Multi-Scale Geostatistical History Matching using Block-DSS and Uncertainty Quantification

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Outline

Introduction
  • Proposed Work. Theoretical Concepts

Multiscale Geostatistical History Matching
  • MSGHM. MSGHMEA. Case Study

Uncertainty Quantification – Work In Progress
  • Particle Swarm Optimisation. Case Study

Conclusions
  • Conclusions
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Challenge

Reservoir modelling conditioning to dynamic data and well log data:

- Modelling the geological properties conditioned to production data
- Very time-consuming
- Provides a better reservoir knowledge
- Essential to investment decisions

CPU time demanding

Flow Sim. 2 hours

RUN A LOT

Improve efficiency

DSS + Flow Sim. 0.50 sec

RUN A LOT

Block-DSS + Flow Sim. 2 hours

RUN A FEW
Project Contribution

• Build a 3D high resolution model:
  • conditioned to the known data, dynamic data and well log data
  • faster and with accuracy
  • uncertainty assessment

• Provide a new workflow and a software tool that is able to optimize the 3D model construction in two different scales
Workflow

Coarse Grid

Downscaling

Geost. HM

Fine Grid

Geost. HM

Uncertainty Quantification

Stochastic adaptive sampling, PSO

Stochastic sequential simulation, DSS
Geostatistical History Matching

Mata Lima (2008)

Iteration 1

Hard Data

Spatial Continuity

Direct
Sequential
Simulation

N
simulations

Production
Data

Best Fit Compose Model

Simulated vs Observed

Misfit

3/May/2016
Geostatistical History Matching

Multi-Criteria Objective Function

\[ Misfit = \sum_{i=1}^{N_{wells}} \sum_{j=1}^{N_{variables}} \sum_{k=1}^{N_{time}} \frac{(q_{ijk}^{obs} - q_{ijk}^{sim})^2}{2\sigma^2_{ij}} \]

Local Perturbation

Well P1
Well P2
Well P3
Well P4

Best Fit Composed Model

Well P2

WOPR\textsubscript{sim} | WOPR\textsubscript{obs}
WBHP\textsubscript{sim} | WBHP\textsubscript{obs}
Geostatistical History Matching

Mata Lima (2007)

Iteration 2, 3,...,n

Hard Data

Spatial Continuity

Soft Data

Direct Sequential Simulation

N simulations

Production Data

Best Fit Compose Model

Simulated vs Observed

Direct Sequential Co-Simulation

Best Fit Compose Model used as soft data in the next loop
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Multi-Scale Geostatistical History Matching

Coarse Grid
Geost. HM

Best Fit Coarse Grid Reservoir Model

Downscaling Block-DSS

Geost. HM

Fine Grid

Best Fit Fine Grid Reservoir Model from Block-DSS
Multi-Scale Geostatistical History Matching

![Diagram](image)

**Coarse Grid Model:**
- Hard Data
- Spatial Continuity
- Soft Data

**Iteration 1:**
- Direct Sequential Simulation

**Production Data:**
- Simulated vs Observed

**Best Compose Image:**
- Used as soft data in the next loop

**Iteration 2, 3, ..., n:**
- Production Data

**Best Fine Grid Model:**
- Downscaling Block DSS

**Traditional Geostatistical History Matching:**
- Coarse Grid

3/May/2016

Instituto Superior Técnico
Multi-Scale Geostatistical History Matching

Coarse Grid

Geost. HM

Best Fit Coarse Grid Reservoir Model

Downscaling Block-DSS

Fine Grid

Geost. HM

Best Fit Fine Grid Reservoir Model from Block-DSS
Multi-Scale Geostatistical History Matching

Coarse Grid -> Best Fit Coarse Grid Reservoir Model -> Downscaling Block-DSS -> Best Fit Fine Grid Reservoir Model from Block-DSS

Geost. HM -> Best Fit Coarse Grid Reservoir Model

Fine Grid

Geost. HM
• Stochastic Downscaling

1 Coarse Block  ➔  25 Fine Block

• Simulate models with a high resolution conditioned to low resolution models

• Incorporate information from different scales: Block data and Point data

Covariance Matrix
Best Fit Coarse Grid Reservoir Model

Downscaling Block-DSS

Best Fit Fine Grid Reservoir Model from Block-DSS

Geost. HM

Coarse Grid

Geost. HM

Fine Grid

Best Fit Coarse Grid Reservoir Model
Best Coarse Grid Reservoir Model

Best Fine Grid Reservoir Model from Block-DSS

Downscaling Geostatistical History Matching

Block-Kriging Covariance Matrix

N simulations

Production Data

Misfit

Simulated vs Observed

Best Fine Image from Block-DSS
Block-DSS Liu & Journel (2009)

Coarse Grid

Best Fit Coarse Grid Reservoir Model

Downscaling Block-DSS

Geost. HM

Geost. HM

Fine Grid

Best Fit Fine Grid Reservoir Model from Block-DSS
Case Study: Synthetic 3D Model

Synthetic reservoir

- Five spot
- Sand + Shale
- Aquifer

Well Oil Production Rate

- 5½ years
- Liquid Rate
Case Study: Synthetic 3D Model

Initial Model

100x100x16

Matched Fine Model

100x100x16

Upscaling

300 simulations (1h47)

Coarse Model

20x20x16

Matched Coarse Model

Downscaling

15 simulations (1h34)
MSGHM - Case Study: Coarse Model

- True Model (Permeability)
- True Model (Porosity)

Best Coarse Iteration
- Iteration 30 (Permeability)
- Iteration 30 (Porosity)
MSGHM - Case Study: Fine Model from Block-DSS

- Coarse Model (Permeability)

- Coarse Model (Porosity)

Best Fine Iteration

- Iteration 07 (Permeability)

- Iteration 07 (Porosity)
MSGHM - Case Study: Fine Model from Block-DSS

- True Model (Permeability)
  - Iteration 07 (Permeability)

- True Model (Porosity)
  - Iteration 07 (Porosity)

Best Fine Iteration
- Iteration 07 (Permeability)
- Iteration 07 (Porosity)
Oil Production Rate – Well P3

Bottom Hole Pressure – Well P3
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Uncertainty Quantification

• Assume stationarity and no uncertainty in the geological parameters → huge lack of parameters information
  
  • Spatial continuity of geological properties: porosity and permeability

  • Range = 280 → [200  600]

• Particle Swarm Optimization
Uncertainty Quantification - Workflow

Prior Distributions

Multiscale Geostatistical History Matching

Geological Scenarios

Dynamic Responses

Simulated vs Observed
Coarse Grid

- Variogram angle: [75,90]
- Variogram range:

```
[200,600]
```

Fine Grid

- Variogram angle: [75,90]
- Variogram range:

```
[200,600]
```

```
[50,150][400,1000]
```
UQ – Case Study: Best HM per Well

Oil Production Rate – Well P2

Oil Production Rate – Well P3

Oil Production Rate – Well P4

Oil Production Rate – Well P5
UQ – Case Study: Parameter Evolution through HM

[400, 1000] → 520

[75, 90] → 84
UQ – Case Study: Parameter vs Misfit

[Graph showing scatter plots with data points and regression lines.]

- [200,600] → 280
- [75,90] → 84
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Conclusions

- **Reduces** the over parameterization problem in the fluid flow equations;
- **Faster assimilation** of large scale corrections into history matching;
- The coarse geological **model is retained** through the downscaling step, providing a better initial model for the final adjustment on the fine scale;
- The **downscaling** allows us to characterize the small scale heterogeneity in the fine grid reservoir model and history match it;
Conclusions

• Both results from the fine grid and the coarse grid are consistent with the true model geology;

• The best-fit model is able to reproduce the spatial distribution of the main channels;

• The space of uncertainty is reduced and can be assessed, generating multiple history matched models;
References