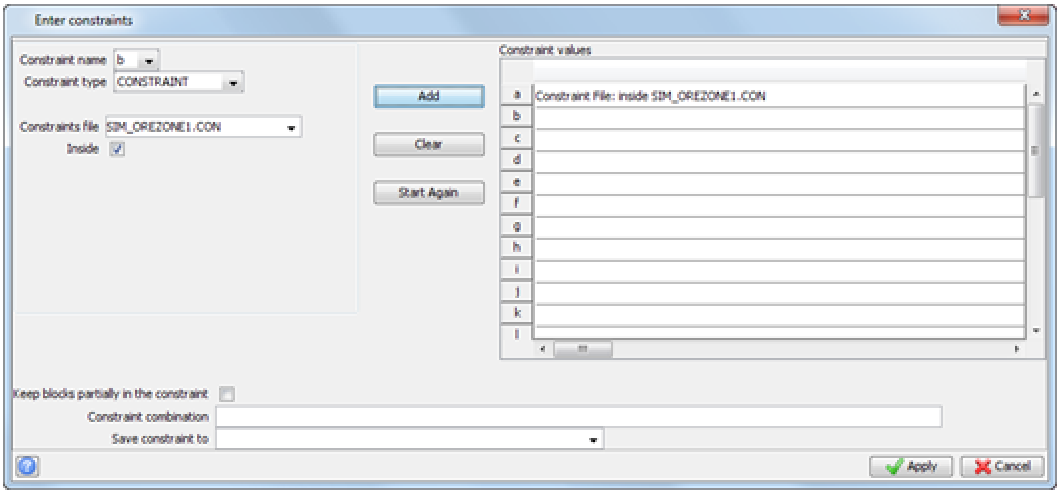
Note: To see each of the steps performed in this task, run **2d_12d_conditional_simulation.tcl** .

Task: Display conditional simulation results

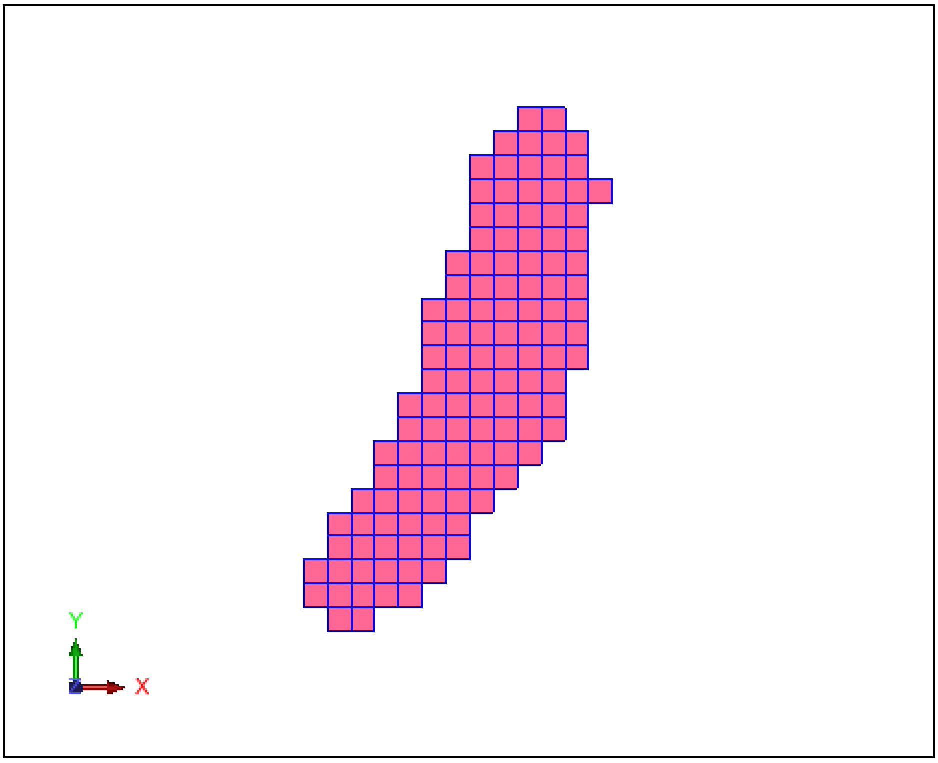
1. Open **gc_simulation_completed.mdl**.
2. Choose **Display > Display block model**.
3. Enter the information as shown, and click **Apply**.



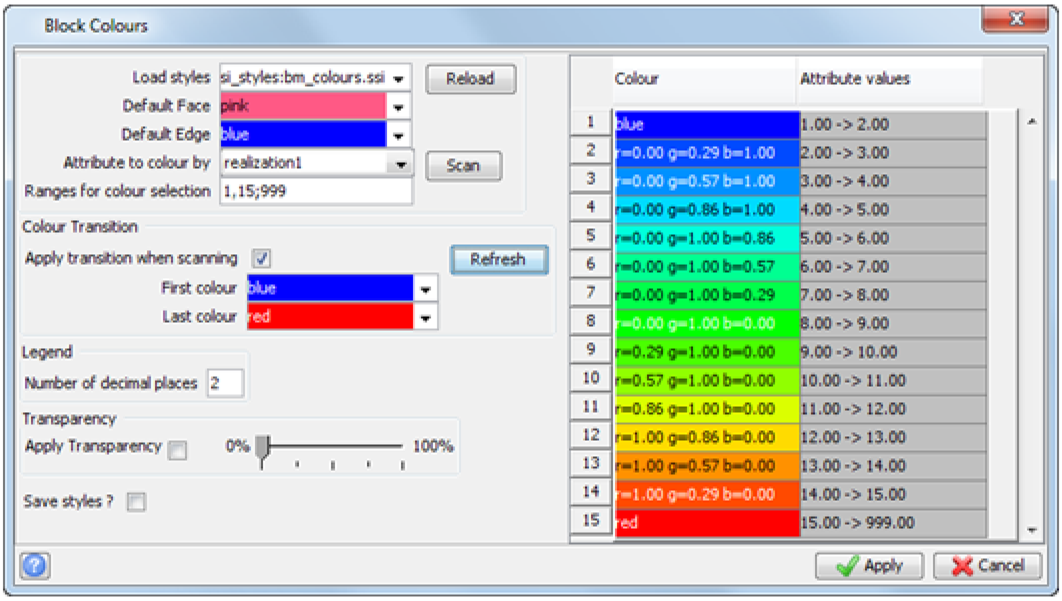
4. Choose **Constraints > New graphical constraint**.
5. Enter the information as shown, and click **Apply**.



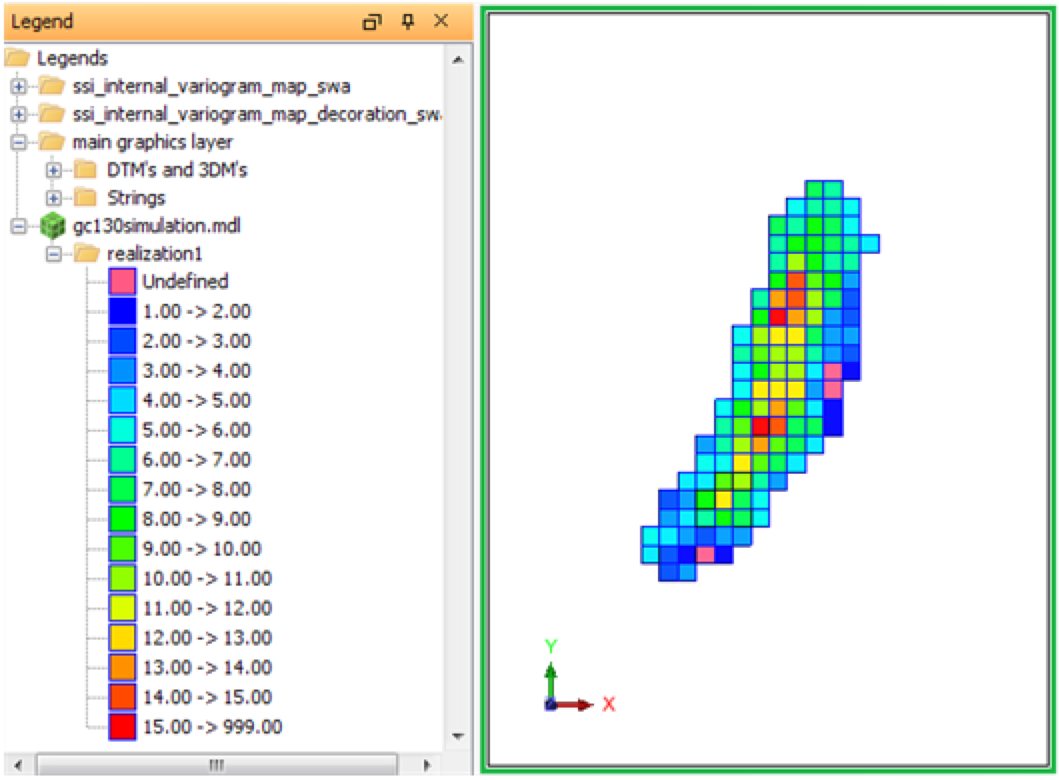
The constrained model is displayed.



6. Choose **Display > Colour model by attribute**.
7. In the **Attribute to colour by** field, select **realization1**, and click **Scan**, for the **Range for colour selection** type **0,15;999** and click **Refresh**.
8. Click **Apply**.

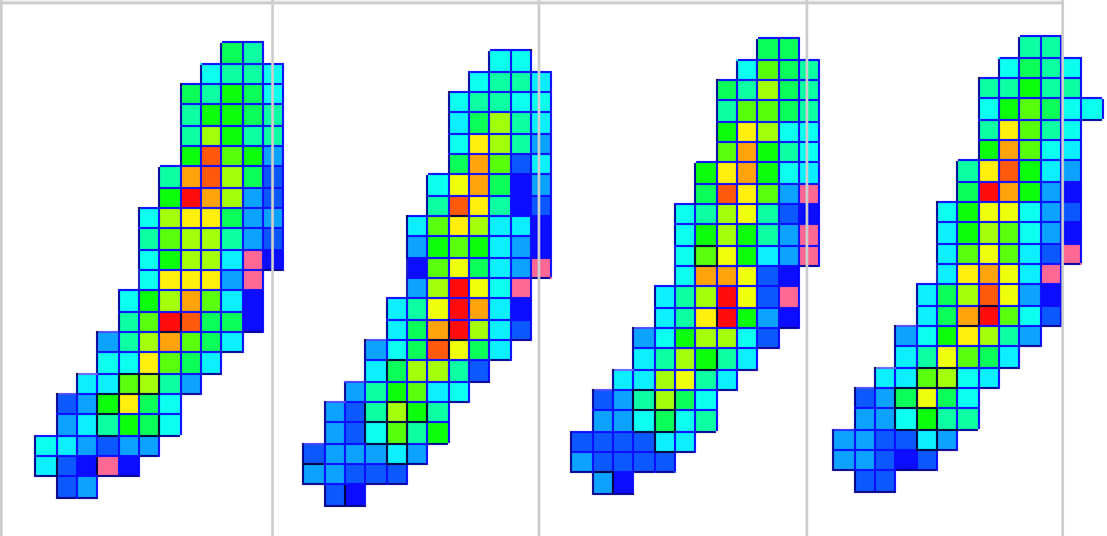


9. Display the legend on the **Legend** tab.
   The data and model are displayed, as shown.



10. Repeat the display for **realization2**, **realization3**, and **block_estimate**.

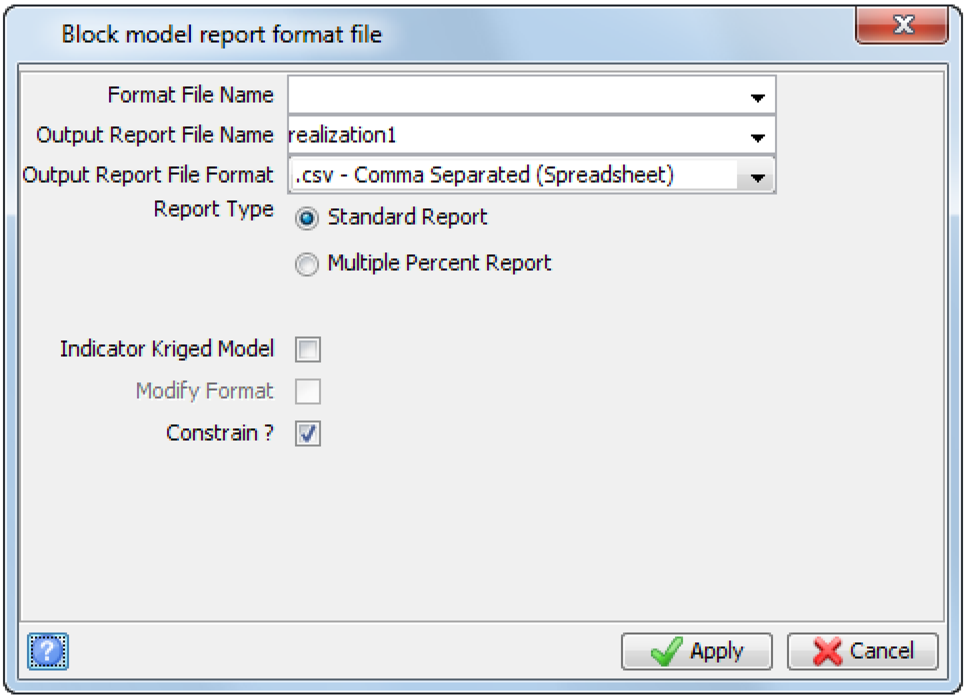
realization1	realization2	realization3	block_estimate

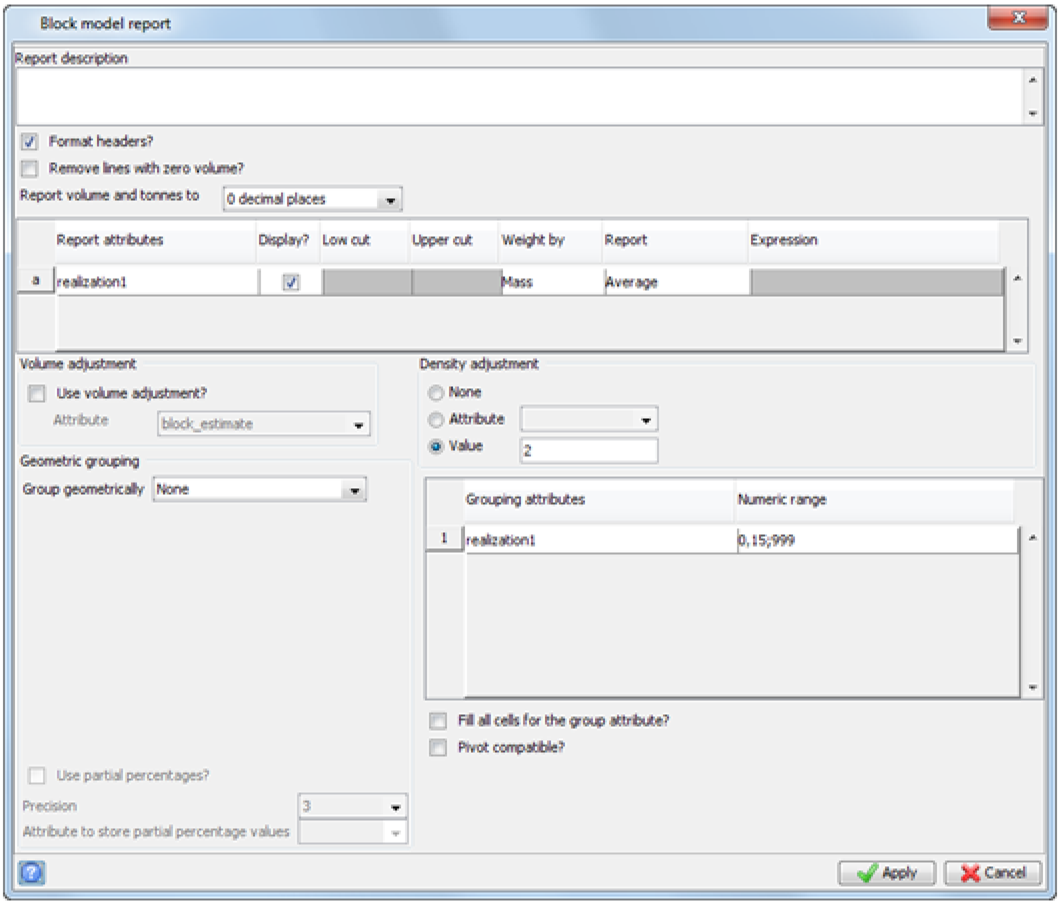


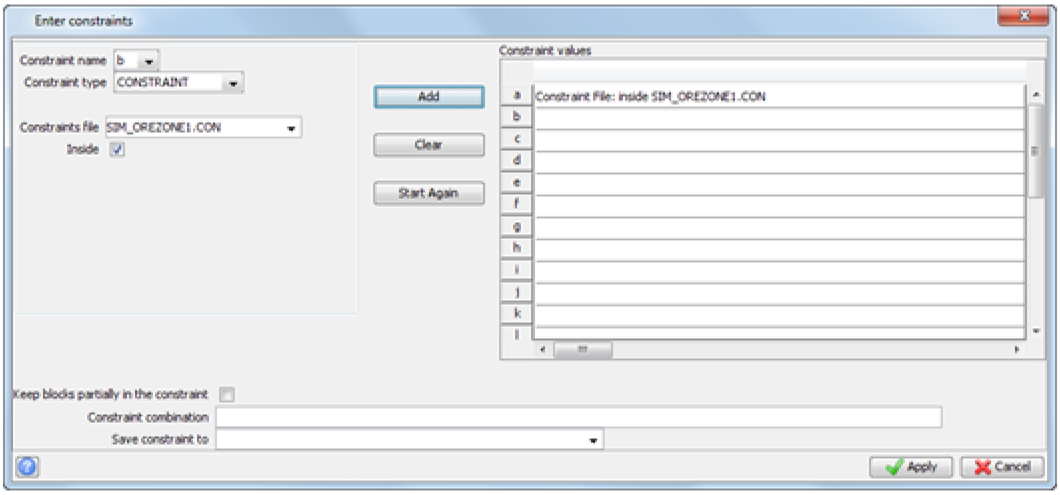
11. Choose **Block Model > Close**.

Task: Report tonnes and grade for a conditional simulation model

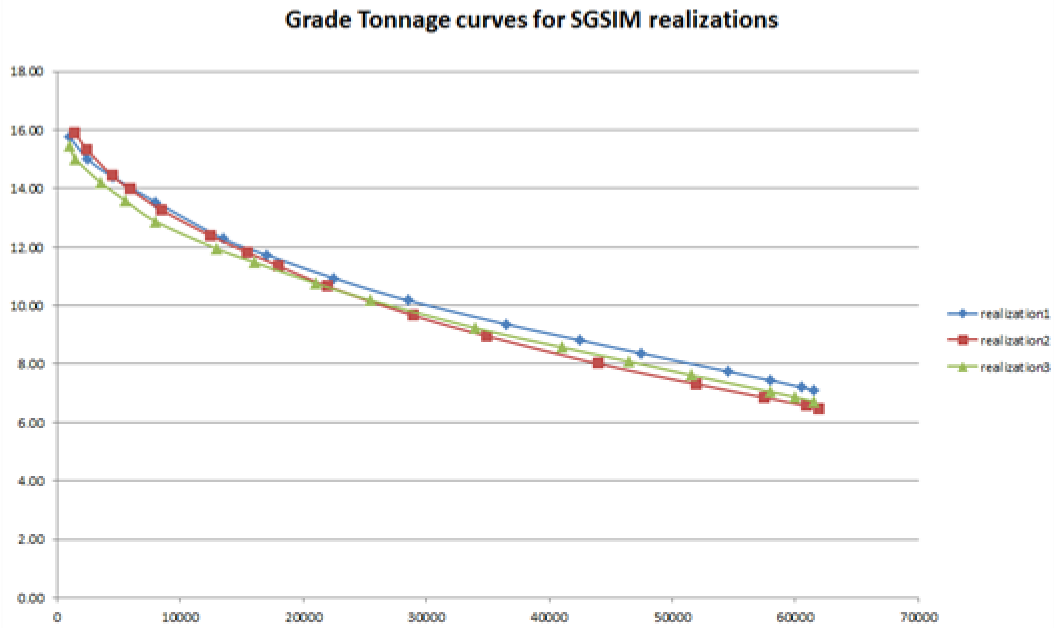
1. Open **gc_simulation_completed.mdl**.
2. Choose **Block model > Report**.
3. Enter the information as shown on each of the following forms, and click **Apply**.


Block model report format file
Format File Name
Output Report File Name
realization1
Output Report File Format
.csv - Comma Separated (Spreadsheet)
Report Type
Standard Report
Multiple Percent Report
Indicator Kriged Model
Modify Format
Constrain ?
Apply
Cancel


Block model report
Report description
Format headers?
Remove lines with zero volume?
Report volume and tonnes to
0 decimal places
Report attributes
Display?
Low cut
Upper cut
Weight by
Report
Expression
realization1
Mass
Average
Volume adjustment
Use volume adjustment?
Attribute
block_estimate
Density adjustment
None
Attribute
Value
2
Geometric grouping
Group geometrically
None
Grouping attributes
Numeric range
realization1
0,15;999
Fill all cells for the group attribute?
Pivot compatible?
Use partial percentages?
Precision
3
Attribute to store partial percentage values
Apply
Cancel



4. Repeat the block model report for each realization.
5. When you are finished, combine the ***.csv** files into one ***.xls** file.
6. Open **SGSIM_grade_tonnage.xls** as an example of the combined reports.



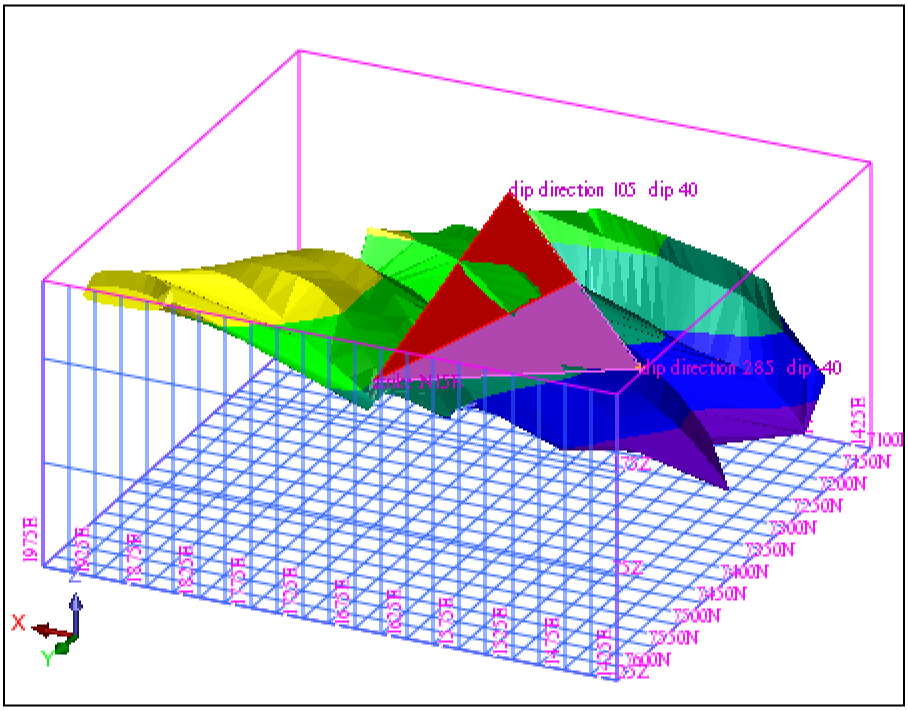
Note: To see each of the steps performed in this task, run **2d_12f_simulation_report.tcl**.

3D Case Study: Ore Reserve

Overview

This is a sample project which presents many geostatistical concepts in a common workflow in Surpac. There are many different types of deposits and the techniques demonstrated here may or may not be relevant to you.

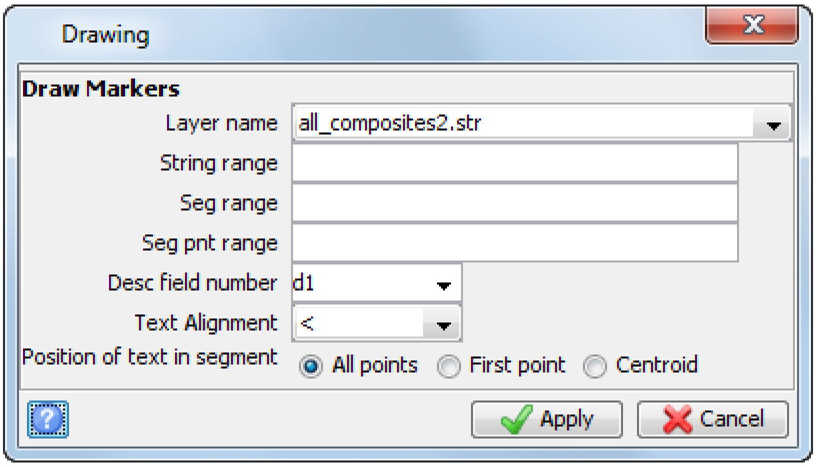
The concepts presented here use a three dimensional data set representing an area of grade control. You should have gone through the two dimensional case in order to understand all of the concepts here.



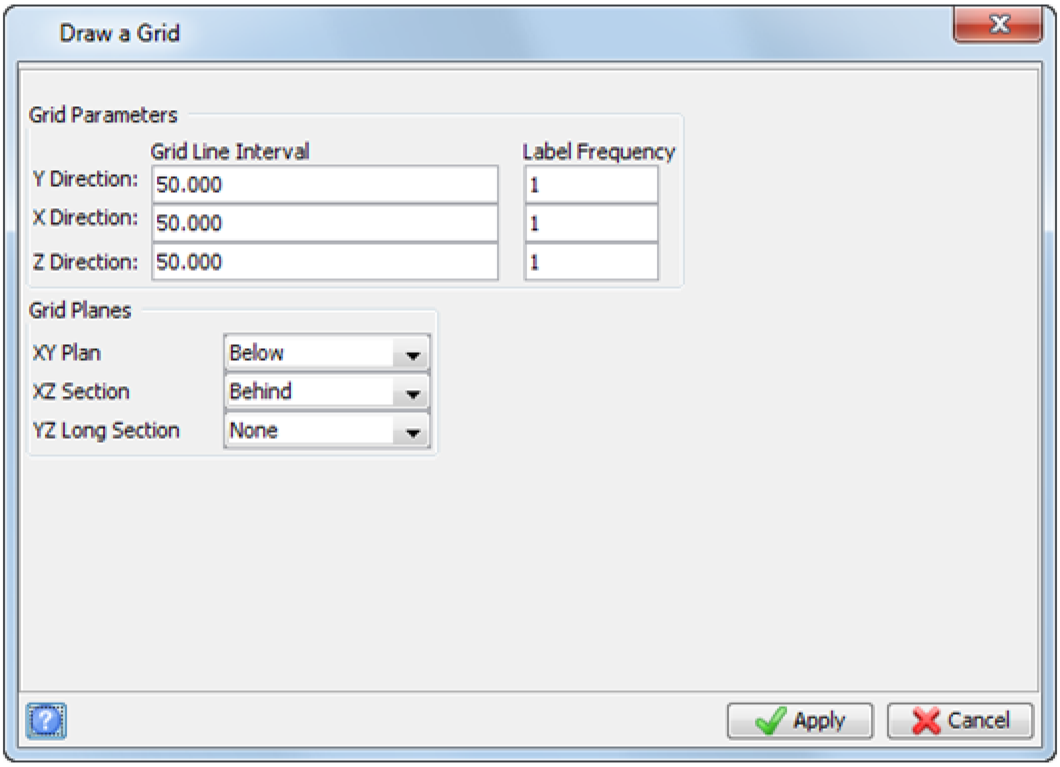
Domains

Task: View domain

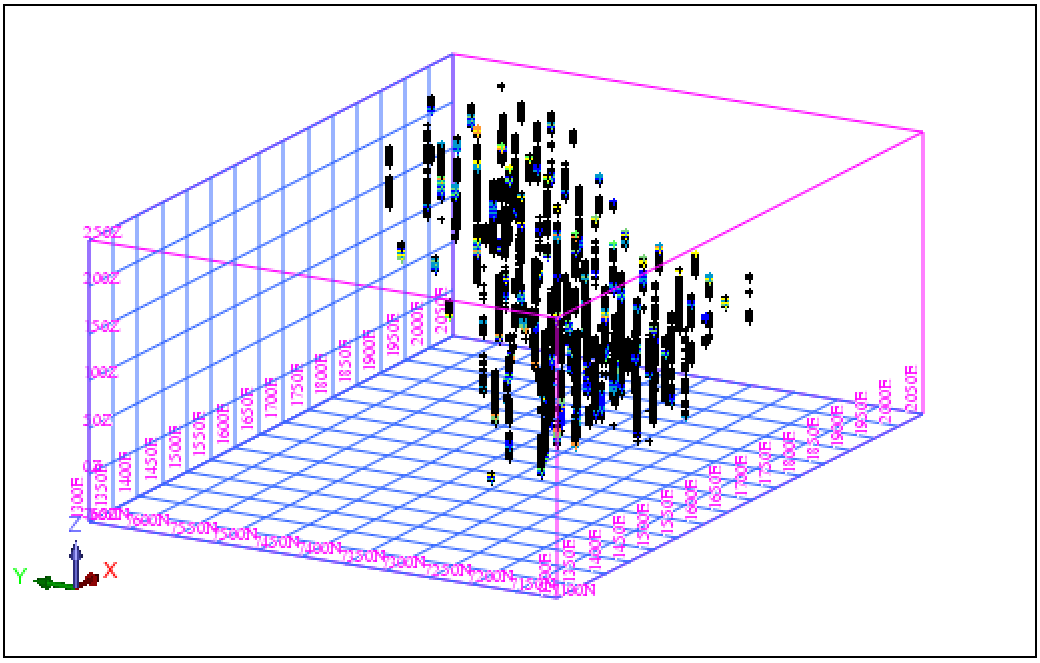
1. Open **all_composites2.str** in **Graphics**.
2. Choose **Display > Hide everything**.
3. Choose **Display > Point > Markers**.
4. Enter the information as shown, and click **Apply**.



5. Choose **Display > 3D grid**.
6. Enter the information as shown, and click **Apply**.



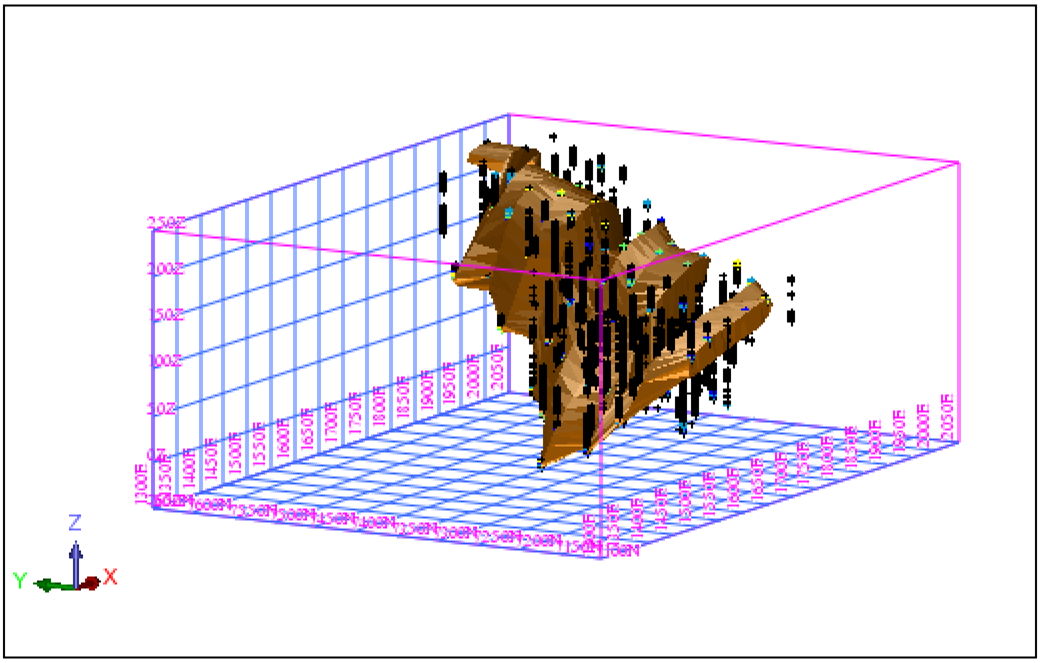
7. Rotate the data in **Graphics** as shown.



The points in this string file represent 2 metre downhole composites of all gold values for all drillholes. The D1 field contains the composited value for gold, and have been used to classify the points into different strings.

String	D1
1	< 1.000
2	1 – 1.999
3	2 – 2.999
4	3 –3.999
5	4 – 4.999
6	5 – 5.999
7	>= 6.000

8. With **all_composites2.str** still displayed on the screen, open **ore_solid1.dtm**.



This solid represents a single domain. Only composites that fall inside this domain should be used to estimate blocks inside the domain.

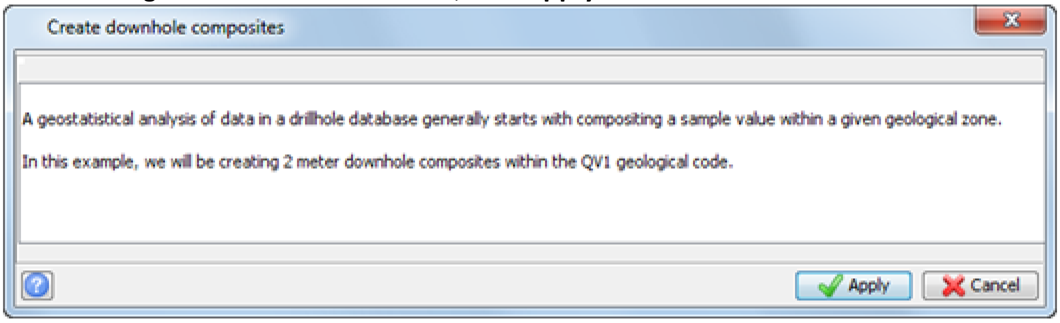
Create composites

You create composites to allow data from drillholes of different sample lengths to be compared. For example, to be able to use both exploration and diamond drilling data. Composites are artificial divisions of the drillholes to a particular sample length, with the grade for the sample being calculated using the actual sample values.

Task: Create composites within a domain

The domain **ore_solid1.dtm** represents an ore zone known as the QV1 zone. In this task you will extract composites only inside the QV1 domain.

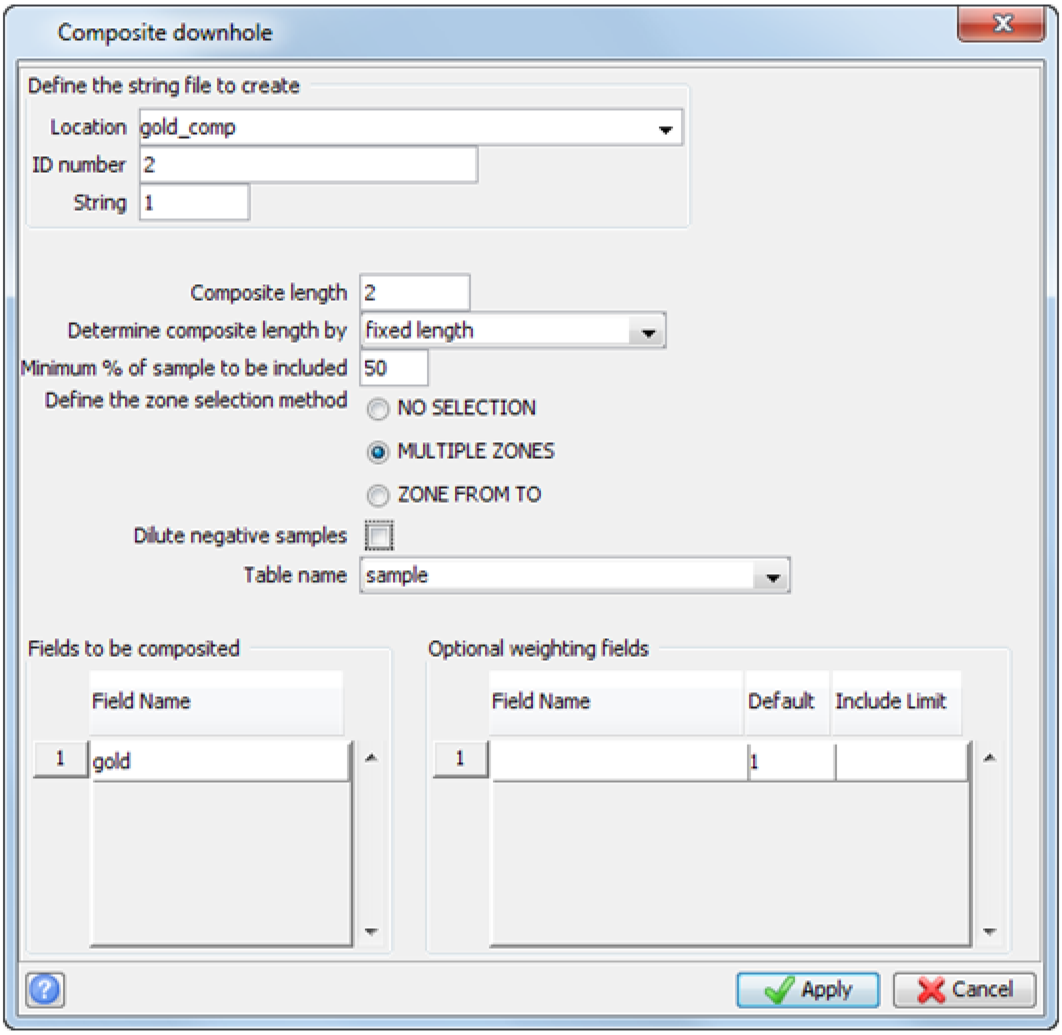
1. Run **01_create_downhole_composites.tcl**.
2. After reading the text on the first form, click **Apply**.



The *Create downhole composites* form is displayed by choosing **Database > Composite > Downhole**.

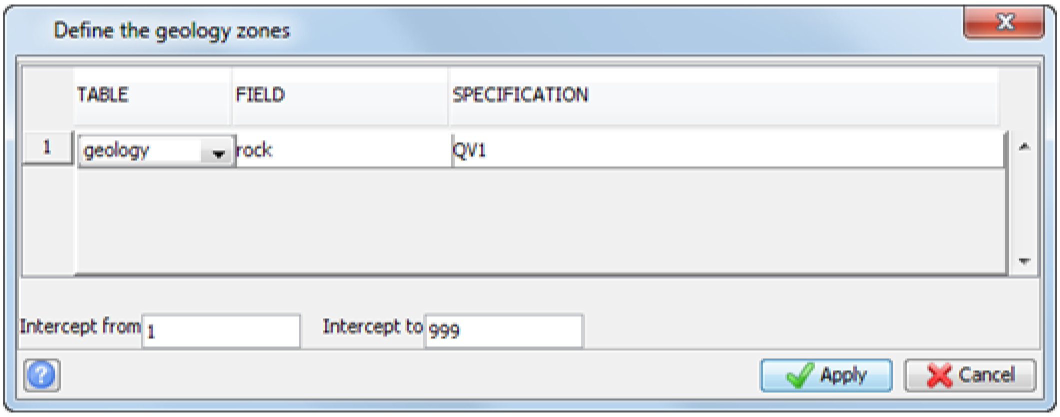
A composite length of 2 metres has been selected. The selection of a composite length is important, but the explanation of how to determine the correct composite length is beyond the scope of this tutorial. You might want to consider the opinion of a geostatistical consultant to determine the optimal composite length for your data set.

3. After viewing the following form, click **Apply**.

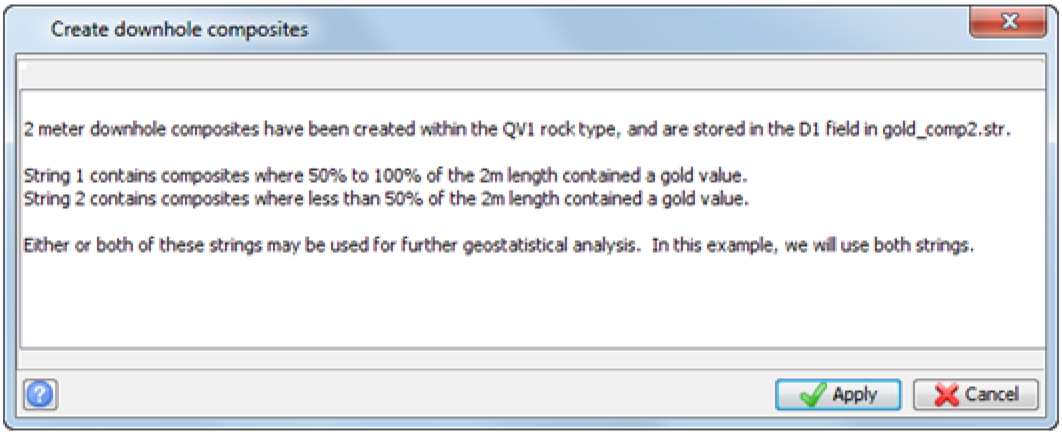


On the next form, the character field **rock** has been set up in the **geology** table, which is an interval table. The text "QV1" has been inserted into the field **rock** for every interval of a drillhole which is inside **ore_solid1.dtm**.

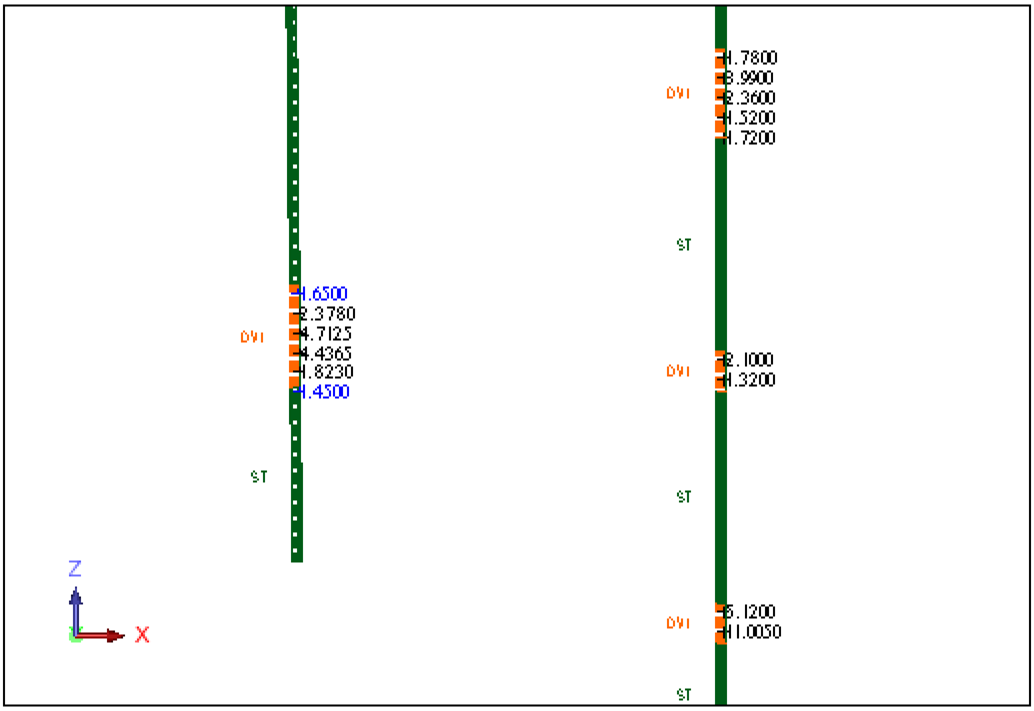
4. After viewing the form, click **Apply**.



5. After reading the text on the following form, click **Apply**.



You will see an east-west section of the database and the composites which were created.



Menu commands:

Select...	to...
Database > Composite > Downhole	perform downhole compositing.

Basic Statistics

Overview

One of the important preliminary steps in performing a geostatistical evaluation is to understand the statistical properties of the data. Two characteristics which can potentially reduce the quality of your estimations are bimodalism and outliers. A histogram can be used to identify whether either of these conditions are present in your data.

You will learn about:

- histograms
- bimodal distributions
- creating a histogram

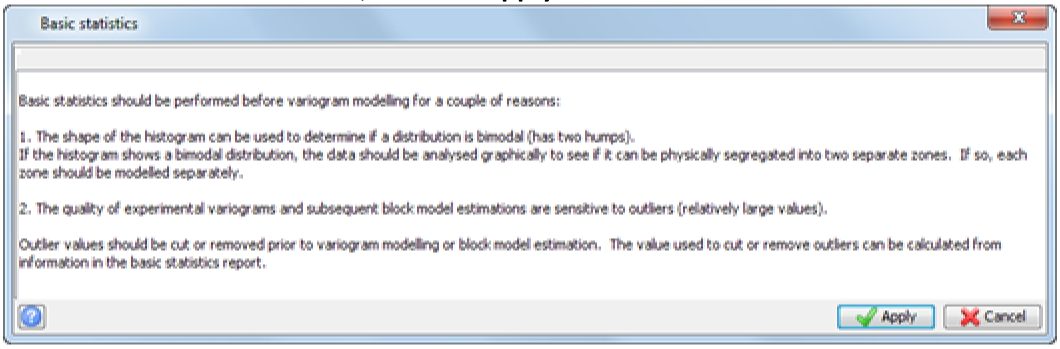
Requirements

In order to understand this information, you should:

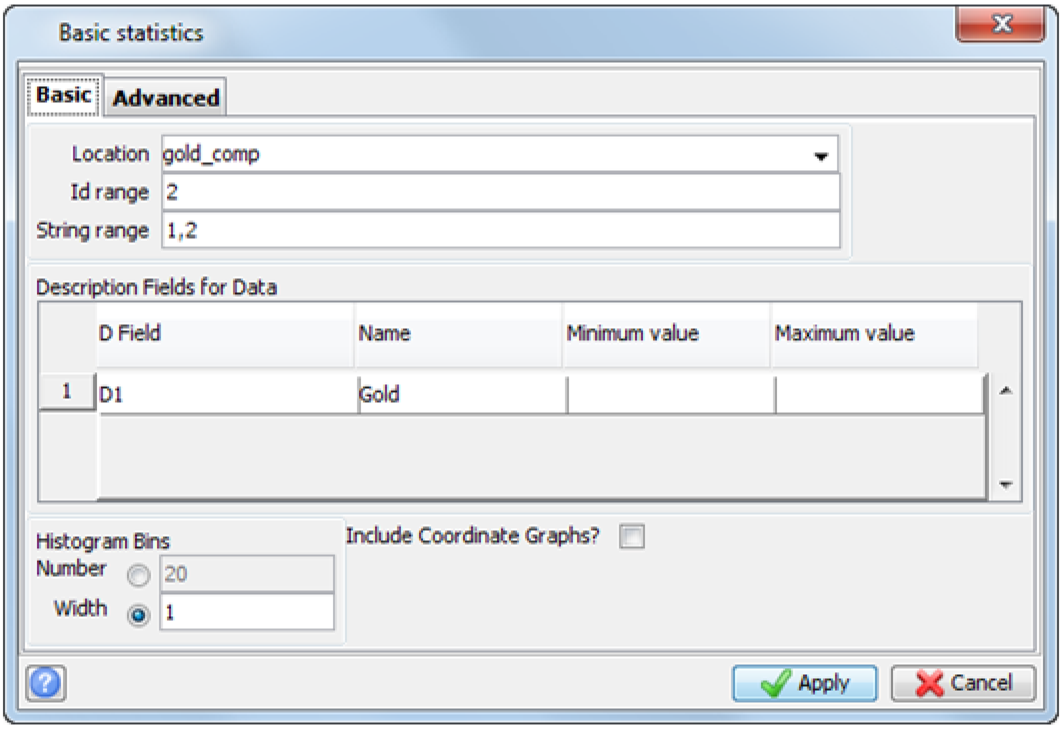
- be familiar with Surpac string files
- know how to run a Surpac macro

Task: Displaying histograms

1. Run the macro **02_basic_statistics.tcl**.
2. Read the text on the first form, and click **Apply**.

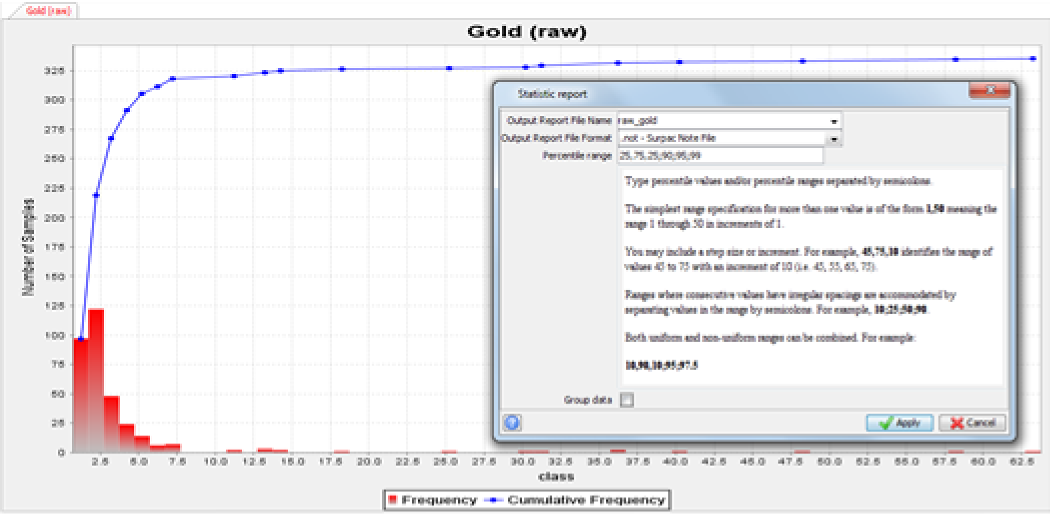


3. Review the settings on the *Basic statistics* form, and click **Apply** .

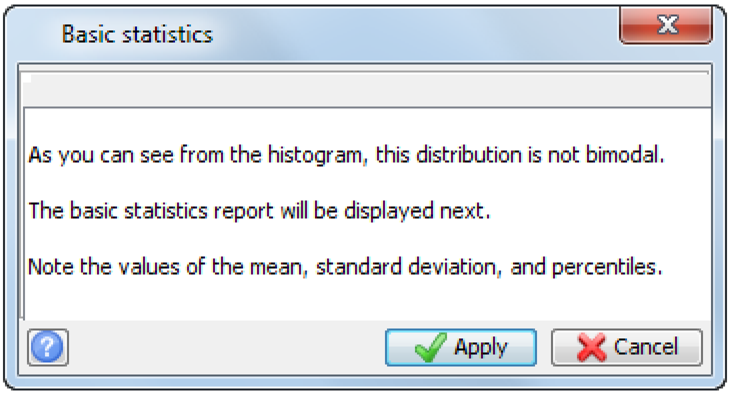


A histogram and a line representing the cumulative frequency is displayed. The cumulative frequency is an accumulation of the values of all previous histogram bins.

4. Review the settings on the *Statistic report* form, and click **Apply**.



5. Read the text below on the following form, and click **Apply**.



The output report **raw_gold.not** is displayed in your default text editor. This report contains several output statistics, including the specified percentiles. You will refer to this report in the next section of this tutorial.

```
Output Filename: raw_gold
                                Statistics Report


File                            Gold Comp2.str
----------------------------------------------
String range                               1,2
Variable                                  Gold

Number of samples                          335
Minimum value                         0.730000
Maximum value                        63.490000

                                Ungrouped Data
Mean                                  3.828476
Median                                2.120000
Geometric Mean                        2.533744
Variance                             46.672186
Standard Deviation                    6.831704
Coefficient of variation              1.784445

Moment 1 About Arithmetic Mean        0.000000
Moment 2 About Arithmetic Mean       46.672186
Moment 3 About Arithmetic Mean     1870.710266
Moment 4 About Arithmetic Mean    90362.538844

Skewness                              5.867044
Kurtosis                             41.483189

Natural Log Mean                      0.929698
Log Variance                          0.500146

25.0 Percentile                       1.657500
50.0 Percentile (median)              2.120000
75.0 Percentile                       3.297850
90.0 Percentile                       5.120000
95.0 Percentile                       9.280000
99.0 Percentile                      44.112500

Trimean                               2.298838
Biweight                              2.234705
MAD                                   0.704705
Alpha                                -0.729756
Sichel-t                              3.250600

Normal Histogram Tabulation
Gold
```

Class From	Class To	Count	Mean	Freq %	Cum Count	Cum Mean	Cum Freq %	Dec Count	Dec Mean	Dec Freq %
0.730000	1.730000	97	1.358301	0.290	97	1.358301	28.9552	335	3.828476	100.0000
1.730000	2.730000	122	2.155034	0.364	219	1.802143	65.3731	238	4.835227	71.0448
2.730000	3.730000	48	3.166762	0.143	267	2.047468	79.7015	116	7.654051	34.6269
3.730000	4.730000	24	4.194958	0.072	291	2.224581	86.8657	68	10.821549	20.2985
4.730000	5.730000	14	5.094464	0.042	305	2.356313	91.0448	44	14.436052	13.1343
5.730000	6.730000	6	6.167500	0.018	311	2.429841	92.8358	30	18.795460	8.9552
6.730000	7.730000	7	7.198400	0.021	318	2.534809	94.9254	24	21.952450	7.1642
10.730000	11.730000	2	11.095000	0.006	320	2.588310	95.5224	17	28.027647	5.0746
12.730000	13.730000	3	13.040000	0.009	323	2.685385	96.4179	15	30.285333	4.4776
13.730000	14.730000	2	14.252500	0.006	325	2.756567	97.0149	12	34.596667	3.5821
17.730000	18.730000	1	18.435000	0.003	326	2.804660	97.3134	10	38.665500	2.9851
24.730000	25.730000	1	25.390000	0.003	327	2.873729	97.6119	9	40.913333	2.6866
29.730000	30.730000	1	30.355000	0.003	328	2.957513	97.9104	8	42.853750	2.3881
30.730000	31.730000	1	30.750000	0.003	329	3.041989	98.2090	7	44.639286	2.0896
35.730000	36.730000	2	36.060000	0.006	331	3.241493	98.8060	6	46.954167	1.7910
39.730000	40.730000	1	40.225000	0.003	332	3.352889	99.1045	4	52.401250	1.1940
47.730000	48.730000	1	48.000000	0.003	333	3.486965	99.4030	3	56.460000	0.8955
57.730000	58.730000	1	57.890000	0.003	334	3.649848	99.7015	2	60.690000	0.5970
62.730000	63.730000	1	63.490000	0.003	335	3.828476	100.0000	1	63.490000	0.2985

1/1

Menu commands:

Select...	to...
Geostatistics > Basic statistics	open the Statistics Window.
From the Statistics Window:	
File > Load data from string files	create a histogram.
Statistics > Report	create a report.

Outliers

Overview

Outliers are data values outside the range of most of the data within one domain. If left in the data set, outliers can cause problems with variograms, and can reduce the quality of estimations.

You will learn about:

- outliers
- how to remove outliers
- Selection of a cutoff value

Requirements

In order to understand this information, you should:

- be familiar with Surpac string files
- know how to run a Surpac macro

Outliers

An “outlier” is a statistical term for a data value which is relatively distant from the majority of all other values in the data set. For example, in the following data set, the number 236 would be considered to be an outlier:

1 3 5 5 8 8 8 236

Outliers can cause problems with the calculation of variograms. Additionally, if used in an estimation, outliers can cause an unrealistic results. One technique used to reduce the impact of outliers is to apply a “cutoff” to them. In the example above, the value of 236 could be “cut”, or changed to a value of 9.

1 3 5 5 8 8 8 9

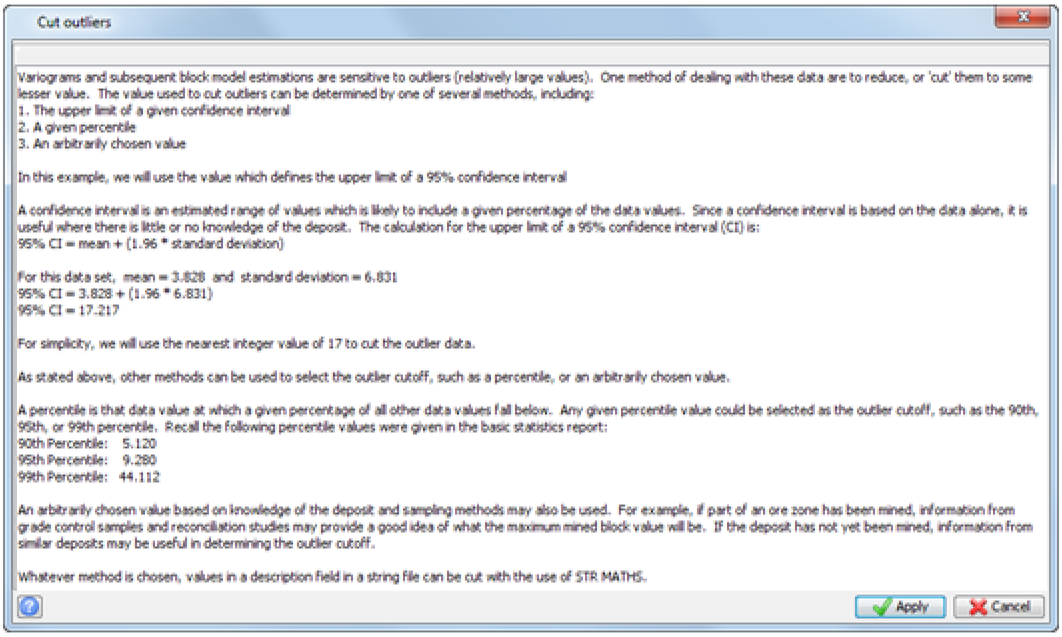
Another alternative is to remove the outlier value(s).

Removing outliers

Looking back to the histogram of **gold_comp2.str**, as well as the output report, you can see that the majority of the data is grouped between values of 0 and 10 grams per tonne. You can also see that there are several outlier values above 10 grams per tonne.

Task: Removing outliers

1. Run **03_cut_outliers.tcl**.
2. After reading text on the first form, click **Apply**.



STR MATHS is invoked by selecting **File tools > String maths**.

This form prompts you to enter the name of the input and output files, as well as an expression. Prior to viewing this form, the macro has opened **gold_comp2.str** and saved it as **gold_cut17.str**.

The D1 field will receive the result of the expression:

iif(d1>17,17,d1)

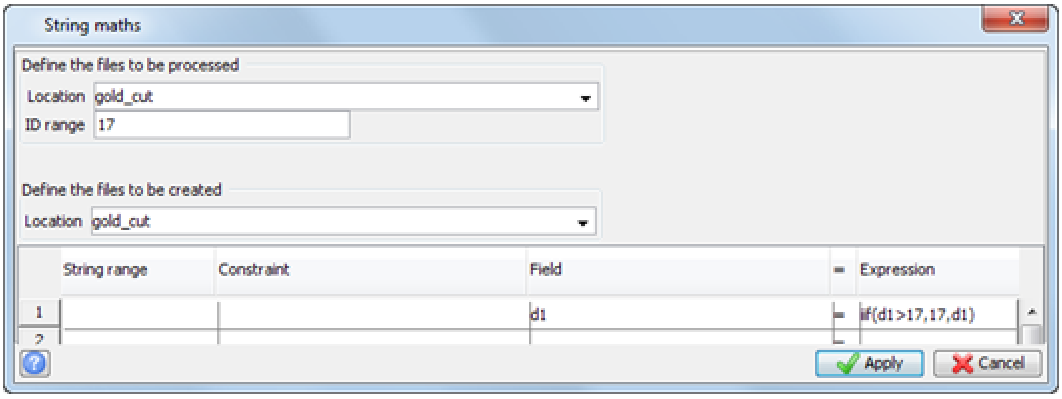
This expression can be reworded as:

If the initial value of d1 is greater than 17,

then set the value of d1 equal to 17,

else leave the value of d1 as it was initially.

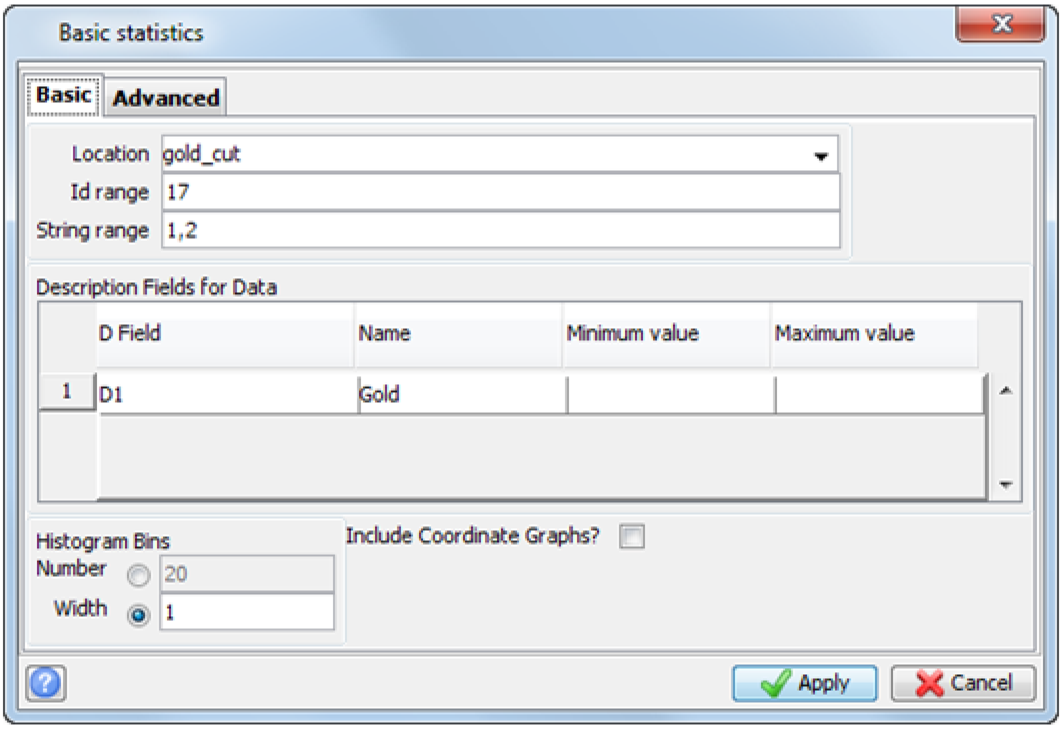
3. After viewing the form, click **Apply**.



In order to validate the output from STR MATHS, you will analyse the data in the **Basic Statistics** window. Again, you run this function by selecting **Geostatistics > Basic statistics**.

Next, the macro will choose **File> Load data from string files**, and the form below is displayed. Notice that **gold_cut17.str** is the file being analysed.

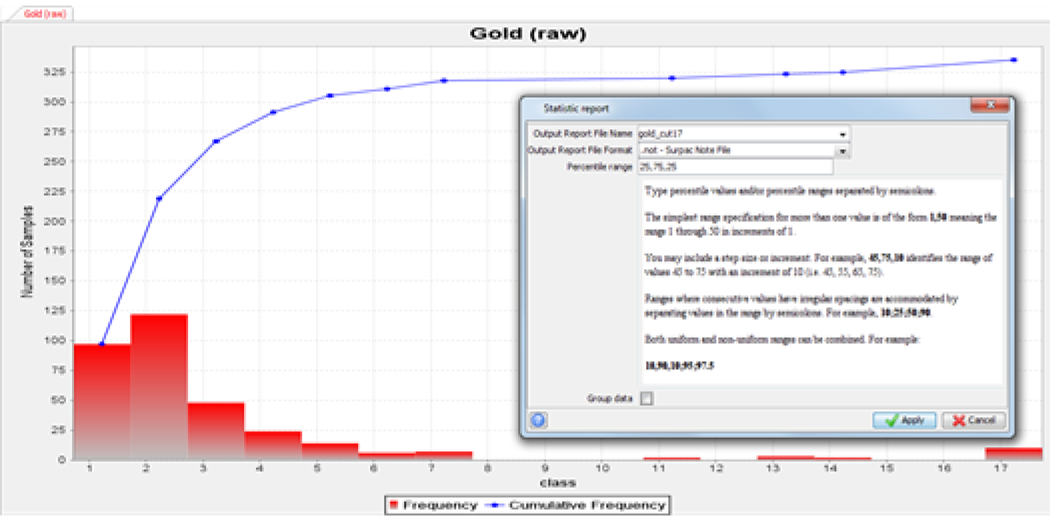
4. After viewing the form, click **Apply**.



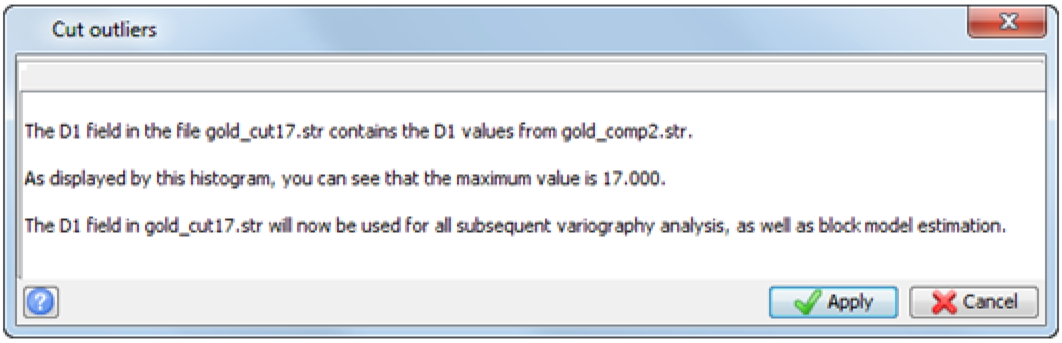
Next, a histogram and a line representing the cumulative frequency is displayed. Notice that the maximum data value is now 17.

Then, the macro selects **Statistics > Report**. The *Statistics report* form prompts you to enter the name of an output report, the report format, and a range of percentiles which will be written to the report.

5. After viewing the form, click **Apply**.



6. After reading the following form, click **Apply**.



The output report **gold_cut17.not** contains several output statistics, including the specified percentiles. This file is created in the directory, but not displayed by the macro. You can open it if you want to verify that the maximum value is 17.

```
Output Filename: gold_cut17
                                Statistics Report


File                            Gold Cut17.str
------------------------------------------------
String range                               1,2
Variable                                  Gold

Number of samples                          335
Minimum value                         0.730000
Maximum value                        17.000000

                                Ungrouped Data
Mean                                  3.181744
Median                                2.120000
Geometric Mean                        2.476903
Variance                              9.813599
Standard Deviation                    3.132666
Coefficient of variation              0.984575

Moment 1 About Arithmetic Mean        0.000000
Moment 2 About Arithmetic Mean        9.813599
Moment 3 About Arithmetic Mean       98.371421
Moment 4 About Arithmetic Mean     1298.903259

Skewness                              3.199827
Kurtosis                             13.487150

Natural Log Mean                      0.907009
Log Variance                          0.392231

25.0 Percentile                       1.657500
50.0 Percentile (median)              2.120000
75.0 Percentile                       3.297850

Trimean                               2.298838
Biweight                              2.234705
MAD                                   0.704705
Alpha                                -0.729756
Sichel-t                              3.011461

Normal Histogram Tabulation
Gold

Class From  Class To  Count      Mean  Freq %  Cum Count  Cum Mean  Cum Freq %  Dec Count  Dec Mean  Dec Freq %
-----------------------------------------------------------------------------------------------------------------
  0.730000   1.730000    97   1.358301  0.290        97  1.358301    28.9552        335   3.181744   100.0000
  1.730000   2.730000   122   2.155034  0.364       219  1.802143    65.3731        238   3.924912    71.0448
  2.730000   3.730000    48   3.166762  0.143       267  2.047468    79.7015        116   5.786335    34.6269
  3.730000   4.730000    24   4.194958  0.072       291  2.224581    86.8657         68   7.635446    20.2985
  4.730000   5.730000    14   5.094464  0.042       305  2.356313    91.0448         44   9.512075    13.1343
  5.730000   6.730000     6   6.167500  0.018       311  2.429841    92.8358         30  11.573627     8.9552
  6.730000   7.730000     7   7.198400  0.021       318  2.534809    94.9254         24  12.925158     7.1642
 10.730000  11.730000     2  11.095000  0.006       320  2.588310    95.5224         17  15.283235     5.0746
 12.730000  13.730000     3  13.040000  0.009       323  2.685385    96.4179         15  15.841667     4.4776
 13.730000  14.730000     2  14.252500  0.006       325  2.756567    97.0149         12  16.542083     3.5821
 16.730000  17.730000    10  17.000000  0.030       335  3.181744   100.0000         10  17.000000     2.9851
                                                                          1/1
```

Menu commands:

Select...	to...
Geostatistics > Basic statistics	open the Statistics window.
From the Statistics Window:	
File > Load data from string files	create a histogram.
Statistics > Report	create a report.
File tools > String maths	invoke STR MATHS.

Variogram maps

Overview

An important aspect of performing any geostatistical evaluation is to understand the anisotropy of the data, or which direction has the longest continuity. it is also important to understand how data values change with regard to the direction of longest continuity, as well as the two mutually perpendicular directions.

A variogram map is a tool within Surpac, which allows you to visualise anisotropy in a plane. Additionally, you can use variogram maps to define the anisotropy ellipsoid. These concepts are explained through the following:

- primary variogram map
- secondary variogram map
- calculation of anisotropy ellipsoid parameters

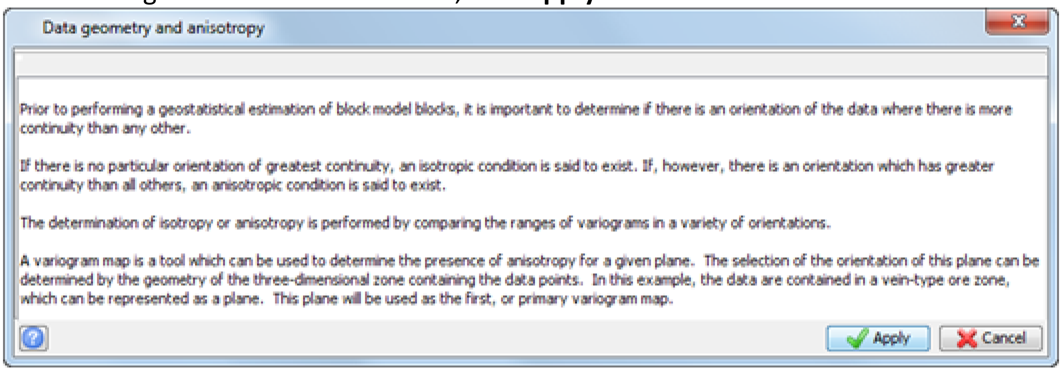
Requirements

In order to understand this information, you should:

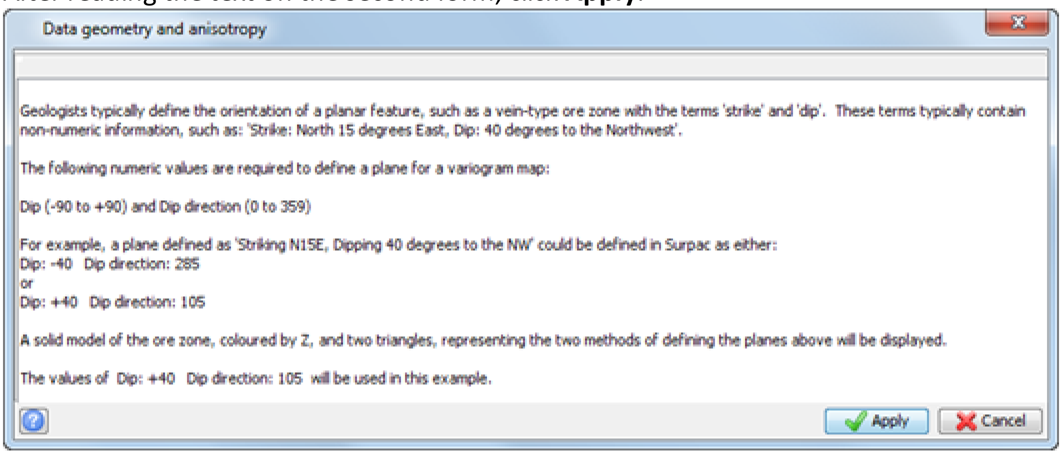
- be familiar with Surpac string files
- know how to calculate and model a variogram in Surpac
- understand the concept of an anisotropy ellipsoid
- understand the parameters which define an anisotropy ellipsoid

Task: View variogram map dip plane

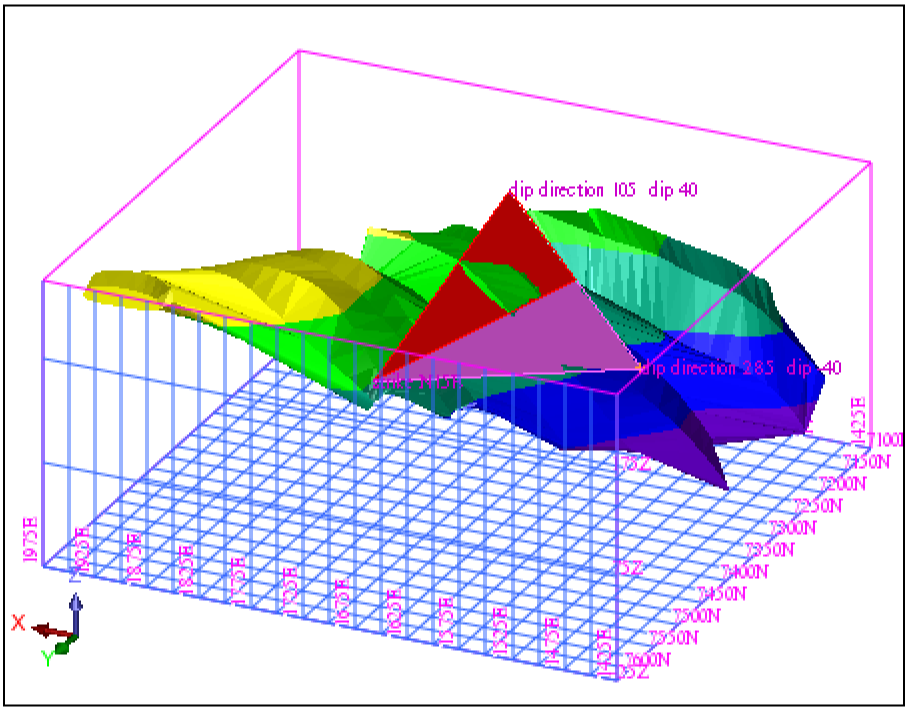
1. Run **05_data_geometry.tcl**.
2. After reading the text on the first form, click **Apply**.



3. After reading the text on the second form, click **Apply**.



The data is displayed in **Graphics**.

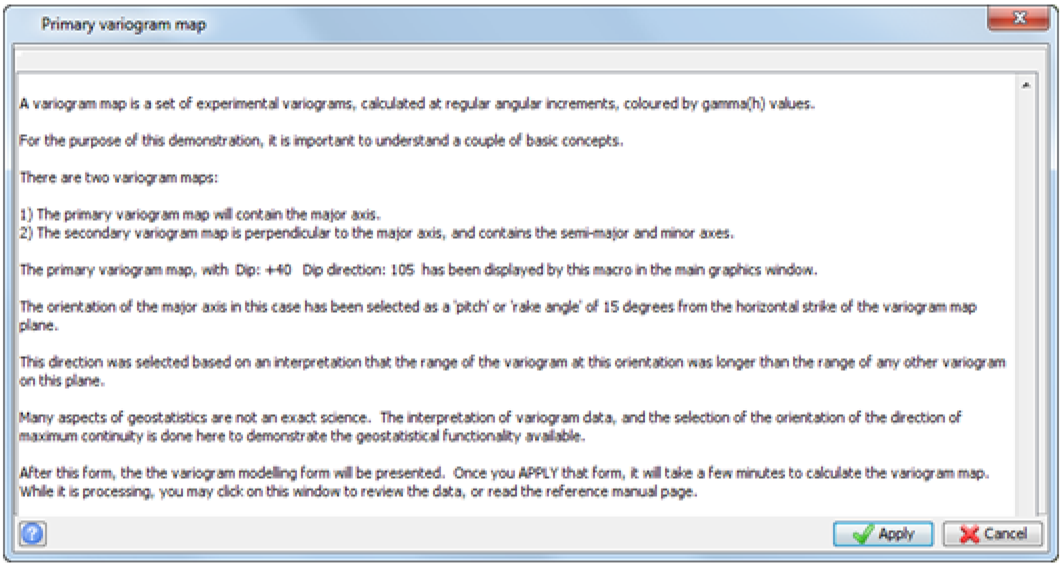


Task: Calculate the primary variogram map

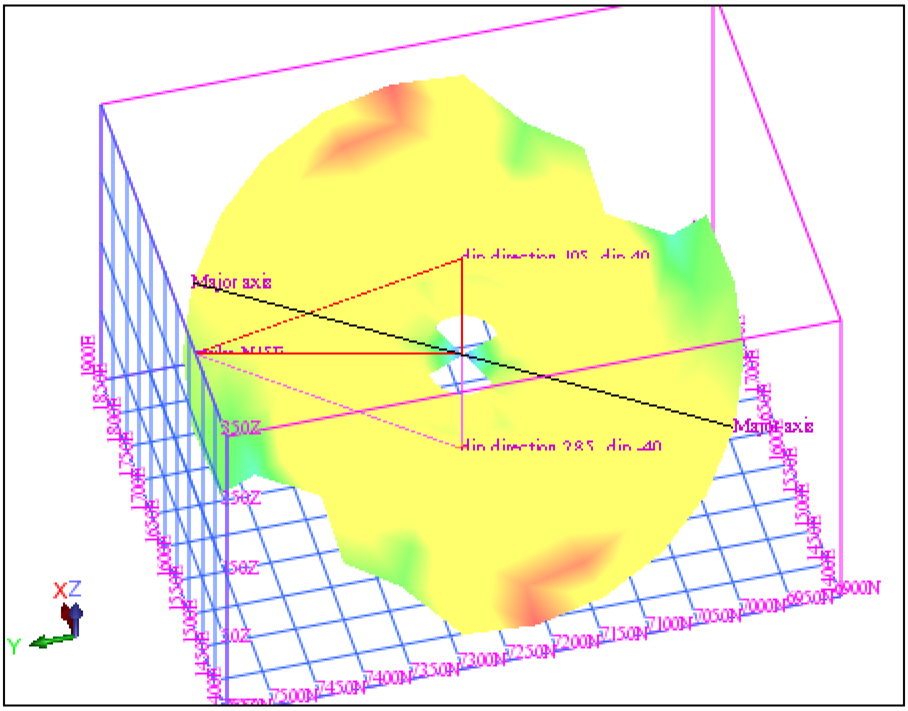
1. Run **06_primary_variogram_map.tcl**.
   You will see:
   - a variogram map displayed in three dimensions
   - a form displayed

   After reading the text the *Primary variogram map* form, move the form to the side so that you can see the image in **Graphics**.

   Caution: Do ***NOT*** click **Apply** yet.

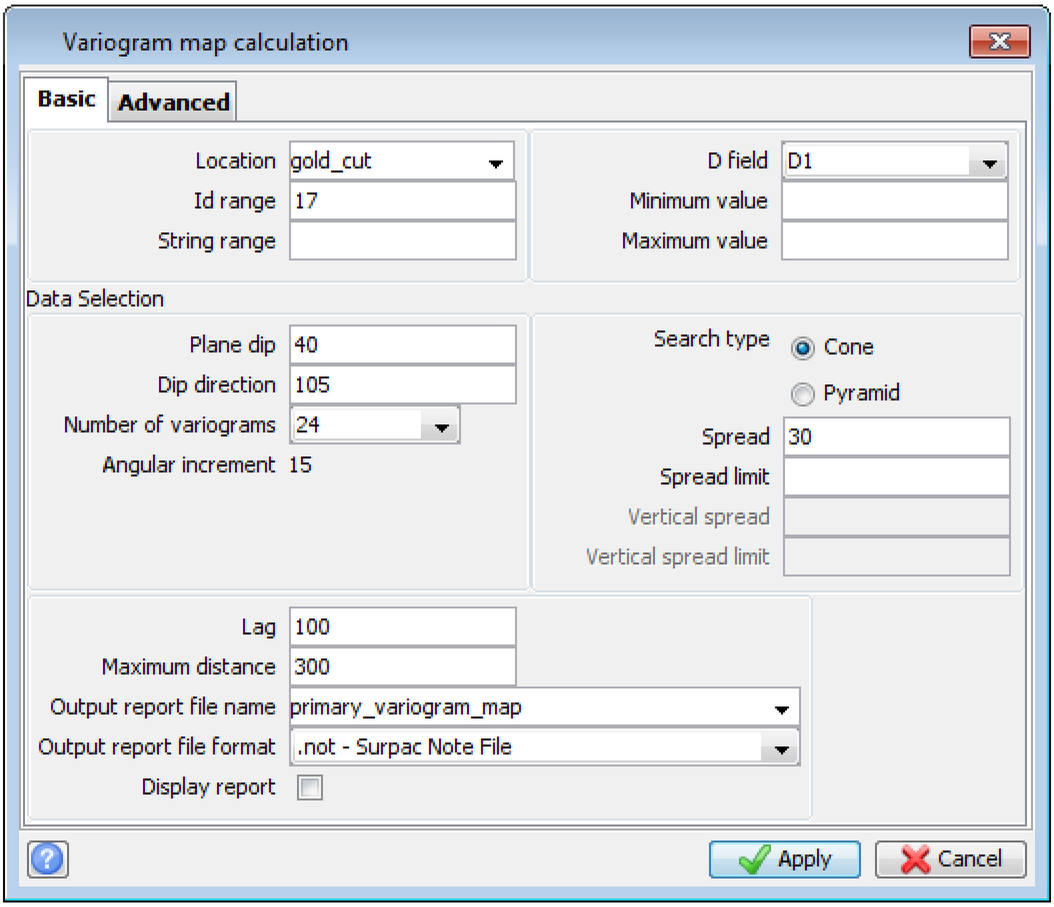


   The primary variogram is displayed in **Graphics**.



By definition, the primary variogram map will contain the major axis of the anisotropy ellipsoid. The semi-major axis could lie within the plane of the primary variogram map, but it does not have to be located on this plane.

2. After you have viewed the primary variogram map, move the form back into view and click **Apply**.
   The macro now opens the **Variogram modelling** window by choosing **Geostatistics > Variogram modelling**. It then displays the *Variogram map calculation* form by choosing **Variogram map > New variogram map**.



In the top panel, string file information (Location, ID, string range) is defined using the same parameters as in variogram calculation.

In the middle panel, the plane containing the primary variogram map is defined. You are using: **Dip: +40** and **Dip direction: 105**.

This same plane could be defined using a dip of -40 and a dip direction of 285.

The number of variograms selected will determine the angular increment. In our example, 24 variograms will result in a 15 degree angular increment (360/24=15). If the number of variograms was set to 36, you would get a 10 degree increment (360/36=10).

The spread and spread limit parameters are the same as in normal variogram modelling.

The relationship between the angular increment and the spread angle should be considered.

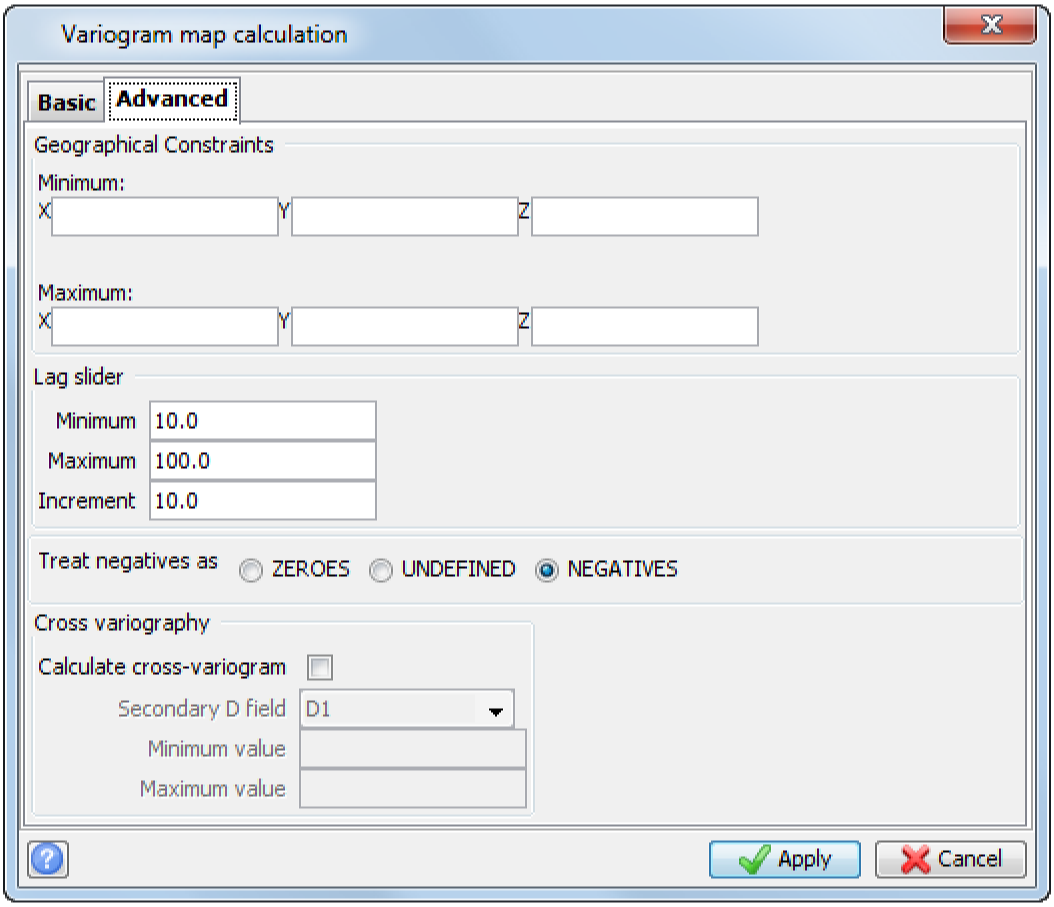
It could be considered unreasonable to define a spread tolerance anything greater than half of the angular increment. For this data set, because of the small number of pairs, if a 7.5 degree spread were used (half of the 15 degree angular increment between adjacent variograms), the number of data pairs would be so small that very few, if any reasonable variograms would result. A spread of 30 degrees is used for this data set to ensure that enough samples are included to produce meaningful variograms.

Given that a spread of 30 degrees is used, you could argue that the number of variograms should be reduced to minimise the “overlap” of the cones for adjacent variograms. Although this is a reasonable argument, the resulting variograms would not be suitable to use to use to visually determine anisotropy

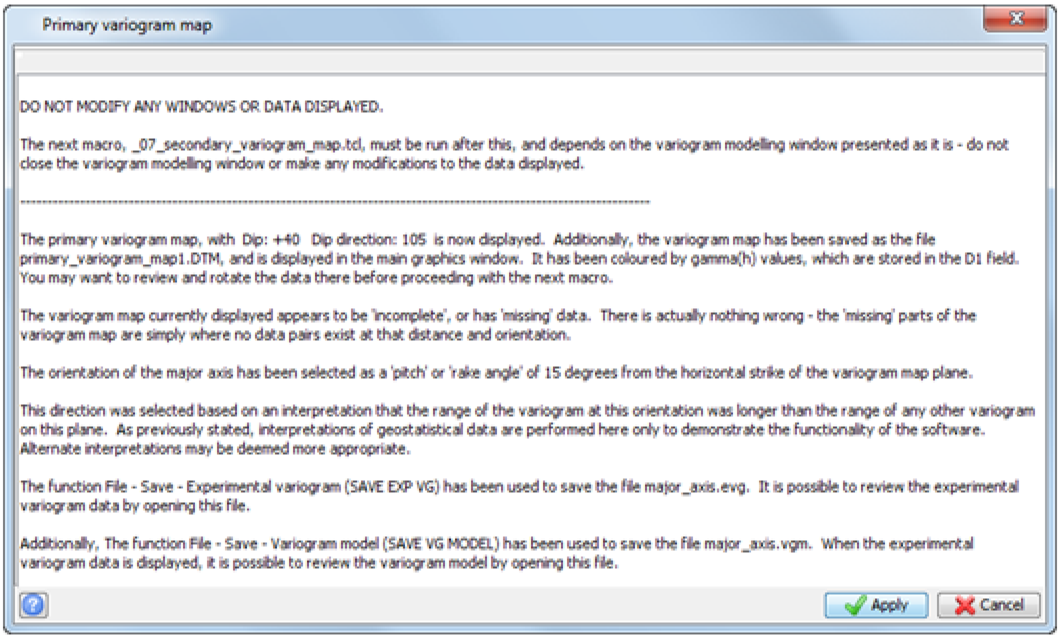
It is up to you, based on the data set you are working with,to determine the values you will use to produce a usable variogram without over-smoothing your data. This is an example of how geostatistics is an inexact science. Experience with a data set will usually allow you to determine what combination of parameters will give an acceptable result.

In the bottom panel, the lag, maximum distance, and variogram report parameters are specified, exactly as they are in variogram modelling. One thing you should consider is that the maximum distance will be the radius of the variogram map. You might find that you need to try a few variations of this value to get one that gives an adequate result.

3. Click the **Advanced** tab.
   You will see that the fields here are identical to those on the **Advanced** tab of the variogram calculation form.

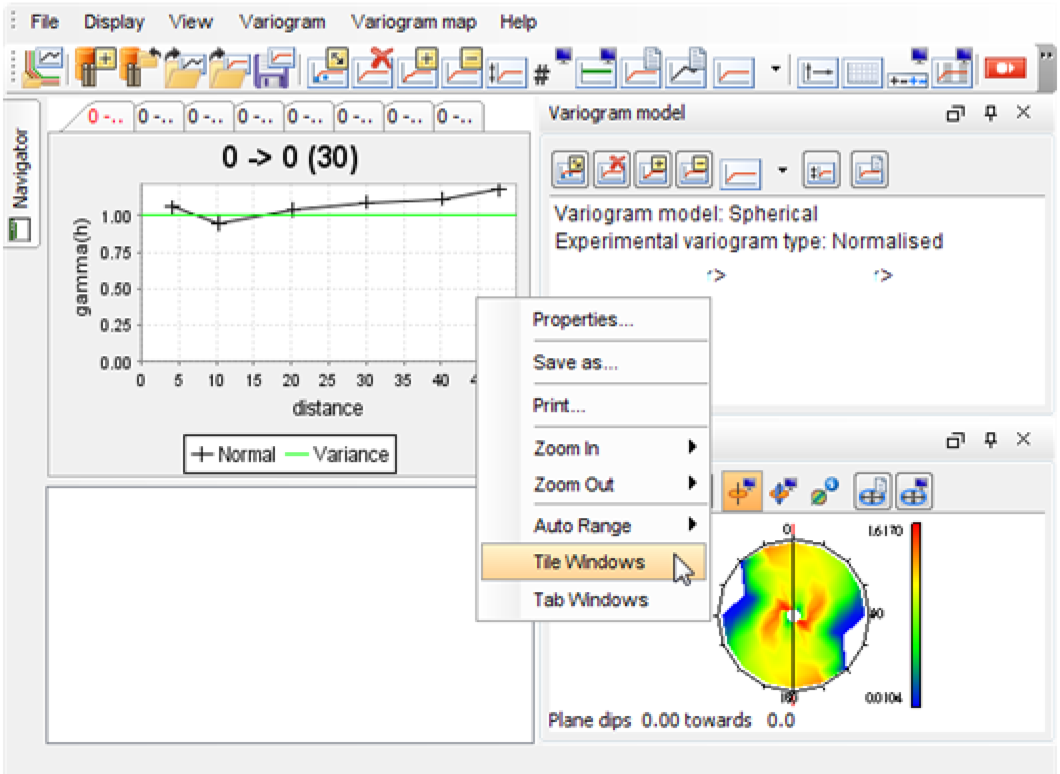


4. After viewing the form, click **Apply**.
5. Read the text on the second form, then click **Apply**.



You will see the variogram map, as well as the variogram for the orientation displayed on the variogram map.

6. Click the tab to display the orientation as shown.



The purpose of the primary variogram map is to determine the orientation of the major axis. As described previously, by definition, the major axis lies within the primary variogram map. The example given here is based upon the premise that you, as a geologist know that the orientation of the major axis will lie somewhere in this dipping plane for this dataset. For a horizontal seam deposit, the orientation of the primary variogram map would be horizontal.

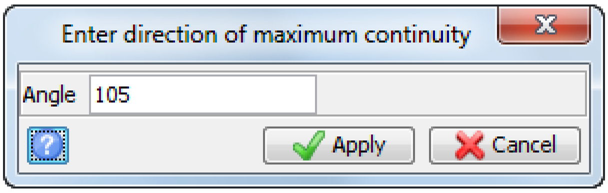
Task: Select the variogram orientation for the longest range of a given sill value

The idea is to select the variogram orientation which has the longest range for a given sill value. The lag slider can help you:

1. Use the lag slider to alert you to areas of high and low variance on the variogram map. In other words, move the lag slider back and forth, and watch the colours on the variogram map change.
   You will most likely see that throughout a range of lag values, there will be areas on the variogram map which will be consistently high, and others which will be consistently low. Using the example given above, note that the orientation of 15 degrees above the horizontal (on the left) will consistently display colours on the low end of the variance values, as represented by the legend to the right.
2. Once you have an idea of what may appear to be the orientation of the longest range, click the tab for that orientation so that the black line on the variogram matches that direction.
3. Now use the lag slider to improve the quality of the experimental variogram for that direction.
4. After you have an acceptable variogram, create a variogram model for that orientation. The major axis should be that variogram which has the lowest variance for the longest distance.
5. If another orientation appears to have a longer range and a lower variance, modify the model to fit that experimental variogram. Modifying the lag distance for that orientation may help you get a better fit.
6. Repeat the previous two steps until you are satisfied that you have the orientation of the major axis.
7. After you have ascertained a major axis, ask yourself and others who are familiar with the geology if the orientation appears correct.
   As you can see, not only is the subject of variogram modelling a non-scientific process, but the orientation of the major axis is also open to interpretation and debate.

   After you have determined the orientation of the major axis, you must inform the software of your selection.
8. Choose **Variogram map > Select direction of maximum continuity**.
9. In the variogram map viewport, click and drag the red line to your selected orientation, then release.
   A form is displayed, indicating the relative orientation of your selection, as a value between 0 and 180. You will probably need to change this value to fit your desired orientation.

   Note: This is a free rotation, and you are not forced to select a precise orientation of any of the variogram directions. This can be useful if you have found two adjacent orientations which are equally valid – you can set the direction of maximum continuity to midway between these two directions.

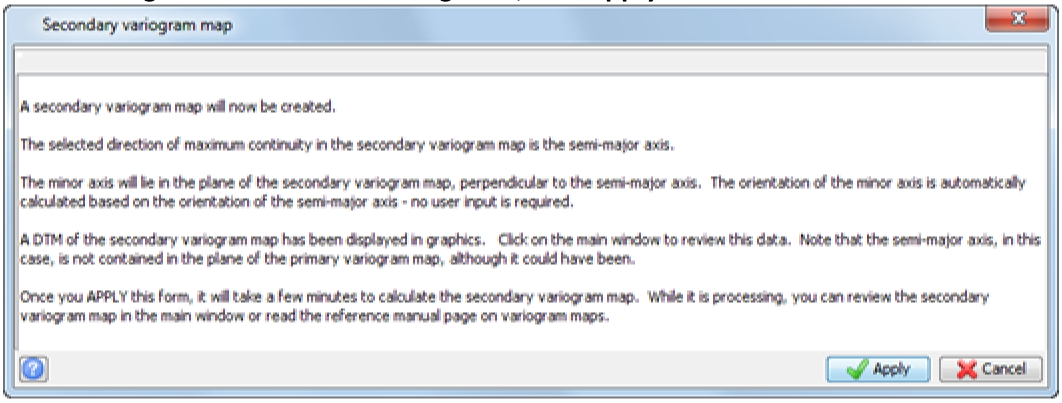
   

10. Click **Apply** to enter the value.

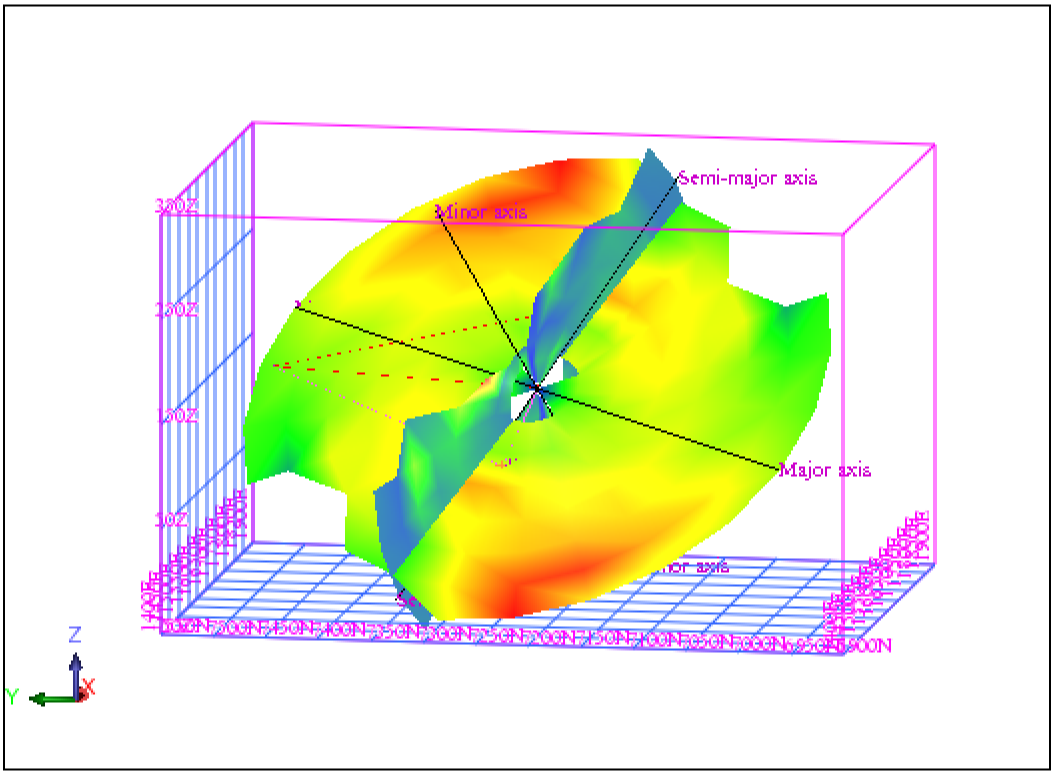
11. Choose **File > Save > Experimental variogram and model** to save both the variogram and the variogram model.

Task: Calculate the secondary variogram map

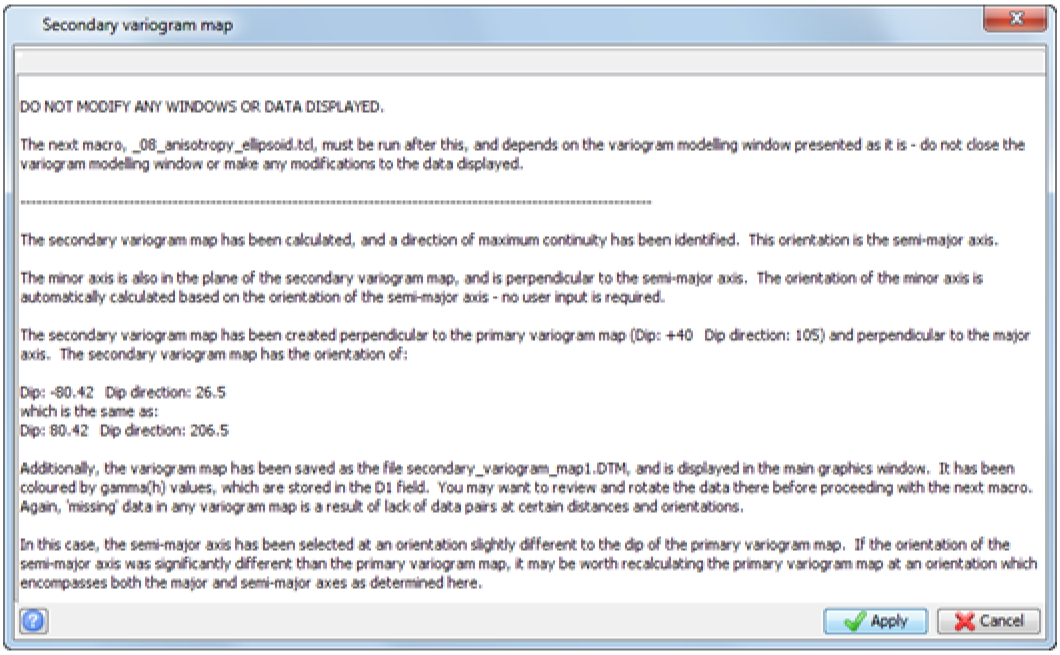
1. Run **07_secondary_variogram_map.tcl**.
   📝 **Note**: If you want to know the steps to perform this task manually see *Task: Use the Secondary Variogram Map to Define the Semi-Major Axis* at the end of this topic.
2. After reading the text on the following form, click **Apply**.



The secondary variogram map, and the selected orientations of all axes, are displayed in **Graphics**.



3. After reading the text on the following form, click **Apply**.


Secondary variogram map

DO NOT MODIFY ANY WINDOWS OR DATA DISPLAYED.

The next macro, _08_anisotropy_ellipsoid.tcl, must be run after this, and depends on the variogram modelling window presented as it is - do not close the variogram modelling window or make any modifications to the data displayed.

The secondary variogram map has been calculated, and a direction of maximum continuity has been identified. This orientation is the semi-major axis.

The minor axis is also in the plane of the secondary variogram map, and is perpendicular to the semi-major axis. The orientation of the minor axis is automatically calculated based on the orientation of the semi-major axis - no user input is required.

The secondary variogram map has been created perpendicular to the primary variogram map (Dip: +40 Dip direction: 105) and perpendicular to the major axis. The secondary variogram map has the orientation of:

Dip: -80.42 Dip direction: 26.5
which is the same as:
Dip: 80.42 Dip direction: 206.5

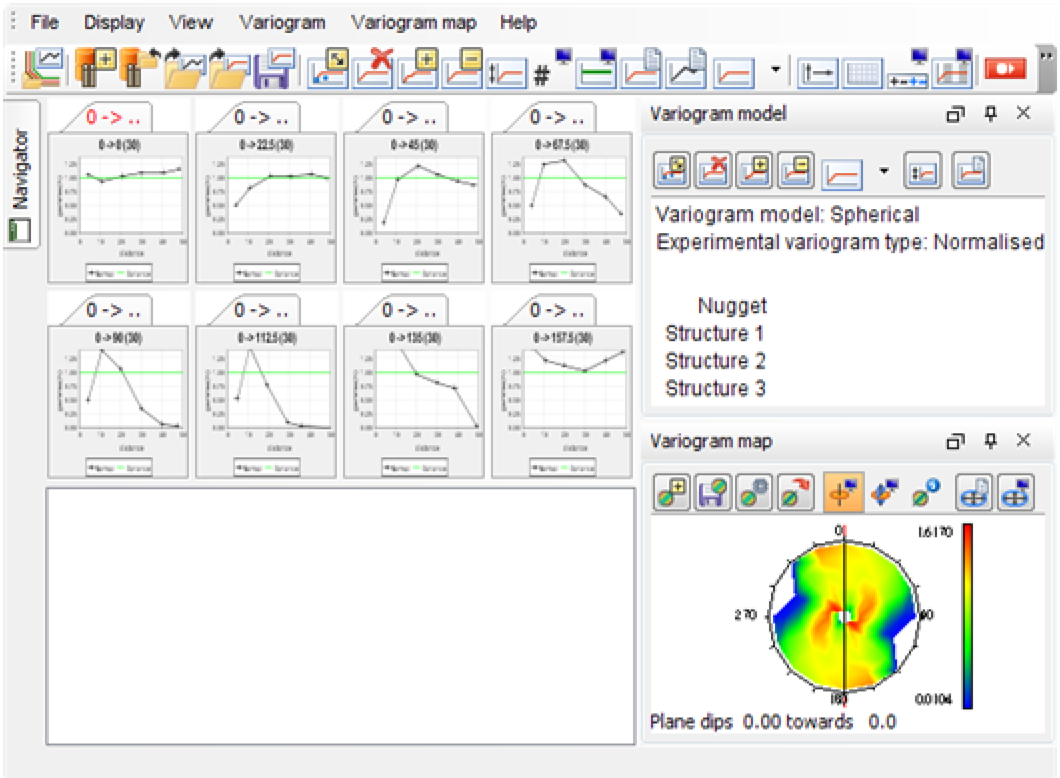
Additionally, the variogram map has been saved as the file secondary_variogram_map1.DTM, and is displayed in the main graphics window. It has been coloured by gamma(h) values, which are stored in the D1 field. You may want to review and rotate the data there before proceeding with the next macro. Again, 'missing' data in any variogram map is a result of lack of data pairs at certain distances and orientations.

In this case, the semi-major axis has been selected at an orientation slightly different to the dip of the primary variogram map. If the orientation of the semi-major axis was significantly different than the primary variogram map, it may be worth recalculating the primary variogram map at an orientation which encompasses both the major and semi-major axes as determined here.

Apply Cancel

Note: The same steps used to select the direction of maximum continuity for the primary variogram map have been used to select the direction of maximum continuity for the secondary variogram map.

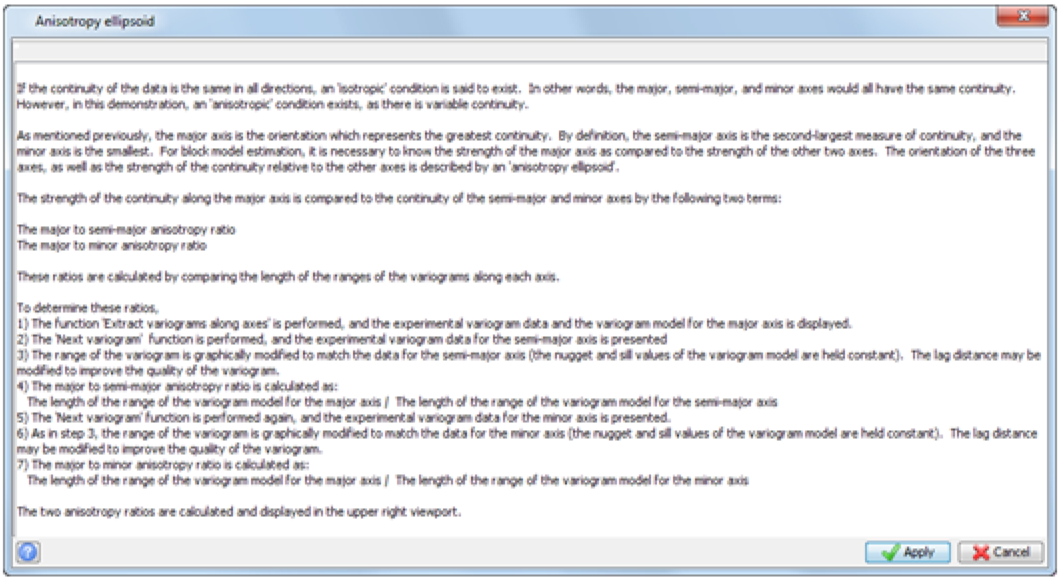
4. Click the tab to display the orientation as shown.



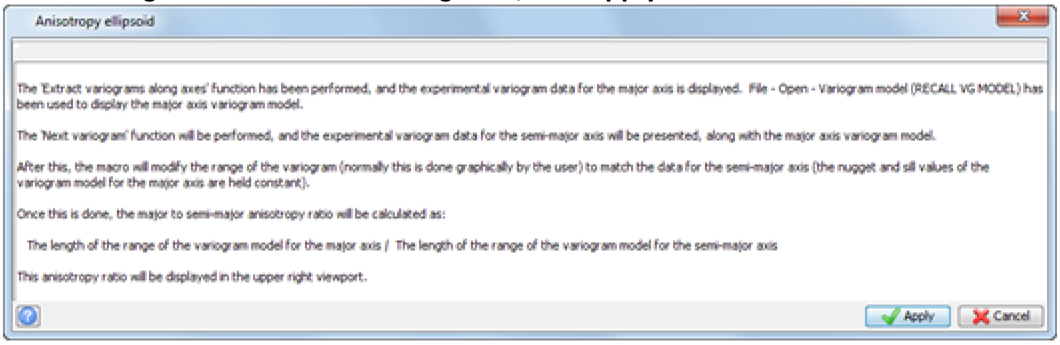
Anisotropy ellipsoid parameters

Task: Calculate ellipsoid parameters with a macro

1. Run **08_anisotropy_ellipsoid.tcl**.
2. After reading the text on the first form, click **Apply**.

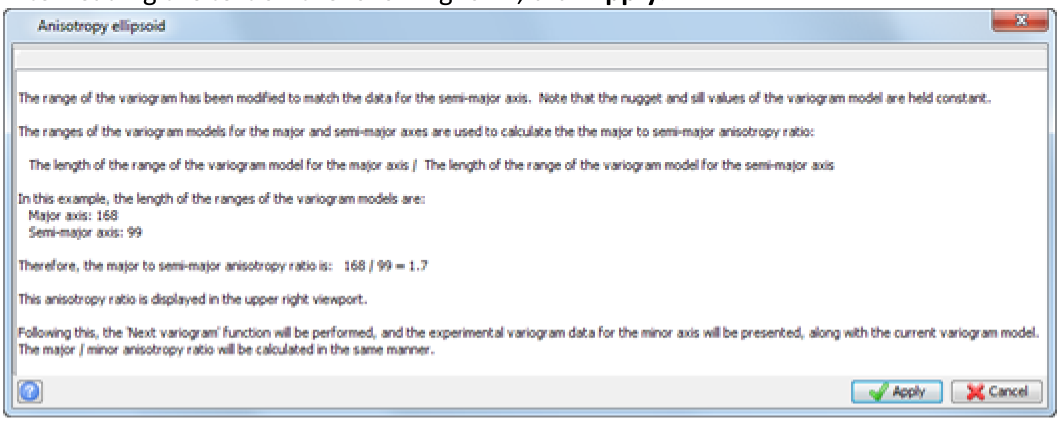


3. After reading the text on the following form, click **Apply**.

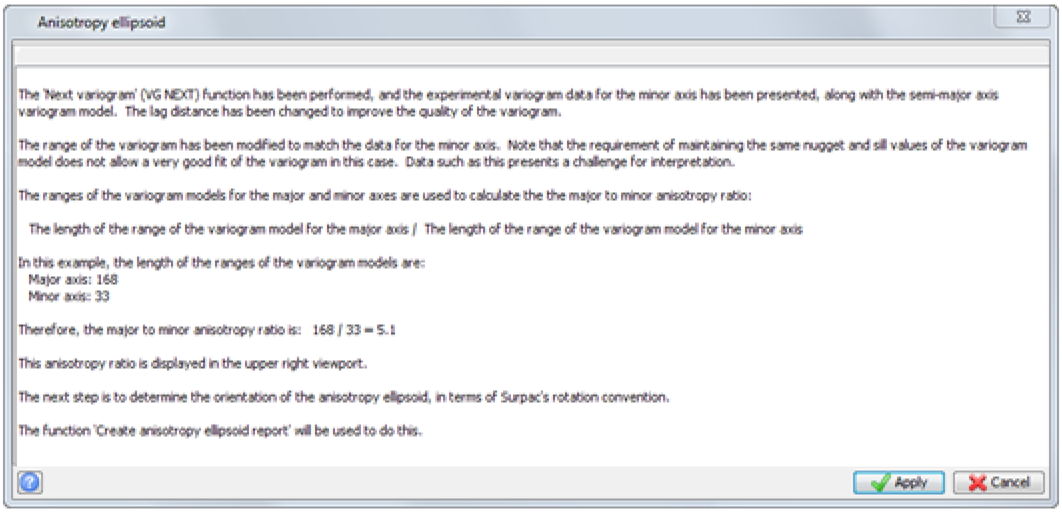


The secondary variogram map, and the selected orientations of all axes are displayed.

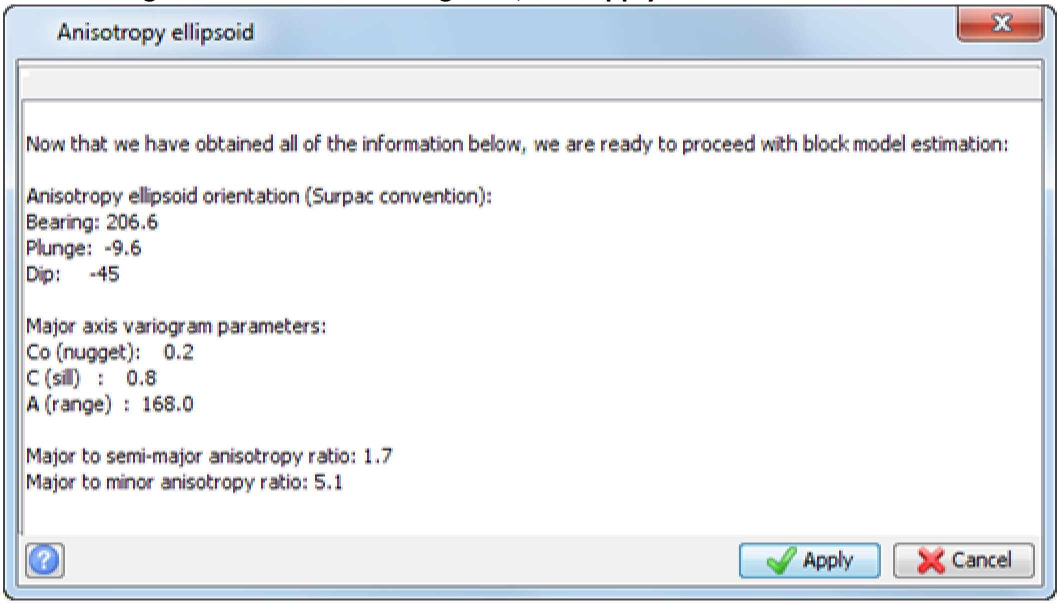
4. After reading the text on the following form, click **Apply**.



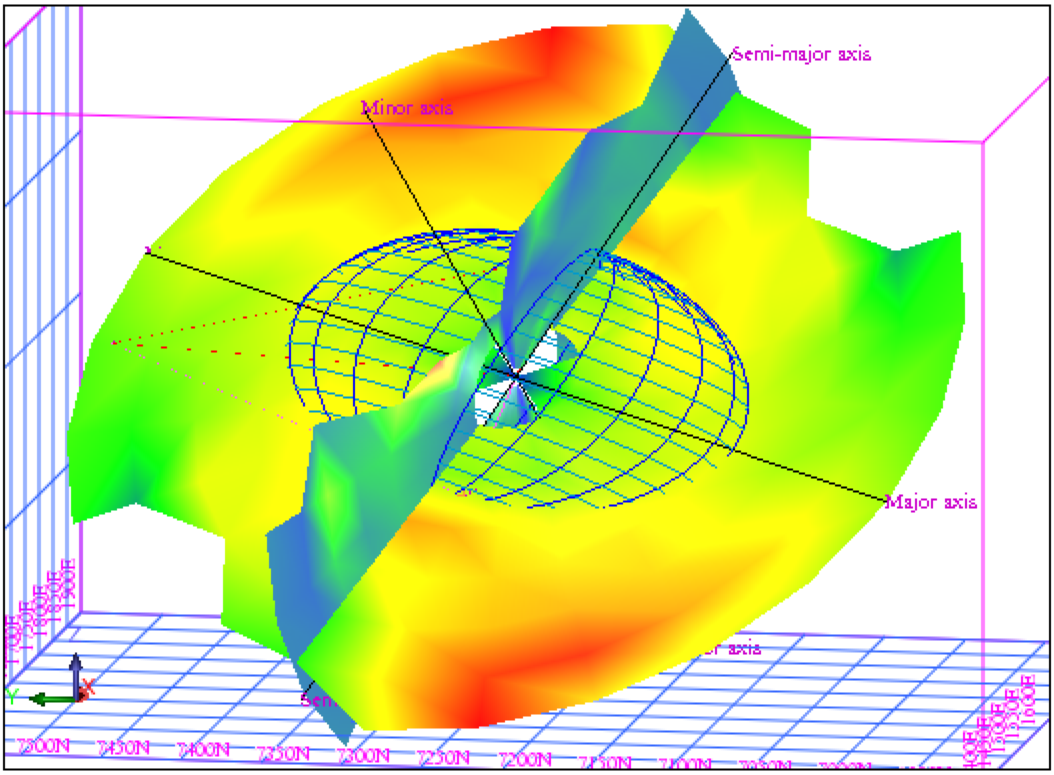
5. When the next form is displayed, click and drag it out of the way so that you can view the variogram modelled for the minor axis.
6. After reading the text on the following form, click **Apply**.



7. After reading the text on the following form, click **Apply**.

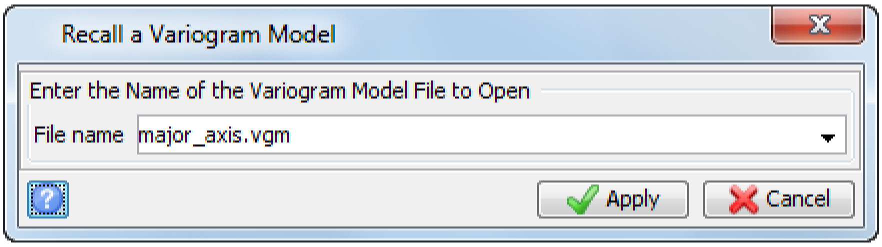


You will see the ellipsoid displayed in **Graphics**.

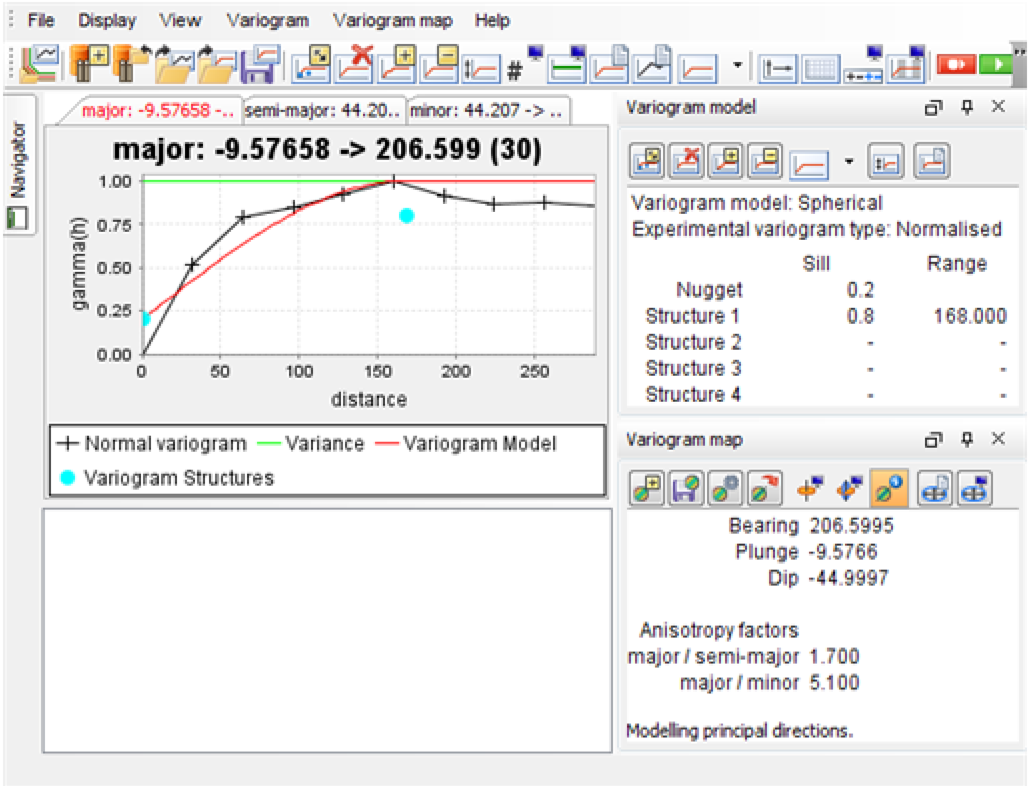


Task: Calculate ellipsoid parameters manually

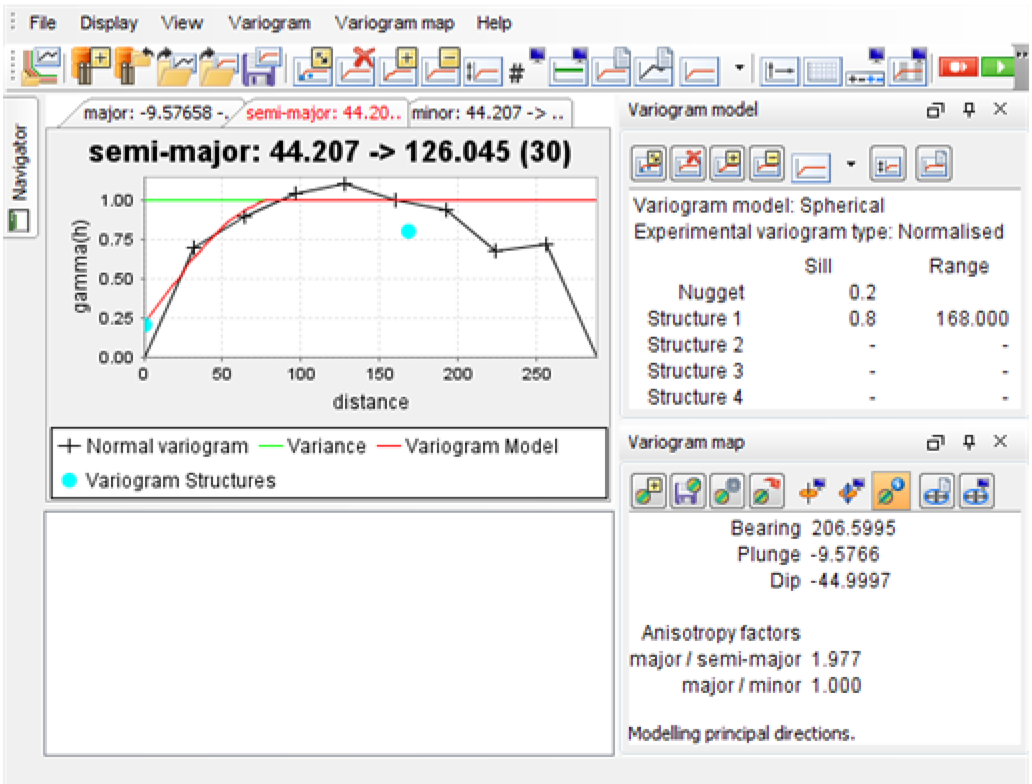
1. Choose **Variogram map > Secondary variogram map**.
2. Choose **Variogram map > Extract variograms along axes.**
3. Choose **File > Open > Variogram model**.
4. Enter the information as shown, and click **Apply**.



The variogram model is displayed.



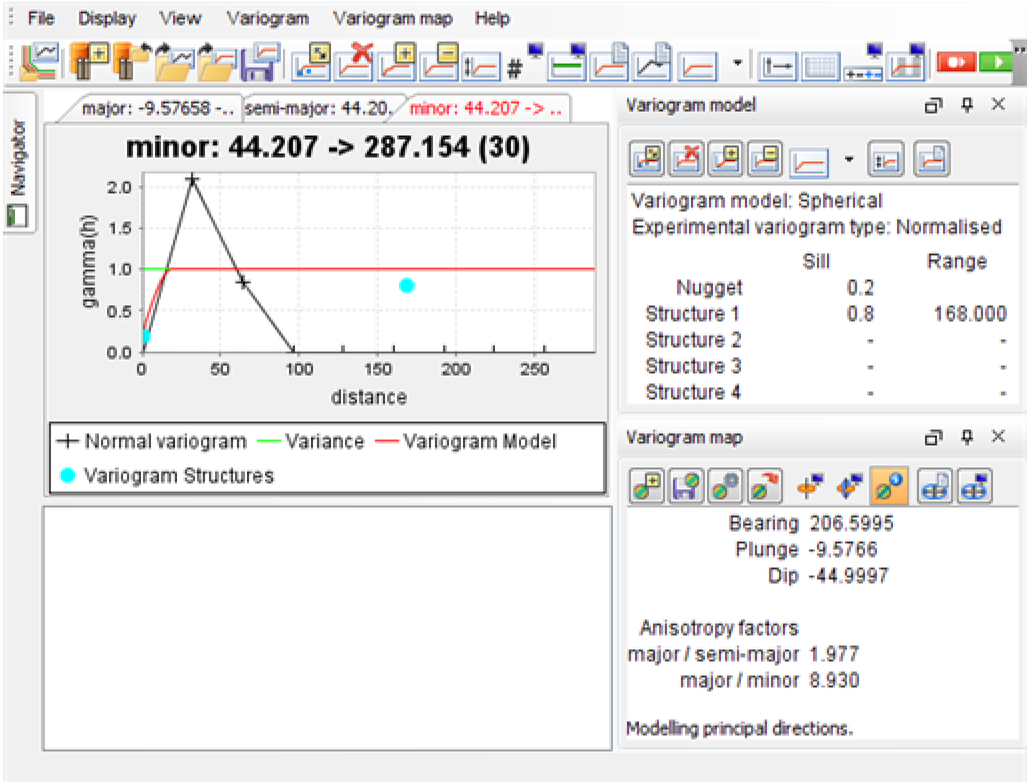
5. Click the **semi-major** tab.
6. Click and drag the variogram structure to the left, until the model matches the experimental variogram, as shown.



Note: The major/semi-major anisotropy ratio changes as you move the model.

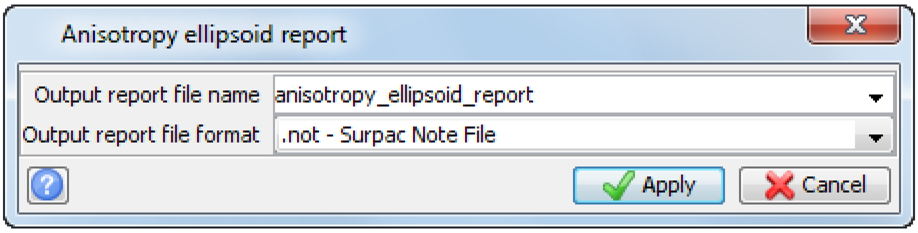
7. Click the **minor** tab.

8. Click and drag the variogram structure to the left, until the model matches the experimental variogram, as shown.

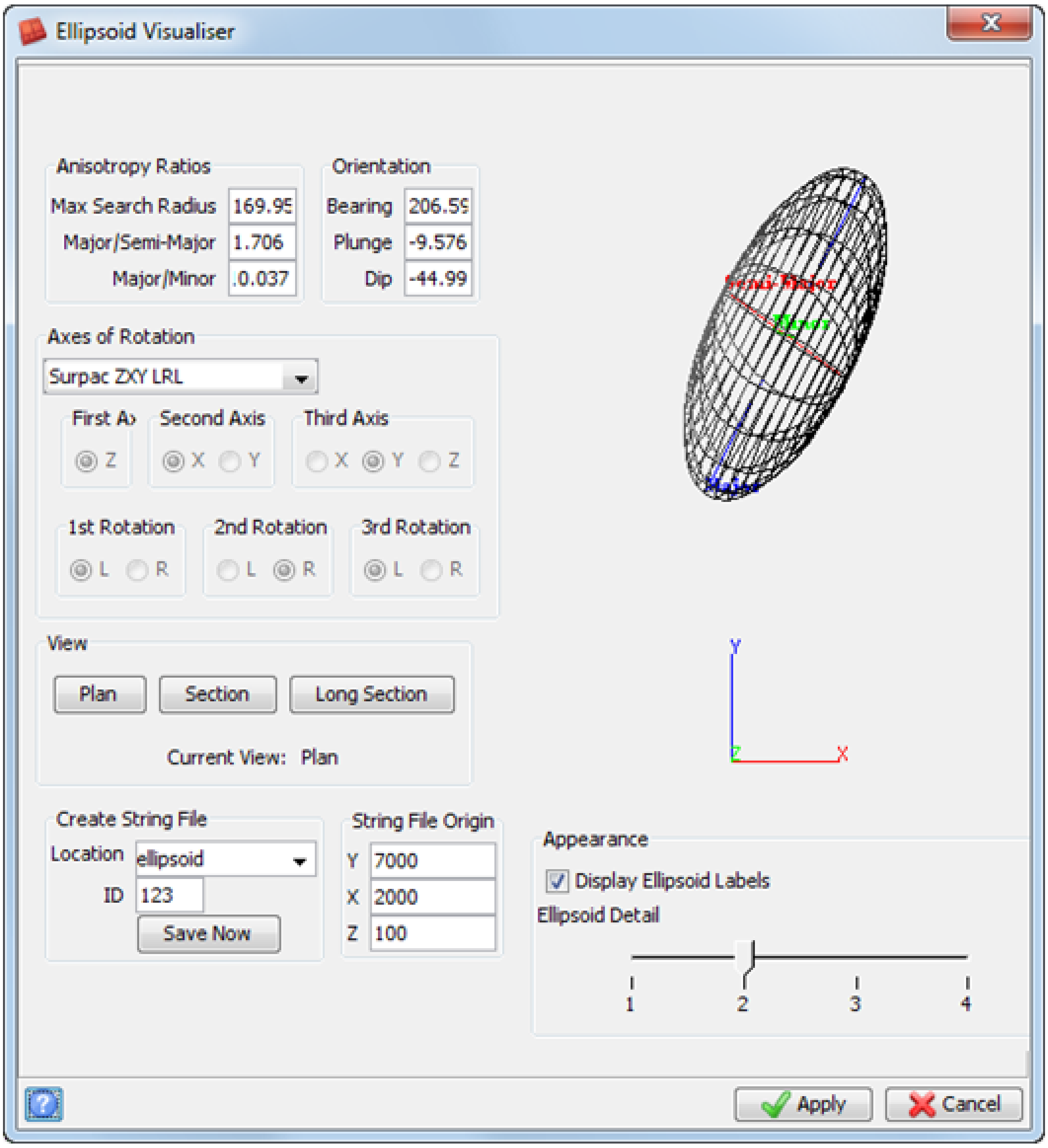


Note: The major/semi-major anisotropy ratio changes as you move the model.

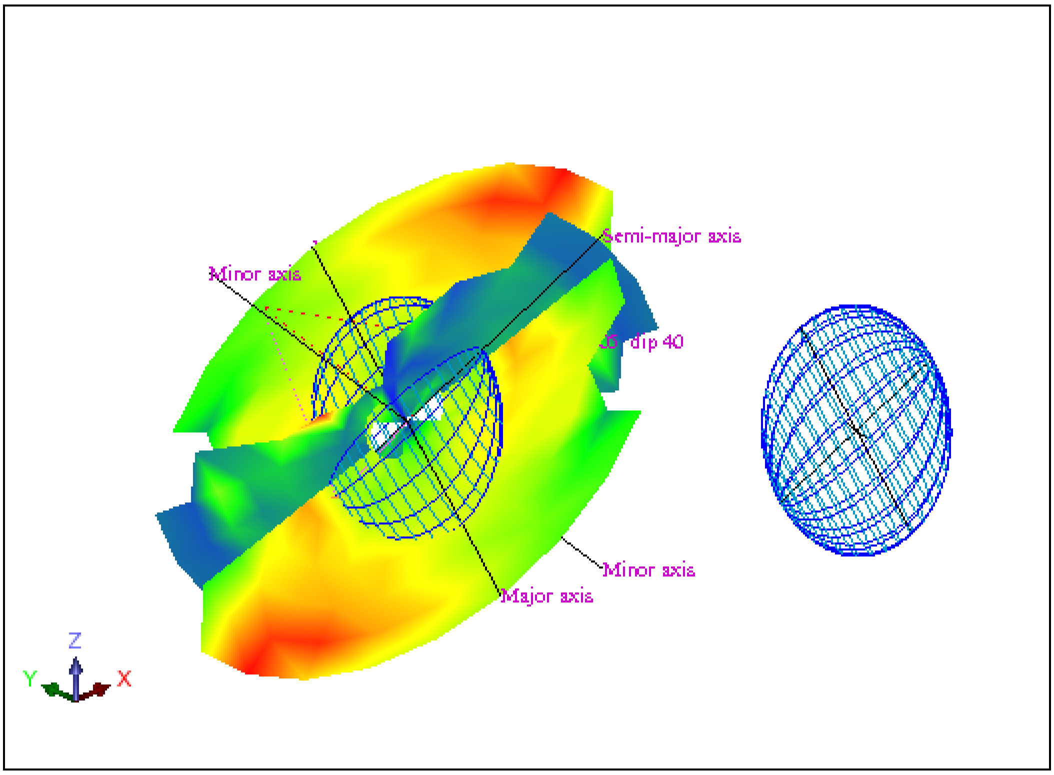
9. Choose **Variogram Map > Create anisotropy ellipsoid report**.
10. Enter the information as shown, and click **Apply**.



11. If the file exists, the Confirm File Replace form appears. Click **Yes**.
12. Choose **Variogram Map > Ellipsoid visualiser**.
13. Enter the information as shown, and click **Save Now**.



14. Click **Apply**.
15. In the main Surpac main window, choose **Display > Hide grid**.
16. Open **ellipsoid123.str** in **Graphics**.
    It should resemble the previous ellipsoid created by the macro.



17. In the **Variogram modelling** window, choose **File > Close**.

Steps for using variogram maps to create anisotropy ellipsoid parameters

In summary, here are the complete set of steps to obtain all of the anisotropy ellipsoid parameters:

Task: Use the primary variogram map to define the major axis

1. Choose **Geostatistics > Variogram modelling** to open the **Variogram modelling** window.
2. Choose **Variogram map > New variogram map**.
3. Enter the variogram map parameters and click **Apply**.
4. Use the lag slider to show you areas of high and low variance on the variogram map. That is, move the lag slider back and forth, and watch the colours on the variogram map change. You will most likely see that throughout a range of lag values, there will be areas on the variogram map which will be consistently high, and others which will be consistently low. Using the example given above, note that the orientation of 15 degrees above the horizontal (on the left) will consistently display colours on the low end of the variance values, as represented by the legend to the right, and that very small lag values are usually not useful.
5. Once you have an idea of what appears to be the orientation of the longest range, select the variogram tab that represents that orientation.
6. Use the lag slider to improve the quality of the experimental variogram for that direction.
7. Create a variogram model for that orientation.
8. Look at the model on all other orientations. The major axis should be that variogram which has the lowest variance for the longest distance.
9. If another orientation appears to have a longer range and a lower variance than your current model, modify the model to fit that experimental variogram.
10. Repeat the previous two steps until you are satisfied that you have the orientation of the major axis. Choose **File > Save > Variogram model** to save a variogram (***.vgm**) for this orientation. Saving this is optional, but can be helpful in a future step.

11. Choose **Variogram map > Select direction of maximum continuity**.
12. Click and drag the red line on the variogram map until it is aligned with the orientation of the major axis.
13. Choose **Variogram map > Save DTM**. This is an optional step, but can help you to display the orientation of the primary variogram map in three dimensions in **Graphics**.

Task: Use the secondary variogram map to Ddfine the semi-major axis

1. Choose **Variogram map > Secondary Variogram map**. The direction of maximum continuity (the red line) will display as the intersection of the primary and secondary variogram maps. The orientation of this line should be relatively close to what will become the semi-major axis.
2. Select a variogram to rotate the black line on the variogram map to that direction.
3. Now use the lag slider to improve the quality of the experimental variogram for that direction.
4. Create a variogram model for this orientation, which will become the semi-major axis. You can choose **Display > Display/Hide variance** to show the data variance (often used as the total sill).
5. Look at the model on all other orientations. The semi-major axis should be that variogram which has the lowest variance for the longest distance.
6. If another orientation appears to have a longer range and a lower variance than your current model, modify the model to fit that experimental variogram.
7. Repeat the previous two steps until you are satisfied that you have the orientation of the semi-major axis.
8. Choose **Variogram map > Select direction of maximum continuity**.
9. Click and drag the red line on the variogram map until it is aligned with the orientation of maximum continuity.
10. Choose **Variogram map > Save DTM**. This is an optional step, but can help you to display the orientation of the secondary variogram map in three dimensions in **Graphics**.

Task: Create and view anisotropy ellipsoid parameters

1. Choose **Variogram map> Extract variograms along axes**.
2. Choose **File> Open > Variogram model** to display the variogram model for the major axis. If you did not previously save a variogram model, create a variogram to fit the major axis.
3. Ensure that the variogram for the semi-major axis is either the same as, or to the left of, the variogram model for the major axis. You might need to use the lag slider to improve the quality of the variogram. By definition, the range of the major axis must be equal to, or longer than, the range of the semi-major axis for a given sill.
4. If the variogram representing the semi-major axis is to the right of the model for the major axis, you need to start again. The current semi-major axis is a more likely candidate for the orientation of the major axis.
5. Ensure that the variogram for the minor axis is either the same as, or to the left of the variogram model for the semi-major axis. You might need to use the lag slider to improve the quality of the variogram. By definition, the range of the semi-major axis must be equal to, or longer than, the range of the minor axis for a given sill.
6. If the variogram representing the minor axis is to the right of the model for the semi-major axis, you need to go back to the secondary variogram map. The current minor axis is a more likely candidate for the orientation of the semi-major axis.

Note: It is often difficult or impossible to interpret the experimental variogram for the minor direction. If you cannot get a visually acceptable minor variogram, but you do have good quality variograms for the major and semi-major axes, you can choose to continue. Then you can determine the ratio for the minor axis based on other factors, such as geometry.

7. View the semi-major axis. Modify the lag if required to improve the quality of the experimental variogram.
8. Click and drag the sill/range marker to the left until the variogram model matches the experimental variogram for the semi-major axis.
   Note: You will not be able to modify either the nugget or the sill - only the range is changed to calculate the anisotropy ratio.
9. View the minor axis. Modify the lag if required to improve the quality of the experimental variogram.
10. Click and drag the sill/range marker to the left until the variogram model matches the experimental variogram for the minor axis.
    Note: It is often difficult or impossible to interpret the experimental variogram for the minor direction. If you cannot get a visually acceptable minor variogram, but you do have good quality variograms for the major and semi-major axes, you can choose to modify the range until the ratio for the minor axis is equal to some value you have chosen based on other factors, such as geometry.
11. Choose **Variogram map > Create anisotropy ellipsoid report**. This report contains values for the orientation of the anisotropy ellipsoid, as well as the major/semi-major and major/minor anisotropy ratios.
12. Choose **Variogram map > Ellipsoid visualiser**. You can view or save the ellipsoid.
13. Choose **File > Close** to exit the **Variogram modelling** window.

Create a 3D block model

Overview

This covers the basics of creating a block model, and adding attributes, which you must do before performing an estimation.

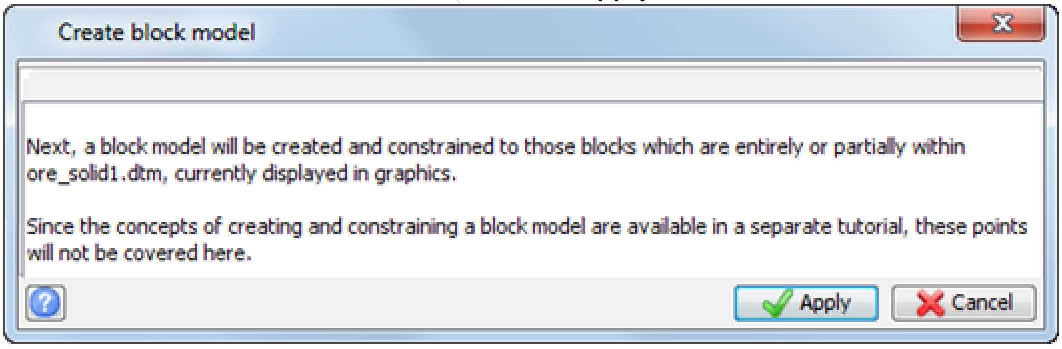
Requirements

In order to understand this information, you should understand the following concepts:

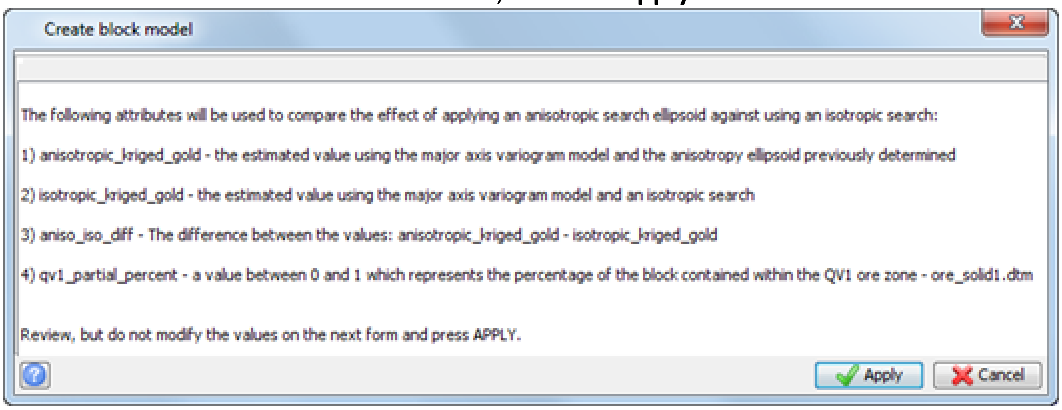
- Surpac menubars
- Surpac string files
- Surpac block models
- isotropy and anisotropy
- anisotropy ellipsoid
- the parameters which define an anisotropy ellipsoid

Task: Create a 3D block model

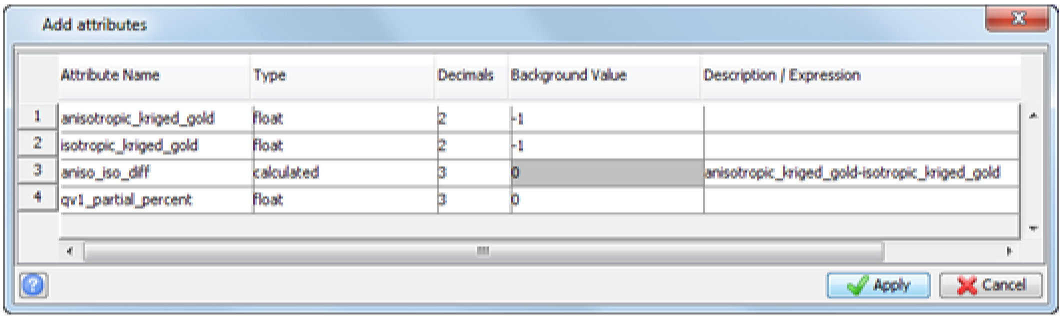
1. Right-click in the blank area next to the menus, and choose **Profiles > block_model**.
2. Run **_09_create_block_model.tcl**.
3. Read the information on the first form, and click **Apply**.



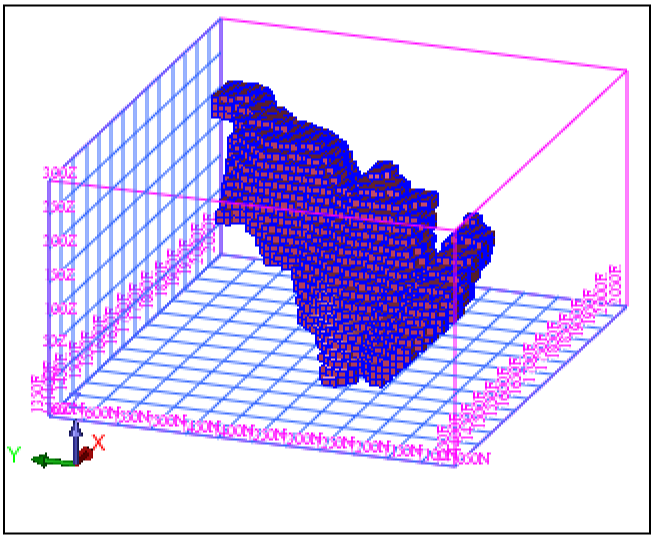
4. Read the information on the second form, and click **Apply**.



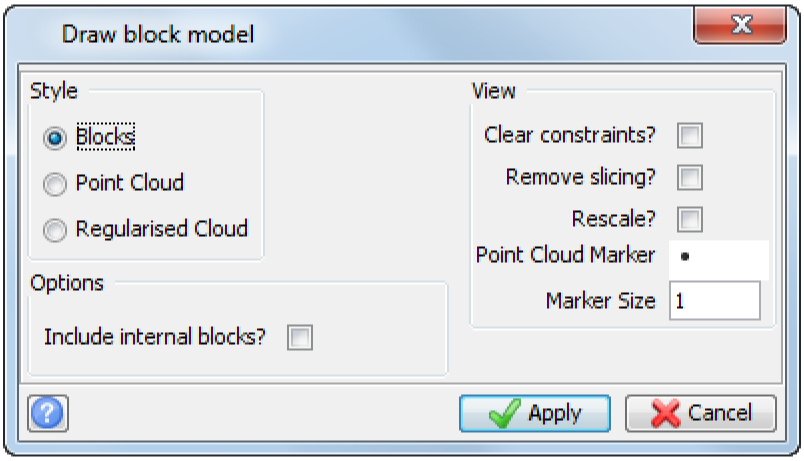
5. View the *Add attributes* form, and then click **Apply**.



The model is displayed.



6. Choose **Block model > Close**.
7. Click **Reset graphics** .
8. Open **geostats_example.mdl**.
9. Choose **Display > Display block model**.
10. Enter the information as shown, and click **Apply**.



11. Open **qv1.con** in **Graphics**.

Ordinary kriging

Overview

An important end product of a geostatistical evaluation is a "model", or a set of points in space which contain estimated values. One of the methods for estimating values at points in a model is known as ordinary kriging.

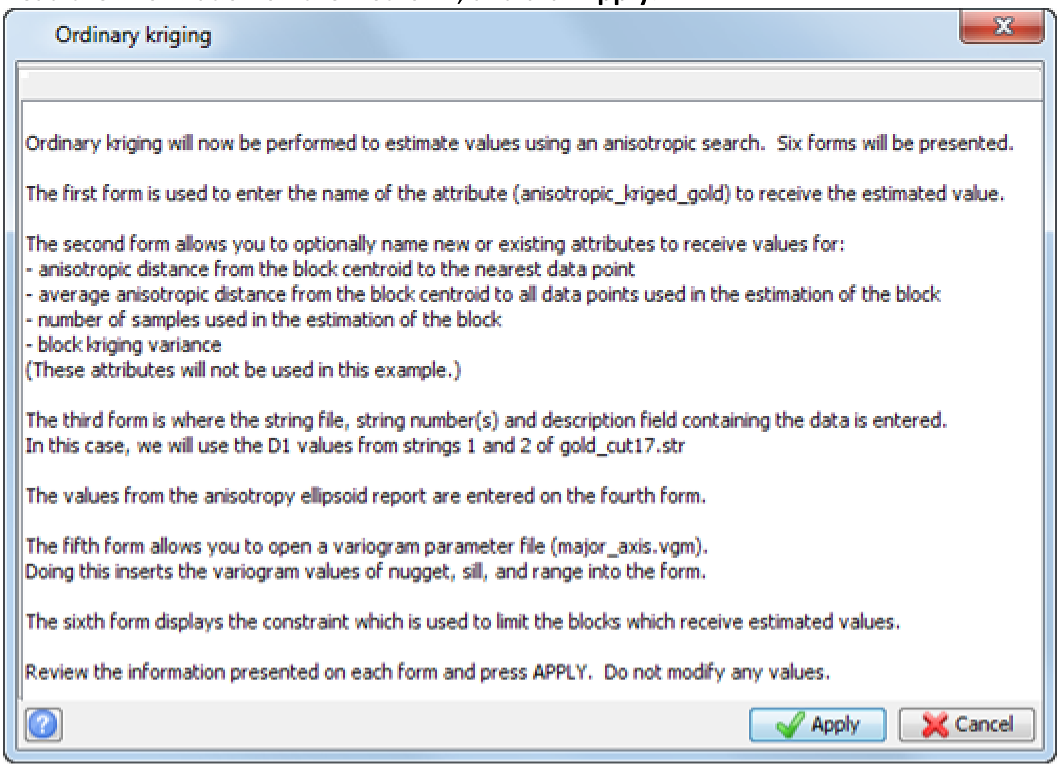
Requirements

In order to understand this information, you should understand the following concepts:

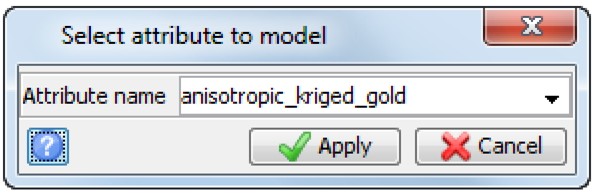
- Surpac menubars
- Surpac string files
- Surpac block models
- isotropy and anisotropy
- anisotropy ellipsoid
- the parameters which define an anisotropy ellipsoid

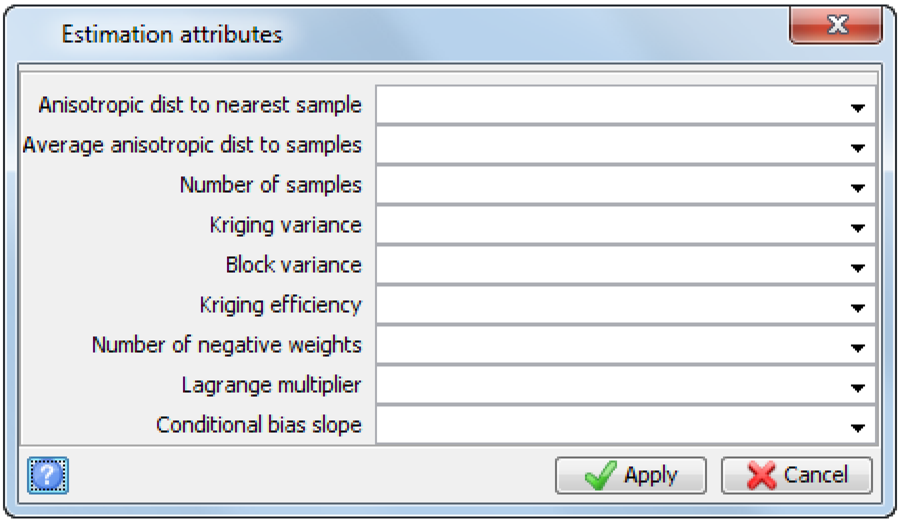
Task: Perform ordinary kriging estimation on a 3D block model

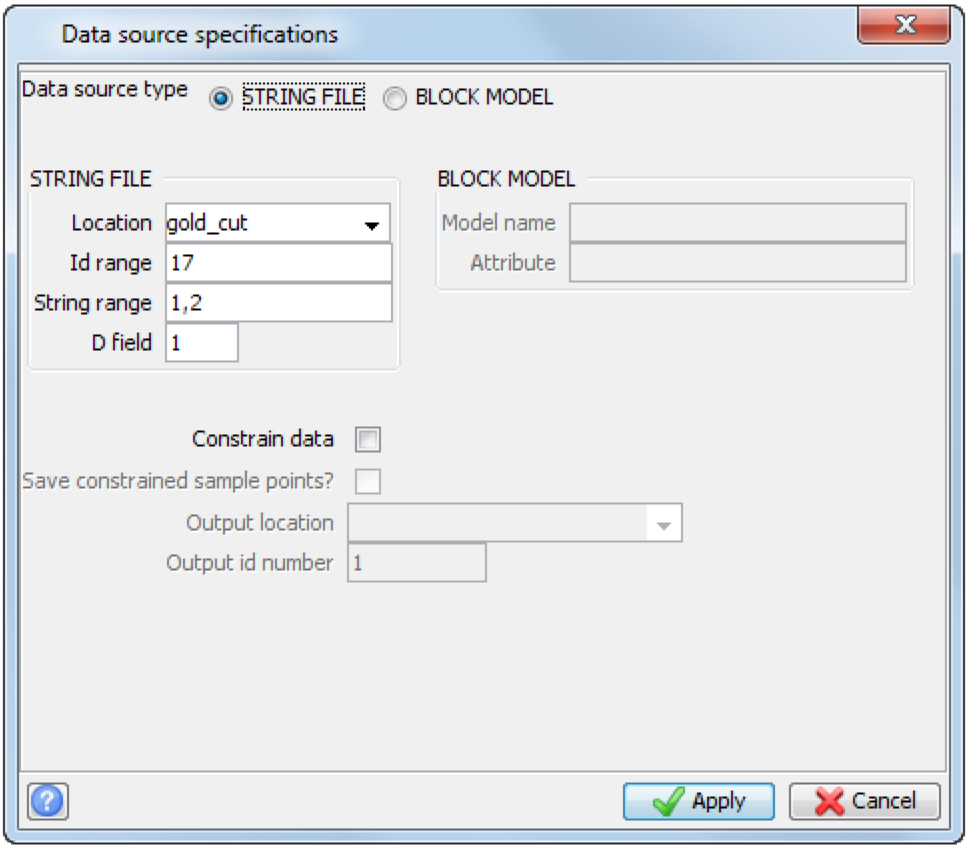
1. Run **_10_ordinary_kriging.tcl**.
   Note: This macro selects the menu command **Block model > Estimation > Ordinary kriging**.
2. Read the information on the first form, and click **Apply**.

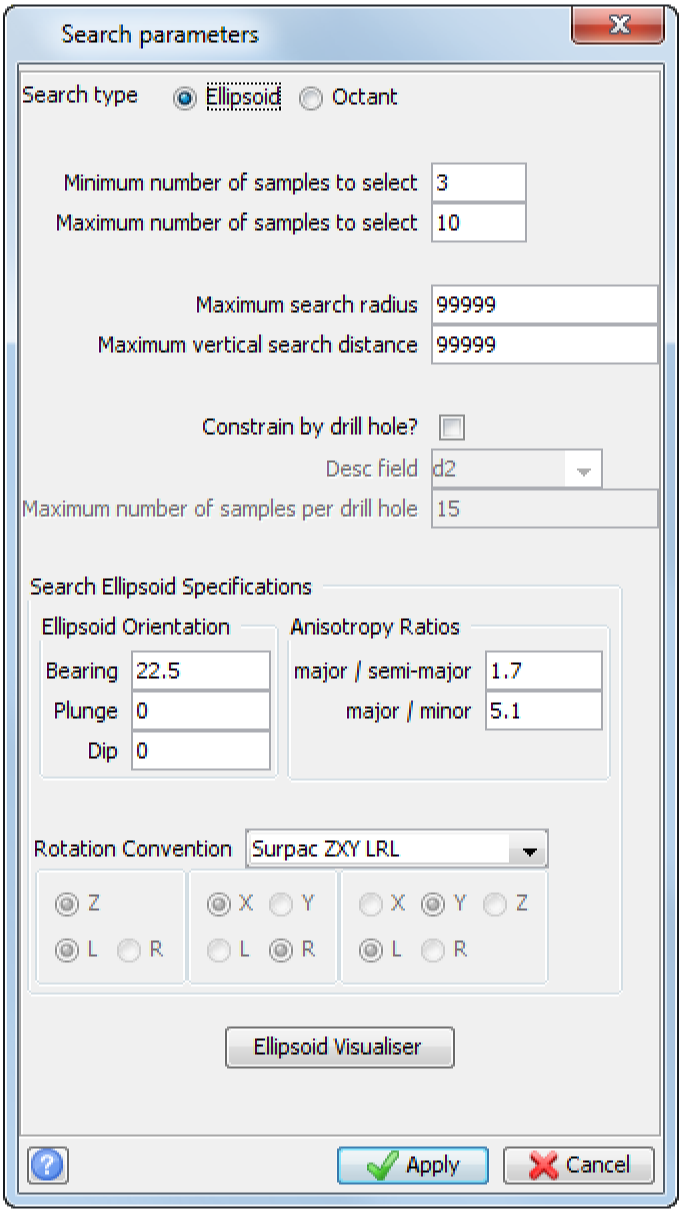


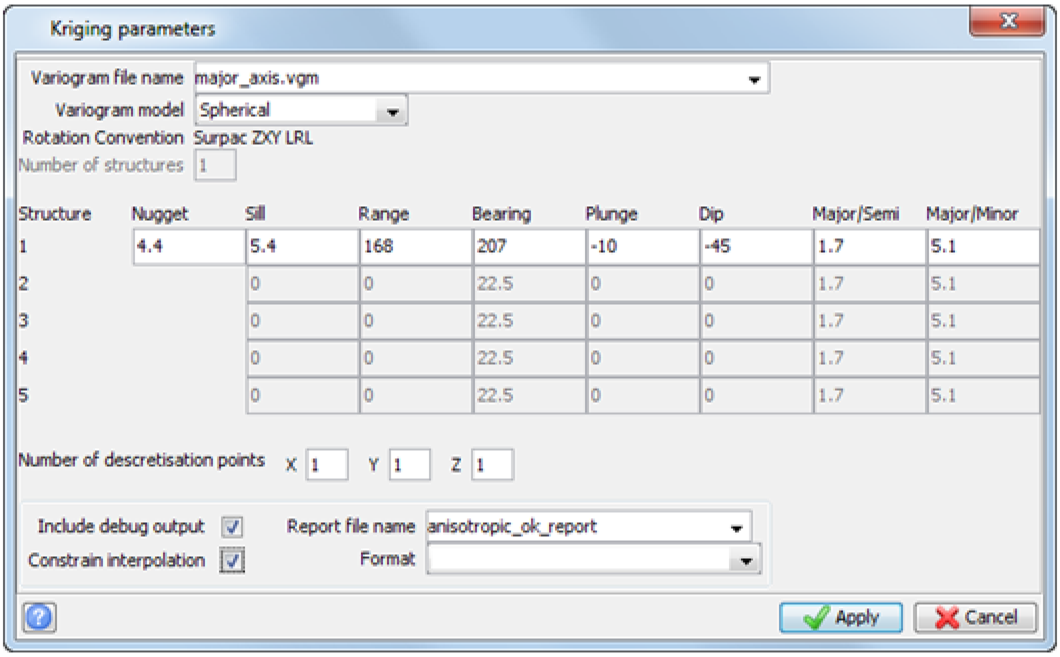
3. View and click **Apply** on each of the six following forms.

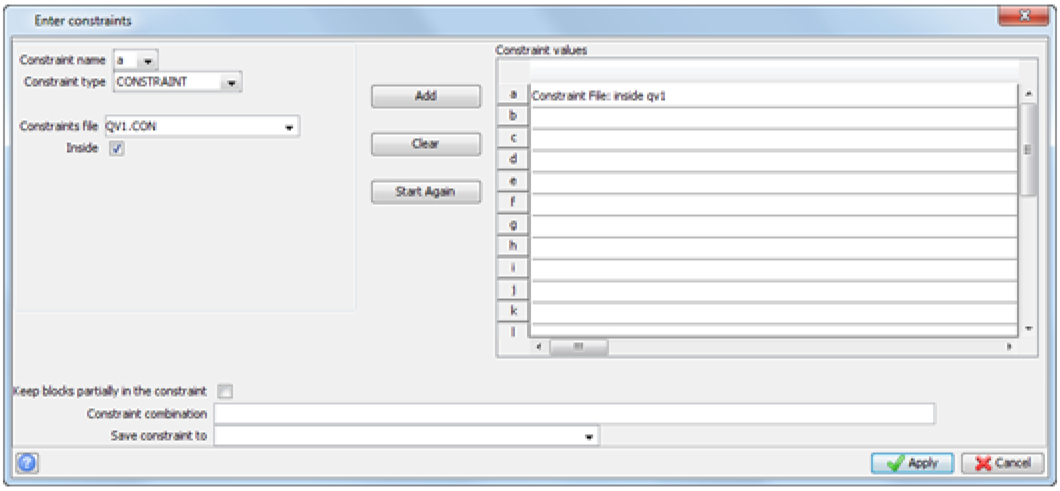



Estimation attributes
Anisotropic dist to nearest sample
Average anisotropic dist to samples
Number of samples
Kriging variance
Block variance
Kriging efficiency
Number of negative weights
Lagrange multiplier
Conditional bias slope
Apply
Cancel

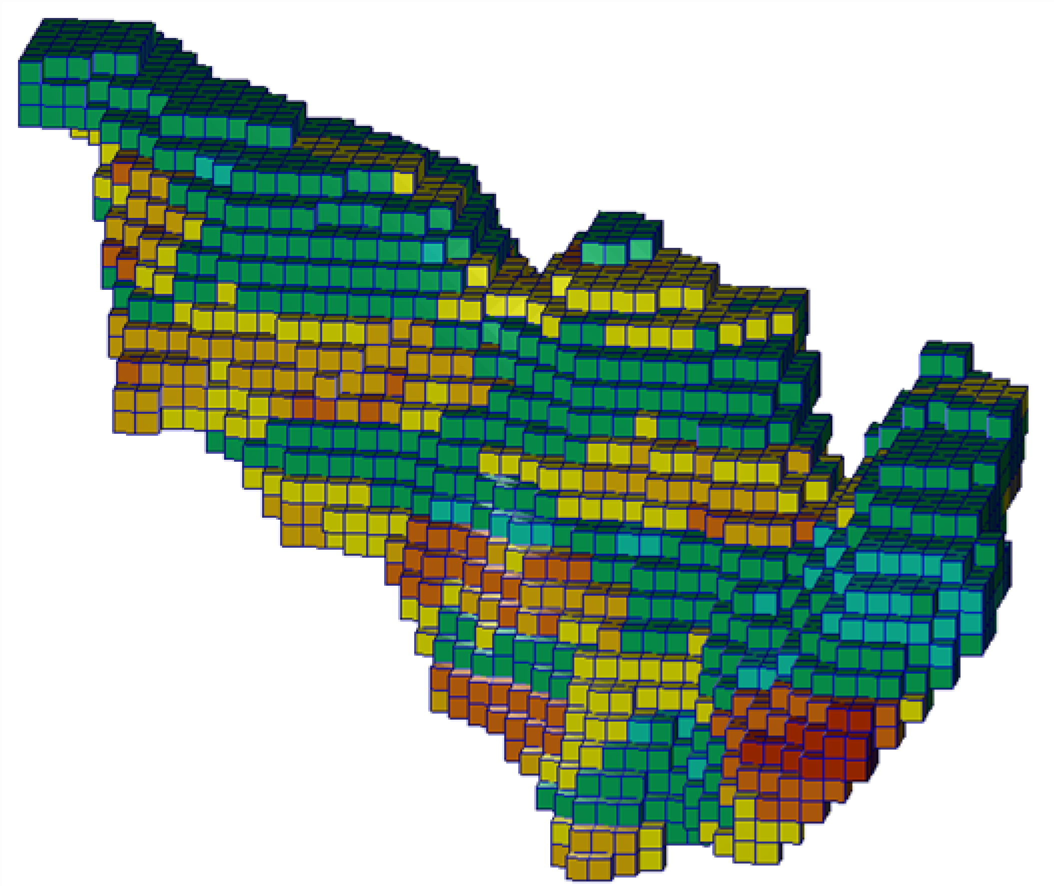

Data source specifications
Data source type
STRING FILE
BLOCK MODEL
STRING FILE
Location
gold_cut
Id range
17
String range
1,2
D field
1
BLOCK MODEL
Model name
Attribute
Constrain data
Save constrained sample points?
Output location
Output id number
1
Apply
Cancel


Search parameters
Search type
Ellipsoid
Octant
Minimum number of samples to select
3
Maximum number of samples to select
10
Maximum search radius
99999
Maximum vertical search distance
99999
Constrain by drill hole?
Desc field
d2
Maximum number of samples per drill hole
15
Search Ellipsoid Specifications
Ellipsoid Orientation
Bearing
22.5
Plunge
0
Dip
0
Anisotropy Ratios
major / semi-major
1.7
major / minor
5.1
Rotation Convention
Surpac ZXY LRL
Z
L R
X Y
L R
X Y Z
L R
Ellipsoid Visualiser
Apply
Cancel

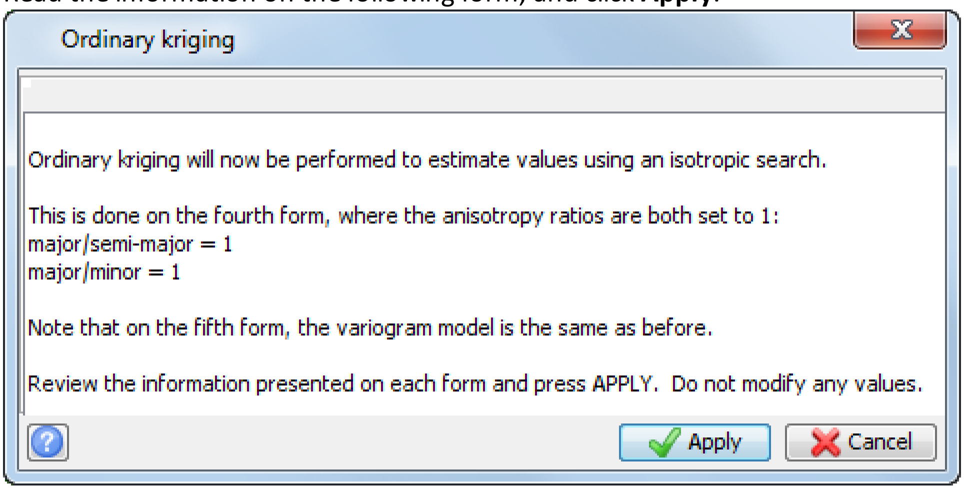




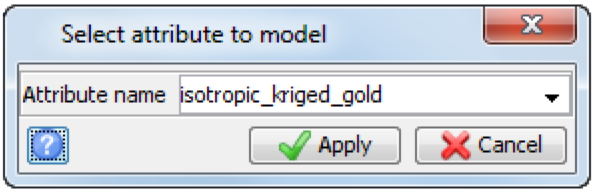
The model is displayed.

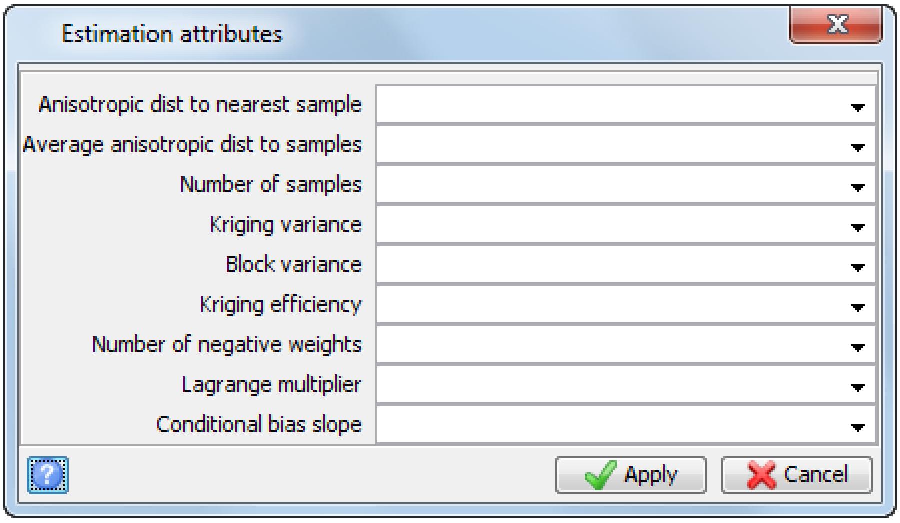


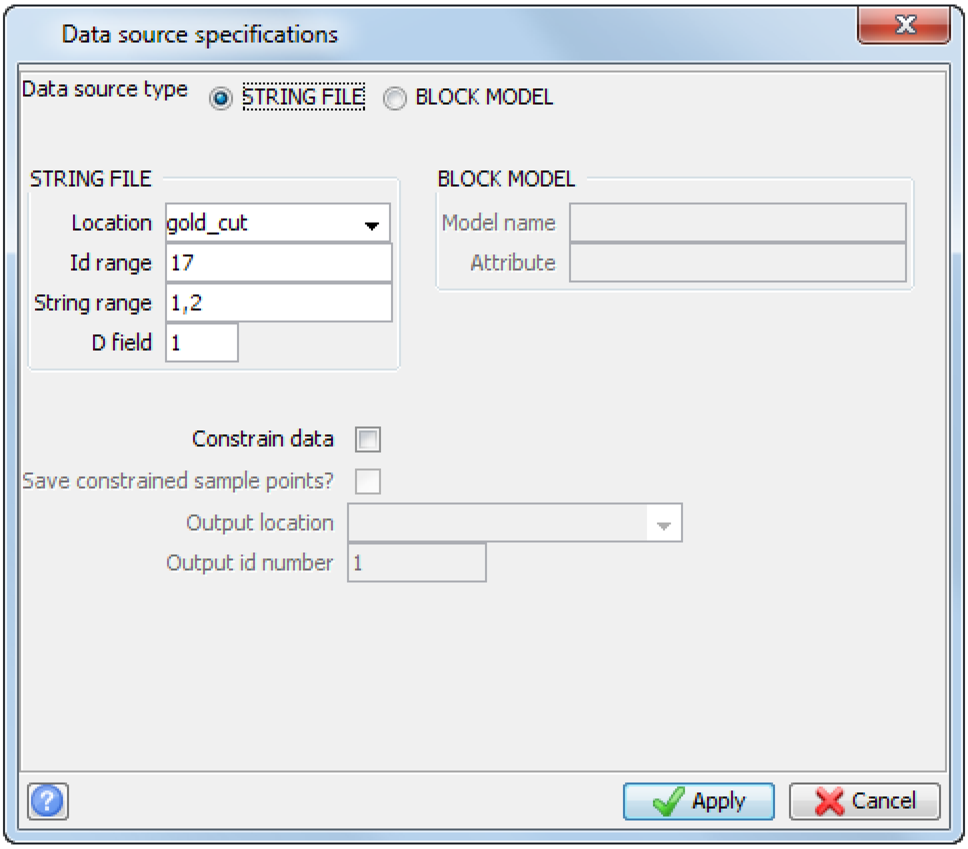
4. Read the information on the following form, and click **Apply**.

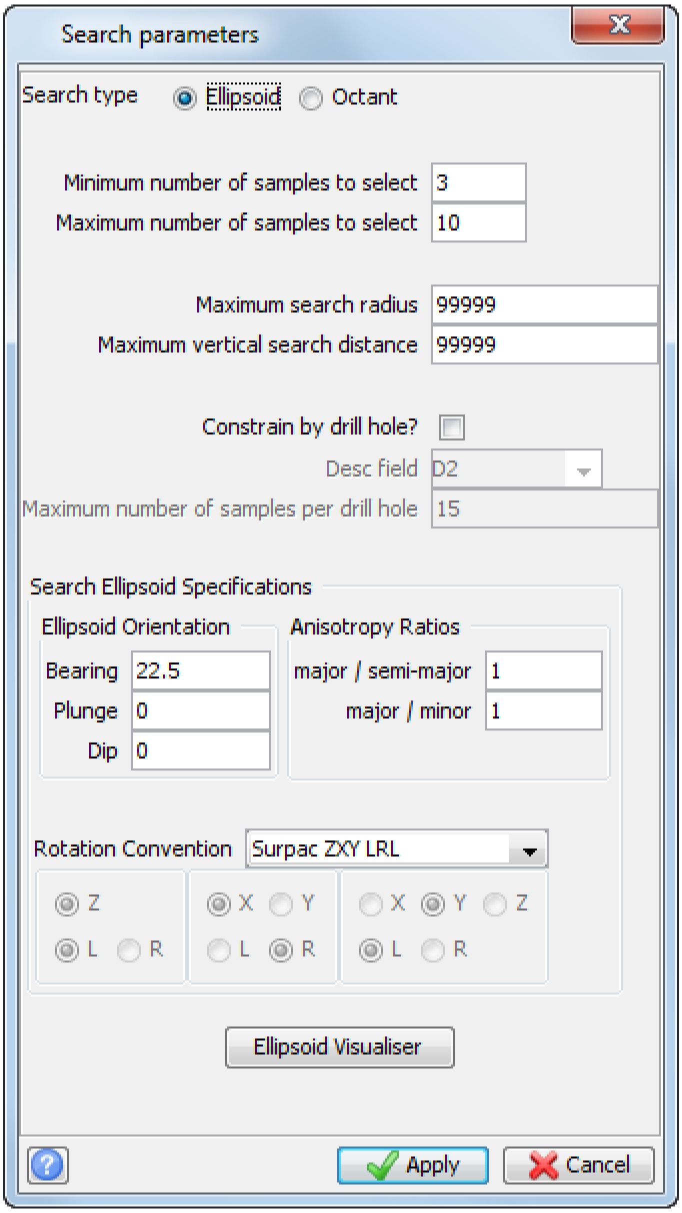


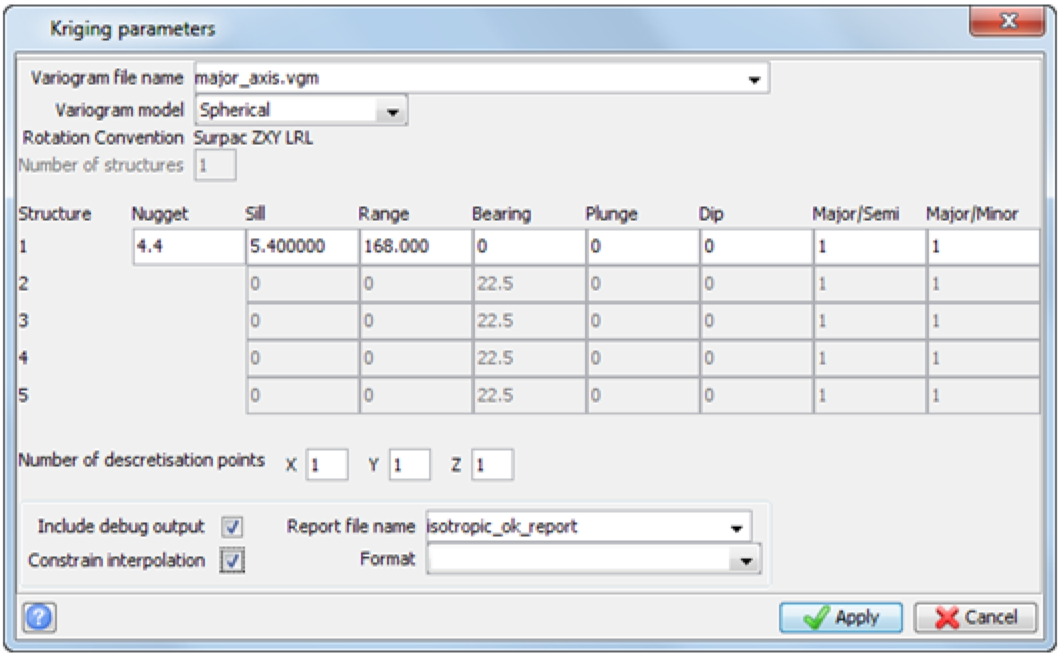
5. View and click **Apply** on each of the six following forms.

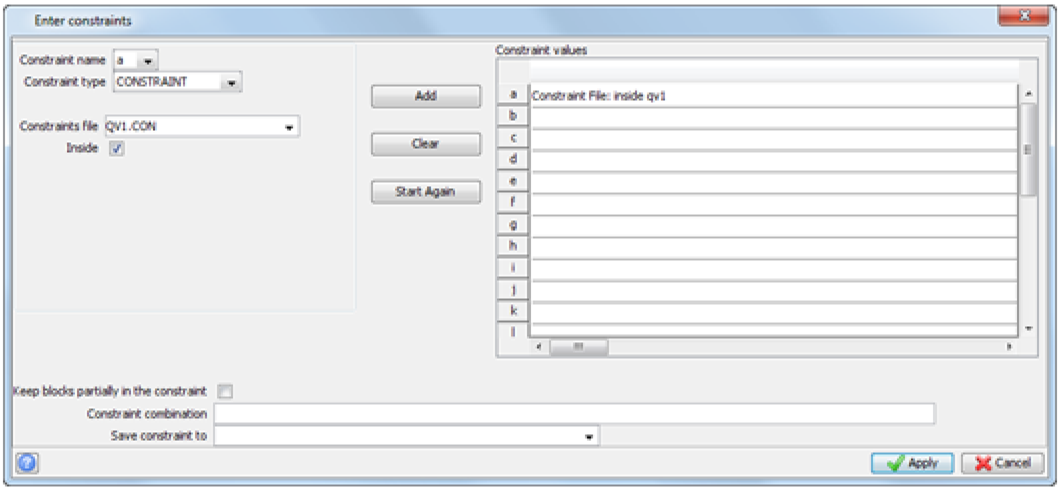



Estimation attributes
Anisotropic dist to nearest sample
Average anisotropic dist to samples
Number of samples
Kriging variance
Block variance
Kriging efficiency
Number of negative weights
Lagrange multiplier
Conditional bias slope
Apply
Cancel


Data source specifications
Data source type
STRING FILE
BLOCK MODEL
STRING FILE
Location
gold_cut
Id range
17
String range
1,2
D field
1
BLOCK MODEL
Model name
Attribute
Constrain data
Save constrained sample points?
Output location
Output id number
1
Apply
Cancel


Search parameters
Search type
Ellipsoid
Octant
Minimum number of samples to select
3
Maximum number of samples to select
10
Maximum search radius
99999
Maximum vertical search distance
99999
Constrain by drill hole?
Desc field
D2
Maximum number of samples per drill hole
15
Search Ellipsoid Specifications
Ellipsoid Orientation
Bearing
22.5
Plunge
0
Dip
0
Anisotropy Ratios
major / semi-major
1
major / minor
1
Rotation Convention
Surpac ZXY LRL
Z
L
R
X
Y
L
R
X
Y
Z
L
R
Ellipsoid Visualiser
Apply
Cancel





The model is displayed.

6. Choose **Block model > Save**.
7. Choose **Block model > Close**.

Partial percentage calculation

Overview

This chapter covers the basics of applying a partial percentage calculation to a block model. This is an optional step, and is effective if you choose not to use sub-blocking.

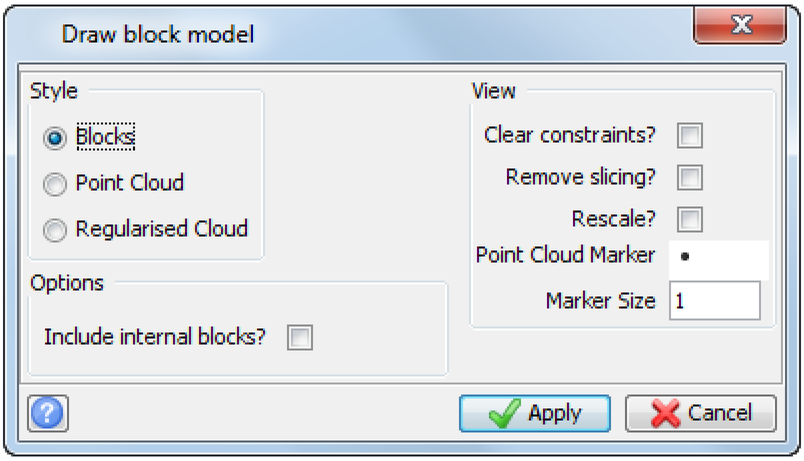
Requirements

In order to understand this information, you should understand the following concepts:

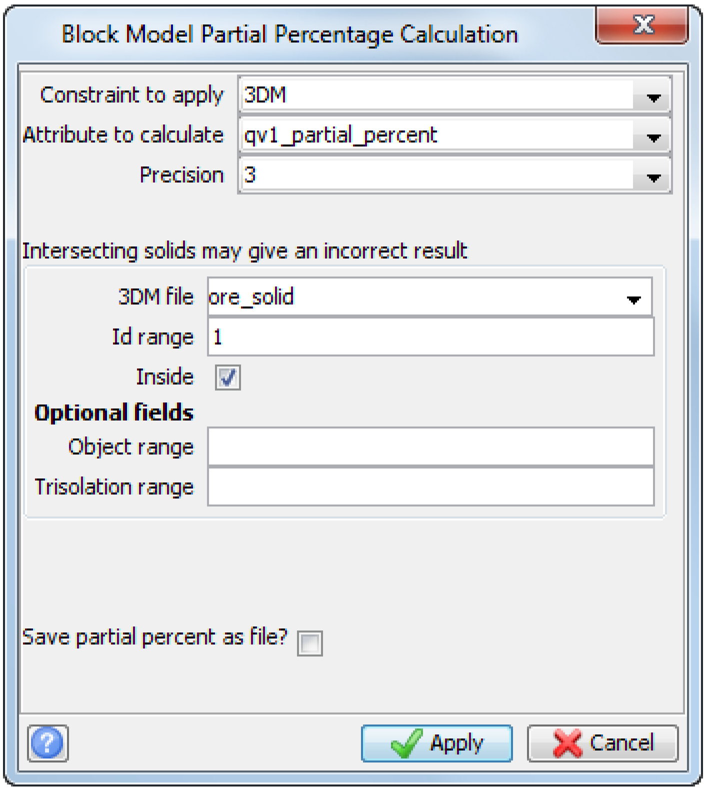
- Surpac solid models
- Surpac block models

Task: Calculate a partial percentage value for blocks within a 3D solid model

1. Click **Reset graphics** .
2. Open **geostats_example.mdl**.
3. Choose **Display > Display block model**.
4. Enter the information as shown, and click **Apply**.



5. Open **qv1.con** in **Graphics**.
6. Choose **Estimation > Partial Percentage.**
7. Enter the information as shown, and click **Apply**.



8. Choose **Block model > Save**.
9. Choose **Block model > Close**.

Note: To see all of the steps performed in this task, run **_11_partial_percentage.tcl**.

Model Validation

Overview

An important step in a geostatistical evaluation is to validate the model after it has been created. There are several means of validation:

- comparing cross-sectional data with model values
- grade-tonnage curves from block model reports
- basic statistics of model values
- trend analysis

Requirements

In order to understand this information, you should understand the following concepts:

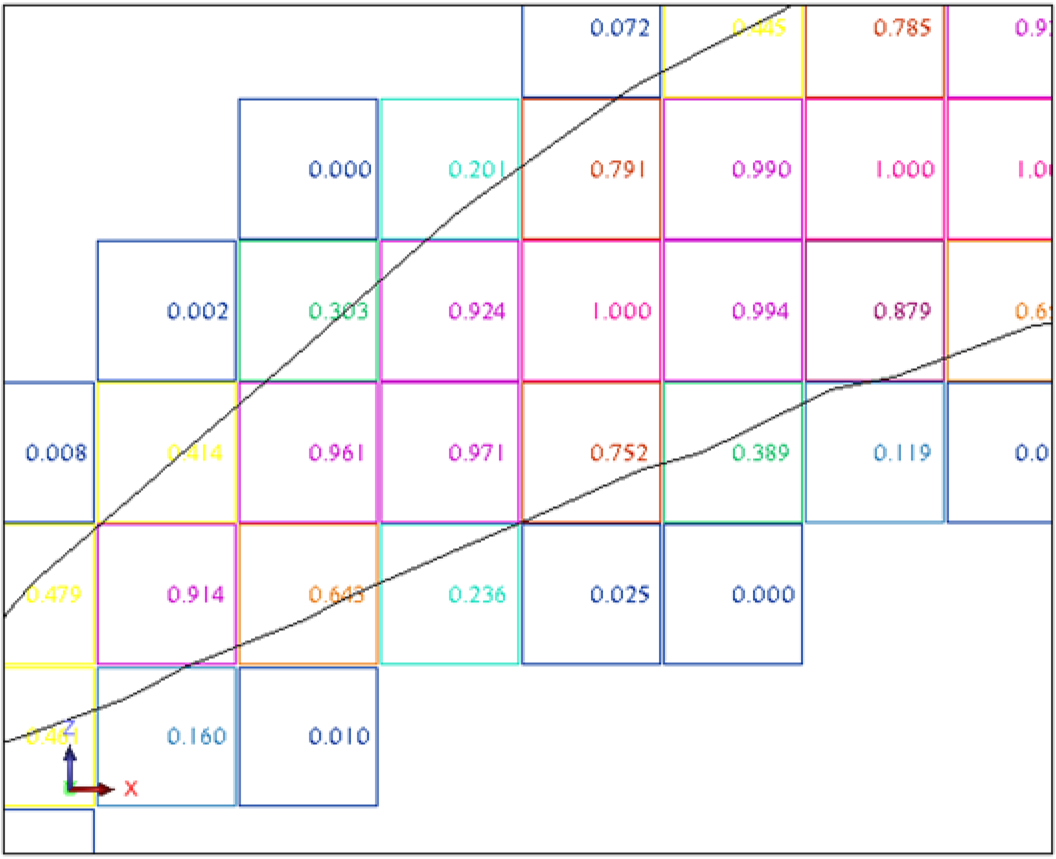
- Surpac menu bars
- Surpac string files
- Surpac block models
- isotropy and anisotropy
- anisotropy ellipsoid
- ordinary kriging

Comparing cross-sectional data with a model

One method of validating a model is to view cross-sections of it compared to other data.

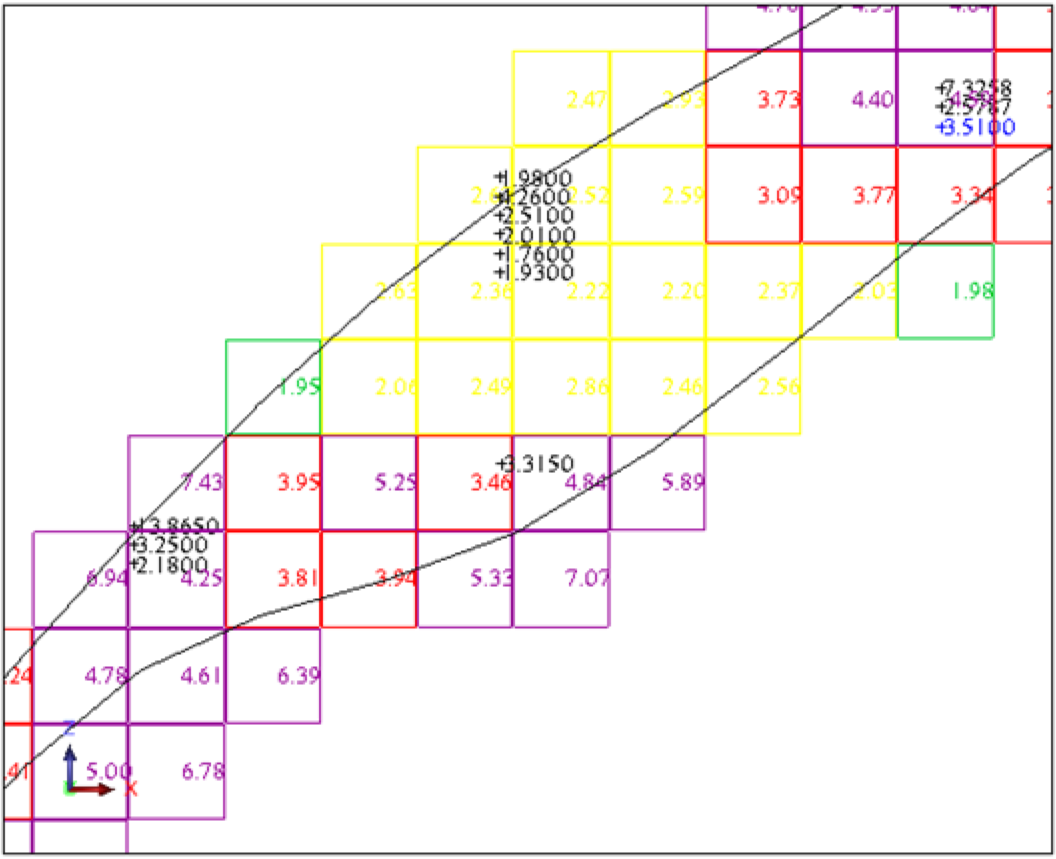
Task: Comparing cross-sectional data with a model

1. Run **_15a_display_partial_percent.tcl**.
   This macro will display a cross-section of a 3D solid, and the calculated partial percentage of blocks inside the solid.



You want to ensure that the values in the model appear to be correct. In the example, this does appear to be correct. Blocks entirely within the model have a partial percent value of 1.00 and blocks partially within the model have a partial percentage value between 0 and 1.00.

2. Run **_15b_display_blocks&composites.tcl**.
This macro will display a cross-section of a 3D solid, raw and composited drillhole data, as well as kriged values of blocks inside the solid.



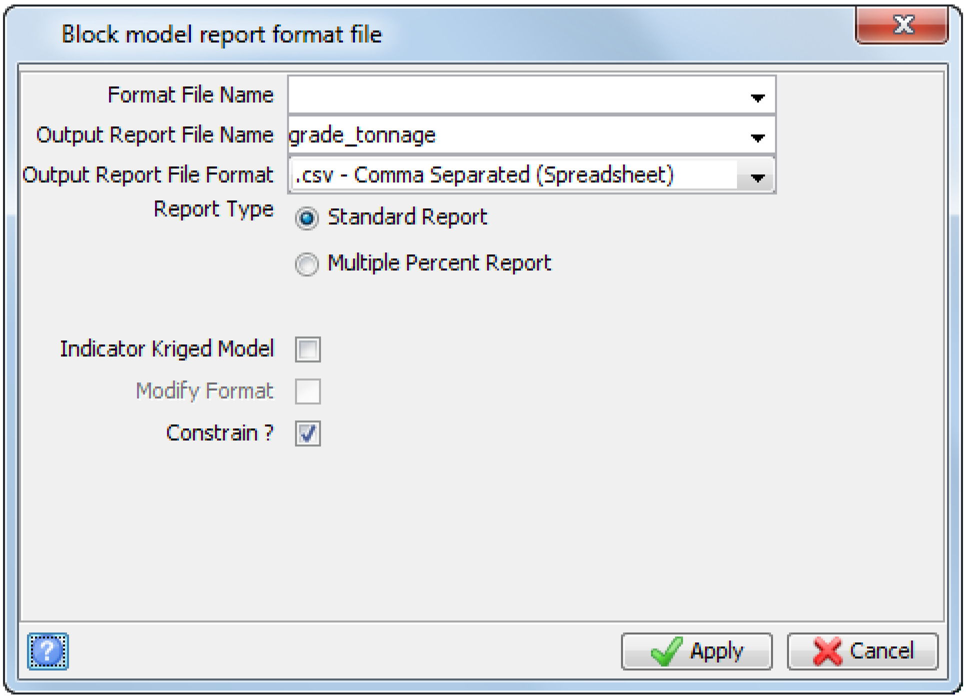
Again, you want to check that block values and model values appear to be correct.

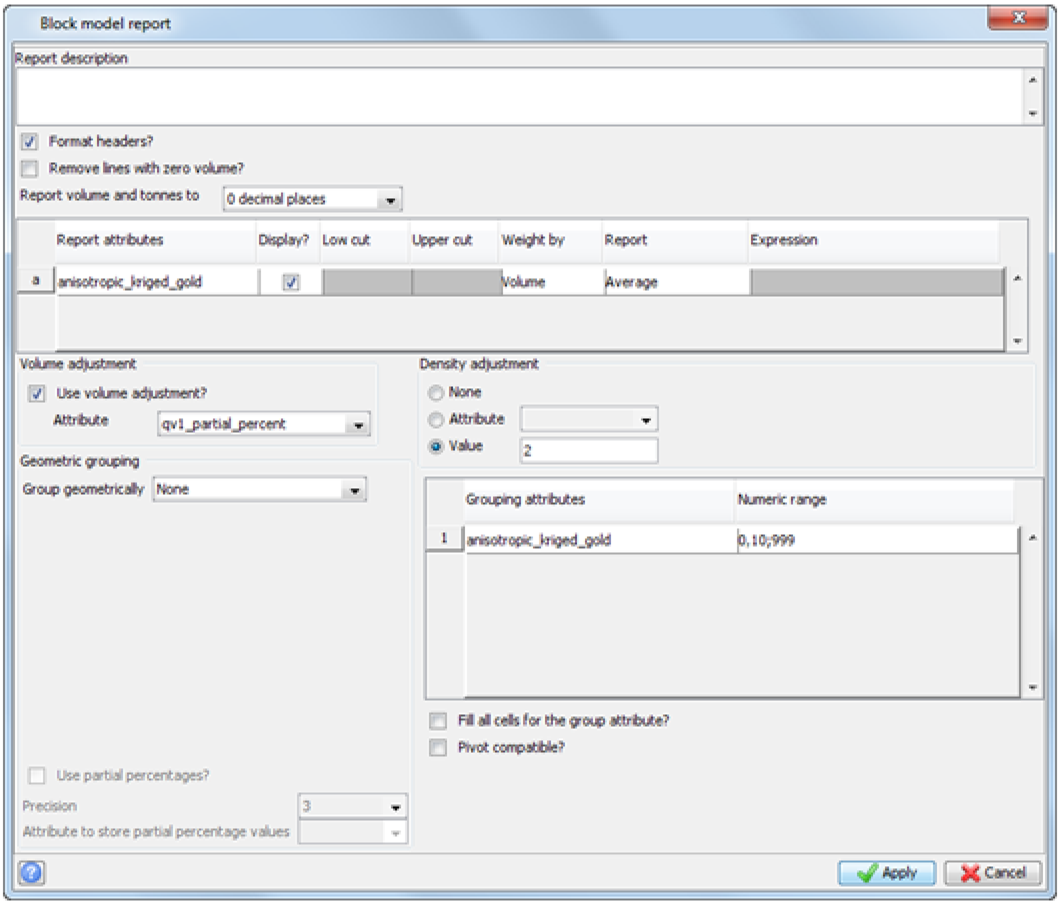
Grade-tonnage curves

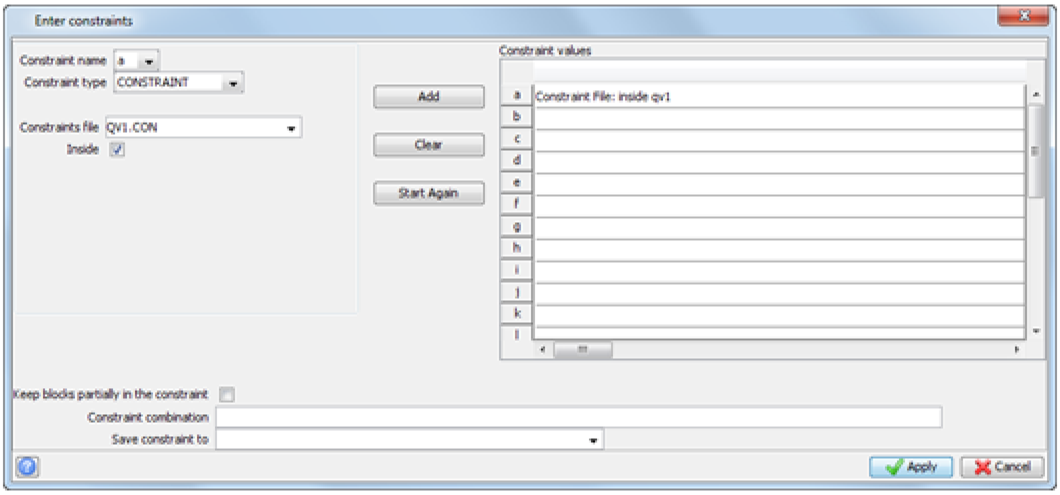
Another means of validating a model is to report tonnes and grade and construct a grade-tonnage curve.

Task: Create grade-tonnage curves

1. Run **_16a_bm_report.tcl**.
   This macro will perform block model reporting to create a ***.csv** file containing grade and tonnes. A pre-defined ***.xls** file is displayed at the end with a graph of the grade-tonnage curve.
2. View, and then click **Apply** on each of the three following forms.

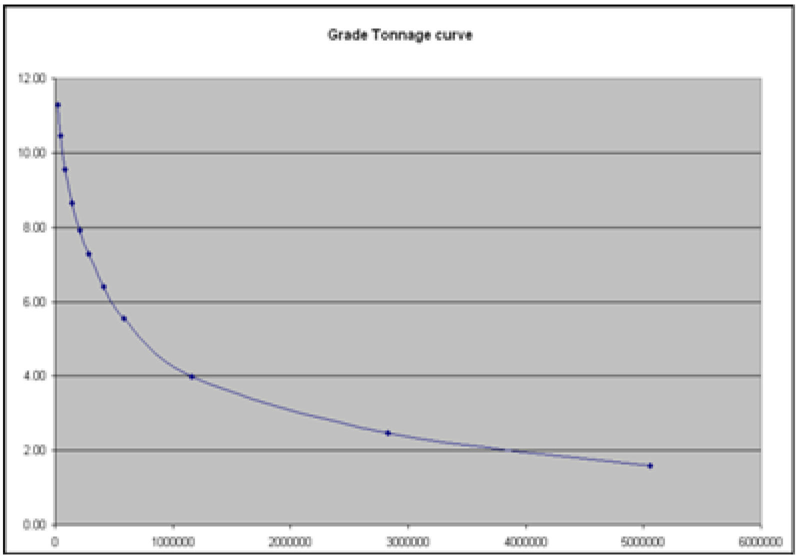

Block model report format file
Format File Name
Output Report File Name grade_tonnage
Output Report File Format .csv - Comma Separated (Spreadsheet)
Report Type Standard Report
Multiple Percent Report
Indicator Kriged Model
Modify Format
Constrain ?
Apply
Cancel


Block model report
Report description
Format headers?
Remove lines with zero volume?
Report volume and tonnes to 0 decimal places
Report attributes Display? Low cut Upper cut Weight by Report Expression
anisotropic_kriged_gold Volume Average
Volume adjustment
Use volume adjustment?
Attribute qv1_partial_percent
Density adjustment
None
Attribute
Value 2
Geometric grouping
Group geometrically None
Grouping attributes Numeric range
anisotropic_kriged_gold 0,10;999
Fill all cells for the group attribute?
Pivot compatible?
Use partial percentages?
Precision 3
Attribute to store partial percentage values
Apply
Cancel



The file **grade_tonnage.xls** has been prepared with a graph of the output data.

3. Open **grade_tonnage.xls**.

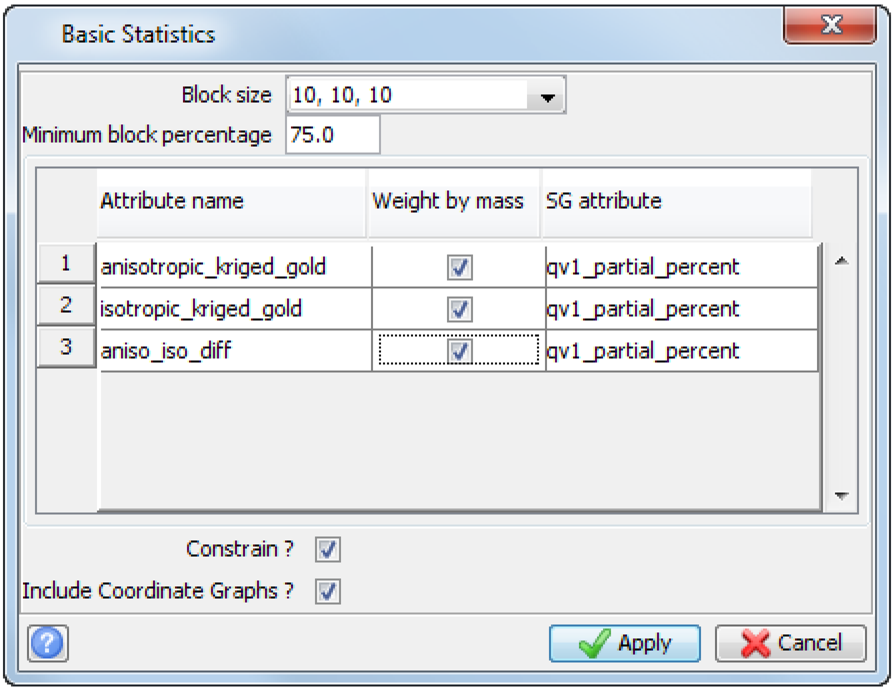


Basic statistics of model values

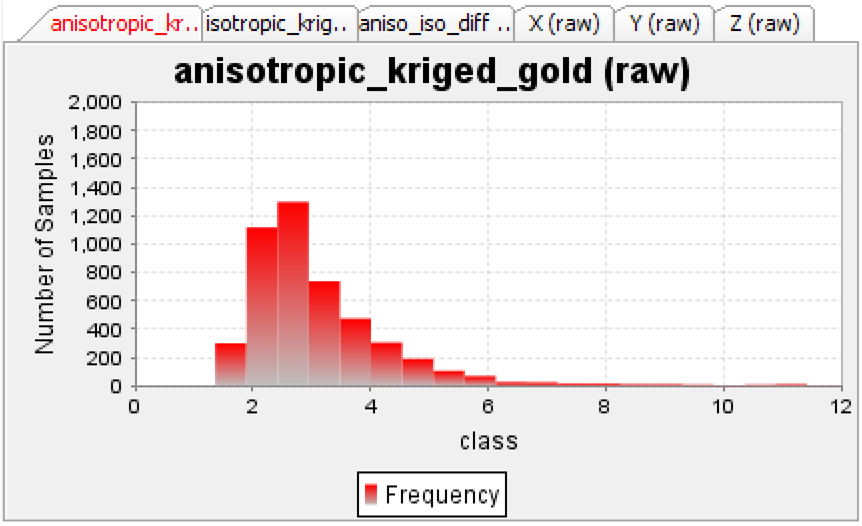
Basic statistics of the block model values is another way to validate the output from the model.

Task: Display basic statistics of model values

1. Run **_12_bm_basic_stats.tcl**.
   This macro will display basic statistics on three block model parameters.
2. Select the check boxes on the *Basic statistics* form as shown, and click **Apply**.



You will see a histogram of the data displayed.



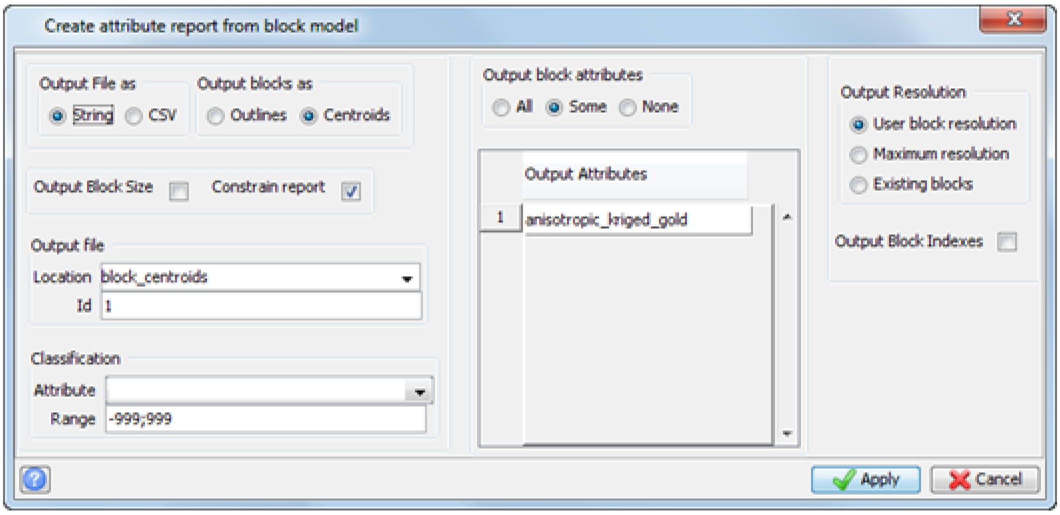
3. Choose **File > Close**.

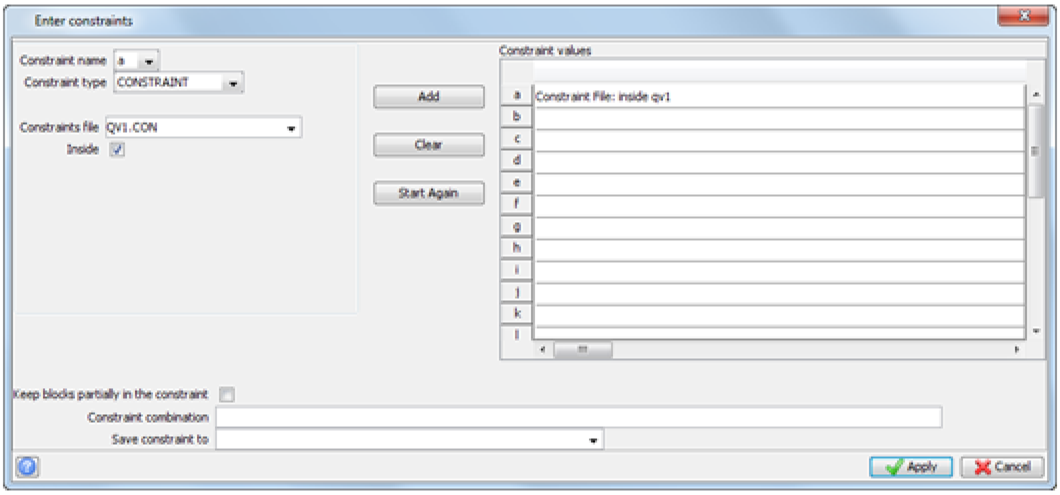
Trend analysis

You can also analyse the trends in the data to validate the output from the model.

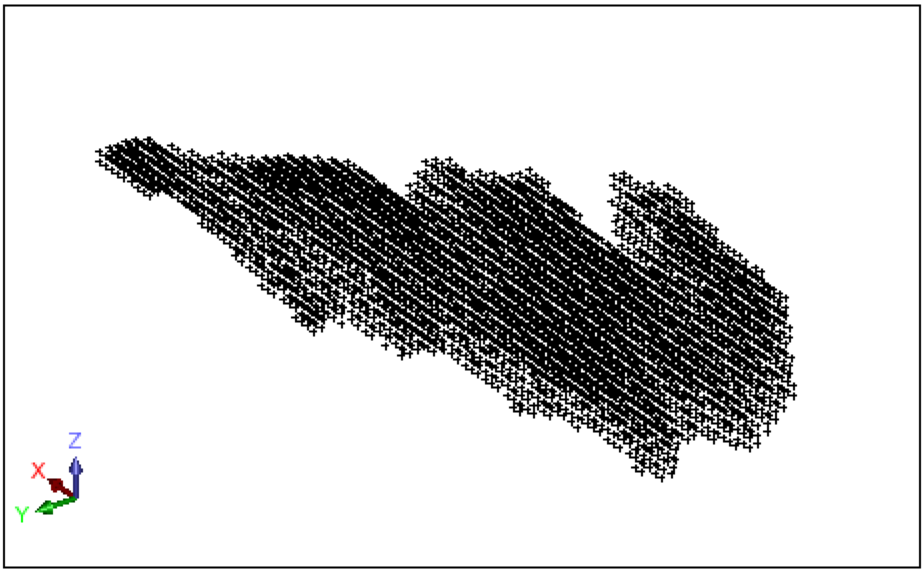
Task: Display trend analysis

1. Run **_16b_export_centroids.tcl**.
2. View, and then click **Apply** on both of the following forms.



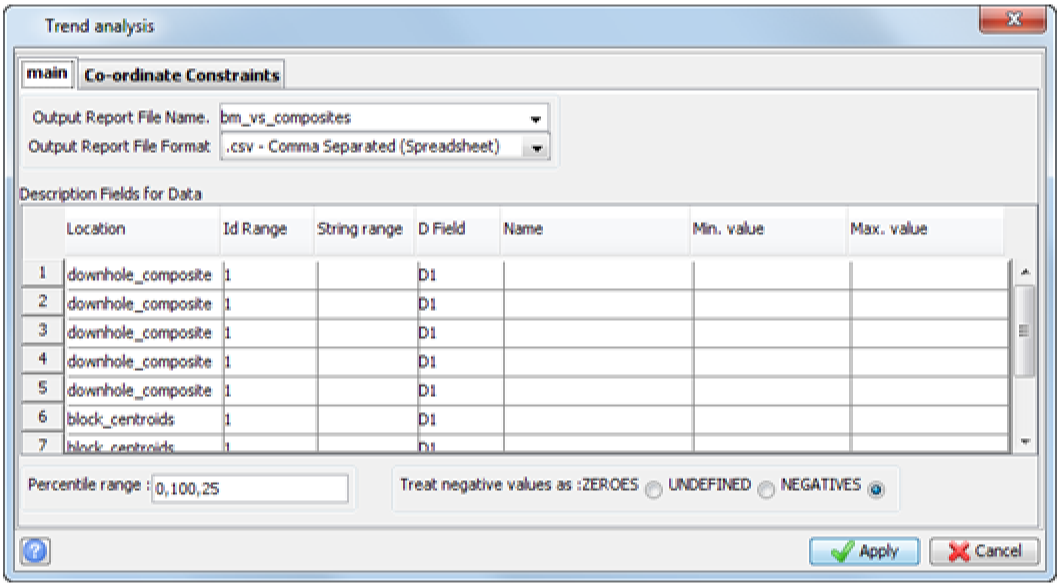


When the data has been exported, you will see the data in **Graphics**.

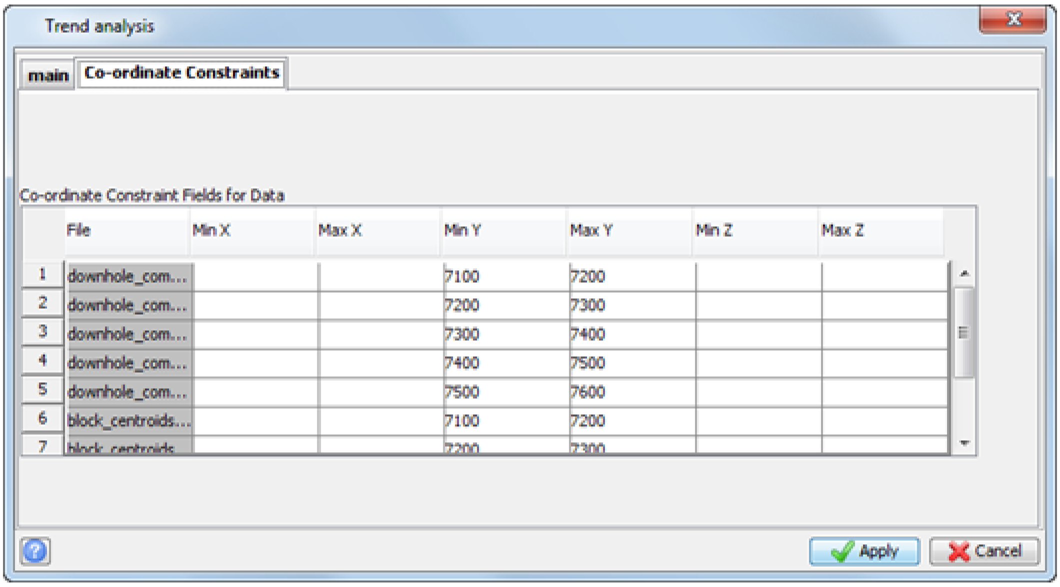


3. Run the macro **_16c_bm_vs_composites.tcl**.
   This macro performs the function **Geostatistics > Trend analysis**. There are two tabs on the *Trend analysis* form.

   The main tab contains the names of the file(s) to be analysed.



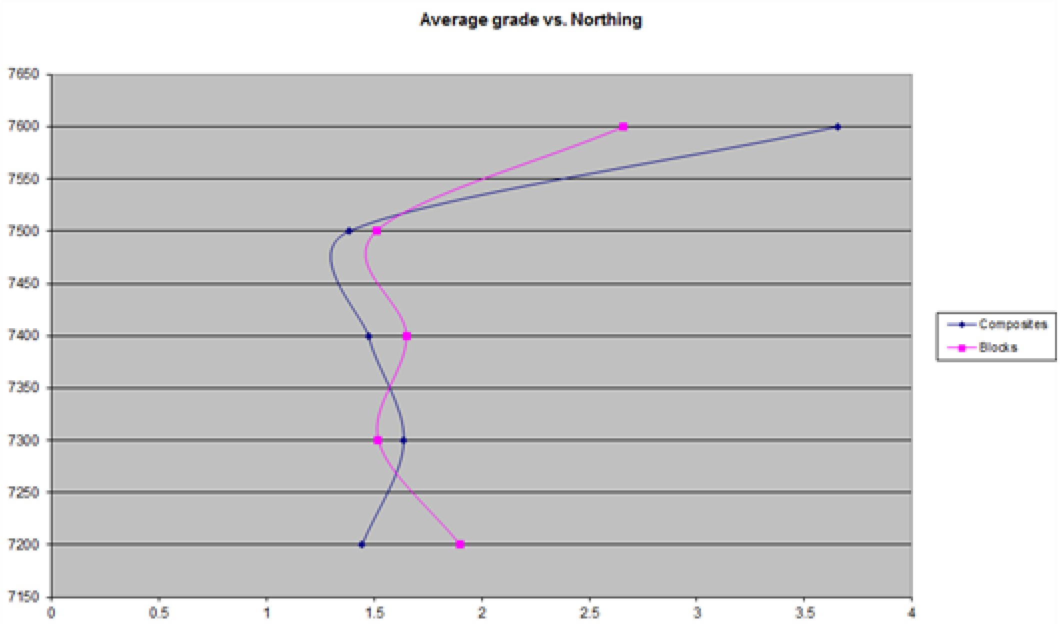
4. Click the **Co-ordinate Constraints** tab to view the range of coordinate values.



📝 **Note**: In this case, you want to compare the downhole composite values against the block centroids for a range of northings.

5. View the form, and then click **Apply**.
   The previously prepared file **bm_vs_composites.xls** contains the data and a graph.

   Open **bm_vs_composites.xls**.



Trend analysis can be used to identify regions where block model estimations might be different to the composited data.

Block size analysis

Overview

An important end product of a geostatistical evaluation is a "model", or a set of points in space which contain estimated values. The points are representative of the centroid of a block of material. The determination of the spacing between these points, or the block size is often a critical factor in a geostatistical estimation. By evaluating two parameters derived from ordinary kriging, you can determine the optimal block size. The ultimate selection of the block size, however, may be based on other factors, such as minimum mining width.

You will learn about:

- debugging output from ordinary kriging
- using kriging efficiency and conditional bias slope
- block site selection

Requirements

In order to understand this information, you should be familiar with:

- Surpac string files
- Surpac block models
- isotropy and anisotropy
- anisotropy ellipsoid
- ordinary kriging

Debug output from ordinary kriging

When using ordinary kriging to estimate values in a block model, the debug output will contain two parameters which you can use in the analysis of block size.

1. Run **kriging_debug.tcl**.
   This macro:
   1. creates a block model
   2. performs ordinary kriging within a constraint to estimate a value for a single block
   3. uses debug output in the report file

The output file, **block_size.not** is displayed. Near the bottom of the file, you will see the following parameters:

Estimated grade: 4.452
Kriging variance: 0.250
Twice std. dev.: 1.000
Block variance: 0.907
Kriging efficiency: 0.724
Slope of regression: 0.112
Lagrange multiplier: 0.053
Conditional bias slope: 0.930

The values of kriging efficiency and conditional bias slope are used in analysing block size.

Block variance – kriging variance

Kriging Efficiency = block variance

Block variance – kriging variance + | lagrange multiplier |

Conditional Bias Slope = Block variance – kriging variance + 2x | lagrange multiplier |

Using kriging efficiency and conditional bias slope

Ideally, both the kriging efficiency and the conditional bias slope should have a value of 1.00. In practice, this is impossible, but what you can do is compare the values of these two parameters for a variety of block sizes.

To do this in Surpac, you would perform the following procedure for a set of block sizes:

1. Select the X, Y, and Z coordinates of a location where you wish to perform the analysis.
2. Select the X, Y, and Z block dimensions.
3. Create a block model using an origin such that the coordinates of the centroid of the first block in the model are the same as the coordinates in step 1.
4. Perform ordinary kriging within a constraint to estimate a value for the first block.
5. Ensure "debug output" option is used in the report file .
6. Note the values for kriging efficiency and conditional bias slope in the debug file.

For example, using the data from the **kriging_debug.tcl** example:

- coordinates to perform the analysis: Y=7340 X=1660 Z=110
- block dimensions: Y=10 X=10 Z=10
- block model origin: Y=7335 X=1655 Z=105
- ordinary kriging within constraint: Y< 7345, X<1665, Z<115
- debug output selected
- output file: **block_size.not** contained:

```
Estimated grade:  4.452
Kriging variance:  0.250
Twice std. dev.:  1.000
Block variance:  0.907
Kriging efficiency:  0.724
Slope of regression:  0.112
Lagrange multiplier:  0.053
Conditional bias slope:  0.930
```

Given these same data in step 1, here are some examples for different block sizes. In each example, the coordinates of the centroid will be the same.

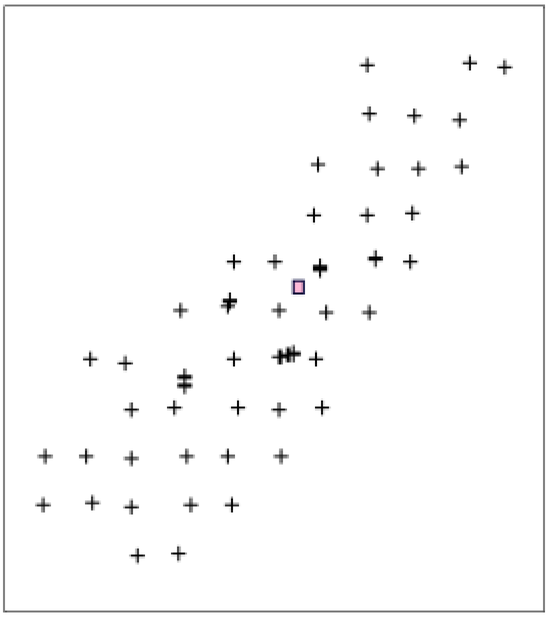
Coordinates to perform the analysis: Y=7340 X=1660 Z=110

- block dimensions: Y=10 X=5 Z=5
- block model origin: Y=7335 X=1657.5 Z=107.5
- ordinary kriging within constraint: Y< 7345., X<1662.5, Z<112.5
- block dimensions: Y=5 X=5 Z=2
- block model origin: Y=7337.5 X=1657.5 Z=109
- ordinary kriging within constraint: Y< 7342., X<1662.5, Z<111
- block dimensions: Y=2 X=2 Z=2
- block model origin: Y=7339 X=1659 Z=109
- ordinary kriging within constraint: Y< 7341., X<1661, Z<111

Block site selection

If your data is fairly regular, as is the case with the string file **gold_cut17.str**, you would want to choose a location which is in the middle of the data.

For example, using the block site location and string file data used in the **kriging_debug.tcl** example:



However, if there were one or more clusters within the data, you should perform the study at each of several locations, each representative of different types of data clustering. This is because the kriging efficiency and conditional bias slope are determined by block size and sample locations near the block. For example, you may want to choose several locations as demonstrated in the following list:

1. area representative of average sample spacing
2. within or near cluster #1
3. within or near cluster #2
4. within or near cluster #3
5. within or near cluster …

Kriging efficiency and conditional bias slope are not dependent upon sample values, but are related to block size, sample locations, and variogram parameters.

After you have determined an optimal block size, you can use the procedure described here to compare other factors, such as maximum number of samples, search radius, and discretisation points.