

# Geostatistical History Matching coupled with Adaptive Stochastic Sampling

A Geologically consistent approach using Stochastic Sequential Simulation

Eduardo Barrella Nº 79909

Project Thesis Presentation

MSc in Petroleum Engineering – 2015/2016



TÉCNICO  
LISBOA



# Outline

• History-matching .....	3
• Proposed Project .....	9
• Methodology .....	11
• Results.....	19
• Closing Remarks.....	29

# History Matching

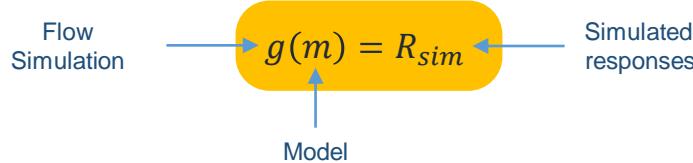
- Integral part of the reservoir modeling workflow
- The reservoir model is used to predict fluid flow and make decisions
- Reliable if it respects the data already collected
- Production data  $\Rightarrow$  Production history
- Matching of production data  $\Rightarrow$  History Matching



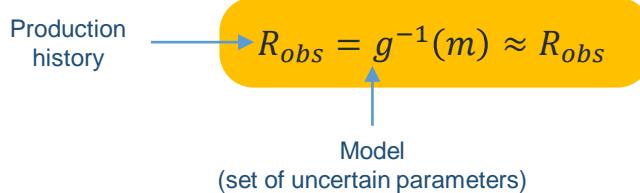
Comparison of production data with simulated responses

# History Matching

- Forward problem

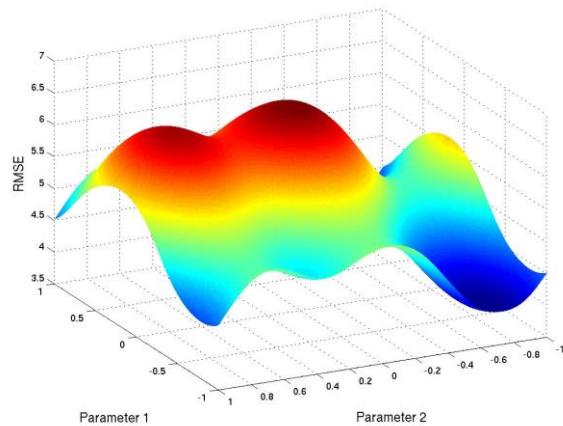


- Inverse problem



# History Matching

- Non linear problem



Parameter Optimization



Dynamic response

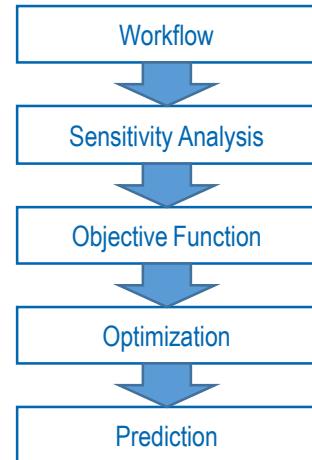
This relationship can depend on:

- Type of perturbation
- Observed production data
- Scale of the problem
- Local and global phenomena
- Geologic traits, etc.

# History Matching

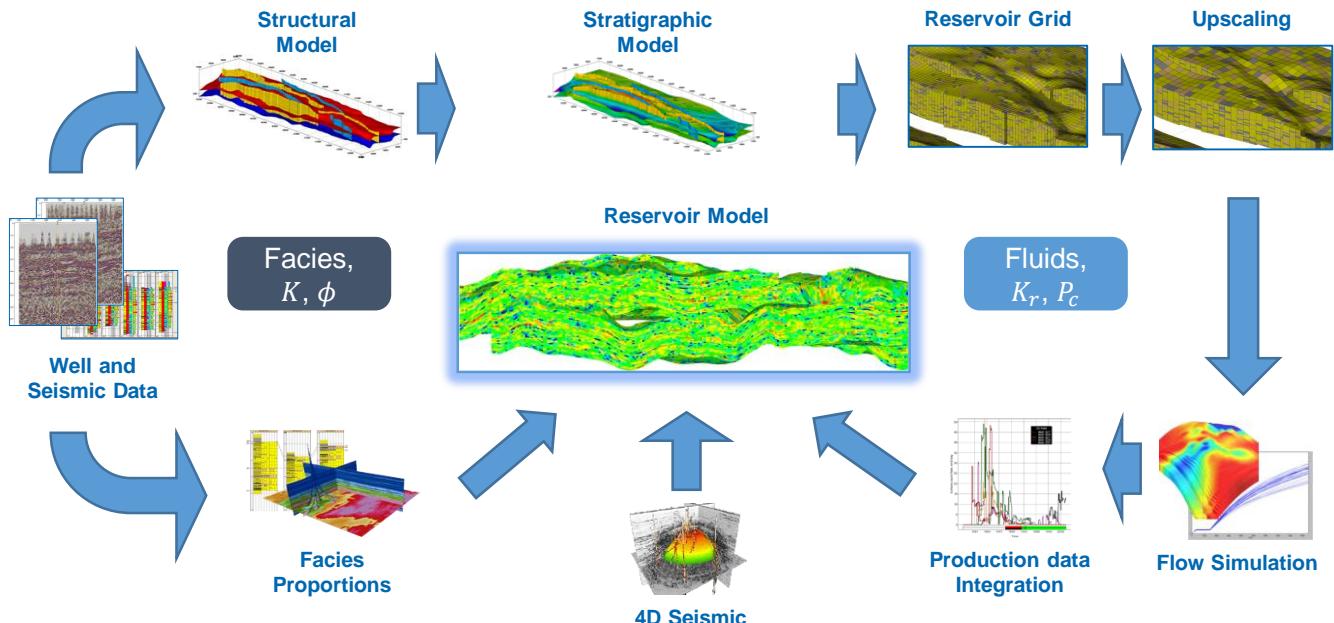
## Modern history-matching (general approach)

- 1) Definition of the forward modeling workflow
  - 2) Definition of an objective function
  - 3) Identification of the most influential uncertain parameters
  - 4) Minimization of the objective function by calibrating the selected parameters
  - 5) Prediction
- The final solution is a distribution that is usually unachievable simply by using reservoir engineering knowledge



# History Matching

## Definition of the geo-modeling workflow



# Watt Field Case Study

## Watt Field Case Study:

Considers interpretational uncertainty integrated throughout the reservoir modelling workflow (multi-level uncertainty).

- Interpretational choices:

- Grid resolution
- Top structure seismic interpretation
- Fault network definition
- Facies cutoff values
- Facies modelling approach
- Relative permeability data

Model property	Description	File name	
Grid	100 m by 100 m by 5 m	G-1	Total of 81 different combinations of these properties
	100 m by 100 m by 10 m	G-2	
	200 m by 200 m by 5 m	G-3	
Top Structure	1	TS-1	Total of 81 different combinations of these properties
	2	TS-2	
	3	TS-3	
Fault Model	1	FM-1	Total of 81 different combinations of these properties
	2	FM-2	
	3	FM-3	
Facies Model (Cutoffs)	0.6	CO-1	Total of 81 different combinations of these properties
	0.7	CO-2	
	0.8	CO-3	
Modelling approach			Data is provided for different possible field depositional models based on different outcrop analogues. Data from these sources could be used in the construction of the geological model
Relative permeability data	Coarse sand relperms		RP_0_1
	RP_0_2		RP_0_3
	RP_1_1		RP_1_2
Simulation model	Fine sand relperms		RP_1_3
	100 m by 100 m by 5 m		100 100 5
	100 m by 100 m by 10 m		100 100 10
			200 200 5

# Proposed Project

Coupling of:

**Geostatistical History  
Matching with geologically  
consistent zonation**

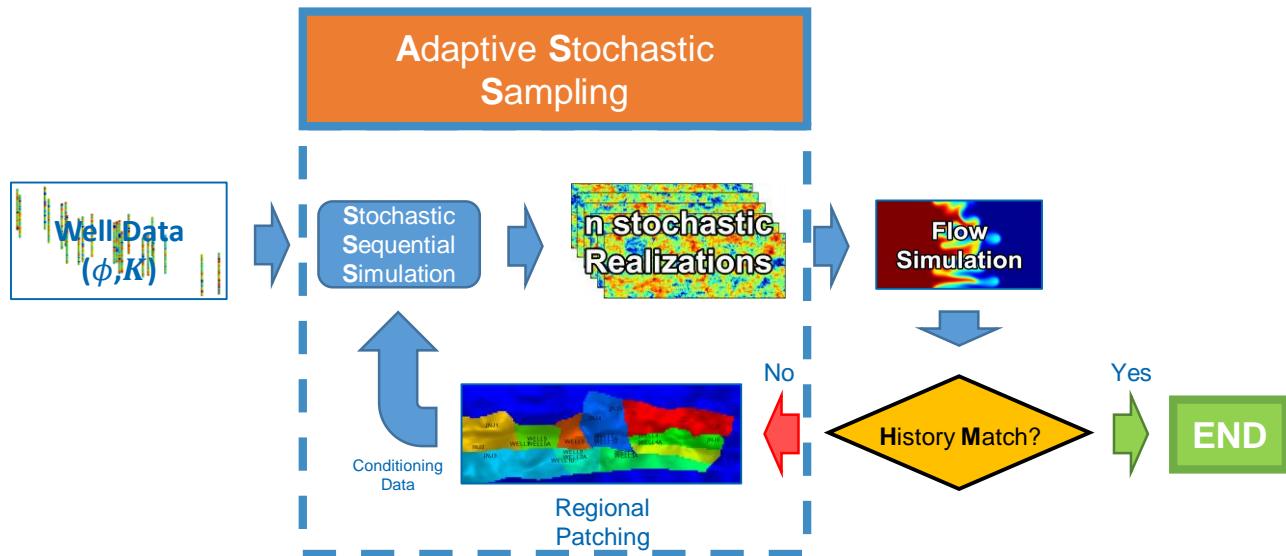


**Adaptive Stochastic  
Sampling**

- Addresses local matching of the well data
- Geologically consistent zonation methodology, exploring the value in fault zonation
- Avoids geologically unrealistic solutions
- Iterative updating through conditional assimilation constrained to the production data

- Addresses global matching of the well data
- Calibration of geologic uncertain parameters (e.g. variograms, corr. coef.) or relevant engineering parameters (e.g. fault transm)

# Proposed Project

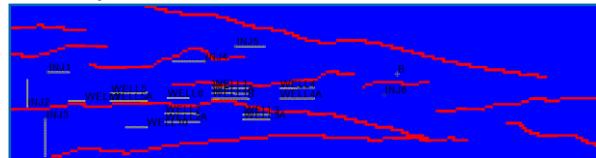


# Methodology

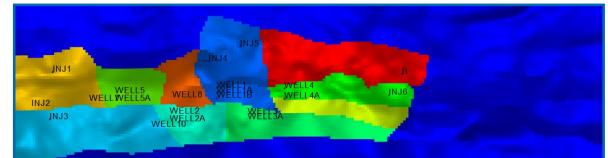
A proposal for geologically consistent zonation on the Watt Field Case Study:

- Fault regionalization and well area of influence

Example: 2D Fault Model-1 cut



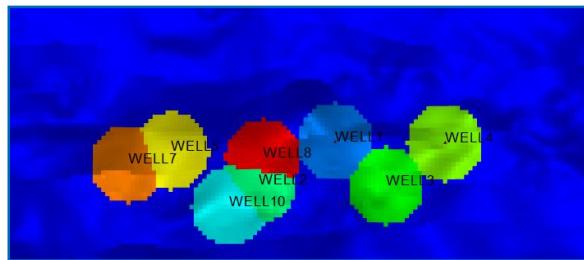
Example: Proposed regionalization



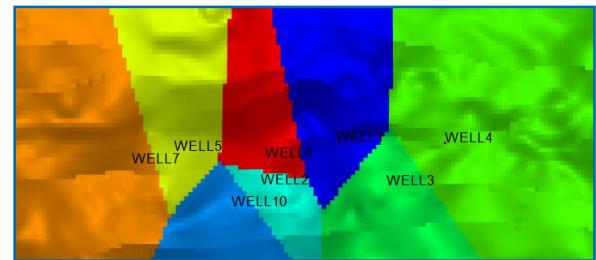
# Methodology

In opposition to standard regionalization methodologies:

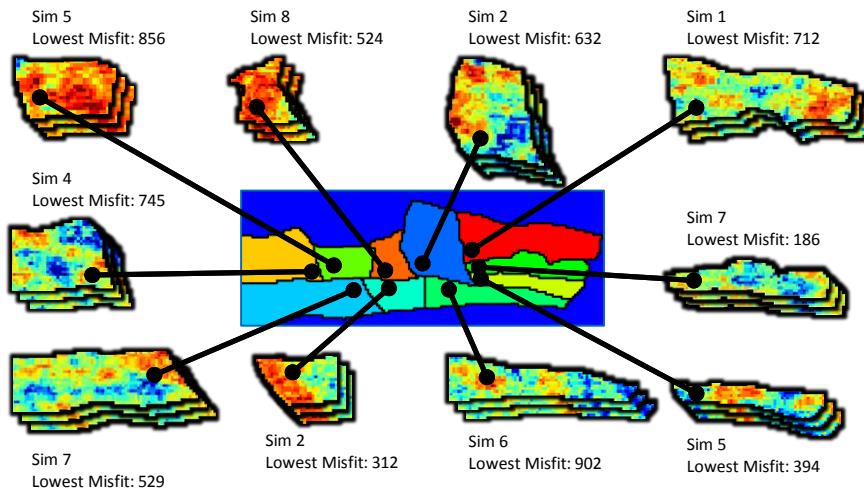
Well radius of influence:



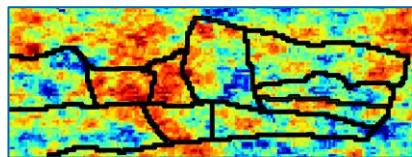
Voronoi Cells:



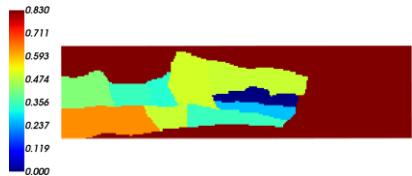
# Methodology



HM model (patch composition):



Correlation Coefficients:

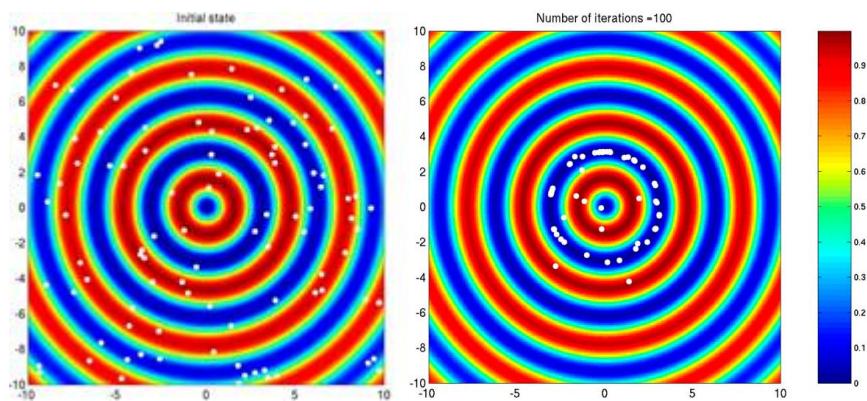
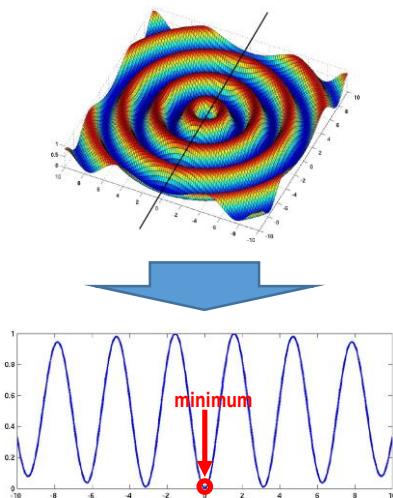


# Methodology

## Particle Swarm Optimization (PSO)

- A set of particles searching for the optimum value
- Each particle has a velocity for browsing the search space
- Each particle remembers its personal best position
- The particles exchange information:
  - Every particle has its own associated neighborhood
  - Every particle knows the fitness of all other particles in its neighborhood
  - Every particle uses the position of the one with best fitness in its neighborhood to adjust its own velocity

# Methodology



# Methodology

## Definition of the Objective Function

- Least-square difference between the dynamic data  $R_{t,obs}$  and the corresponding simulated responses  $R_{t,sim}$

Production history  
at timestep  $t$

$$M = \min \sum_{t=i}^n \frac{(R_{t,obs} - R_{t,sim})^2}{2\sigma^2}$$

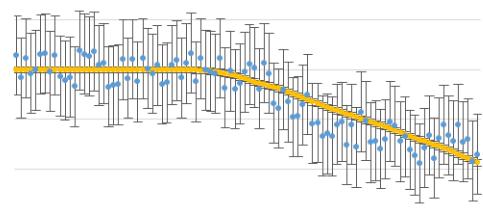
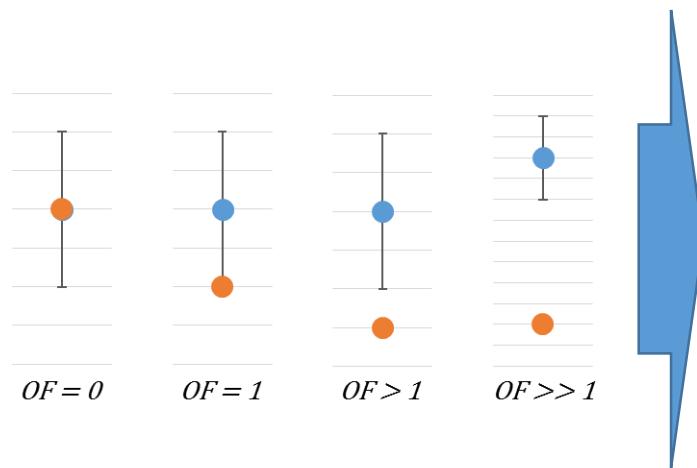
Simulated  
responses  
at timestep  $t$

Measurement error  
in the observed data  
at timestep  $t$

- More parameters than independent data → Ill-posed problem
  - There is no unique solution
  - There may be no solution to the problem
  - The solution is highly sensitive to variations in data

# Methodology

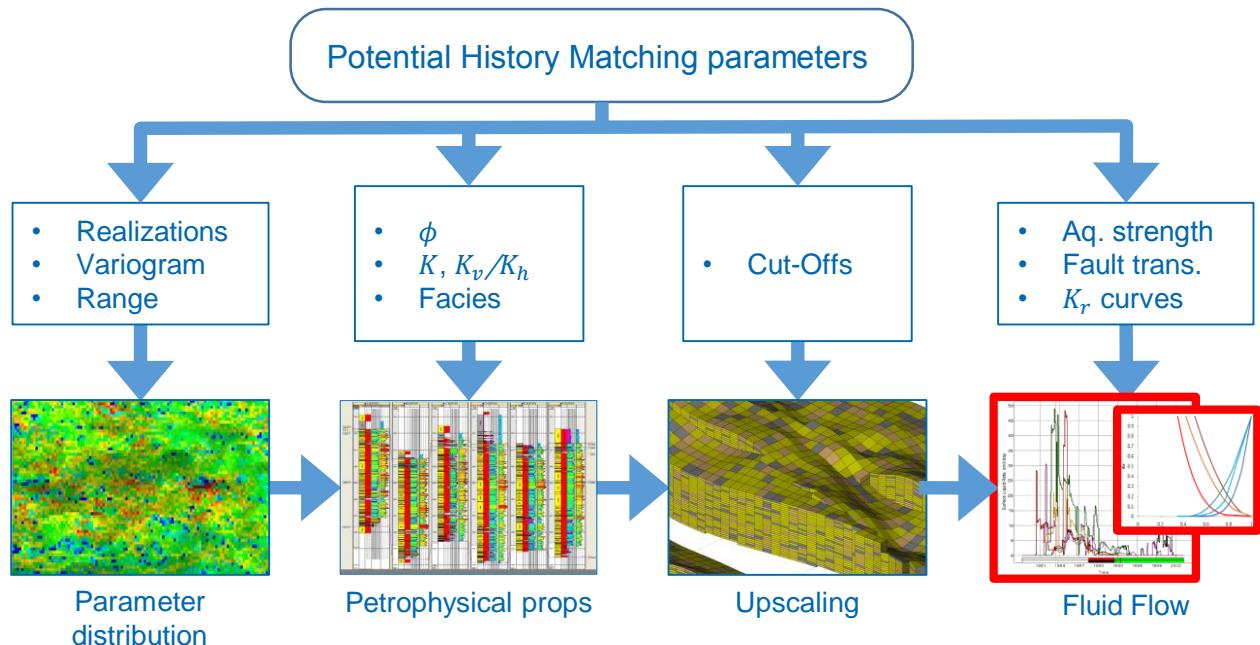
## Definition of the Objective Function



If  $t = 100 \rightarrow M \ll 100$

Immediate measure of mismatch quality

# Methodology

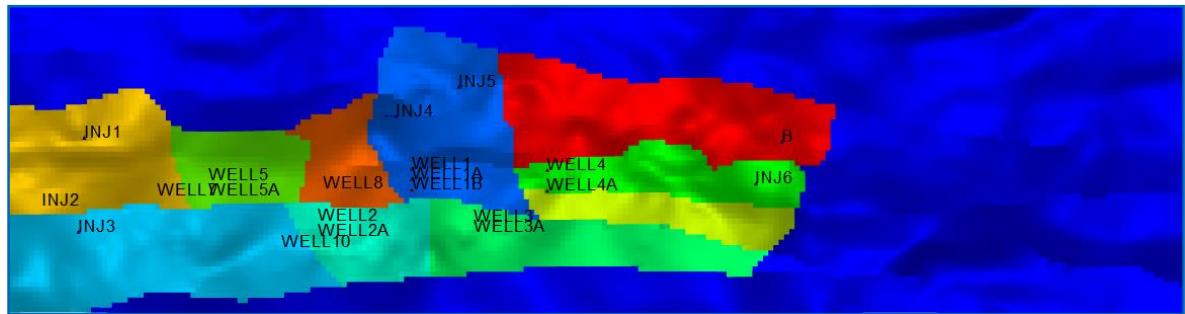


# Results

Demonstration run:

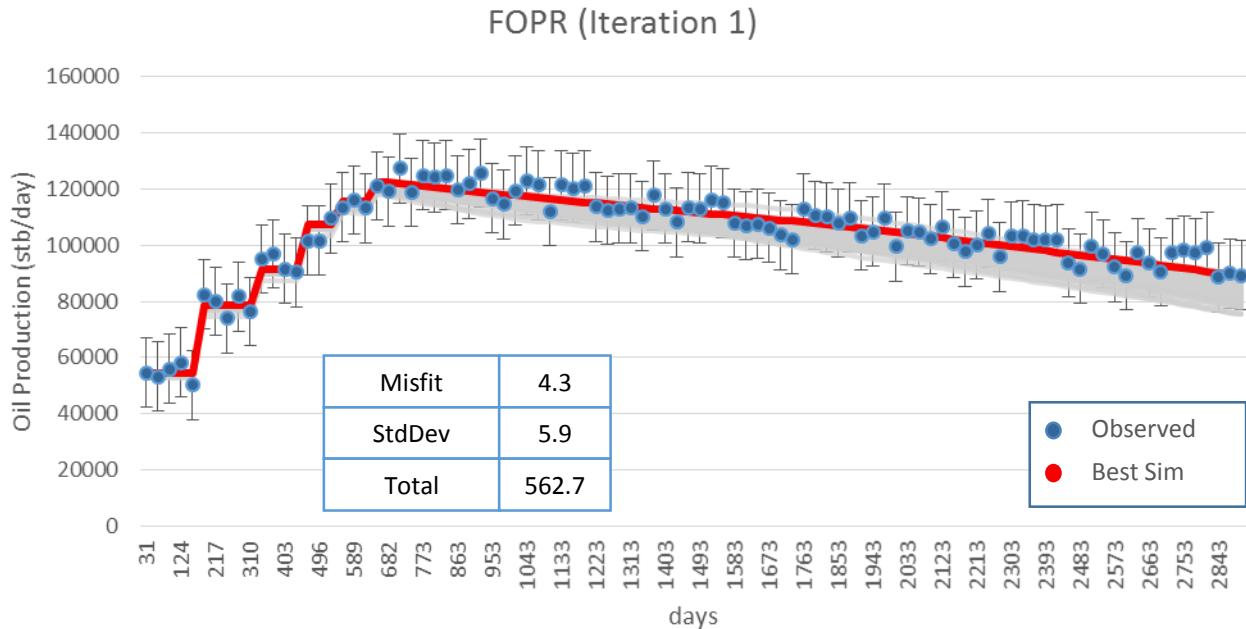
- 11 iterations
- 50 runs
- Perturbed parameters
- $K$ ,  $\phi$ , variogram ranges, Zone correlation coefficients

## Regionalization Method



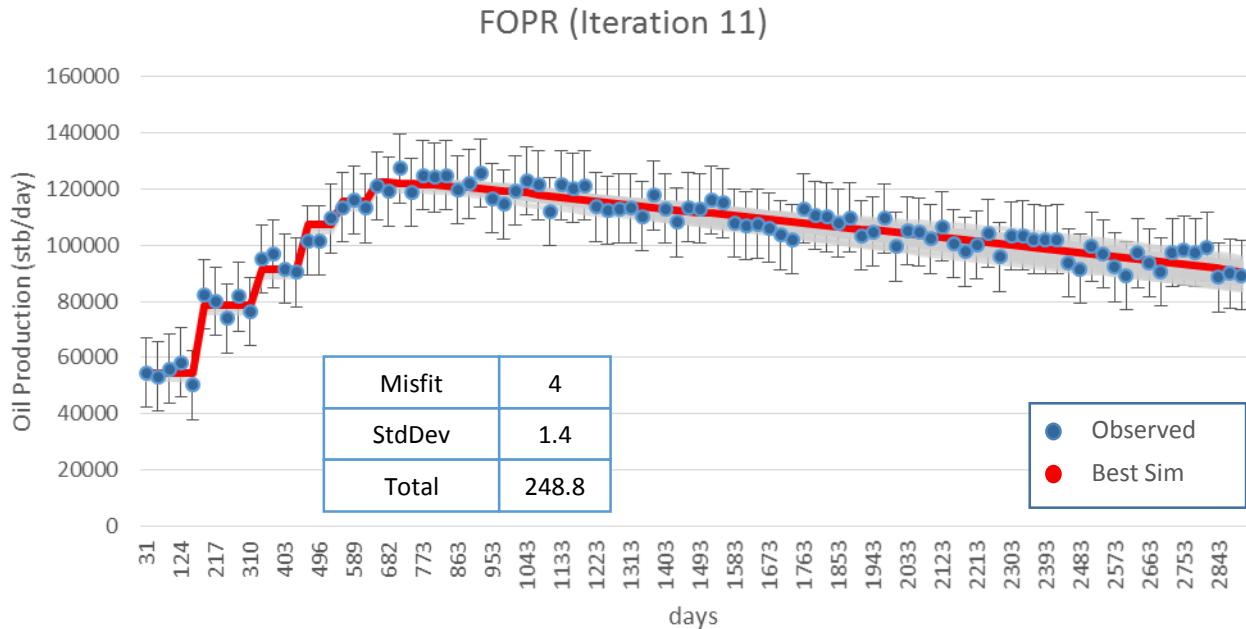
# Results

Misfit evolution of all simulations per iteration:



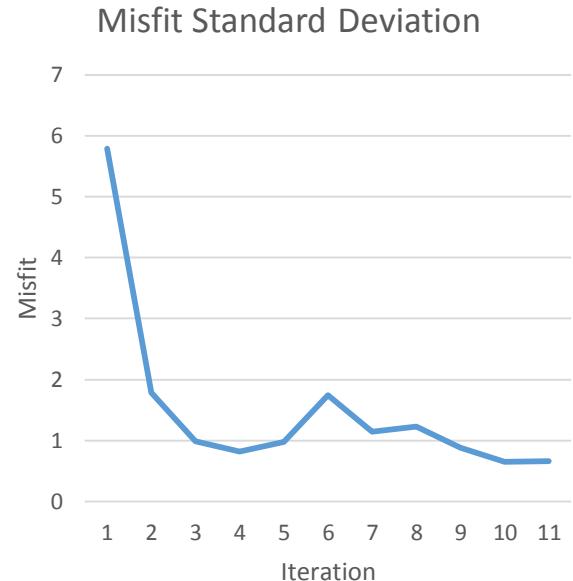
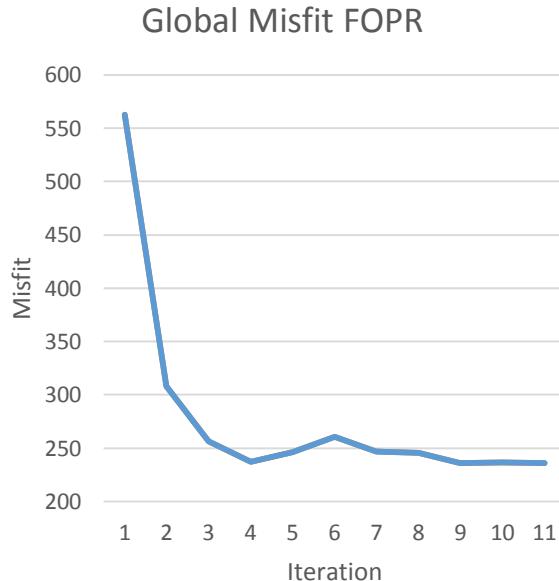
# Results

Misfit evolution of all simulations per iteration:



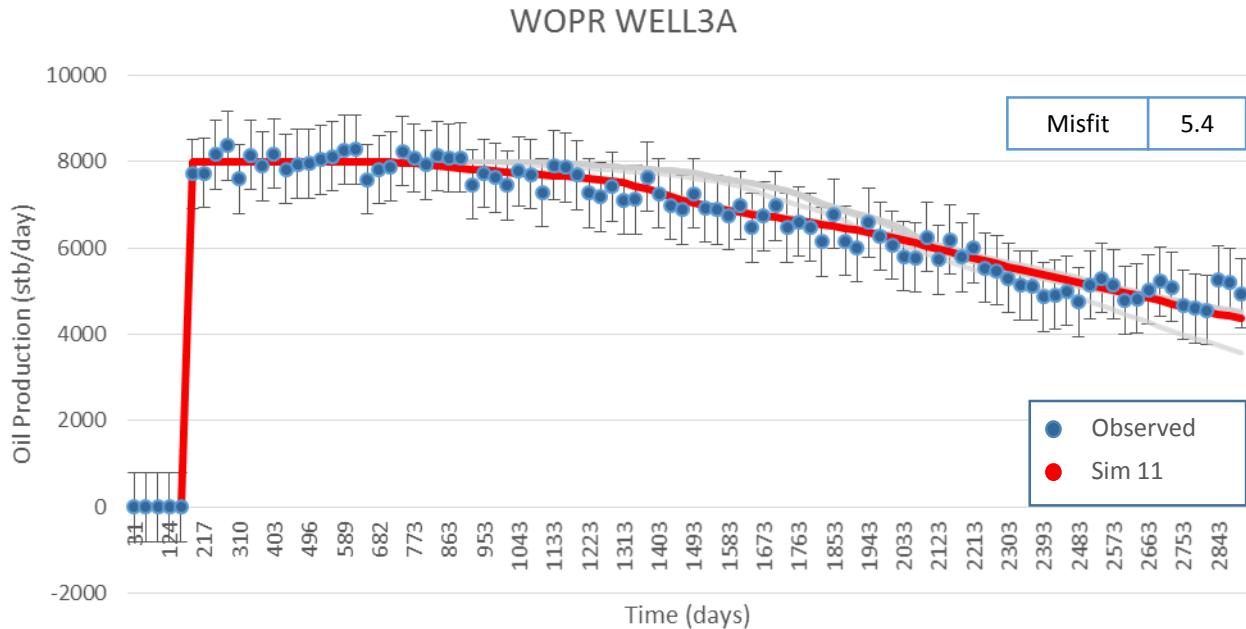
# Results

Misfit convergence per iteration:

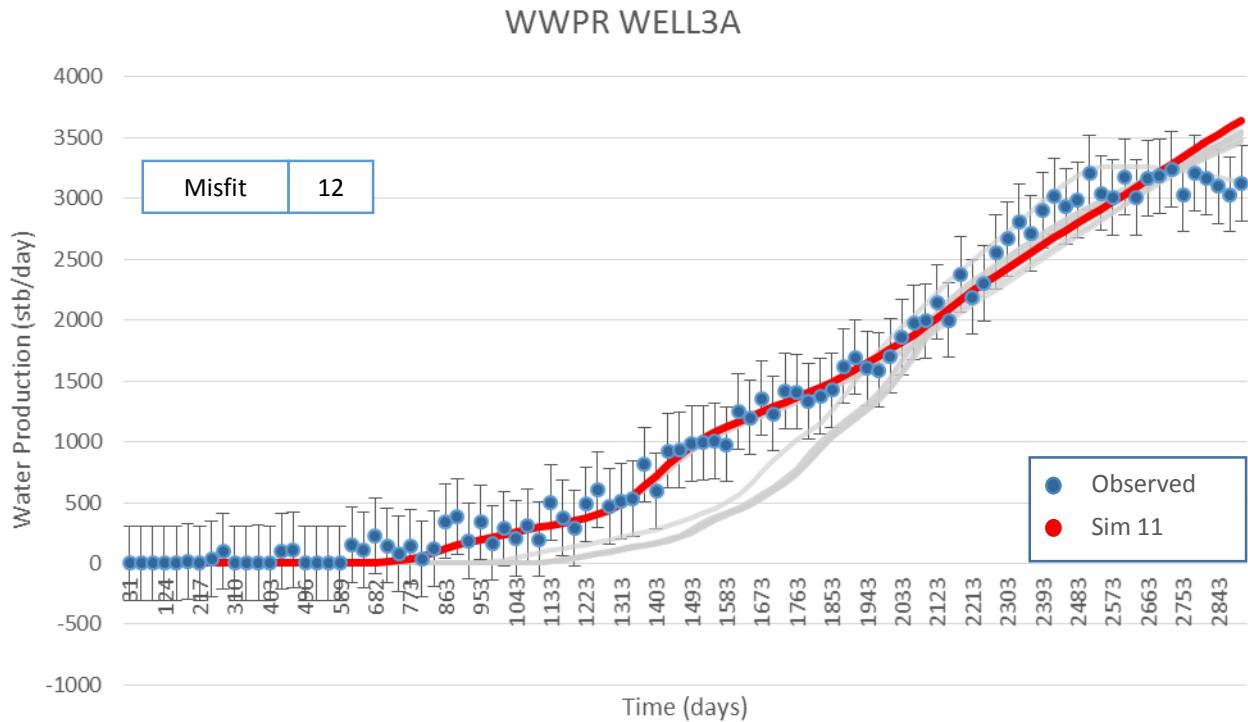


# Results

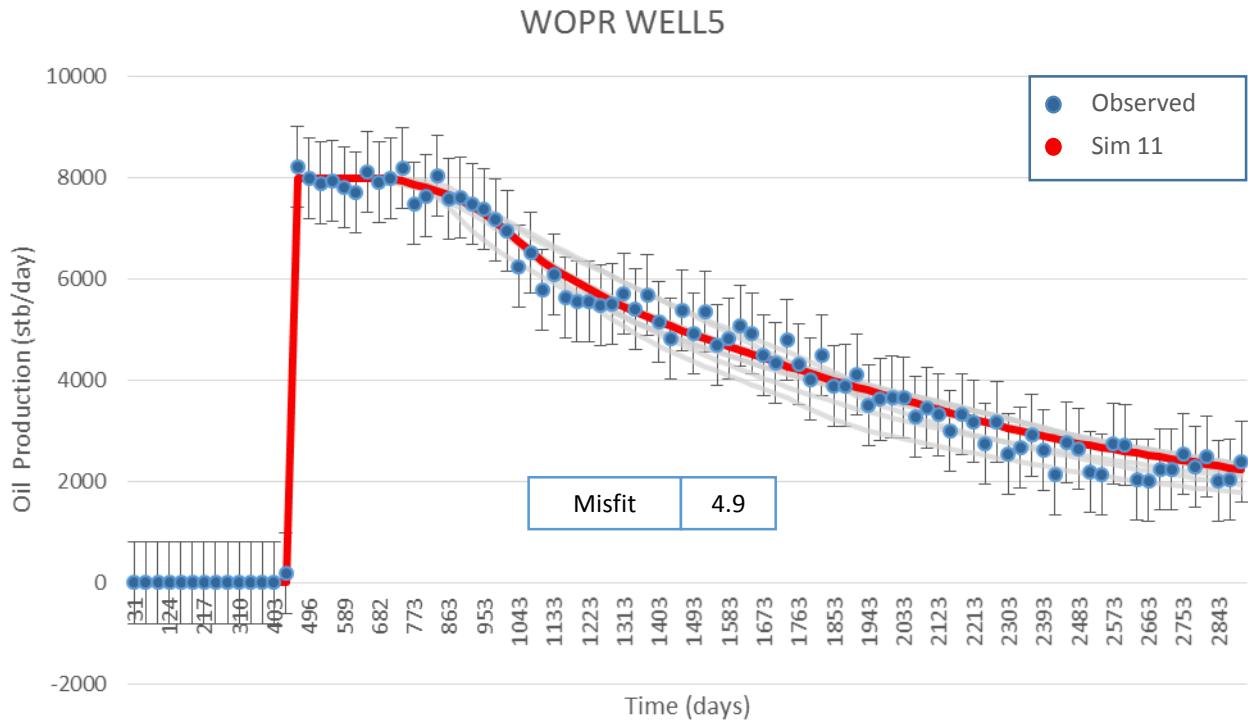
Final models after each iteration:



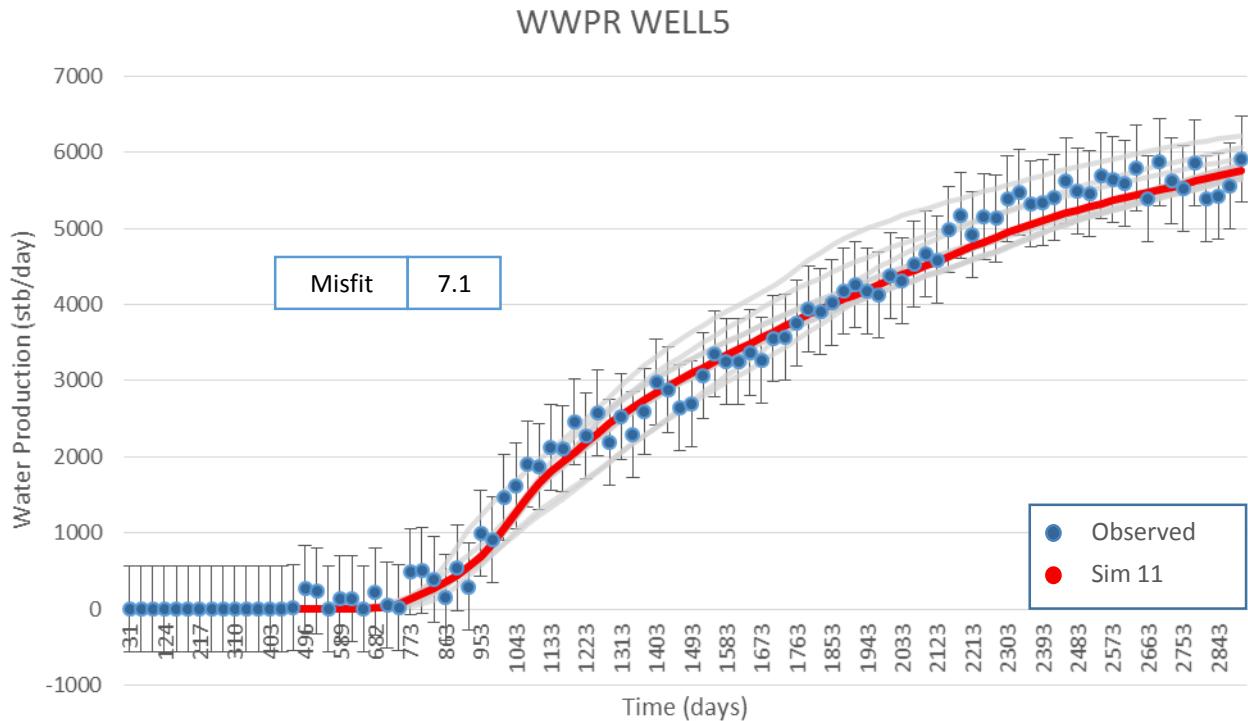
## Results



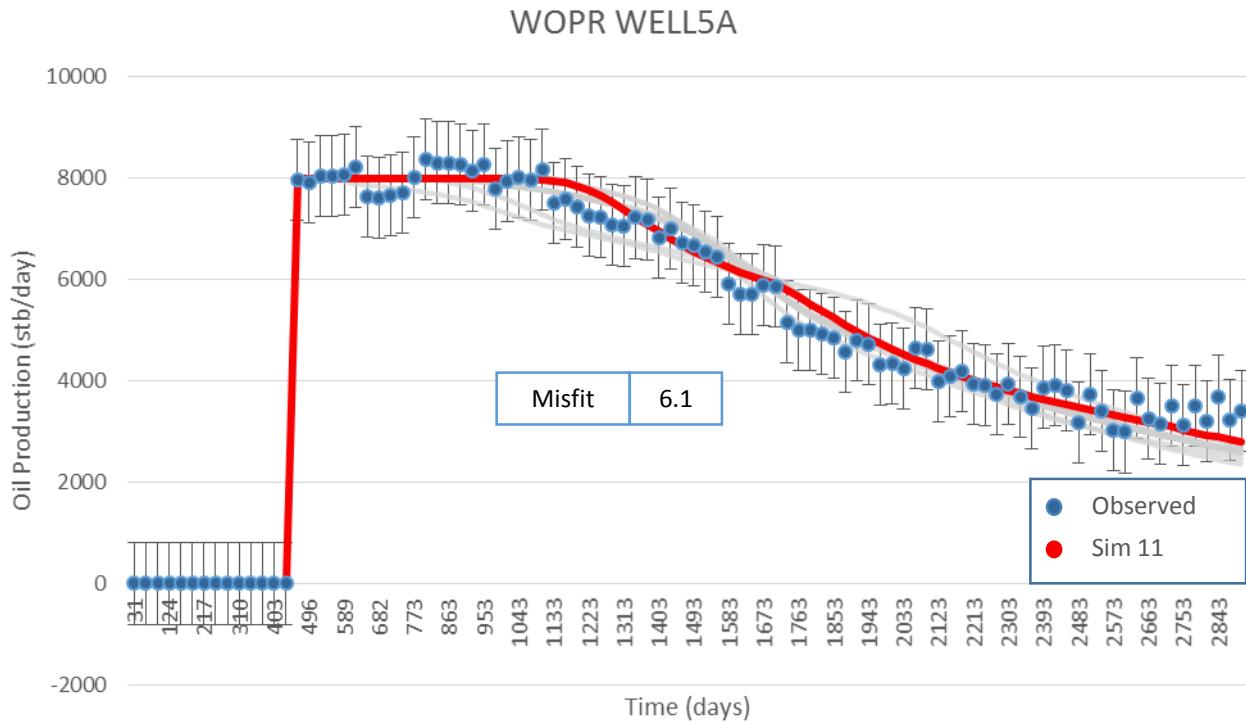
## Results



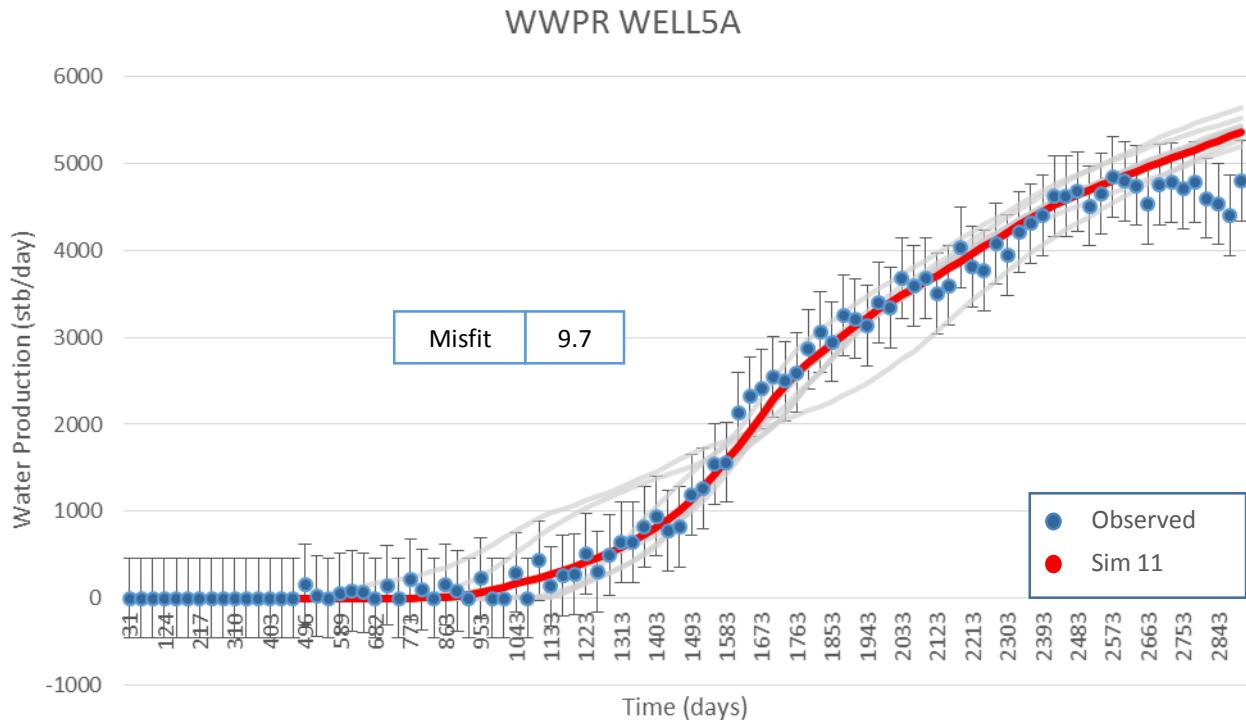
# Results



## Results



## Results



# Closing Remarks

The proposed project is aimed at:

- Coupling of Geostatistical HM and Adaptive Stochastic Sampling Optimization
  - Under a Geological consistent perturbation methodology
  - Exploring the value of fault zonation versus other zonation methods
  - Using an evolving geostat correlation coefficient, considering the match quality of each individual zone
- Matching geological parameters locally, through geostatistical assimilations by iterative soft conditioning
- Calibrating geological and engineering parameters globally, through adaptive stochastic sampling

# References

- Arnold, D., Demyanov, V., Tatum, D., Christie, M., Rojas, T., Geiger, S., & Corbett, P. (2013). Hierarchical benchmark case study for history matching, uncertainty quantification and reservoir characterisation. *Computers and Geosciences*, 50, 4–15. <http://doi.org/10.1016/j.cageo.2012.09.011>
- Caeiro, M. H., Demyanov, V., Christie, M., & Soares, A. (2012). Uncertainty Quantification for History-Matching of Non-Stationary Models Using Geostatistical Algorithms. *Proceedings Geostats 2012*, 1–15.
- Hajizadeh, Y., Demyanov, V., Mohamed, L., & Christie, M. (2011). Comparison of Evolutionary and Swarm Intelligence Methods for History Matching and Uncertainty Quantification in Petroleum Reservoir Models. *Intelligent Computational Optimization in Engineering*, 209–240. [http://doi.org/10.1007/978-3-642-21705-0\\_8](http://doi.org/10.1007/978-3-642-21705-0_8)
- Mata-lima, H. (2008). Reducing Uncertainty in Reservoir Modelling. *Oil Gas European Magazine*, 2.
- Soares, A. (2001). Direct Sequential Simulation and Cosimulation. *Mathematical Geology*, 33(8), 911–926. <http://doi.org/10.1023/A:1012246006212>

# Acknowledgements

