

Importance of input error in reservoir simulations

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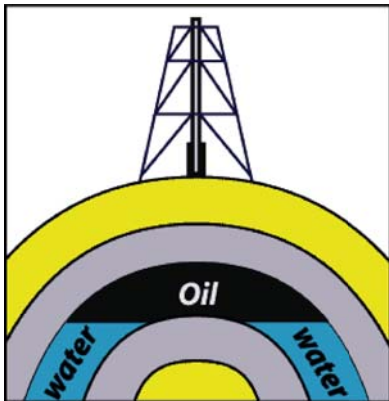


The Eighth International Workshop on Adjoint Model Applications
in Dynamic Meteorology, Tannersville 18-22 May 2009

Outline

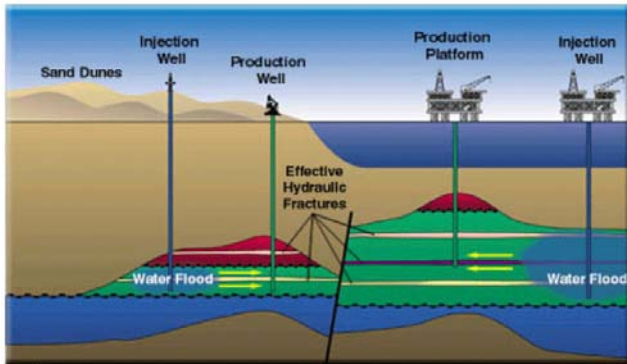
- 1 Project Motivation
- 2 Reservoir Simulator
- 3 Accounting for input error in 4D-Var
- 4 Results
- 5 Summary

How is oil produced?



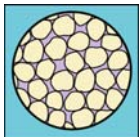
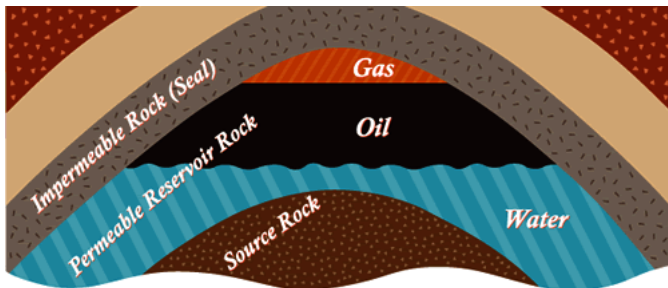
With primary recovery
oil production is usually
less than 30%.

How is oil produced?



Water is injected into the reservoir field to force more oil into production wells

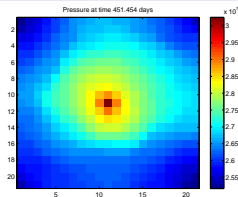
What mathematics has to do with oil?



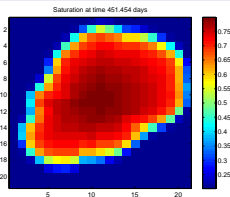
A suitable reservoir rock must be porous and permeable

Reservoir Simulator

State vector

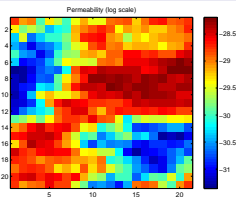


PRESSURE

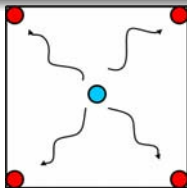


SATURATION

Parameters



PERMEABILITY



- Water injector
- Oil producer

$$x_i = \mathcal{M}_i(x_{i-1}) \quad \text{where} \quad x_i = [p_i \ s_i]^T$$

INPUTS: prescribed bottom hole pressures and prescribed flow rates



4D Variational Data Assimilation

Cost function in 4D-Var

$$J(p) = \sum_{i=1}^n \underbrace{(\mathcal{H}_i(x_i) - y_i)^T}_{\text{Distances}} R_i^{-1} \underbrace{(\mathcal{H}_i(x_i) - y_i)}_{\text{Distances}} + \underbrace{(p - p_b)^T B^{-1} (p - p_b)}_{\text{Background term}}$$
$$\sum_{i=1}^n \underbrace{(\mathcal{M}_i(x_{i-1}) - x_i)^T Q_i^{-1} (\mathcal{M}_i(x_{i-1}) - x_i)}_{\text{Model error term}}$$

minimization with
constraints:

$$x_i = \mathcal{M}_i(x_{i-1}) + \epsilon$$

CONTROL VARIABLES:

- parameters p (permeabilities)
- model error ϵ

Twin Experiment

The Truth

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

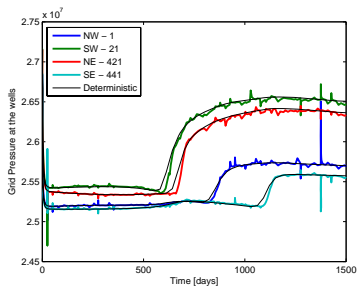
Observations

Observations are generated with a chosen measurement error from THE TRUTH.

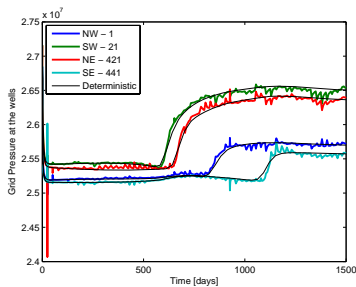
Imperfect truth construction

In reservoir simulator perturbing grid pressure is not effective and unrealistic

White noise



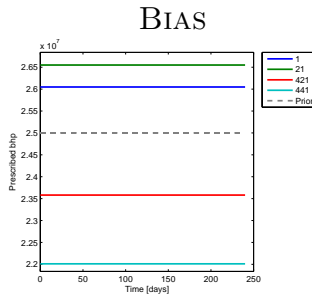
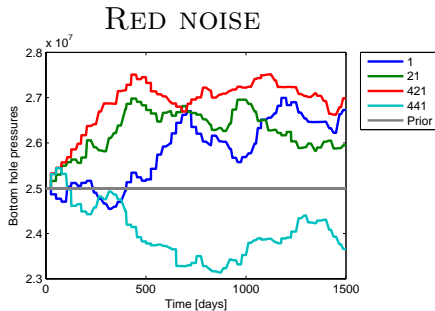
Red noise



Perturbed grid pressure at the production wells

Imperfect truth construction

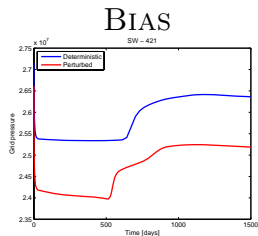
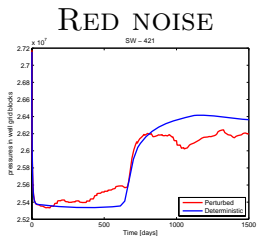
THE IDEA: perturb inputs instead of the state vector



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



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

Accounting for input error in 4D-Var

Cost function in 4D-Var

$$J(p, u) = \sum_{i=1}^n \underbrace{(\mathcal{H}_i(x_i) - y_i)^T}_{\text{Distances}} R_i^{-1} \underbrace{(\mathcal{H}_i(x_i) - y_i)}_{\text{Distances}} + \underbrace{(p - p_b)^T B^{-1} (p - p_b)}_{\text{Background term}}$$

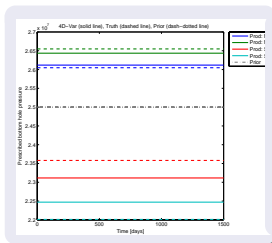
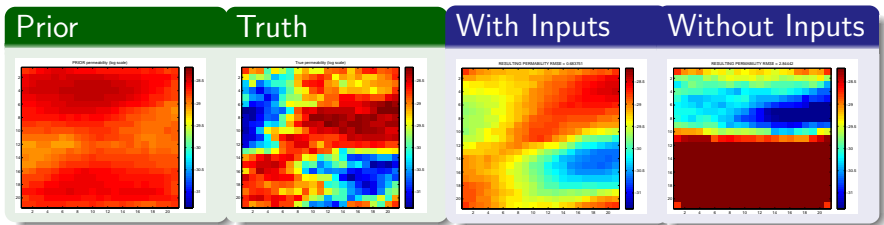
minimization with
constraints:

$$x_i = \mathcal{M}_i(x_{i-1})$$

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

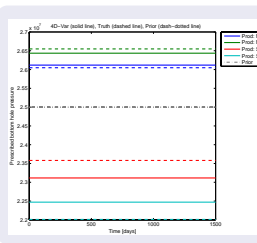
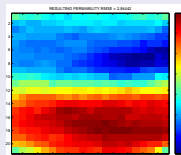
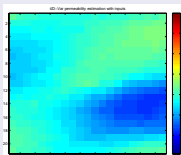
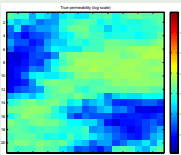
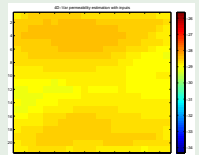
Accounting for input bias - Results

Prior

Truth

With Inputs

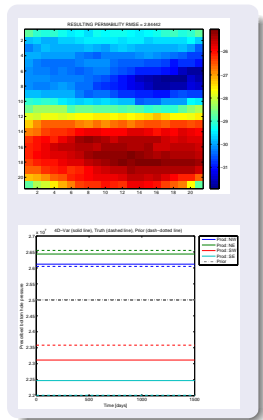
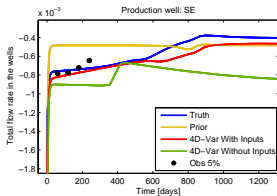
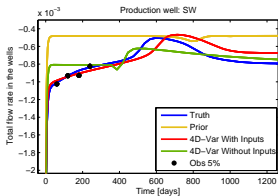
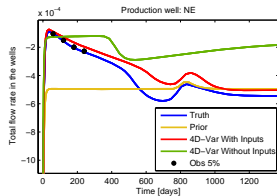
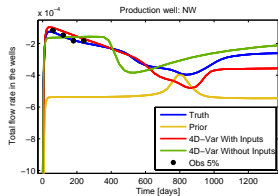
Without Inputs



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Accounting for input bias - Results

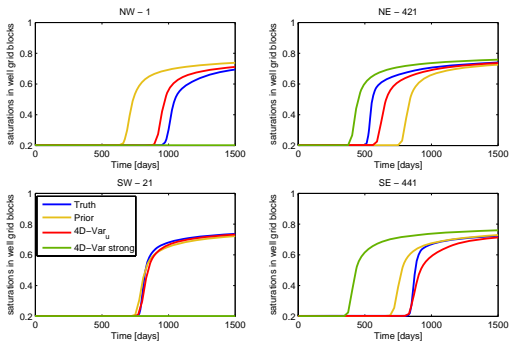
TOTAL FLOW RATE



Accounting for input bias - Results

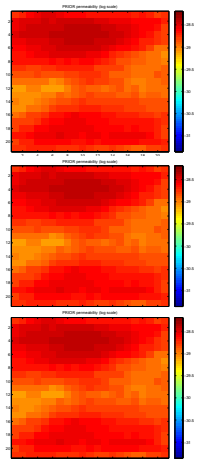
WATER BREAK TROUGH TIME PREDICTION:

Water saturation

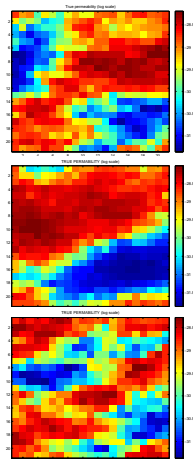


Accounting for input bias - Results

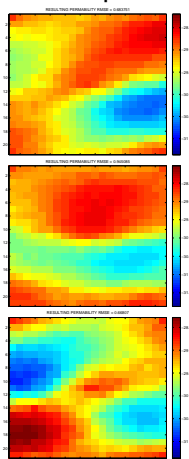
Prior



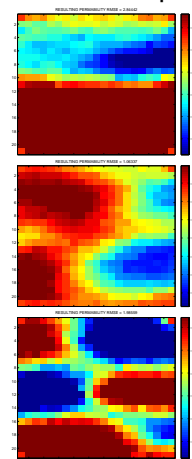
Truth



With Inputs

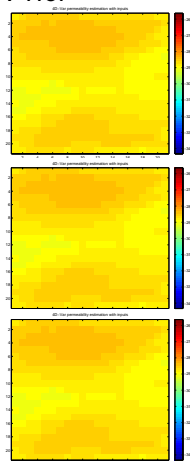


Without Inputs

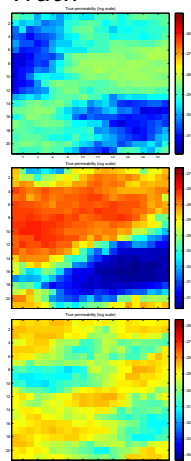


Accounting for input bias - Results

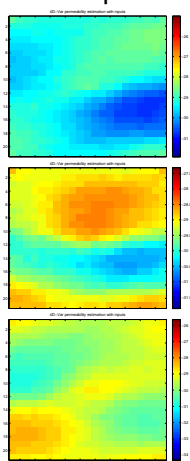
Prior



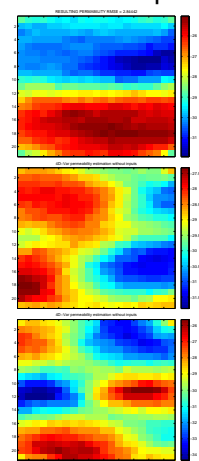
Truth



With Inputs



Without Inputs



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?

