Optimal reservoir management for maximizing production in deep-offshore fields

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VII November Conference – November 13, 2019

Applied Optimal Reservoir Management

Applied Optimal Reservoir Management in Context

Motivation

Mature Field Operation

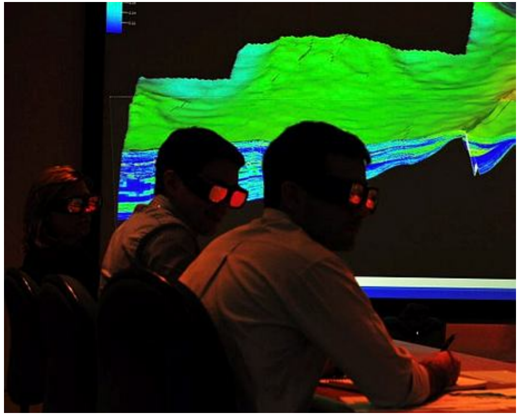
Excessive water production bottlenecks offshore vessels:

- *Constrains oil production;*
- *Increases operational costs.*

Proactive Reservoir Management

Planning is always better than React!

- *Robust techniques are already available;*
- ***Why is not widely applied?***



Applied Optimal Reservoir Management in Context

Motivation

Efficient Ensemble-Based Closed-Loop
...n Optimization
Dean S. Oliver, SPE, University of Oklahoma;
...E, University of Southern Ca...

...ers & Fluids 46 (2011) 40–51
...ts available at ScienceDirect
...puters & Fluids
...ww.elsevier.com/locate/compfluid

Comput Geosci (2013) 17:959–973
DOI 10.1007/s10596-013-9368-9

ORIGINAL PAPER

Theoretical connections between optimization algorithms based on an approximate gradient

Sy T. Do · Albert C. Reynolds

J.D. Janse...
Department of...

Water Injection Optimization Using a Streamline-Based Workflow
Marco R. Thiele and Rod. P. Batycky, Streamsim Technologies

SPE
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Maximization of Water Sweep Efficiency by Controlling Production and Injection Rates
by H. Asheim, Norwegian Inst. of Technology
SPE Member

Robust Waterfloodin...
Multiple Geolog...
G.M. van Essen, SPE, ...
and J...

OPTIMIZATION METHODS
IN
OIL AND GAS DEVELOPMENT
by
Julius S. Aronofsky*
July 18, 1983

...ING

...ts handling for production
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SPE-163645-MS

An Adaptive Hierarchical A...
D. F. Oliveira, SPE, Petrobras, U. of ...

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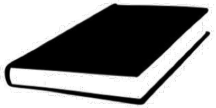


Applied Optimal Reservoir Management in Context

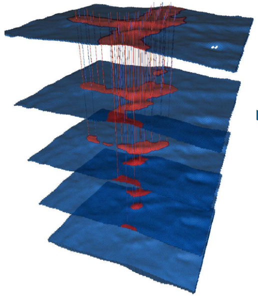
Objective

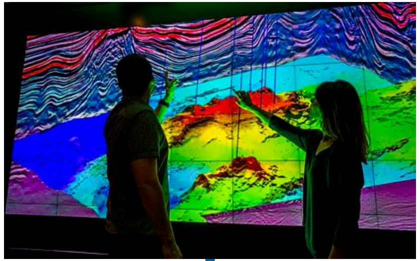
Field implementation is key!

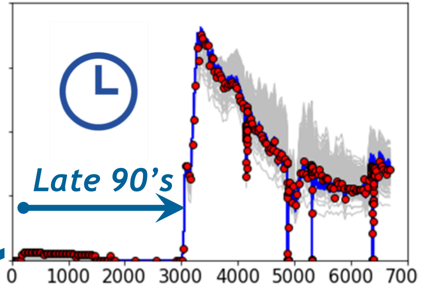
- Overcoming operational barriers;
- Spreading new technical culture;
- Assessing optimization gains!

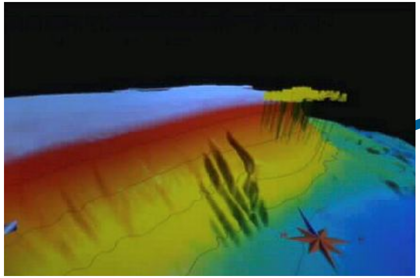
Field Description

Offshore • Brazil • Campos Basin

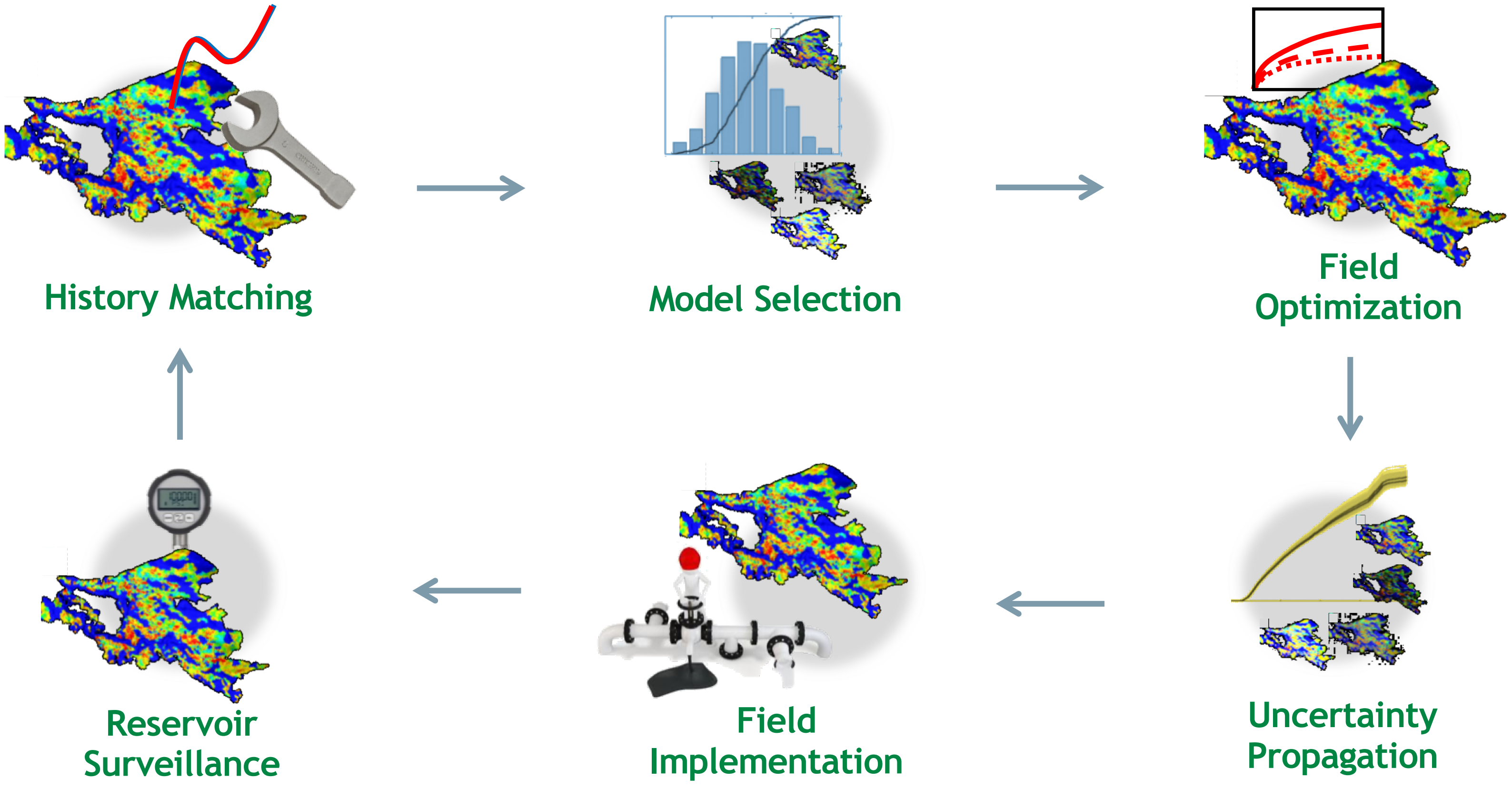




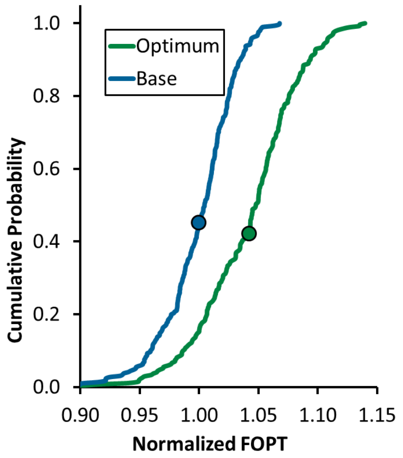


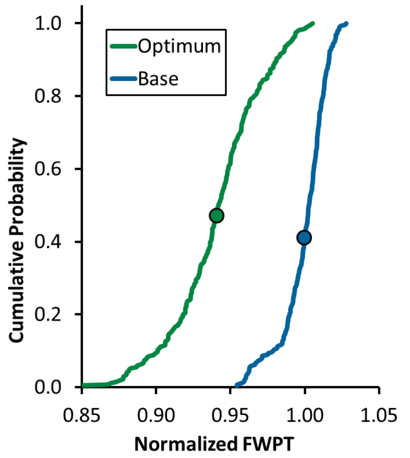


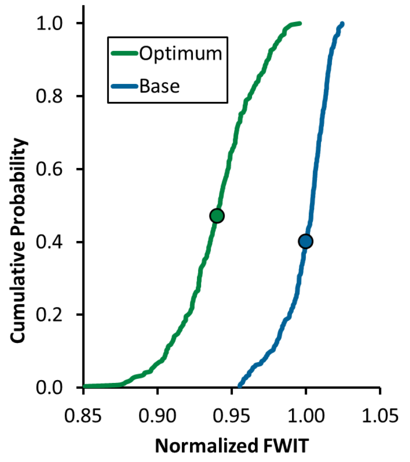
Optimal Reservoir Management Workflow

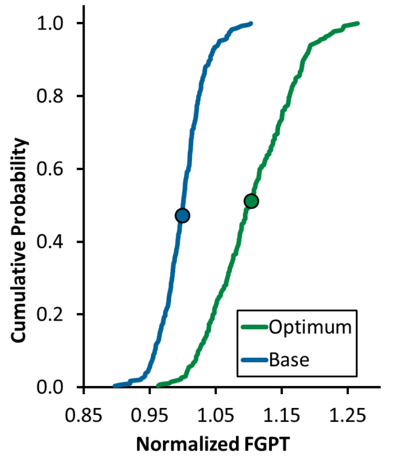


Field Injection Optimization under Uncertainty - Results (1/2)









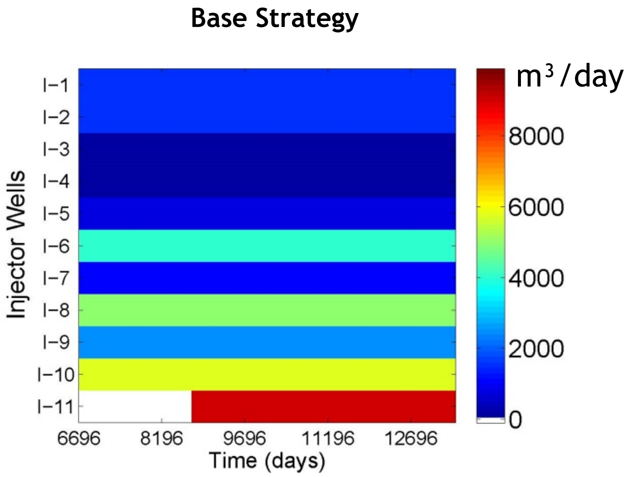
Cumulative Oil Production
- 4.2% increase on average total oil production;

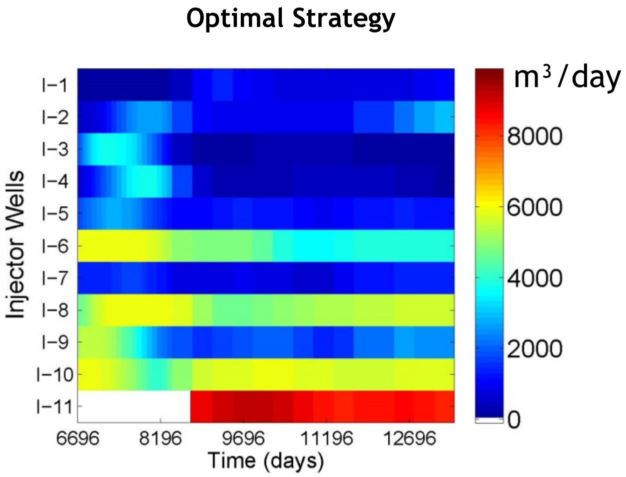
Cumulative Water Production
- 5.9% reduction on average total water production;

Cumulative Water Injection
- 6.0% reduction on average total water injection;

Cumulative Gas Production
- 10.5% increase on average total gas production;

Field Injection Optimization under Uncertainty - Results (2/2)

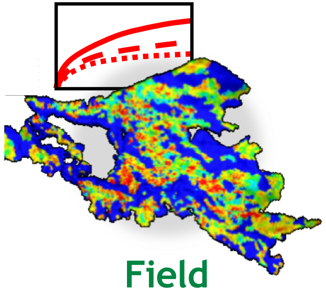




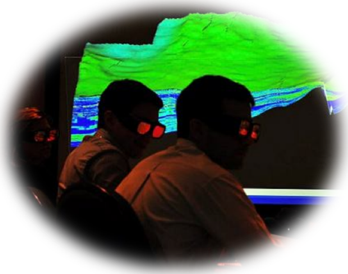
Few Highlights:

- *Life-cycle considered:* ***20 years****;*
- ***Temporal correlation*** *is imposed;*
- *Optimal Solution ensures smoothness (****easier to operational implementation****);*

Operational Pilot: Main targets



Field Optimization



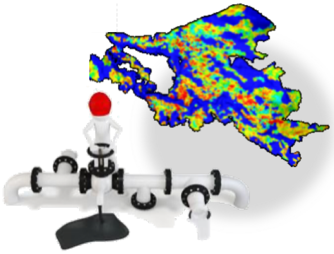
Objective:

Testify simulation models consistency.

Is our work done?

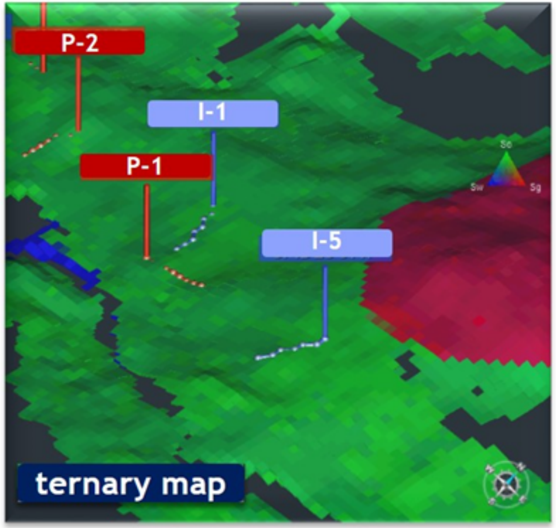
Objective:

Ensure operational capability.



Field Implementation

Operational Pilot: Pioneer Field Implementation

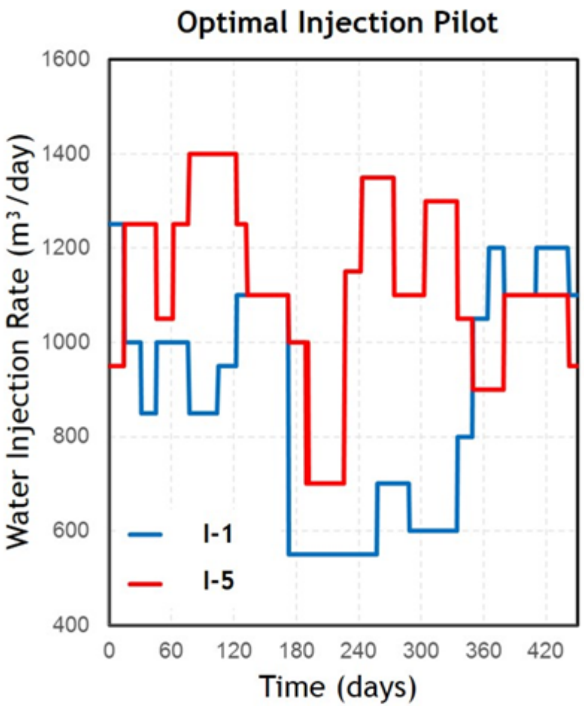


Pilot Site

- Hydraulically **Isolated**;
- Good **Sensors** (PDGs);
- Moderate **Water-cut** level.

Pilot Optimization

- nth;
- field.



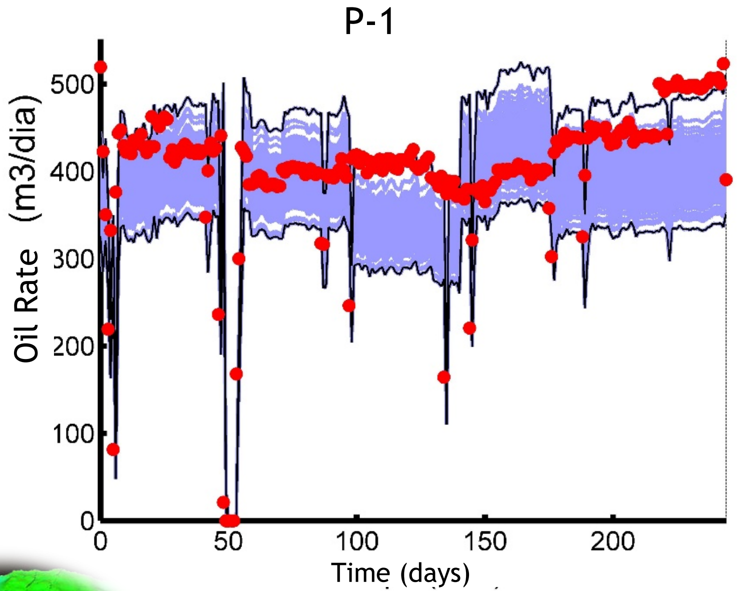
Operational Pilot: Pioneer Field Implementation

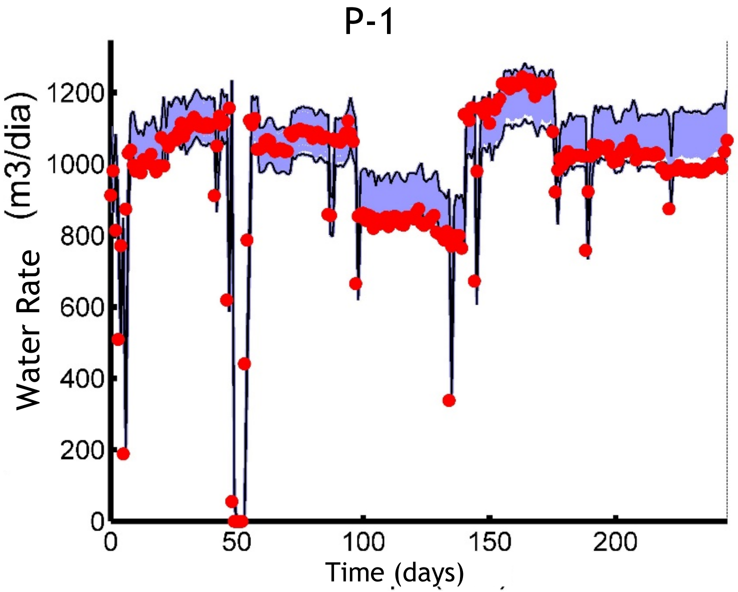
Operational Capability

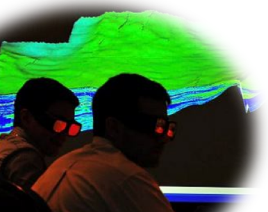
TARGET	TASKS		
	RESERVOIR ENGINEERING	**PLATFORM**	**SURVEILLANCE**
Guarantee operational success	•*Perform OPTIMIZATION;* •*Submit rates to PLATFORM* •*Feedback data to models (VALIDATION)*	• *PURSUE optimal rates;* • *PRIORITIZE optimal rates in operational failures;* •*Report RE of any ISSUE.*	•*Production Tests more often;* •*ALERT: excessive Water or Gas production;* •*ALERT: injection BHP.*

Operational Pilot: Pioneer Field Implementation

Modelling Consistency

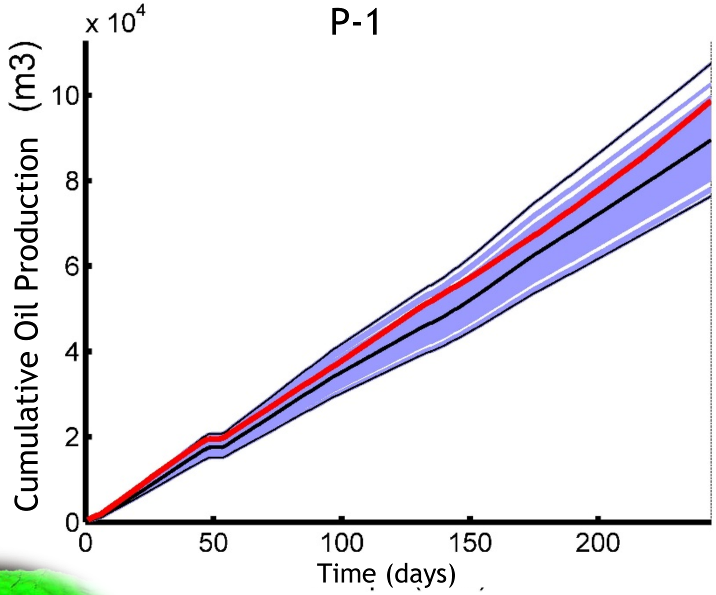


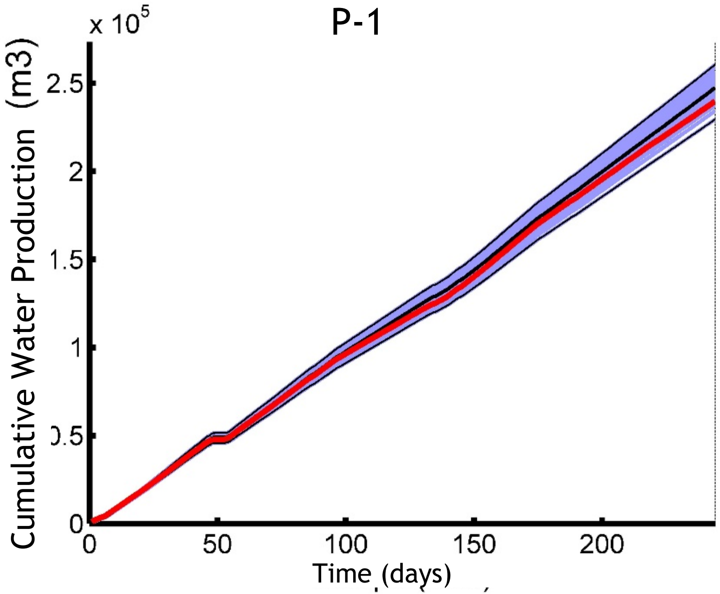


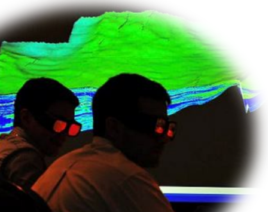


Operational Pilot: Pioneer Field Implementation

Modelling Consistency

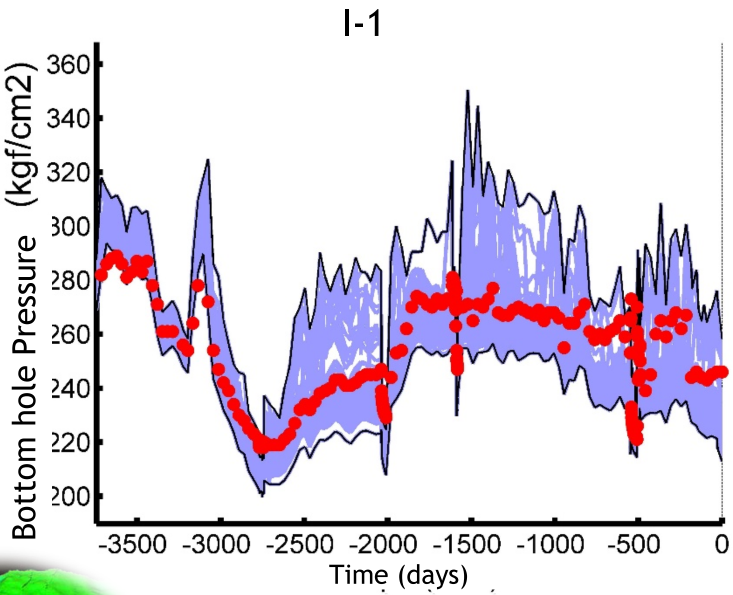


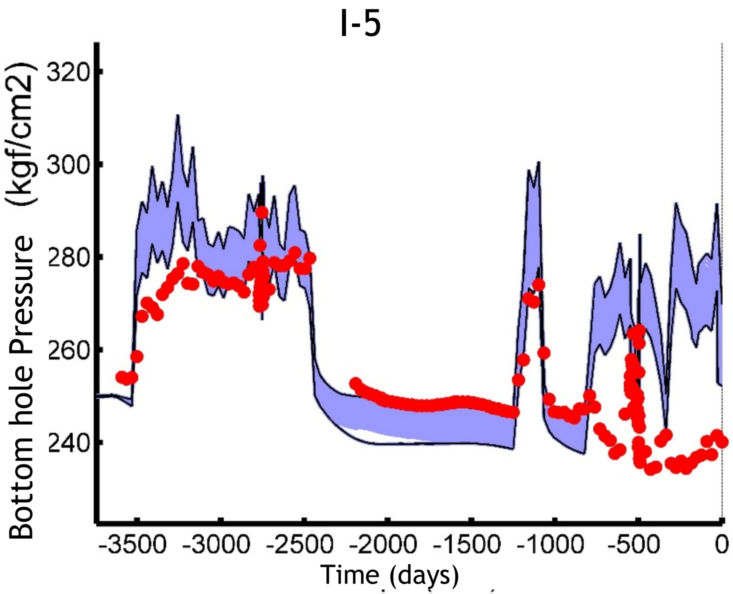


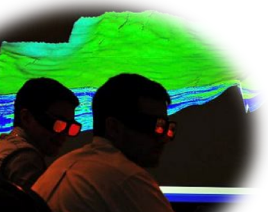


Operational Pilot: Pioneer Field Implementation

Modelling Consistency







Final Remarks

- State-of-art optimization applied in a field offshore Brazil, with robust gains;
- Difficult task: Field Implementation! But a Field Pilot was successfully performed;
- We guaranteed operational feasibility, which is critical for future endeavors, and testified the model consistency;
- We believe the implementation, monitoring and analysis of this field pilot is the main contribution of our work;
- To the best of our knowledge, it is the first time that an offshore field is actually operated based on a set of optimal controls;
- Clearly, this result indicates broader perspectives in terms of full-field applications, which we are currently pursuing.

Ref: Oliveira, D. F. B. de, Pereira, D. F. A., Silveira, G. E., & Melo, P. A. L. S. de. (2019).
Pioneer Field Pilot of Optimal Reservoir Management in Campos Basin.
SPE Reservoir Evaluation & Engineering. doi:10.2118/199355-PA

Thank You!

Questions, suggestions, general comments?

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Backup Slides

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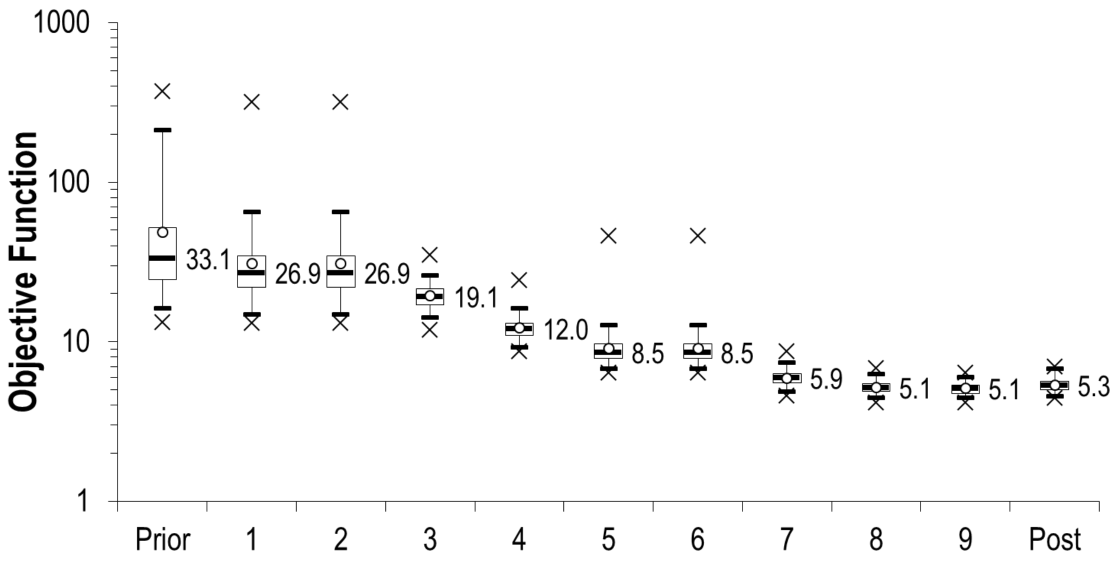
Optimal Reservoir Management Workflow

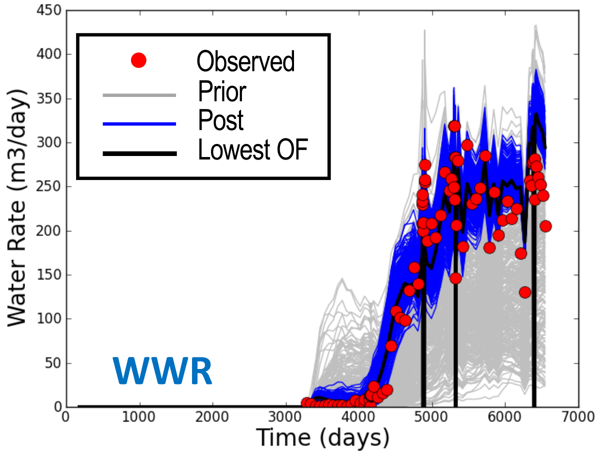
Ensemble-based History Matching

- We have applied **ES-MDA** (Emerick & Reynolds, 2012) to history-match production data from **Petrobras field**;
- Ten iteration were assigned for ES-MDA with decreasing inflation factors (not adaptive) in an ensemble of **300 models**;
- Historical data are composed of:
  - **Producers**: oil and water rates, GOR and bottom-hole pressure (flowing and build-up periods);
  - **Injectors**: water rates and bottom-hole pressure (flowing and fall-off periods);
  - Data available every **60 days** along **10 years**, but during shut-in periods the frequency of **1 to 5 days** is considered for BHP;
- Model **parameters** are horizontal permeability, porosity, vertical transmissibility, relative permeability, anisotropy ratio and fault transmissibilities;
- Model contains **four facies** handled with a **truncated Gaussian transformation**.

Optimal Reservoir Management Workflow

Ensemble-based History Matching





Optimal Reservoir Management Workflow

Model Selection

- We consider a model selection approach proposed by **Heitsch and Römisch** (2003), and modified by **Armstrong et al.** (2012);

- This approach is based on **minimizing the weight of the discarded models**, where weight is a distance-based function as discussed below;

- Given a set of N_ω chosen **model properties** (static/dynamic), for each reservoir model we have a vector

$$\omega_j^T = \begin{bmatrix} \omega_j^1 & \omega_j^2 & \cdots & \omega_j^w & \cdots & \omega_j^{\mathrm{N}_\omega} \end{bmatrix}, \qquad j = 1, \ldots, \mathrm{N}_e$$

where ω_j is the vector of model properties of the j^{th} ensemble member and N_e is the ensemble size. Each vector ω_j is normalized to avoid scaling problems.

Optimal Reservoir Management Workflow

Model Selection

- Let $d_{i,j}$ be the distance between ensemble members i and j, such that

$$d_{i,j} = \sqrt{(\omega_i - \omega_j)^T (\omega_i - \omega_j)}$$

- Let $\mathcal{M}$ be the set of all models that composes the ensemble from which we wish to extract a subset $\mathcal{S}$ with N_s selected models, such that $\mathcal{M} \supset \mathcal{S}$. Also let $\mathcal{D}$ be the subset of discarded models, such that $\mathcal{M} = \mathcal{S} \cup \mathcal{D}$.

- We define the **distance-based selection function** as

$$C(\mathcal{S}) = \sum_{j \in \mathcal{D}} p_j \cdot \min_{i \in \mathcal{S}} d_{i,j}$$

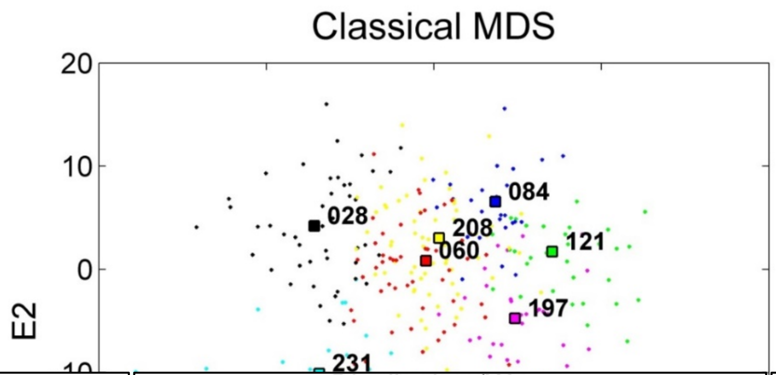
where p_j is the probability or weight of the jth model. So, we find $\mathcal{S}^\star$ by

$$\mathcal{S}^\star = \arg\min C(\mathcal{S})$$

for a fixed and preset value N_s .

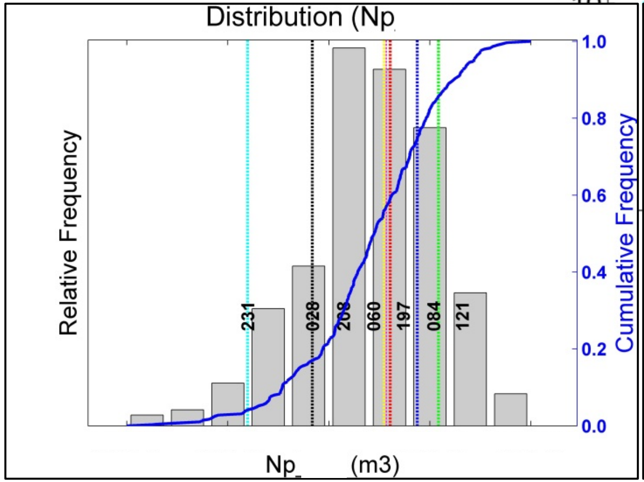
Optimal Reservoir Management Workflow

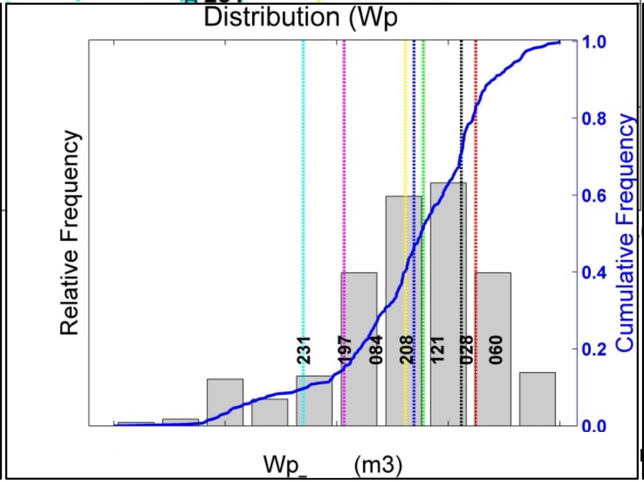
Model Selection

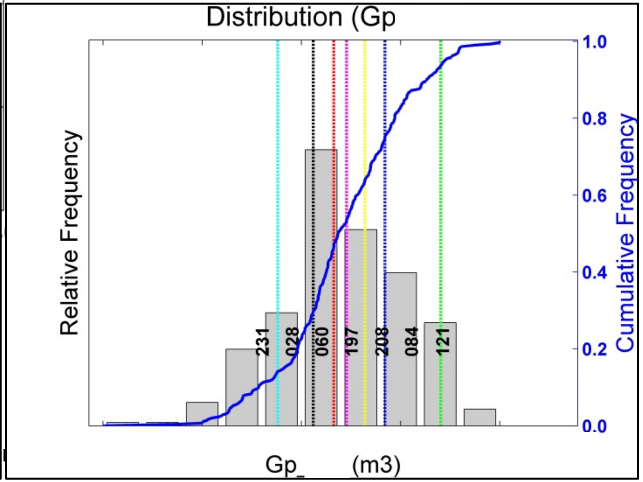


- We have considered 56 properties (static/geological and dynamic);

- 7 representative models were selected.







Optimal Reservoir Management Workflow

Field Injection Optimization under Uncertainty

- We have applied an **ensemble-based approximate gradient method** as optimization algorithm.
- Gradients are approximated using the so-called **Stochastic Simplex Approximate Gradient** (StoSAG) of **Fonseca et al.** (2017), where the search direction at point u is given by

$$\tilde{g}(u) = \frac{1}{\mathrm{N}_s} \sum_{k=1}^{\mathrm{N}_s} \left[\frac{1}{\mathrm{N}_p} \sum_{j=1}^{\mathrm{N}_p} \left[(\hat{u}_{k,j} - u) \left(J(m_k, \hat{u}_{k,j}) - J(m_k, u) \right)^T \right] \right],$$

where N_s is the ensemble size, N_p is the number of perturbed controls, and $\{\hat{u}_{k,j}\}$ are independent samples of u .

- We used **seven (7) selected models** as the ensemble and **five (5) perturbed controls.**
- A line-search procedure is performed based on $\tilde{g}(u)$.

Optimal Reservoir Management Workflow

Field Injection Optimization under Uncertainty

- Current application aims to **maximize the discounted Np (cumulative oil production)** given by

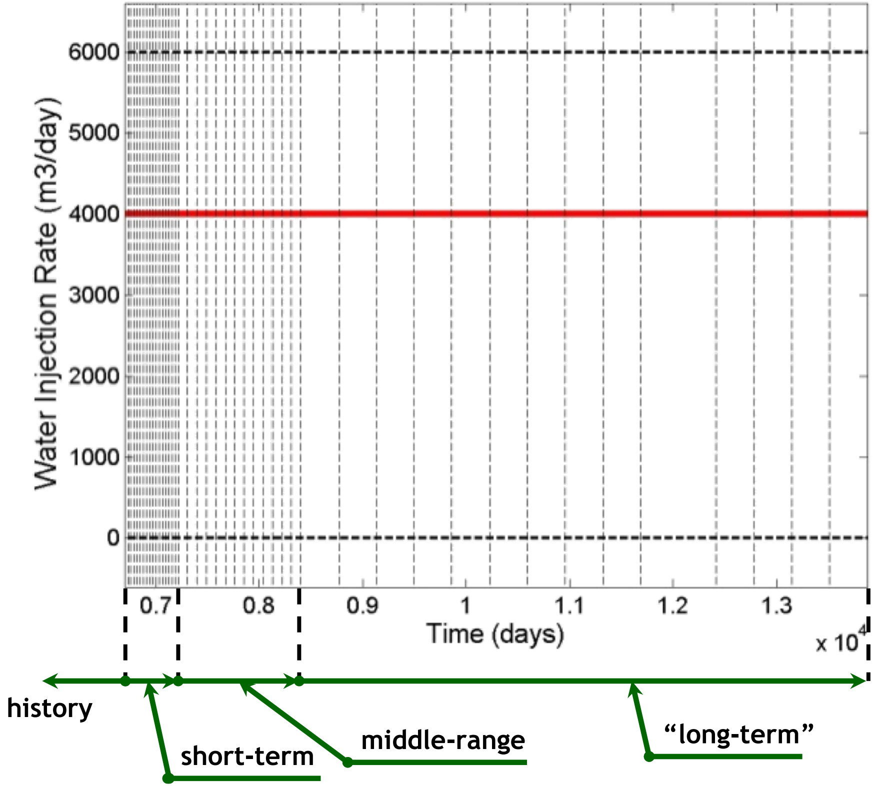
$$J(m_k, u) = \sum_{n=1}^{\mathrm{N}_t} \left\{ \frac{1}{(1+b)^{\frac{t_n}{365}}} \cdot \Delta t_n \sum_{j=1}^{\mathrm{N}_w} \overline{q_{o,j}^{n}} \right\}$$

- Considering the geological uncertainty, the **average among the seven (7) selected models** is set as objective function;

- Except for bound constraints, all other **state constraints are imposed in the simulation deck**, although we recognize that other better approaches may be applied.

Optimal Reservoir Management Workflow

Field Injection Optimization under Uncertainty



As demanded by the field operators, only Water Injection Rates are considered as control variables.

- 20-year remaining production period;
- 5-year Correlation Length;
- 11 Water Injecting wells;
- Non-uniform Control Steps;
- Optimization starts from current injection rates after historical period
  - Different initial value and bounds for each well.
- Logarithm transformation of Gao and Reynolds (2006) is applied to enforce bound constraints.