Localised Multivariate Uniform Conditioning: a BHP Billiton Iron Ore deposit applied case

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Context

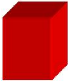
- Recoverable resource estimation:
  - provide an estimation from wide-spaced data
  - Tonnage and Metal quantities
  - cut-offs are applied
  - locally → to selective mining units (SMU's).

- UC: an available geostatistical method
- Can be extended to multivariate settings using the potential correlations between the variables of economical interest
- Localisation of the results

→ Isatis is able to propose a possible flowchart

Context

- Consider a SMU v, with grade Z(v)



- The recoverable resources at cut-off z are defined as:
  - Ore: $$T(z) = 1_{Z(v) \geq z}$$
  - Metal: $$Q(z) = Z(v) 1_{Z(v) \geq z}$$

(to be multiplied by block tonnage = volume*density to be expressed in tons)

Isatis (possible) Workflow

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1. Declustering
Input: Samples
Output: weight

⇒

2. EDA
Experimental Variogram
Input: Samples + weight
Output: experimental Variogram

⇒

3. Variogram Fitting
Input: experimental Variogram
Output: variogram model

⇒

4. Gaussian Anamorphosis
Input: Weight + samples
Output: point anamorphosis

⇓

5. Support Correction
Input: anamorphosis and block size
Output: block anamorphosis

⇐

6. Panel Kriging
Input: samples + model
Output: panel estimate and variance dispersion

⇐

7. Uniform Conditioning
Input panel estimate+ variance dispersion + block anamorphosis
Output: Grade distribution inside each panel

⇓

8. SMU Kriging
Input: samples + model
Output: not reliable SMU estimate

⇒

9. Localized Uniform Conditioning
Input: SMU estimate + grade distribution inside each panel
Output: A block model of grade at the SMU size

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The UC process

- Ordinary Kriging, storing kriged estimate and dispersion variance
- Point anamorphosis
  - An anamorphosis function converts the raw, non-Gaussian data (Z) to a variable (Y) having a Gaussian (normal) distribution
  - The distribution of punctual data is completely represented by the anamorphosis function
- Block anamorphosis (change of support)
  - The block anamorphosis determines the value of the coefficient r, which is used to determine the variance reduction of a particular support

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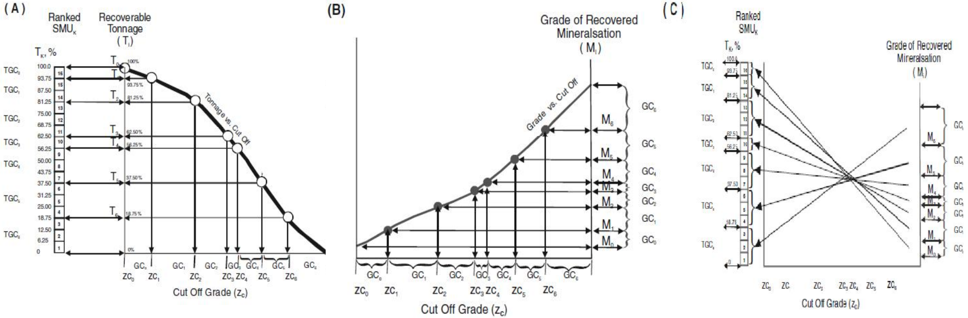
The Localized UC Process

- The methodology has been proposed by Marat Abzalov (Rio Tinto),
  - see paper in Math. Geol.: the choice of the grades assigned to the blocks is guided by the local estimates of the block.



(B) Define the GC_i from the UC

(B) Define M_i of the GC_i

(C) Assign And Sort M_i of the GC_i

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Data Overview

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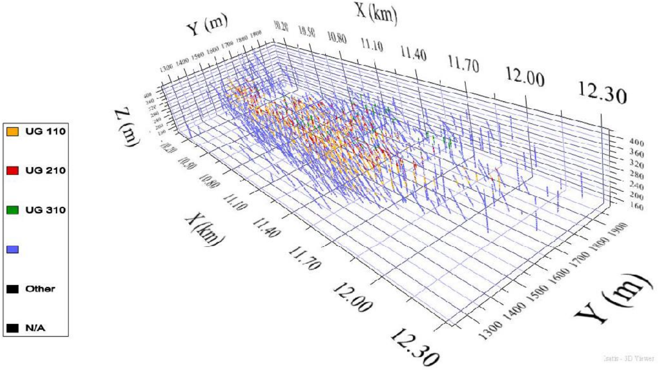
Data: 651inclined boreholes with 19172 3m composites split into 3 main ore domains.

UG	110	210	310	400
Count of composites	3631	1196	355	14530



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Data Overview

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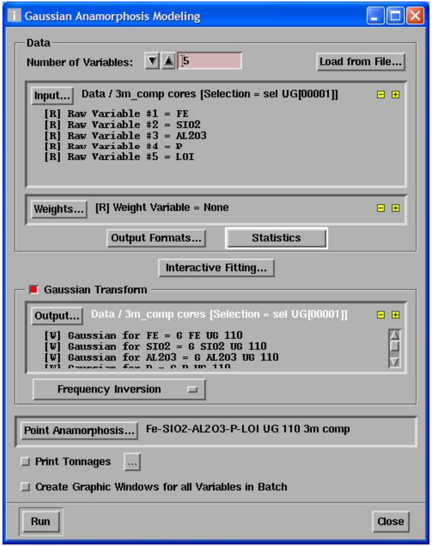
5 grade elements are considered with different statistics in the different domains

VARIABLE	Count	Minimum	Maximum	Mean	Std. Dev.	Variance
FE	19357	0.01	68.55	44.96	18.24	332.81
SIO2	19357	0.25	91.71	22.23	21.82	476.06
P	19168	0.001	4.830	0.104	0.078	0.006
AL2O3	19357	0.05	44.28	4.68	5.89	34.74
LOI	19357	0.01	47.28	6.18	5.60	31.37

The Gaussian Anamorphosis

- Select several variables
- weights from declustering
- Interactive fitting
- Gaussian transformation: not necessary for recoverable resources
- Point Anamorphosis as parameter file
- The anamorphosis are made separately for each variable



The Gaussian Anamorphosis

Gaussian anamorphosis without declustering is applied with 60 Hermite Polynomials

Example of Fe UG110

Change of Support

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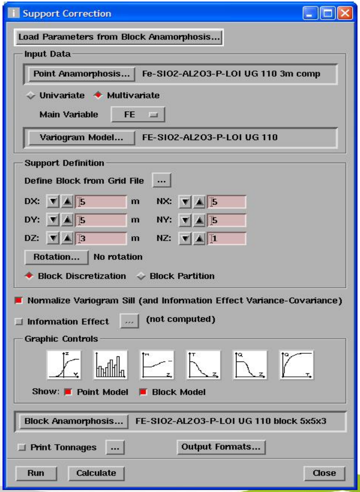
A change of support is applied on smus 5mx5mx3m.

Fe is then declared as the main variable

	FE	SIO2	AL2O3	P	LOI
Punctual Variance (Anamorphosis)	11.47	9.62	1.46	0	2.92
Variogram Sill	10.85	8.56	1.45	0	2.98
Gamma(v,v)	5.42	4.65	0.64	0	1.02
Real Block Variance	6.05	4.97	0.81	0	1.91
Real Block Support Correction (r)	0.7813	0.819	0.7935	0.881	0.8128
Kriged Block Support Correction (s)	0.7813	---	---	---	---
Kriged-Real Block Support Correction	1	---	---	---	---
Main-Secondary Block Support Correction	---	-0.9034	-0.7632	-0.2444	-0.6183



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Co-Kriging of the Panels

- SMU = $5x5x3m^3$

  Panels = $25x25x3m^3$

- Cokriging of panels achieved for each domain.
- All panels containing at least one block of a domain is kriged for that domain:
  - Mixed panels can then be kriged 2 or 3 times.

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Co-Kriging of the Panels

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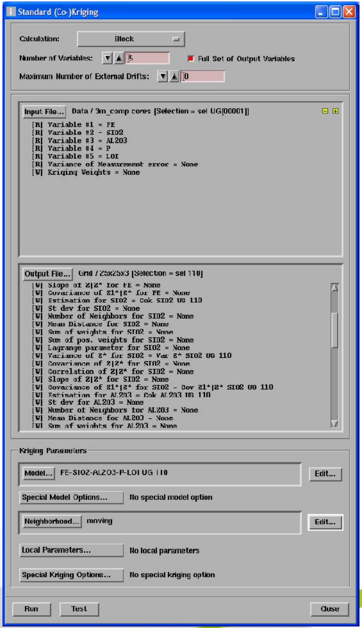
Co-Kriging of the Panels

- **UC Needs:**
  - Estimated values;
  - Dispersion variance of the estimated value (*Var Z*);*
  - For all secondary variables, the covariance between the estimated value and the estimate of the main variable (*Cov Z1*|Z**).



Uniform Conditioning

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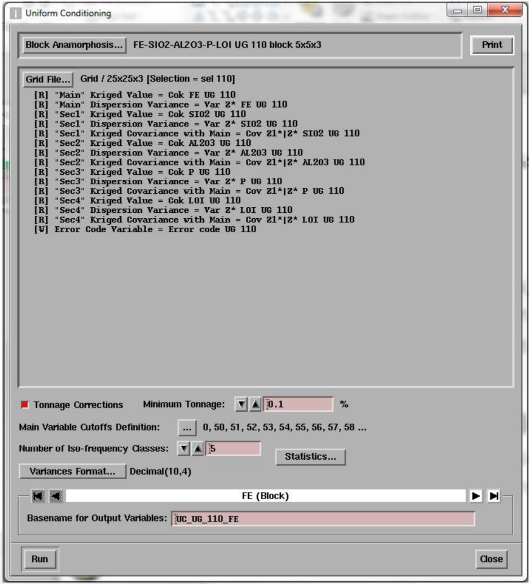

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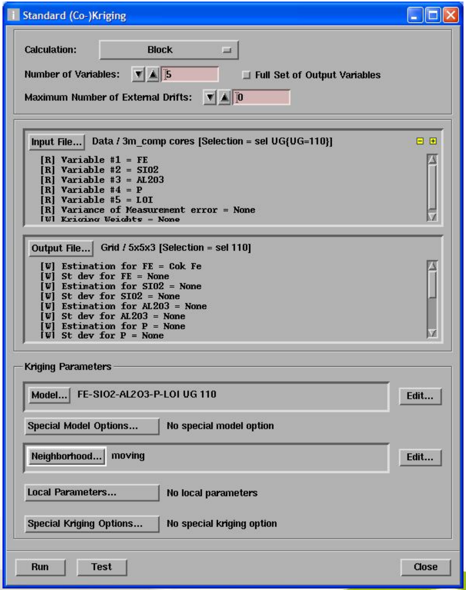
Localisation of the results

- For Localized Uniform Conditioning Post-Processing, Fe grade of blocks $5m \times 5m \times 3m^3$ cokriged.
- Blocks of different domains cokriged in turn with the variogram parameters of the domain they belong to.



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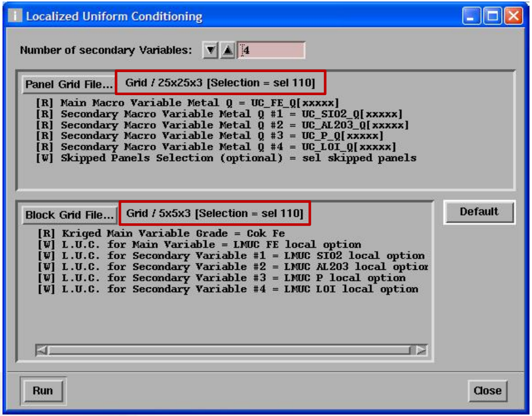
Localisation of the results

- **Local option:** for each individual domain. Q assigned to the blocks of the same domain.
  - The condition: apply on the block file a selection for the blocks of that domain and to transform the tonnage and metals of the panel file by the proportion of the blocks of that domain.
- **Global option:** one Uniform Conditioning of each domain and combine the tonnages and metals by weighting by the proportions of each domain.
  - Then the Localized Uniform Conditioning is run once. In that case there is no guarantee that the grade assigned to one block comes from the grade tonnage curve of the same domain.

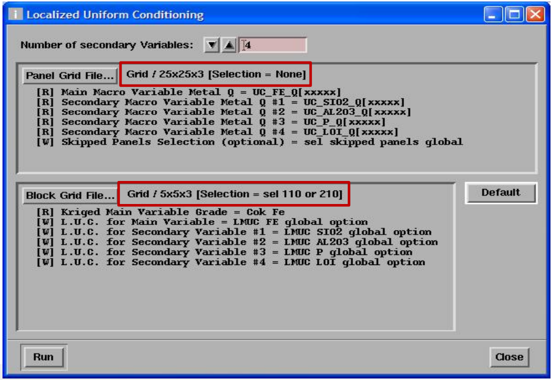
Localized MUC

Local option: then the Localized Uniform Conditioning is achieved with the selection on the blocks file of the same domain activated



UC post-processing

Global option: Then LUC applied once to assign the grades to the blocks (possibly belonging to different domains) inside the panels.



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Results & Conclusions

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The block model obtained by LMUC shows higher dispersion than the direct block cokriging.

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Results & Conclusions

The block model obtained by LMUC shows higher dispersion than the direct block cokriging.

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Results & Conclusions

Warning: Discretisation of the cut-off is a critical parameter of the UC/LMUC quality

22 cut-offs between
50 & 70%

41 cut-offs between
50 & 70%

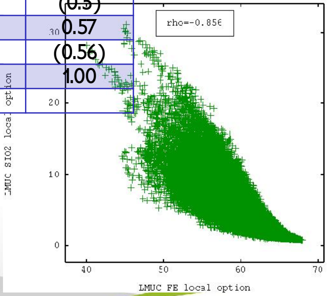
Results & Conclusions

The grade tonnage curves obtained from UC and from LMUC grades are the same, with little difference between local and global LUC methods.

Results & Conclusions

The correlations between all variables, including the second variables correctly reproduced (In parenthesis the coefficient of correlation of 3m composites).

VARIABLE	LMUC FE	LMUC SIO2	LMUC P	LMUC AL2O3	LMUC LOI
LMUC FE	1.00	-0.86	-0.28	-0.83	-0.67
		(-0.84)	(-0.27)	(-0.85)	(-0.66)
LMUC SIO2	-0.86	1.00	0.08	0.54	0.31
	(-0.84)		(-0.03)	(0.58)	(0.26)
LMUC P	-0.28	0.08	1.00	0.27	0.45
	(-0.27)	(0.03)		(0.25)	(0.5)
LMUC AL2O3	-0.83	0.54	0.27	1.00	0.57
	(-0.85)	(0.58)	(0.25)		(0.56)
LMUC LOI	-0.67	0.31	0.45	0.57	1.00
	(-0.66)	(0.26)	(0.5)	(0.56)	



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