Importance of input error in reservoir simulations

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Outline

1. Project Motivation
2. Reservoir Simulator
3. Accounting for input error in 4D-Var
4. Results
5. Summary
How is oil produced?

With primary recovery oil production is usually less than 30%.
How is oil produced?

Water is injected into the reservoir field to force more oil into production wells.
What mathematics has to do with oil?

A suitable reservoir rock must be porous and permeable
Reservoir Simulator

State vector

- Pressure at time 451.454 days
- Saturation at time 451.454 days

Parameters

- Permeability (log scale)

\[ x_i = M_i(x_{i-1}) \]

where \( x_i = [p_i \ s_i]^T \)

Inputs: prescribed bottom hole pressures and prescribed flow rates
4D Variational Data Assimilation

Cost function in 4D-Var

\[
J(p) = \sum_{i=1}^{n} \left( \frac{(H_i(x_i) - y_i)^{T}}{R_i} \right) \frac{1}{R_i} \left( H_i(x_i) - y_i \right) + \left( p - p_b \right)^{T} B^{-1} \left( p - p_b \right) + \sum_{i=1}^{n} \left( M_i(x_{i-1}) - x_i \right)^{T} Q_i^{-1} \left( M_i(x_{i-1}) - x_i \right)
\]

minimization with constraints:

\[ x_i = M_i(x_{i-1}) + \epsilon \]

CONTROL VARIABLES:
- parameters \( p \) (permeabilities)
- model error \( \epsilon \)
**Twin Experiment**

**The Truth**

One model simulation is generated, **SAVED** and called **THE TRUTH**.

**Observations**

Observations are generated with a chosen measurement error from **THE TRUTH**.
In reservoir simulator perturbing grid pressure is not effective and unrealistic.

**White noise**

**Red noise**

*Perturbed grid pressure at the production wells*
Imperfect truth construction

The Idea: perturb inputs instead of the state vector

**Red noise**

**Bias**

Perturbed prescribed bottom hole pressures at the producers
Imperfect truth construction

- Obtained model perturbation looks realistic
- 4D-Var can be applied adding the inputs to the control variable

**Red noise**

**Bias**

Effect of different input perturbations on the grid pressure at the producers

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Input error in reservoir simulations
Accounting for input error in 4D-Var

Cost function in 4D-Var

\[ J(p, u) = \sum_{i=1}^{n} (H_i(x_i) - y_i)^T R_i^{-1} (H_i(x_i) - y_i) + (p - p_b)^T B^{-1}(p - p_b) \]

minimization with constraints:

\[ x_i = M_i(x_{i-1}) \]

CONTROL VARIABLES:
- parameters \( p \) (permeabilities)
- inputs \( u \)
Accounting for input bias - Results

- very good permeability estimation with accounting for input bias
- very bad permeability estimation without accounting for input bias
- very good estimation of inputs
Accounting for input bias - Results

- very good permeability estimation with accounting for input bias
- very bad permeability estimation without accounting for input bias
- very good estimation of inputs

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Input error in reservoir simulations
Accounting for input bias - Results

**Total flow rate**

- **Production well: NW**
  - Truth (solid line), Prior (dash-dotted line), 4D-Var With Inputs (dashed line), 4D-Var Without Inputs (green line)
  - Obs 5%

- **Production well: NE**
  - Truth (solid line), Prior (dash-dotted line), 4D-Var With Inputs (dashed line), 4D-Var Without Inputs (green line)
  - Obs 5%

- **Production well: SW**
  - Truth (solid line), Prior (dash-dotted line), 4D-Var With Inputs (dashed line), 4D-Var Without Inputs (green line)
  - Obs 5%

- **Production well: SE**
  - Truth (solid line), Prior (dash-dotted line), 4D-Var With Inputs (dashed line), 4D-Var Without Inputs (green line)
  - Obs 5%

**Revised permeability RMSE = 2.84442**

**Truth**

**Prior**

**4D-Var With Inputs**

**4D-Var Without Inputs**

Obs 5%

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Input error in reservoir simulations
Accounting for input bias - Results

**Water break through time prediction:**

**Water saturation**

- **NW − 1**
- **NE − 421**
- **SW − 21**
- **SE − 441**

<table>
<thead>
<tr>
<th>Truth</th>
<th>Prior</th>
<th>4D−Var</th>
<th>4D−Var strong</th>
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- Graphs show water saturation over time for different grid blocks.
- The graphs compare truth, prior, and 4D-Var results.
- The 4D-Var strong results show improved agreement with the truth data.

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Accounting for input bias - Results

**Prior**

**Truth**

**With Inputs**

**Without Inputs**
Accounting for input bias - Results

Prior

Truth

With Inputs

Without Inputs

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Summary

- Perturbing the state vector in reservoir simulations is not effective neither realistic
- Model inputs have a big impact on the reservoir behavior
- Accounting for the input bias as control variable in 4D-Var gives very good estimations of the permeability, the outputs of the model, as well as the inputs themselves
Thank you for your attention!

Questions?