Confidence Intervals

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Introduction

- Conditional Simulation currently accepted method for estimating Confidence Intervals. However..
  - Time consuming methods often taking days to generate simulations
  - Complex method to use
  - Not viable in the majority of cases
- Need to find alternative method which produces the reliability of simulation but within much shorter time frame.

Confidence Intervals

- Confidence Interval (CI) reflect the inability to exactly define an unknown value;
  - CI = 0: Value is known exactly
  - CI > 0: Value is not known exactly and the uncertainty increases with magnitude of CI
- If the CI is linked to probability, it is possible to estimate the chance of the unknown estimate lying within a given grade range e.g. 50% probability that the value lies within the range 3g/t +/- 0.8 g/t
- Grade estimation methods calculate the value of a given block or node. What Confidence do we have in that value?

Calculating Confidence Intervals

- Calculated using the following equation:

  CI = Upper Limit – Lower Limit

- Upper and lower limits usually defined in terms of Standard Deviations (SD):

  Upper Limit = Mean + nSD

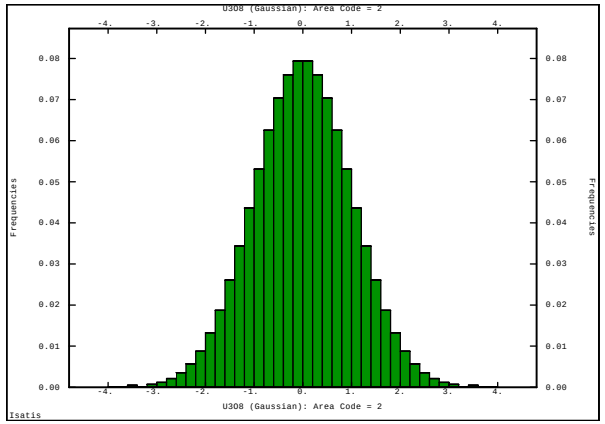
  Lower Limit = Mean – nSD

- 1 SD: Defines 60% Confidence Limits
- 1.96 SD: Defines 95% Confidence Limits

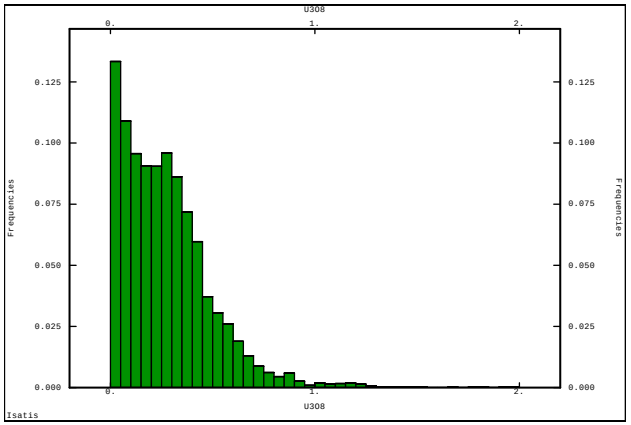
- It should therefore be possible to estimate a confidence interval for each block. However…….

Assumptions

- Block estimates are normally distributed – This is rarely the case!!



Requirement



Actual

- Calculating CI's for skewed data will result in Negative Grades

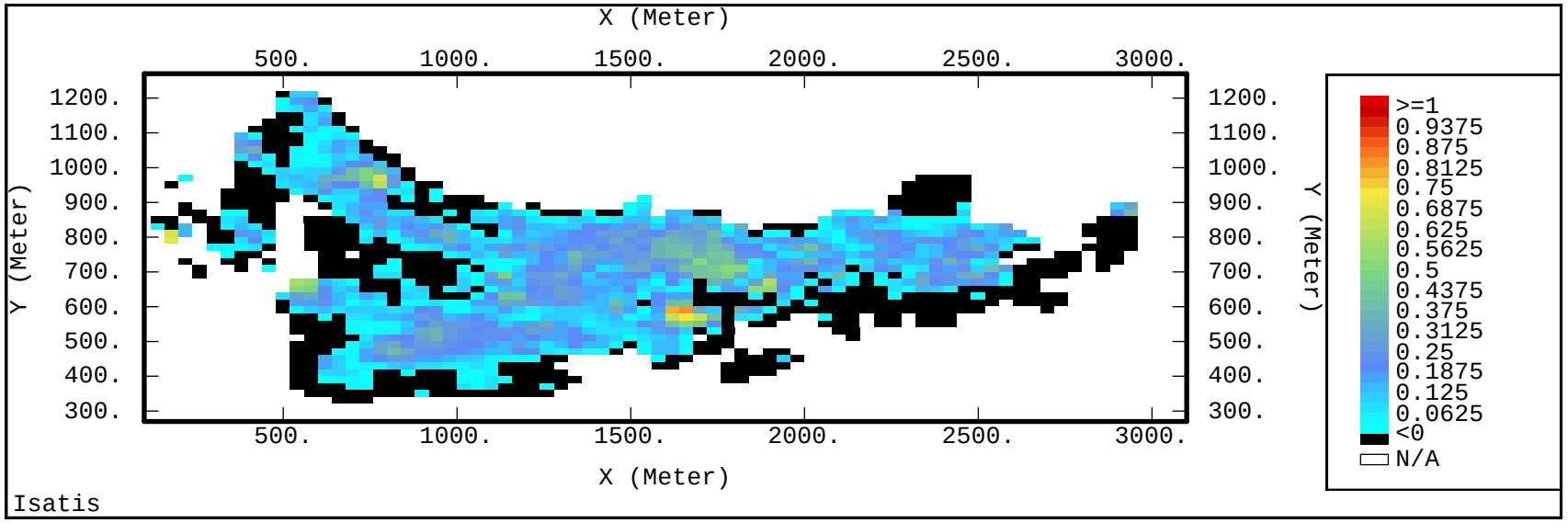
Ordinary Kriging

- Provides an estimate of a block value and an indication of the local precision – kriging variance
- Kriging variance can be converted in SD and CI's determined. However negative lower limits are produced.
- Kriging Variance is based upon sample distance and does not take into account the effects of sample distribution

➔ Alternative Method required

Lower Confidence Limit via Ordinary Kriging

Lower confidence = kriged estimate – 1.96 KSD

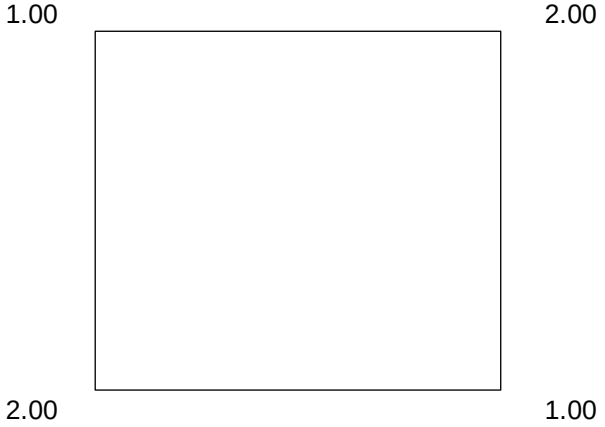


Note: Many blocks with –ve lower values

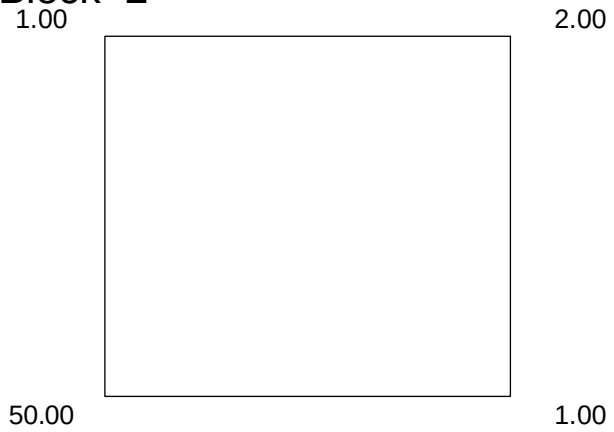
Kriging Variance

- Consider the 2 blocks, whose value is estimated from the samples located at each corner.
  - Both blocks have same sample configuration;
  - The same variogram is used in both cases;

Block 1



Block 2



Block 1 estimate = 1.50

Block 2 estimate = 13.25

- Both blocks have same kriging variance ➔ same confidence!

Alternative Methods

- Conditional Simulation currently accepted method for estimating Confidence Intervals. However..
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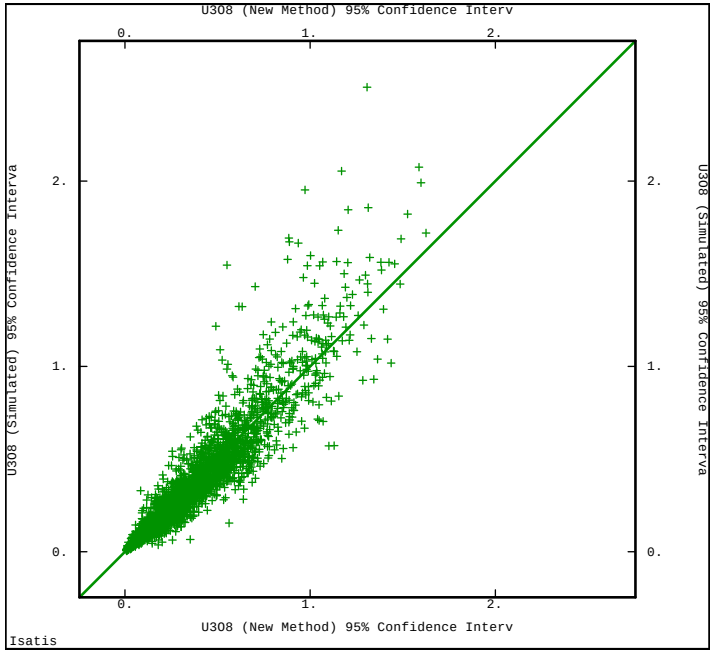
Direct Confidence Interval Method

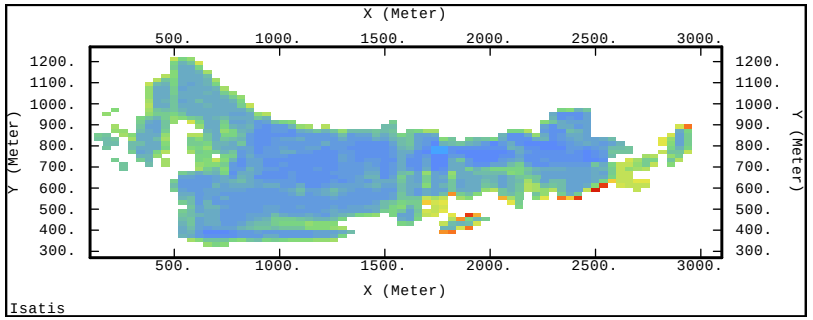
- Idea proposed by Armstrong and Roth;
- Based upon Simple Kriging but with modifications;
- Isatis program modified by Geovariances;
- Hard rock metal mine reserve definition drilling used for study;
- Estimates generated by DCIM and compared against Conditional Simulation

Comparison of Confidence Intervals

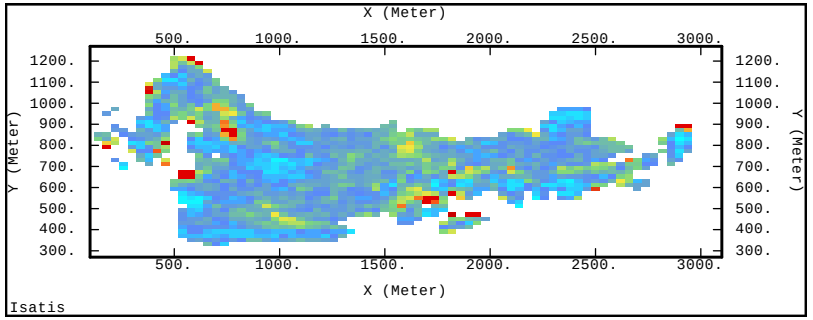
Scatterplot of Simulated CI vs DCIM CI



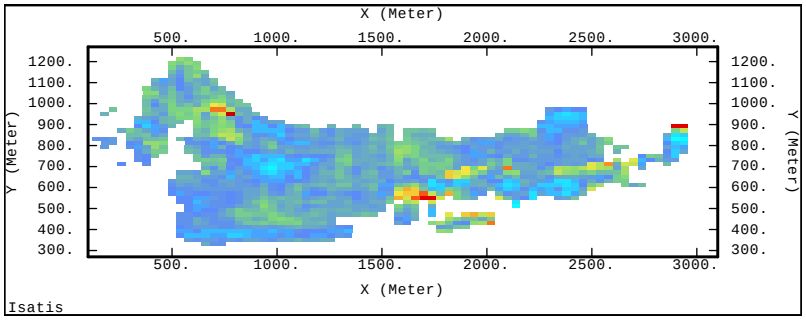
Kriged



Simulated

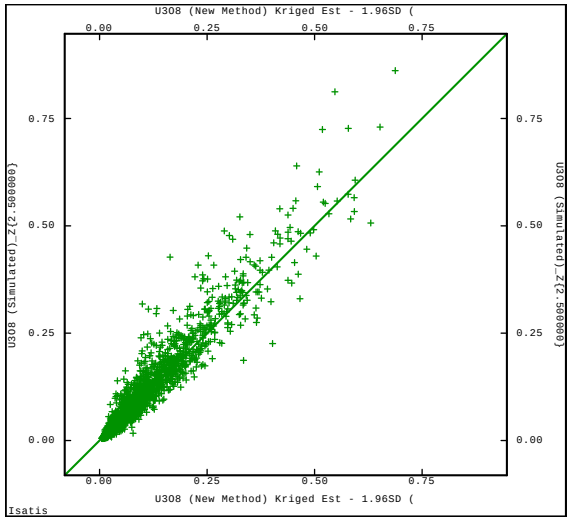


DCIM

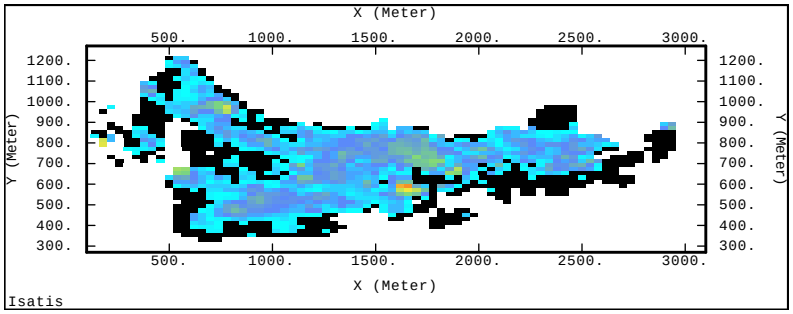


Comparison of Lower Confidence Limit

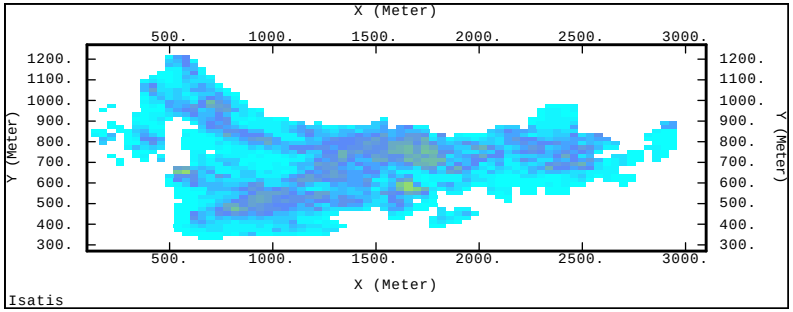
Scatterplot of Simulated CL vs DCIM CL



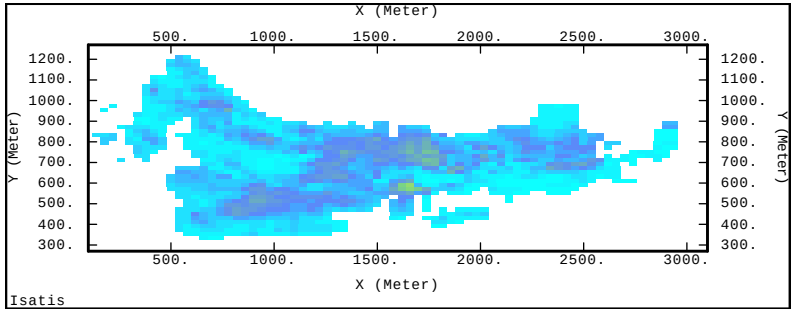
Kriged



Simulation



DCIM

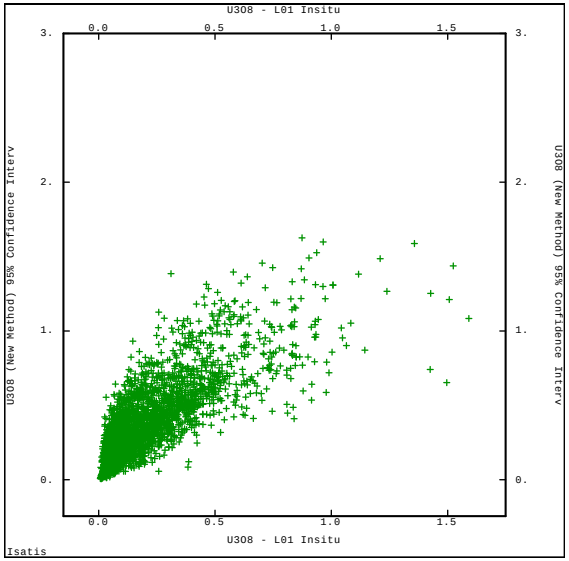


Reliability of Grade Estimates

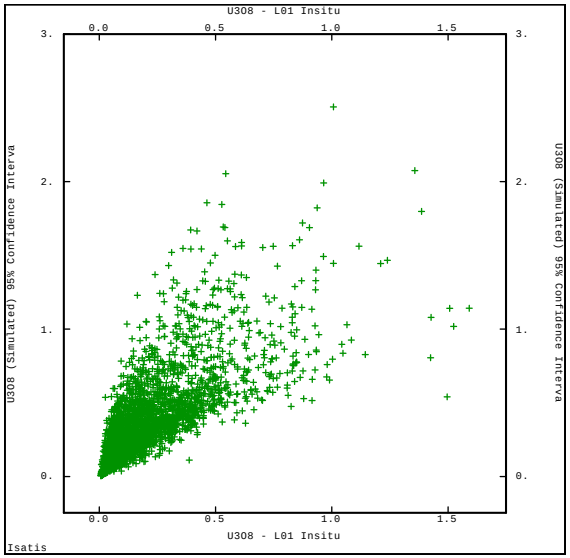
- Simulation and DCIM used to generate Confidence Limits
- Block model grade estimates generated by the mine
- How do the grade estimates relate to the confidence intervals?

Grade vs Confidence Interval

- Confidence Interval increases with grade estimate



DCIM Confidence Interval vs Block Estimate



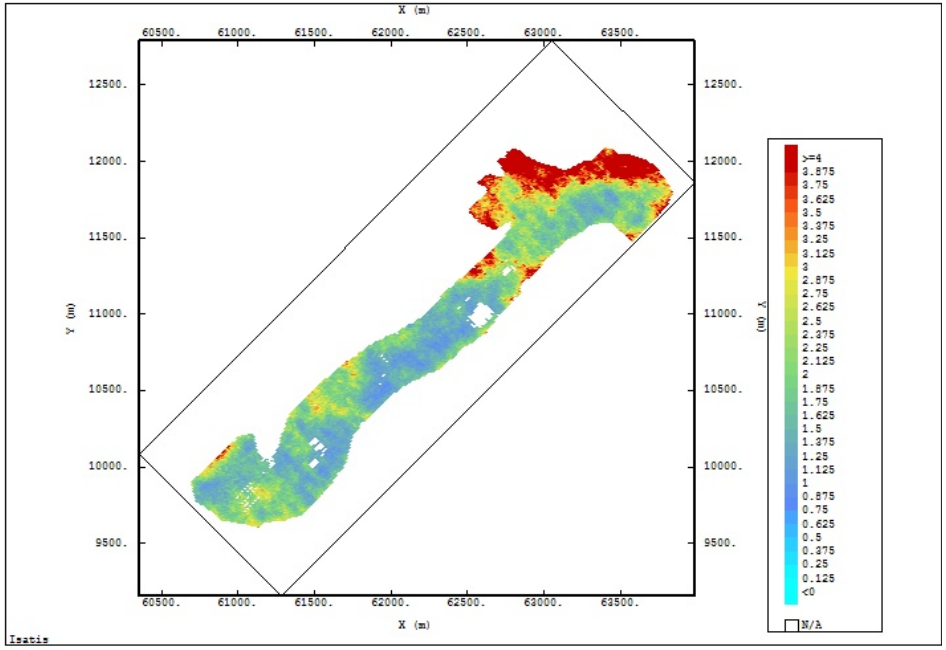
Simulation Confidence Interval vs Block Estimate

Iron Ore

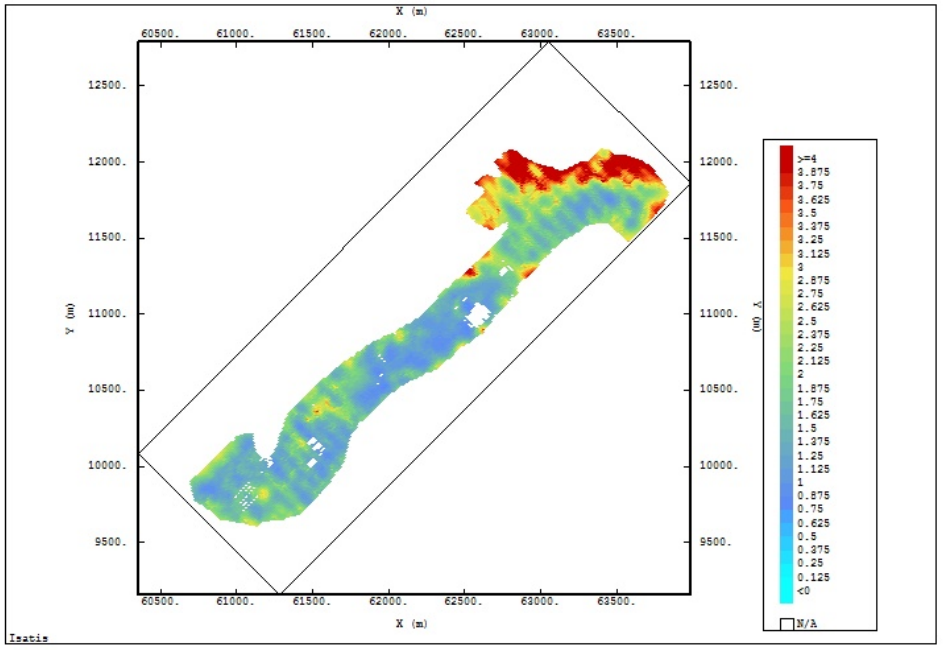
- Wide spaced exploration data available
- Conditional Simulations already in existence

95% Confidence Limits

Simulated



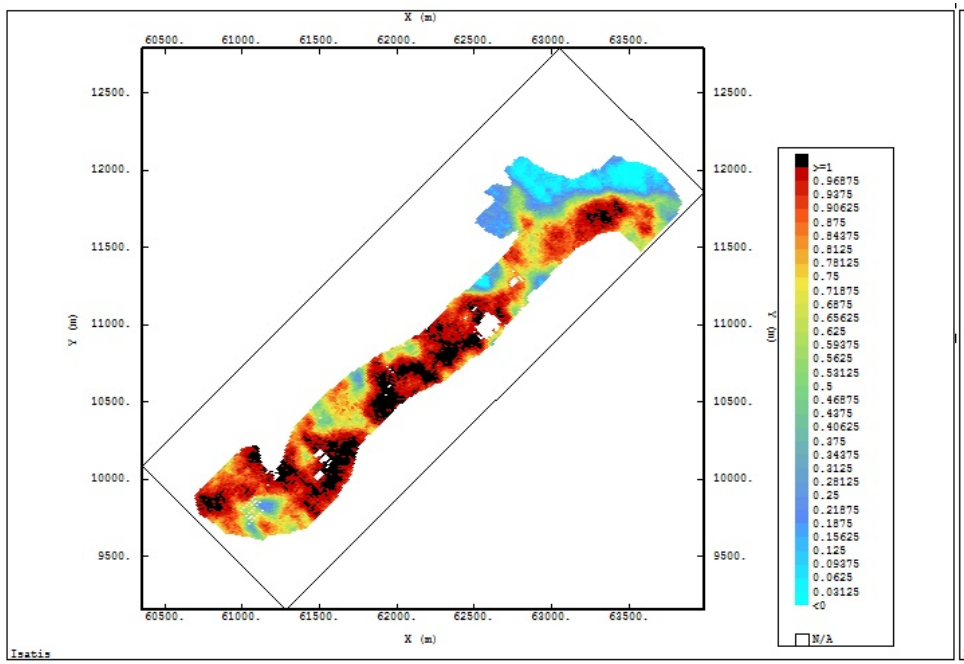
DCIM



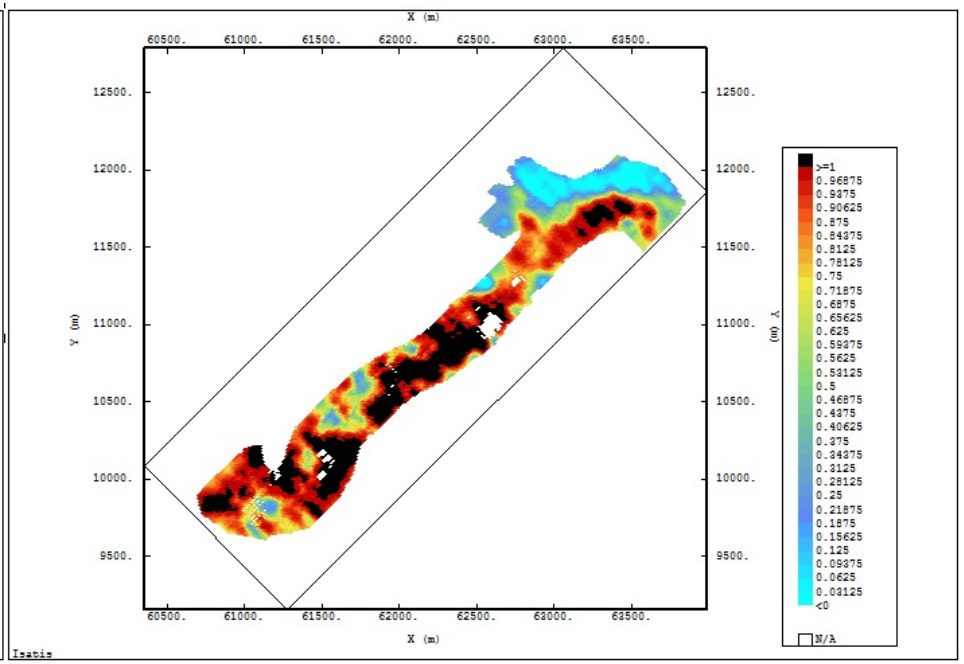
Probabilities

- Simulations can be used to estimate the probability of a block grade exceeding a certain value – requires at least 100 simulations
- DCIM adapted to allow probabilities to be calculated directly

Simulation



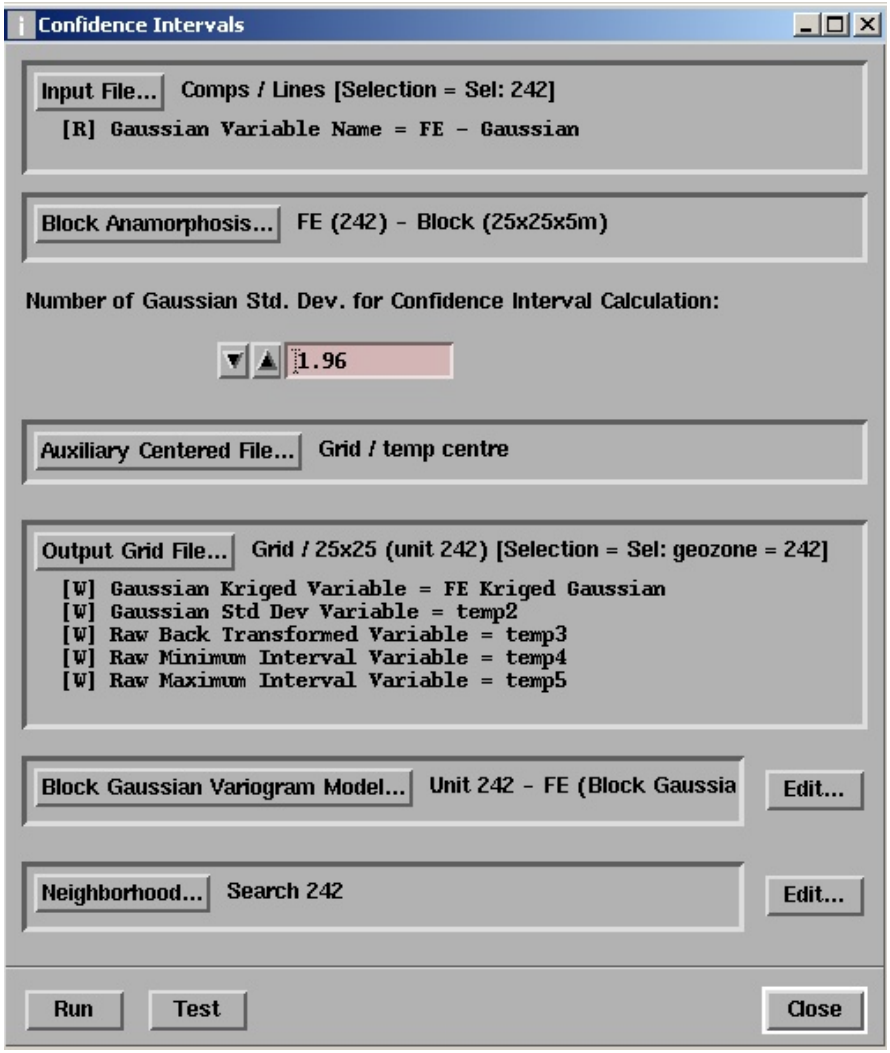
Direct Approach



Generating Confidence Intervals

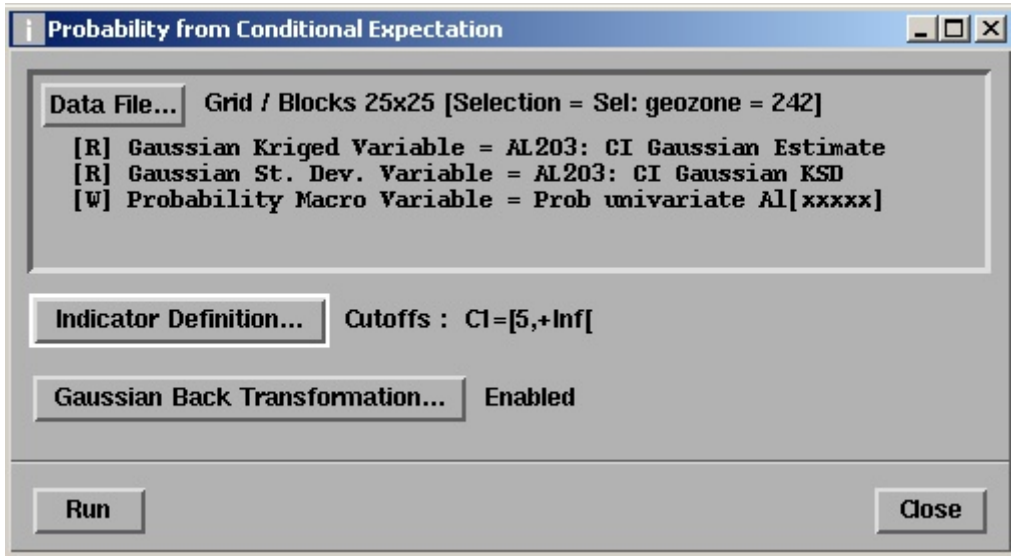
- Process:
  - Convert the input sample data into Gaussian values;
  - Calculate the change of support for the points/blocks;
  - Calculate the gaussian block variogram from the raw point variogram and model;
  - Convert the point values into ‘pseudo’ block gaussian values via the change of support and migrate the points to the required block centres;
  - Krige the ‘gaussian’ block values and determine the gaussian kriging variance
  - Back transform the gaussian values into raw values

Confidence Intervals - Program



- Input requirements
  - Gaussian values
  - Block anamorphosis
  - Block gaussian variogram

Calculation of Probabilities



- Input gaussian values derived from CI program (Kriged estimate & KSD)
- Indicators to be supplied
- Gaussian back transformation to convert gaussian to raw values

Direct calculation of Confidence intervals – Advantages & Disadvantages

- Advantages
  - Provides indication of 'potential' reliability of estimates
  - Direct approach is much quicker to run than simulation
  - Produces results which are similar to those generated by simulation

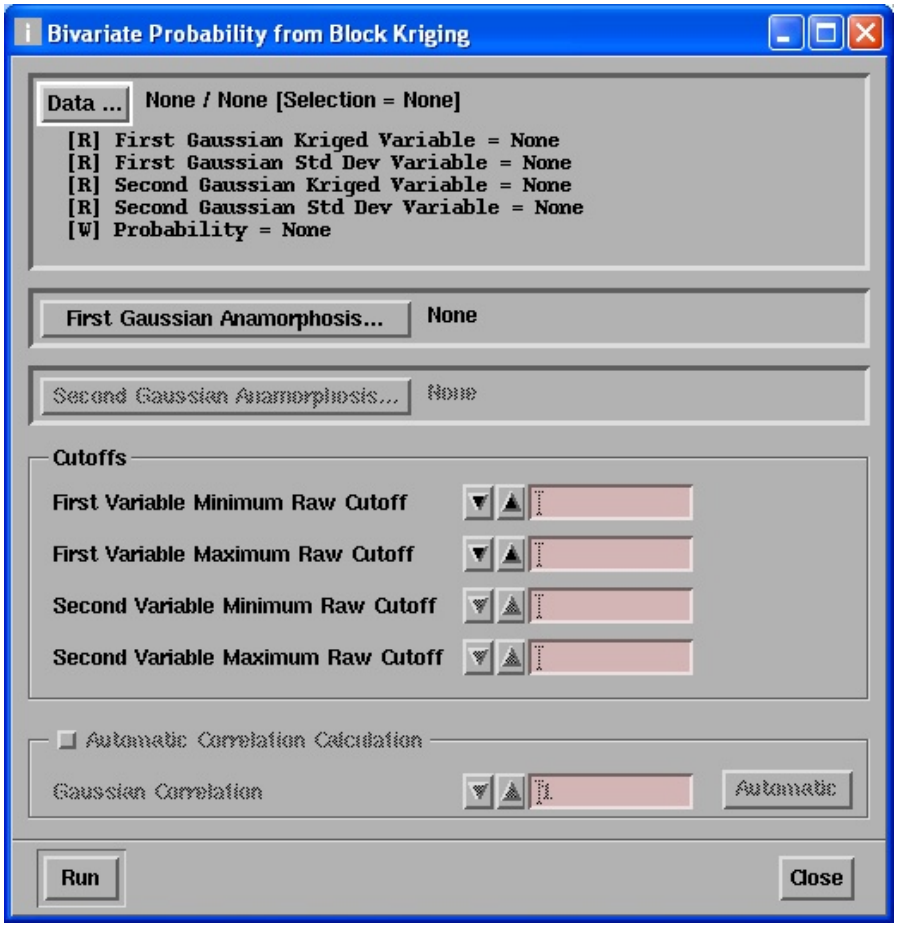
- Disadvantages
  - Reliance upon a good variogram model
  - Number of assumptions made about the data during the calculation process

  - ► However all tests to date provide comparable results

Further Work

- Additional studies completed
  - Iron Ore Deposit, Western Australia (MSc Thesis Faye Jones)
  - Hard Rock Metal Deposit, Middle East (OTX & MSc Thesis George Gestrich)
    - Comparing confidence intervals from simulations and new method
    - Application to impact on mine planning
    - Pit optimisation using Whittle.

New Developments



- Recent addition of bivariate confidence intervals calculation
- Probability that two variables lie within given limits, e.g. Fe and Silica
- Input for each variable:
  - kriged block gaussian values
  - block anamorphosis
- Future development of use for multivariate case…