Uncertainty quantification of a fractured reservoir using distance-based method and streamline simulation

A Preliminary Study and Future Perspectives

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General Modeling Workflow

1. **Build models**
2. **Learn**
3. **Screen models**
4. **Model refinement**
5. **Model(s) for forecasting**

**Sensitivity Runs**
- Need more runs?
  - **Yes**: Make more models
  - **No**: Model(s) for forecasting

**Model Parameters**

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Can We Do Something New?

- Streamsim is exploring distance-based methods
  - Written workflows which employ distances
- Use distances to explore:
  - Sensitivity analysis
  - Uncertainty quantification
  - History matching
- Application to fractured reservoir
  - (client driven)
Classical Sensitivity Analysis

Regression

\[ y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i \]

Sensitivity of parameters on CumOil
Classical Sensitivity Analysis

Traditional sensitivity analysis:

• Continuous, scalar parameters

• Single response
  • Eg. FOPT @ 10 years

\[ y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i \]
Sensitivity Analysis

Challenges:

• Multiple responses
• Discrete parameters
  • Fault interpretations
  • Facies proportion cubes

• Stochastic “noise” in response
  • Spatial uncertainty
    • Geostatistically-derived properties
Sensitivity Analysis – Alternative?

- Sensitivity analysis in Metric Space - 832 Brugge runs
  - Color separation of runs → sensitive parameter
  - Mixing of colors → insensitive parameter
**Synthetic Test Case**

**Reservoir property**

<table>
<thead>
<tr>
<th></th>
<th>Fracture</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability (md)</td>
<td>10,000</td>
<td>100</td>
</tr>
<tr>
<td>Porosity (fraction)</td>
<td>0.02</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Well condition**

- 5 injection wells / 5 producer
- Constant pressure at injection well: 50,000
- Constant production rate at production well: 10

**Grid system**

- # of grid: 100 x 100 x 1
- $\Delta x = \Delta y = 10$ ft

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DKM Workflow – Fractured Model

Model generation

Streamline simulation (StudioSL, DPSP model)

Distance matrix, \( d \)

Sensitivity (RSM)

ECLIPSE runs (720 DPSP models)

DKM (Distance Kernel Method) Clustering

Error in Quantiles (P10, P50, P90)
**Parameterization**

![Diagram showing two objects, O1 and O2, with parameterization details.

### Table 1. Constraints used in generating the models

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Distribution</th>
<th>Fracture length</th>
<th>Volume proportion</th>
<th>Fracture orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of case</strong></td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td><strong>Input variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density map(Fig 2(b))</td>
<td>Random dist.</td>
<td>Length of $O_1$</td>
<td>0.7: 0.3</td>
<td>Object 1, $O_1$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_{1} = T(15,25,30)$</td>
<td>0.5:0.5</td>
<td>$T(30,60,90)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_{2} = T(3,4,5)$</td>
<td>0.3:0.7</td>
<td>$T(60,90,120)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_{1} = T(25,35,40)$</td>
<td></td>
<td>$T(90,120,150)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_{2} = T(4,5,6)$</td>
<td></td>
<td>$T(120,150,180)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$T(0,90,180)$</td>
</tr>
<tr>
<td><strong>Fixed value</strong></td>
<td></td>
<td></td>
<td>2:1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length of $O_2$</td>
<td>$O_2:O_2 = 2:1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_{1} = T(5,10,20)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_{2} = T(1,2,3)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ratio of $O_1$ and $O_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T(0.5,10)$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Streamline-Based Distance

<table>
<thead>
<tr>
<th>Distance measure</th>
<th>Number of data</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance measure 1</td>
<td>720</td>
<td>0.9703</td>
</tr>
<tr>
<td>Distance measure 2</td>
<td>258840</td>
<td>0.9238</td>
</tr>
<tr>
<td>Distance measure 3</td>
<td>720 x 9</td>
<td>0.9356</td>
</tr>
</tbody>
</table>
For this example, 3DSL is an excellent proxy for Eclipse run
Uncertainty Quantification
Sensitivity to # of Clusters

Examination of 2 different distances
Classical Sensitivity Analysis

- Distribution
- Fracture Size
- Fracture Proportion
- Orientation
Classical Sensitivity Analysis

\[ y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i \]
\[ y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \sum_{j>i} \beta_{ij} x_i x_j \]

<table>
<thead>
<tr>
<th>Input parameter, ( x ) (Indicator in Fig. 10)</th>
<th>Normalized value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution map ((M))</td>
<td>Random map [-1], Density map [+1]</td>
</tr>
<tr>
<td>Length of object 1, ( O_1 ) (( L ))</td>
<td>Small: in Table [-1], Large [+1]</td>
</tr>
<tr>
<td>Volume proportion of fracture ((F))</td>
<td>Fracture volume proportion = (0.3, 0.5, 0.7) = [-1, 0, +1]</td>
</tr>
<tr>
<td>Fracture orientation ((O))</td>
<td>[-1, -0.6, -0.2, 0.2, 0.6, +1]</td>
</tr>
</tbody>
</table>

Sensitivity of parameters on Response

- \( O \)
- \( F \)
- \( L \)
- \( M \)
MDS Plot – Color by Parameter

Fracture Probability Map

Clear separation of points in MDS space

Fracture Size

Overlap of points in MDS space

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Takeaways

• DKM workflow implemented and run for synthetic DPSP case
  • Streamline simulation provided good distance measure
• Presented some general thoughts about sensitivity analysis using MDS space
  • Based upon point “separation” in plot
  • Visual information follows classical analysis