Rio Tinto

Direct block simulation in Isatis

Cameron Boyle 2013

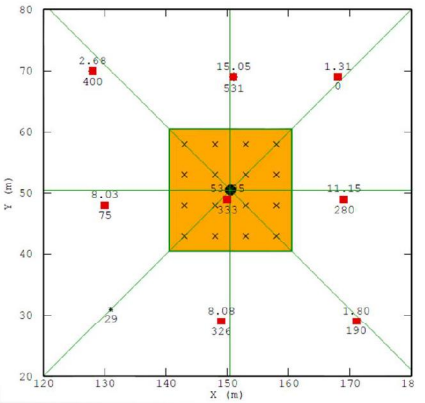
Aim

- To demonstrate the implementation of direct block simulation (DBS)
- Simulation of a large bedded iron ore deposit
- Compare indirect and direct block simulation

Outline

- Introduction to methods
- Case Study
- Findings
- Conclusions

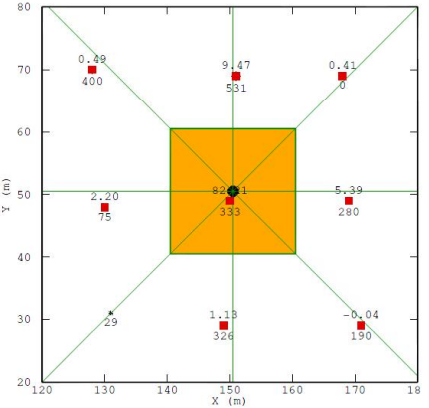
Indirect block simulation



from Geovariances (2010)

- Gaussian anamorphosis
- Gaussian point variogram
- Simulate a block using discretised points
- Gaussian to raw transform for points
- Reblock to SMU by averaging nodes with blocks

Direct Block Simulation



from Geovariances (2010)

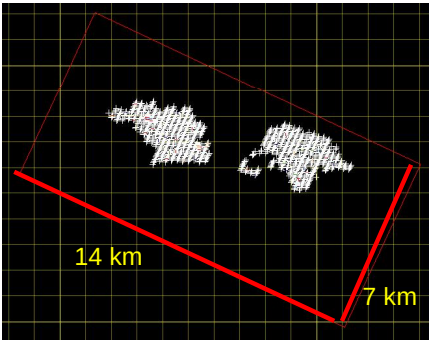
- Gaussian anamorphosis
- Gaussian block variogram
- Simulate blocks
- Gaussian to raw transform for blocks

Case Study – Introduction

- Koodaideri, a large bedded iron ore deposit
- 1 088 drill holes and 34 813 samples
- 14 km by 7 km
- 7 mineralised domains
- 6 chemical variables: iron, silica, alumina, phosphorus, loss on ignition and manganese

Simulation of a large model

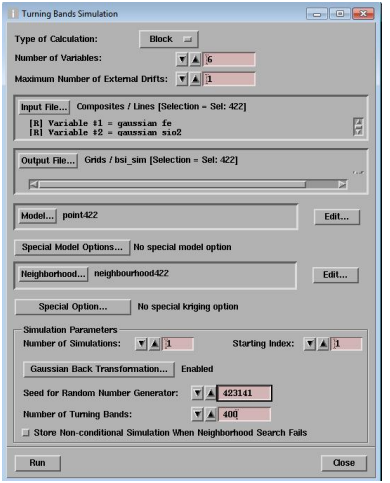
- Grid of 878 000 000 cells with a size of 6.25 m by 6.25 m by 2 m
- Simulating seven mineralised domains assigned as selections of 330 000 to 1 500 000 cells within the grid



Indirect block simulation using turning bands

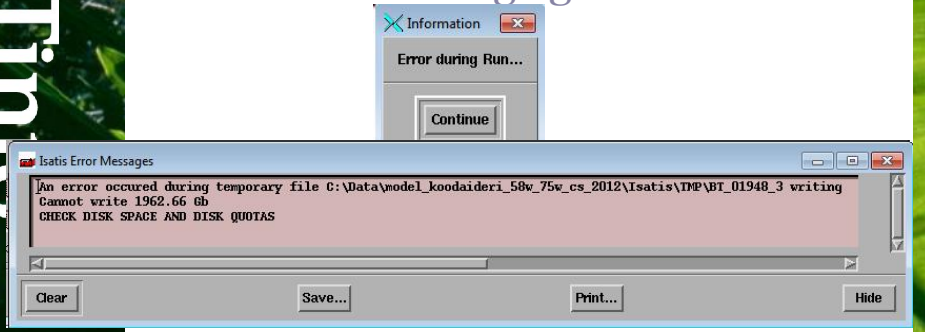
- Long established and reliable method in Isatis
- Blocks are discretised into points that can be averaged to give a block estimate
- Sufficient points to discretise the block
- Works well for small to medium size models
- Good mean and variance reproduction
- Allows immediate back transformation
- After back transformation of point values from Gaussian to data space the Gaussian values and / or point values can be discarded to save space

Attempting indirect block simulation



- Initial non-conditional simulation of all 878 M blocks in the grid
- Then conditioning of the simulation
- The non-conditional simulation will be done for all cells in the grid not just the selected domain

Memory problems with indirect block simulation of a small selection in a large grid



- Only 1.5 M cells are to be simulated but initial non-conditional simulation of all 878 M blocks in the grid before conditioning
- Runs out of memory or disk space for the temporary file
- Simulation of a small or moderate size selection in a large grid may be impractical

Isatis indirect block simulation – memory requirements

- Memory required for storage of the temporary file of the non-conditional sim.:
  = SIMUS * NVARS * (NX*NY*NZ) * (DISCRX*DISCRY*DISCRZ) * 8
- NSIMUS = number of simulations
- NVARS = number of variables (6)
- NX*NY*NZ = size of grid (878 080 000)
- DISCRX = discretisation in X of the block
- DISCRY = discretisation in Y of the block
- DISCR Z= discretisation in Z of the block
- 8 ... For storage in 64 bits

- For a point simulation where DISCRX=5 DISCRY=5 DISCRZ=2), the storage for the temporary file of Gaussian values will be 1 963 Gb (!)
- 1 * 6 * 878 080 000 * 5 * 5 * 2 * 8 = 2 107 392 000 000
- 2 107 392 000 000 / (1024*1024*1024) = 1 963 Gb

A solution:
Direct block simulation (DBS)

- Simulates directly at block support and avoids point simulation
- Needs less memory
- Saves simulation time and storage space

Workflow for DBS – 6 steps

Three extra steps in DBS to add to the Turning Bands workflow

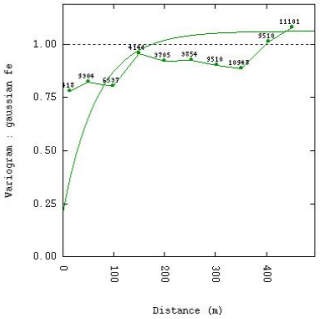
- Model the anamorphosis on the sample support and calculate the Gaussian transformed data;
- Model the variogram of the Gaussian data using Statistics/Exploratory Data Analysis then variogram fitting;
- **Regularize the Gaussian variogram model on the block support using Statistics/Modeling/Variogram Regularization;**
- **Model the regularized Gaussian variogram;**
- **Calculate the change of support coefficients and the block Gaussian variogram related to the normal (0,1) Gaussian block values, using Statistics/Modeling/Gaussian Support Correction;**
- Calculate direct block simulations using the corrected block variogram and anamorphosis (next slide)

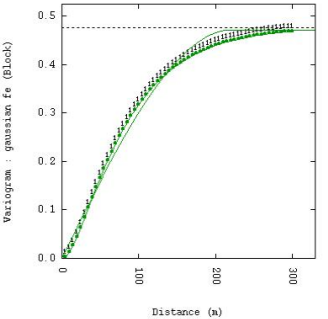
Conditional simulation step in DBS Work flow

- Direct Block Simulation (DBS) module has three stages:
- A centring of data in the output grid blocks is performed and a new auxiliary file is created for this purpose;
- Conditional simulations (turning bands method) of block values using the block Gaussian variogram model and the Gaussian data.
- Gaussian back transformation using the block anamorphosis.

Variogram modelling and modification to block support

- point variogram → block variogram





Variogram may need manual fit

- Stricter conditions on linear model of correlation (LMC) for DBS than in fitting window
- First try Autofit and see if variograms are acceptable before using manual fitting (Gaussian support correction with variogram normalisation has the most checks)
- Autofit can product positive nugget and negative spherical structures (and vice-versa)
- Sometimes variograms from automatic fitting are accepted in fitting window but not accepted at the Gaussian Support Correction stage
- Correlations (even if very small) must match cross structures in variograms in sign
- Sometimes sills of direct and cross variograms must be similar in magnitude to composite variances and covariances; in other cases this is doesn't seem to matter

How to manually fit for multiple elements (if needed)

- Start with direct variogram for most important to least important variables
- Then fit cross variograms for strongest absolute correlations (positive or negative) to weakest absolute correlations
- Has been done for up to 9 variables

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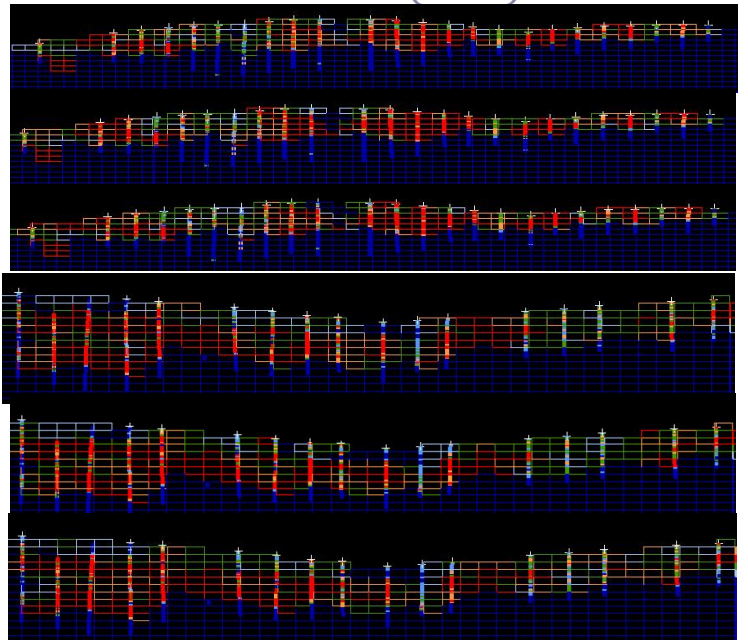
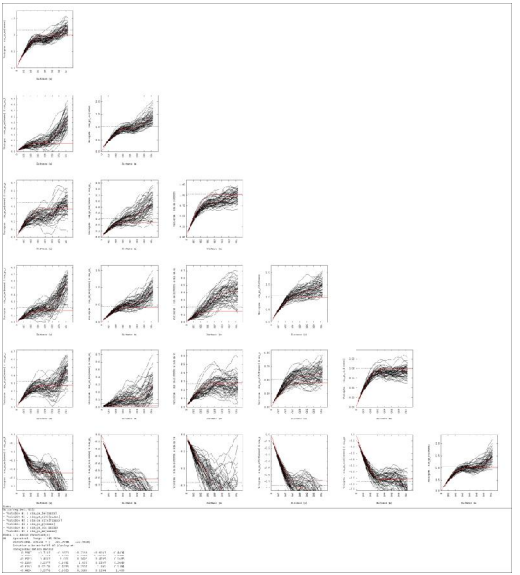
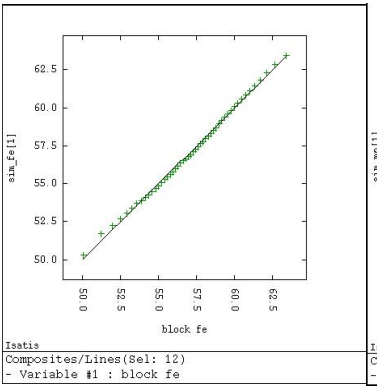
Validation – visual (iron)

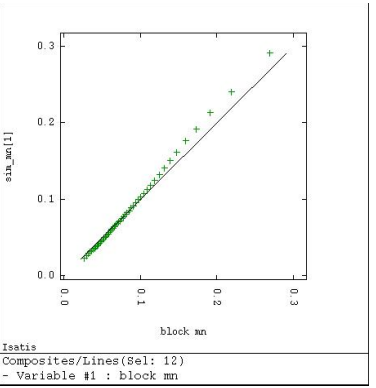


Validation - variograms

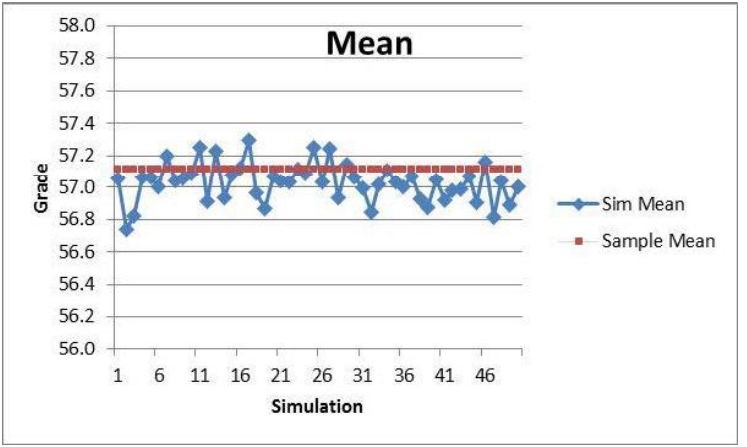


Validation: QQ plots Simulation Versus COS

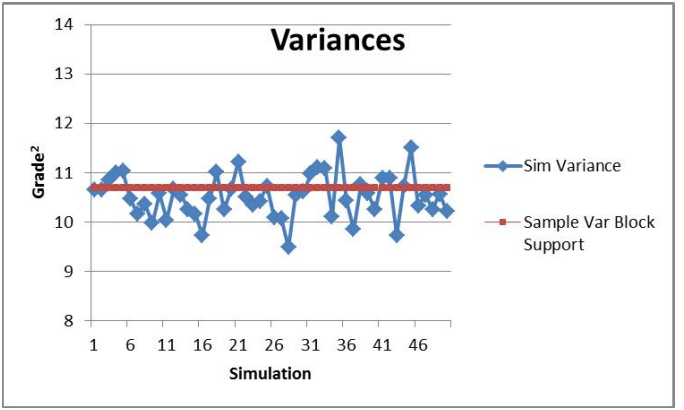




Validation: sample and simulation means – an example



Validation: variances of sample on block support and simulations – an example



Time required

- Cells with a size of 25 m by 25 m by 10 m in a grid of

1 097 600 cells

Time for 1 direct block simulation of 6 variables for selections of different numbers of cells for a single domain

Processor:	Intel(R) Core(TM) i7 CPU Q 740 @ 1.73GHz 1.73 GHz
Installed memory (RAM):	8.00 GB
System type:	64-bit Operating System

Cells	Non-CS	Conditioning	Total
3 614	1 min 50 s	4 s	1 min 54 s
26 560	1 min 52 s	15 s	2 min 07 s
1 097 600	5 min 10 s	28 min 20 s	33 min 30 s

Advantages and Disadvantages of DBS

Advantages

- Fast run time
- Efficient storage
- Allows simulation of large deposits and large models that could not be simulated with indirect block simulation

Disadvantages:

- Cannot be resized like a point simulation
- Three extra steps
- Slower set up

Conclusions on DBS

- For Rio Tinto Iron Ore deposits,
  - Indirect block simulation – may not efficiently handle some of our deposits
  - Direct block simulation – great for scale, but limited in support correction as this is done at the variogram stage
  - **Without DBS – routine simulation would not be possible due to the size, scale and complexity of the deposits**
  - But at the expense of rapid change of support post simulation.

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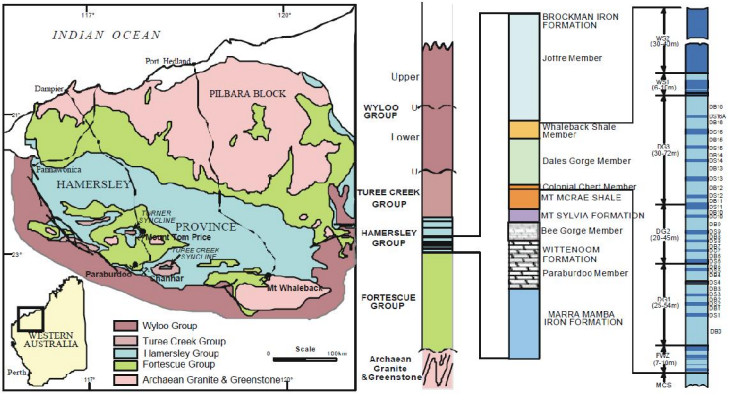
Backup slides

Stratigraphic column



Plan of the Hamersley Province, showing locations of major iron orebodies with a summary of the stratigraphy, from Taylor and others (2001)