

Conditional simulation of channelized meandering reservoirs using particle filtering

Les Journées de Géostatistique

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Outline

- 1 Introduction
- 2 Flumy
 - Particle Filtering in Flumy
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- 3 Conclusions
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Introduction

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 - Conditioning data: **Rich data.**
 - Results: **They do not represent the temporal reservoir development.**

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 - Conditioning data: Rich data.
 - Results: They do not represent the temporal reservoir development.
- **Rule-Based Models**
 - Object-Based Models with rules: Boolean Model [Lantuéjoul, 2002], Surface-based Models, etc.
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 - Results: They represent, with some simplifications, the temporal reservoir development

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- **Process-based Models**
 - Conditioning data: Challenge.
 - Result: Reservoirs' development honored.

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- Flumy:[Lopez, 2003][Lopez et al., 2009] Stochastic and process-based reservoir model developed by MINES-ParisTech for channelized meandering systems in fluvial and turbidite environment [Lemay, 2018].

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 - **Aggradation.**
 - **Avulsion.**

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- The current conditional step: **Dynamic Conditioning** [Bubnova, 2018].
- The proposed conditional step: **Particle Filtering**

Flumy: Sequential Approach

- Flumy fills the reservoir model with lithologies, mimicking the main depositional processes in a fluvial context.
- This continuous process from the base to the top of the reservoir can be split into T layers with a fixed thickness.
- Consolidated layer t : $[z_t, z_{t+1}]$. Cannot be reworked.
- **Unconsolidated zone** t : the upper part of the consolidated layer, just below the current topography \rightarrow can be later reworked due to the avulsions and the lateral migration of the channel.
- The simulation can be separated into a series of **depositional sequences**, each one completing the filling of a given layer.

Flumy: Sequential Approach

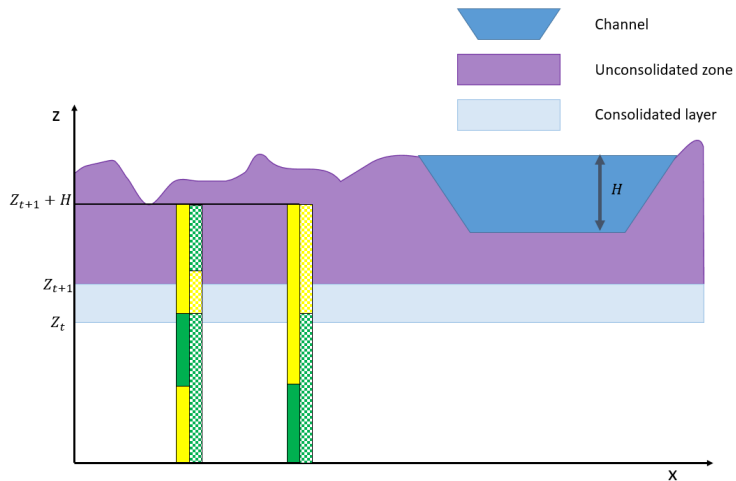


Figure: Sequential definition of Flumy. Well in solid color: Information; well in hatched colors: Cond. Sim. results

Flumy: For the state t : Weighting and Resampling

Weighting

- The weight depends on: Facies match in the consolidated layer and the unconsolidated zone, and the global sand proportion in the consolidated layer.

Resampling

- Residual resampling is used.

Flumy: Conditioning Data

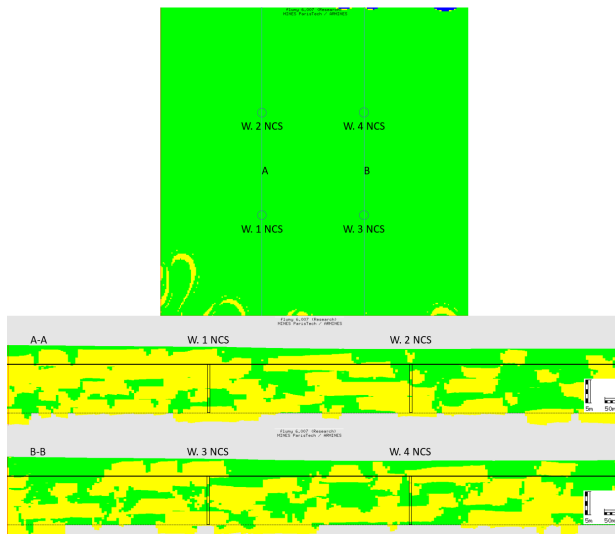
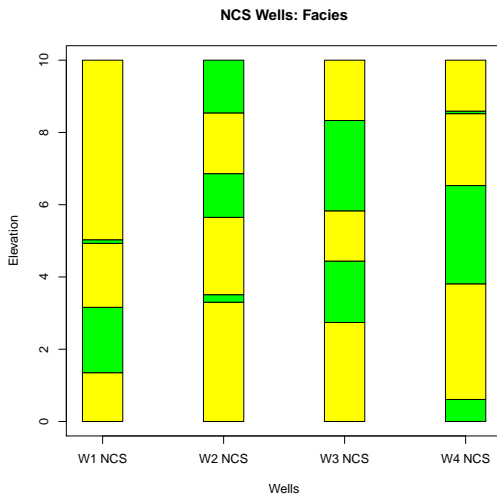
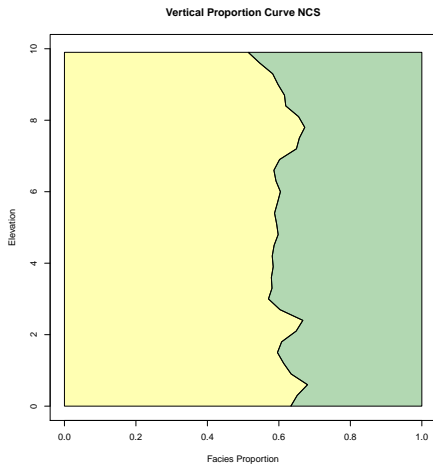


Figure: Flumy Standalone: Non-Conditional Simulation (NCS)

Flumy: Conditioning Data



Flumy: Conditional Data: R



Result of Simulation: Particle Tree

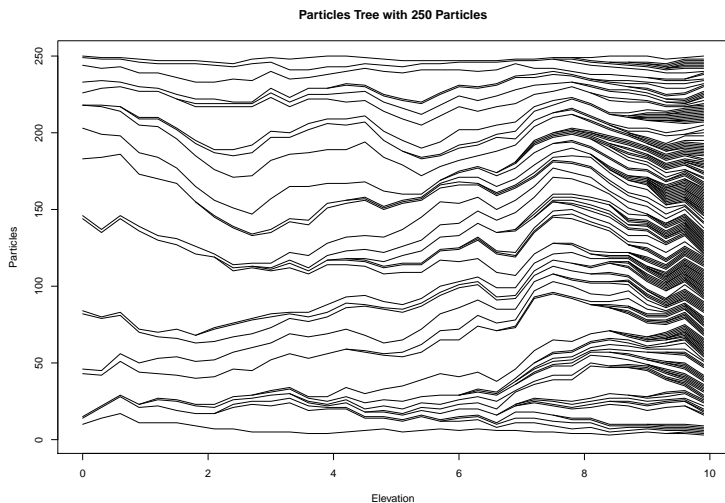


Figure: Particle Tree

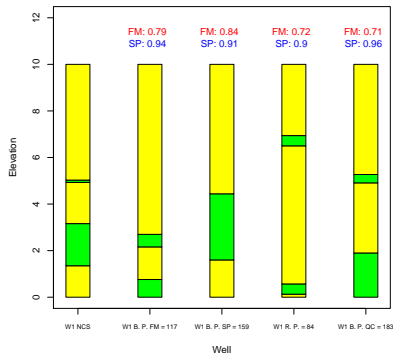
Criteria for the Final Selection

All the particles are candidates to be the channelized meandering reservoir simulation. However, different criteria can be taken on account to choose the particle.

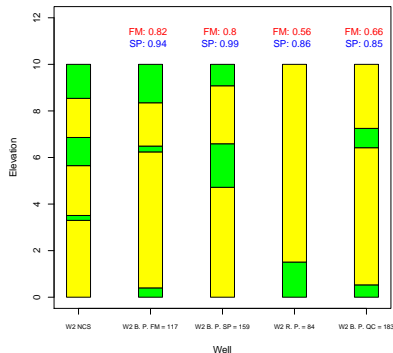
- Random (**R**): One particle is chosen randomly, since all of them have the same probability of being a simulation candidate.
- Best Facies Match (**FM**): The particle that posses the higher facies match in mean related to the data.
- Best Sand Proportion Match (**SP**): The particle that posses the higher sand proportion match in mean related to the data.
- Best Global Sand proportion Match (**QC**): The particle that posses the higher global sand proportion match in mean related to the data.

Example of Conditional Simulation

Comparison Well 1 Facies: $\alpha = 0.5$, $\beta = 0.5$, $\gamma = 0$, $\mu = 1$, $K = 250$

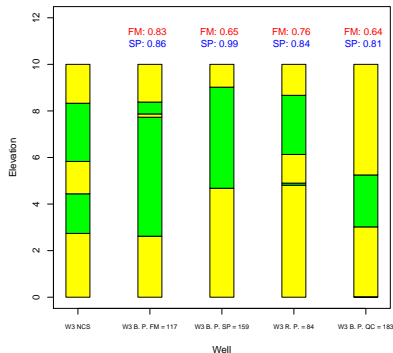


Comparison Well 2 Facies: $\alpha = 0.5$, $\beta = 0.5$, $\gamma = 0$, $\mu = 1$, $K = 250$

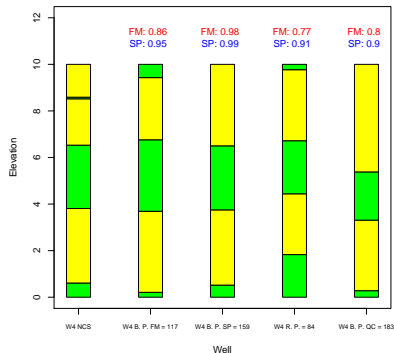


Example of Conditional Simulation

Comparison Well 3 Facies: $\alpha = 0.5$, $\beta = 0.5$, $\gamma = 0$, $\mu = 1$, $K = 250$

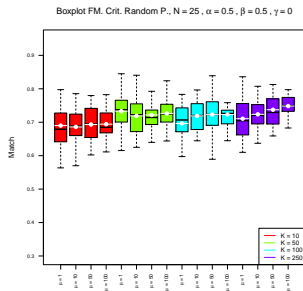
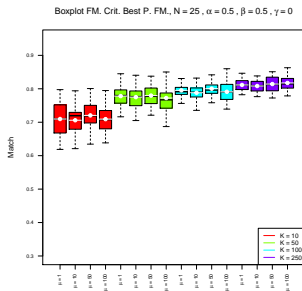


Comparison Well 4 Facies: $\alpha = 0.5$, $\beta = 0.5$, $\gamma = 0$, $\mu = 1$, $K = 250$



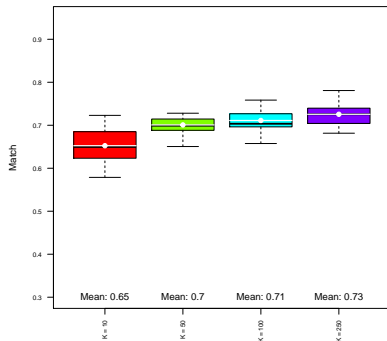
Measuring the Uncertainty

- Is one realization of particle filtering enough to measure the result quality?
- Measuring the uncertainty of the results $\rightarrow N = 25$ independent simulations are performed.
- Best P. FM. and Random P. are shown for a fix the influence of the unconsolidated zone:

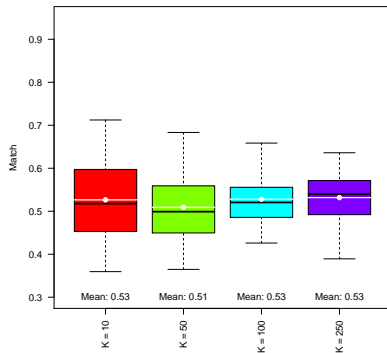


Conditional Simulation: NCS

Boxplot FM. Crit. Best P. FM., N = 25 , NCS



Boxplot FM. Crit. Random P., N = 25 , NCS



Conclusions

- The algorithm has been designed to respect the facies along wells and the global sand proportion.
- There is a vast choice in the implementation of the particle filtering regarding the parametrization of the different factors that specify the weights, the resampling technique and the selection of the final particle.
- It is not clear the influence of the unconsolidated zone in the results.

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Annexes

Flumy: Weight Step

$$PC_{t,j}^{(k)} = \frac{\int_{z_t}^{z_{t+1}} \mathbf{1}_{F_j(z)=F_j^{(k)}(z)} dz}{\int_{z_t}^{z_{t+1}} dz} \quad (1)$$

$$PNC_{t,j}^{(k)} = \frac{\int_{z_{t+1}}^{z_{t,j}} e^{-\mu * R[z-z_{t+1}]} \mathbf{1}_{F_j(z)=F_j^{(k)}(z)} dz}{\int_{z_{t+1}}^{z_{t+1}+H} e^{-\mu * R[z-z_{t+1}]} dz} \quad (2)$$

$$QC_t^{(k)} = 1 - \left| GPC_t - GPC_t^{(k)} \right| \quad (3)$$

- $j \in J$: Well;
- μ : Influence factor from the unconsolidated zone;
- $R = \frac{R_{migg}}{R_{agg}}$: Ratio

Flumy: Weight Step; Unconsolidated Layer

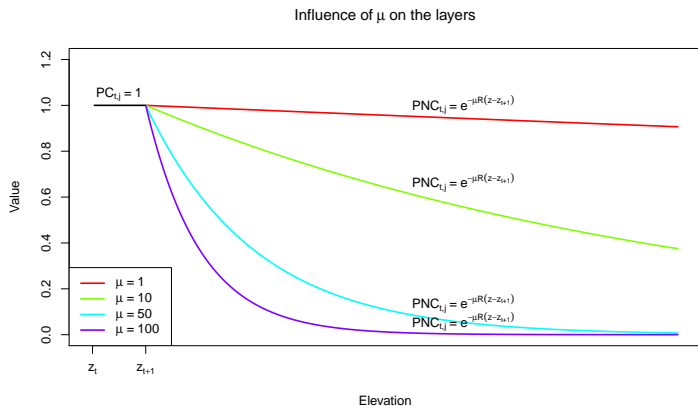


Figure: Sequential definition of Flumy. Well in solid color: Information; well in hatched colors: Cond. Sim. results

Flumy: Weight Step

Grouping the wells:

$$PC_t^{(k)} = \frac{\sum_{j=1}^J PC_{t,j}^{(k)}}{J}; PNC_t^{(k)} = \frac{\sum_{j=1}^J PNC_{t,j}^{(k)}}{J} \quad (4)$$

Calculating the weight of each particle at each stage t :

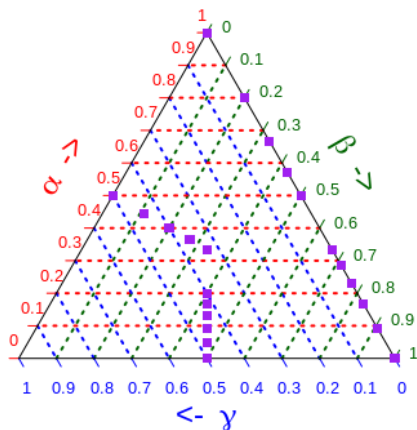
$$\omega_t^{(k)} = \frac{\alpha * PC_t^{(k)} + \beta * PNC_t^{(k)} + \gamma * QC_t^{(k)}}{\sum_{k'}^K \alpha * PC_t^{(k')} + \beta * PNC_t^{(k')} + \gamma * QC_t^{(k')}} \quad (5)$$

With the graphical condition :

$$\alpha + \beta + \gamma = 1$$

Flumy: Conditional Simulation: α, β and γ

Ternary Plot: Example



Parameters		
α	β	γ
1,000	0,000	0,000
0,500	0,000	0,500
0,800	0,200	0,000
0,444	0,111	0,444
0,667	0,333	0,000
0,400	0,200	0,400
0,571	0,429	0,000
0,364	0,273	0,364
0,000	1,000	0,000
0,000	0,500	0,500
0,091	0,909	0,000
0,048	0,476	0,476
0,167	0,833	0,000
0,091	0,455	0,455
0,231	0,769	0,000
0,130	0,435	0,435
0,286	0,714	0,000
0,167	0,417	0,417
0,333	0,667	0,000
0,200	0,400	0,400
0,500	0,500	0,000
0,333	0,333	0,333

Figure: Ternary Plot:

Criteria for The final Selection

4 Criteria:

- Random (R):
- Best Facies Match (FM):

$$PC_j^{(k)} = \frac{\int_0^{z_{lim}^1} F_j(z) = F_j^{(k)}(z) dz}{z_{lim} - 0} \rightarrow \max_{\{k \in K\}} \frac{\sum_{j=1}^J PC_j^{(k)}}{J}$$

- Best Sand Proportion Match (SP):

$$SP_j^{(k)} = 1 - \left| \frac{\int_0^{z_{lim}^1} F_j^{(k)}(z) = SB dz - \int_0^{z_{lim}^1} F_j(z) = SB dz}{z_{lim} - 0} \right| \rightarrow \max_{\{k \in K\}} \frac{\sum_{j=1}^J SP_j^{(k)}}{J}$$

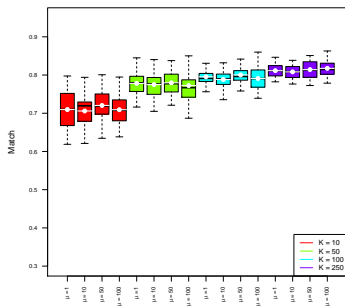
- Best Global Sand Proportion Match (QC):

$$\max_{\{k \in K\}} \sum_{t=1}^T (QC_t^{(k)})^2$$

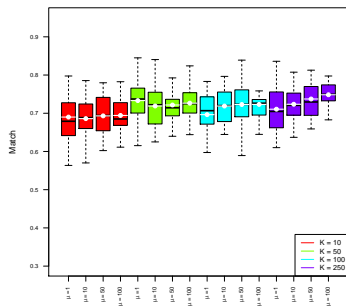
Measuring the Uncertainty

- Is one realization of particle filtering enough to measure the result quality?
- Solution: Measuring the uncertainty $\rightarrow N = 25$ Independent simulations are performed for each parameter combination.
- Best P. FM. and Random P. are shown for a fix α, β and γ :

Boxplot FM. Crit. Best P. FM., $N = 25$, $\alpha = 0.5$, $\beta = 0.5$, $\gamma = 0$

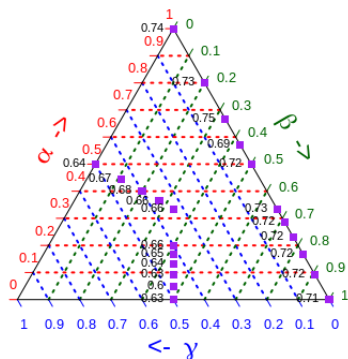
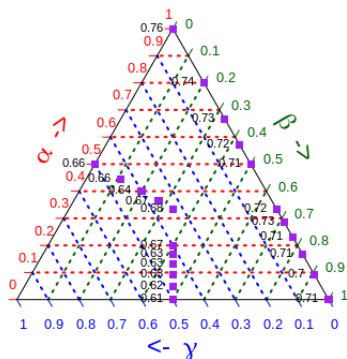


Boxplot FM. Crit. Random P., $N = 25$, $\alpha = 0.5$, $\beta = 0.5$, $\gamma = 0$



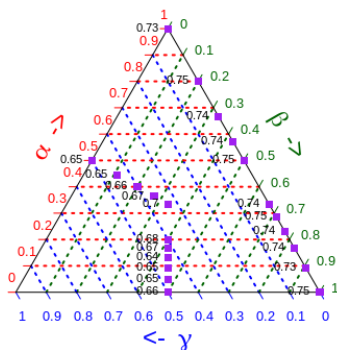
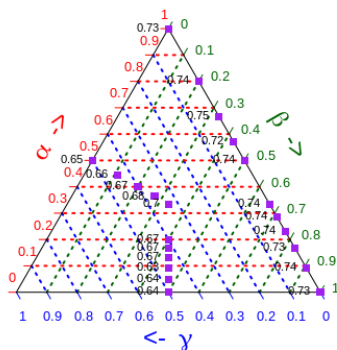
Measuring the uncertainty: Random P.

Ternary Plot FM., Random P., $\mu = 1$, $K = 250$ Ternary Plot FM., Random P., $\mu = 10$, $K = 250$



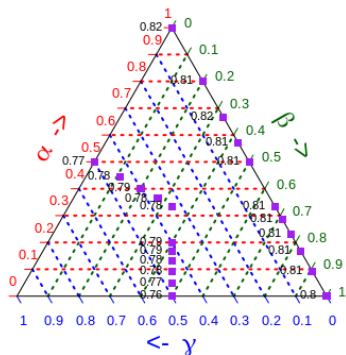
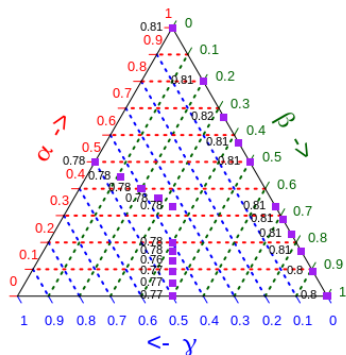
Measuring the uncertainty: Random P.

Ternary Plot FM., Random P., $\mu = 50$, $K = 250$ Ternary Plot FM., Random P., $\mu = 100$, $K = 250$



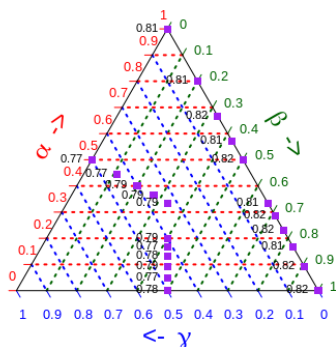
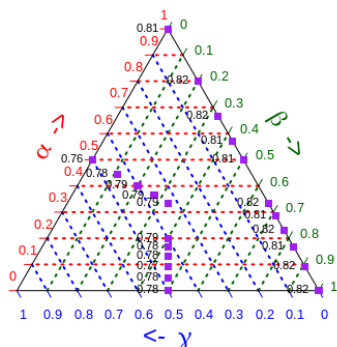
Measuring the uncertainty: Best P. FM.

Ternary Plot FM., Best P. FM., $\mu = 1$, $K = 250$ Ternary Plot FM., Best P. FM., $\mu = 10$, $K = 250$



Measuring the uncertainty: Best P. FM.

Ternary Plot FM., Best P. FM., $\mu = 50$, $K = 250$ Ternary Plot FM., Best P. FM., $\mu = 100$, $K = 250$

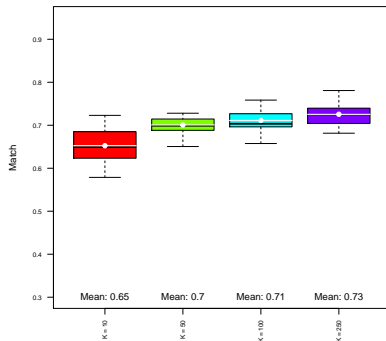


Conditional Simulation: NCS and DCS

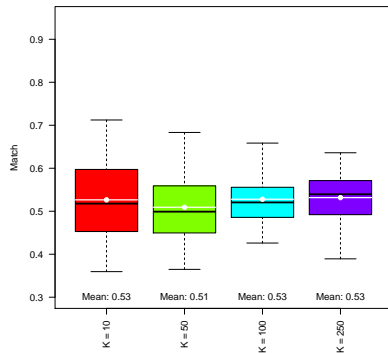
- By the principle of the sequential simulation.
 - One layer is built: $[0, 10][m]$, no resampling.
 - Each particle: NCS (Non-conditional simulation) and DCS (dynamic conditional simulation).
- The conditional results can be compared.

Conditional Simulation: NCS

Boxplot FM. Crit. Best P. FM., N = 25 , NCS

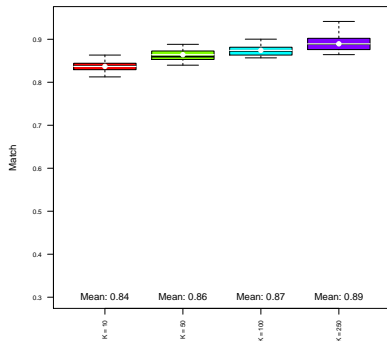


Boxplot FM. Crit. Random P., N = 25 , NCS

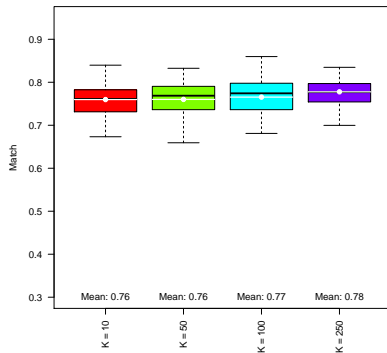


Conditional Simulation: DCS

Boxplot FM. Crit. Best P. FM., N = 25 , DCS

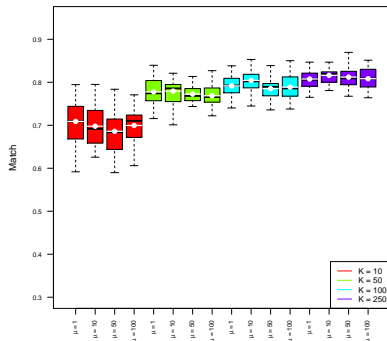


Boxplot FM. Crit. Random P., N = 25 , DCS

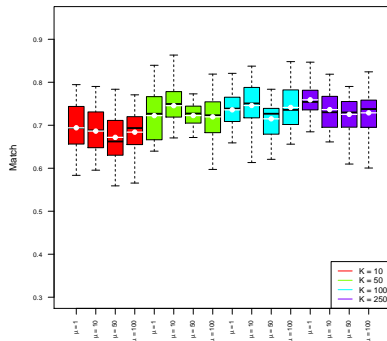


Conditional Simulation: $\alpha = 1, \beta = 0$ and $\gamma = 0$

Boxplot FM. Crit. Best P. FM., $N = 25, \alpha = 1, \beta = 0, \gamma = 0$



Boxplot FM. Crit. Random P., $N = 25, \alpha = 1, \beta = 0, \gamma = 0$



Flumy: Dynamic Conditioning: Flumy Standalone

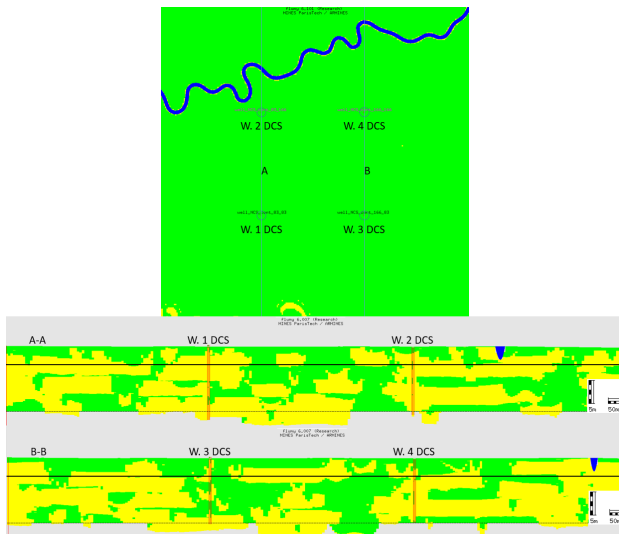


Figure: Flumy Standalone: Dynamic Conditional Simulation (DCS)