More from existing oil fields

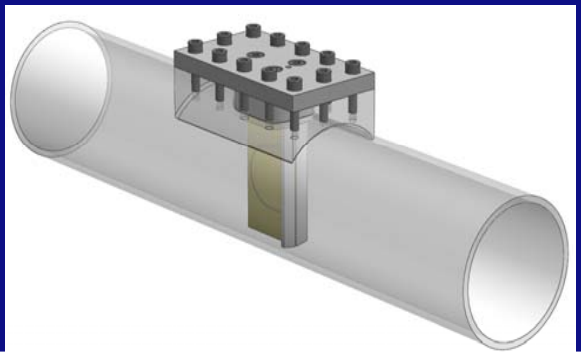
Closed Loop Reservoir Management

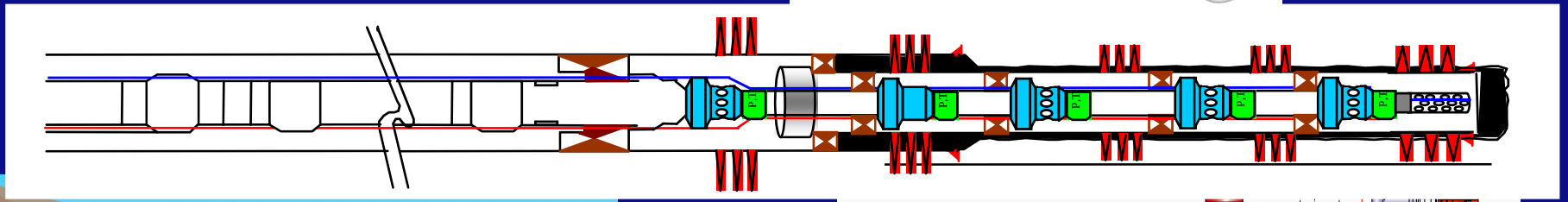
TNO | Knowledge for business

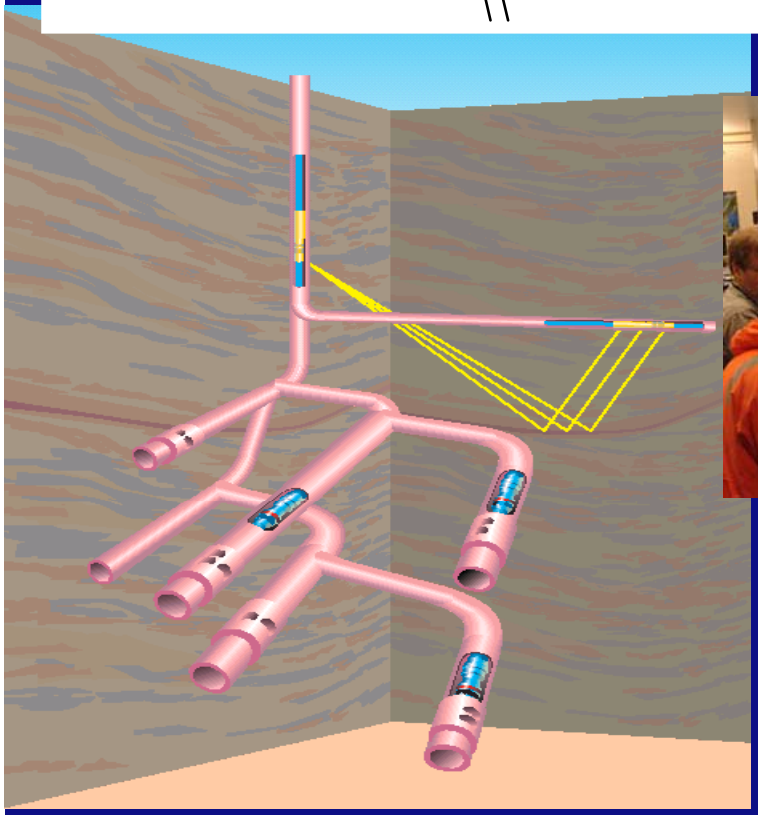
Need for innovation

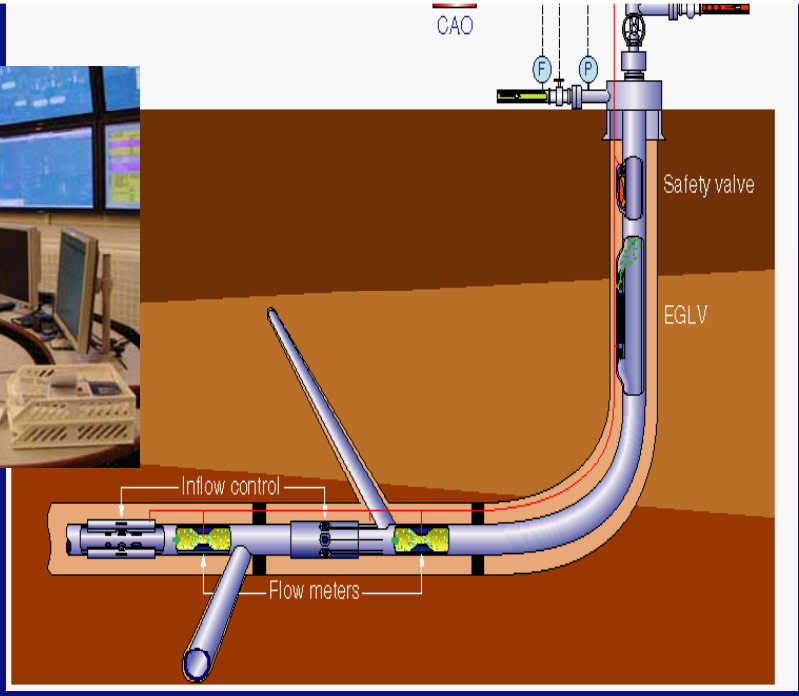
- Increase in energy demand
- Oil production
  - Sweeping efficiency 60 %
  - Displacement oil 60 %
  - around 36 % oil actually recovered
- Quote Dr. Abdallah S. Jum'ah, former CEO Saudi Aramco
  - *… increasing recovery by just one percent could add about 80 billion barrels of oil to global reserves - equivalent to nearly a quarter-century's worth of Saudi Aramco's current production.*

New technologies



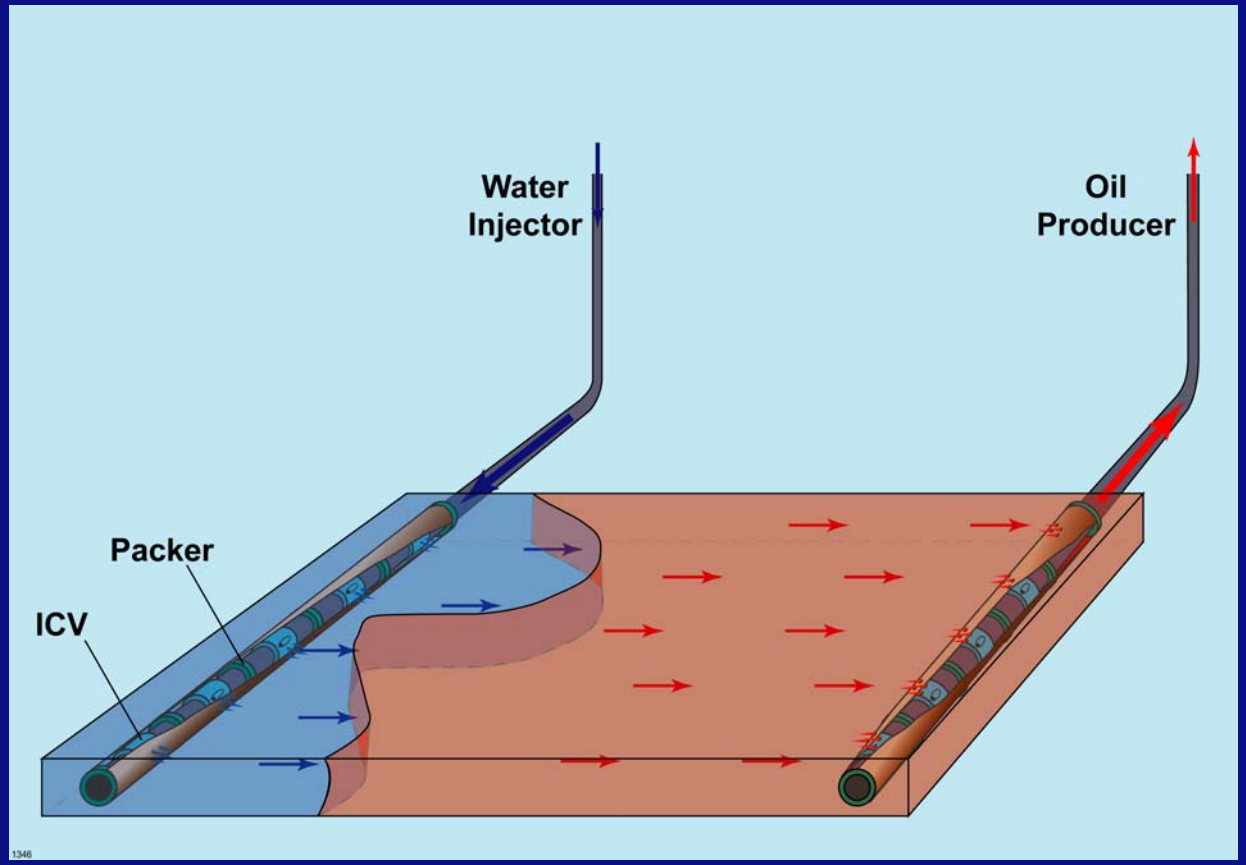


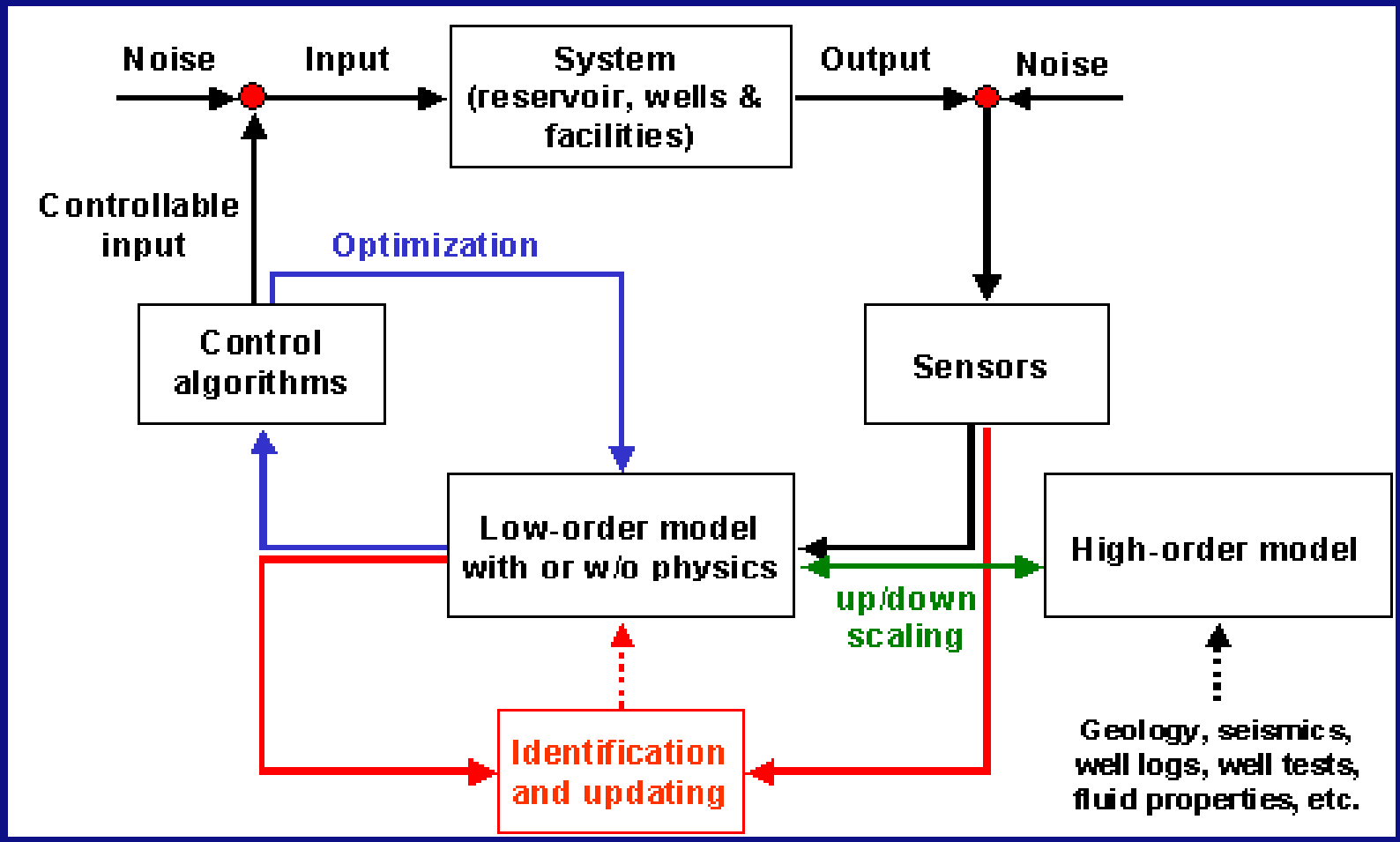


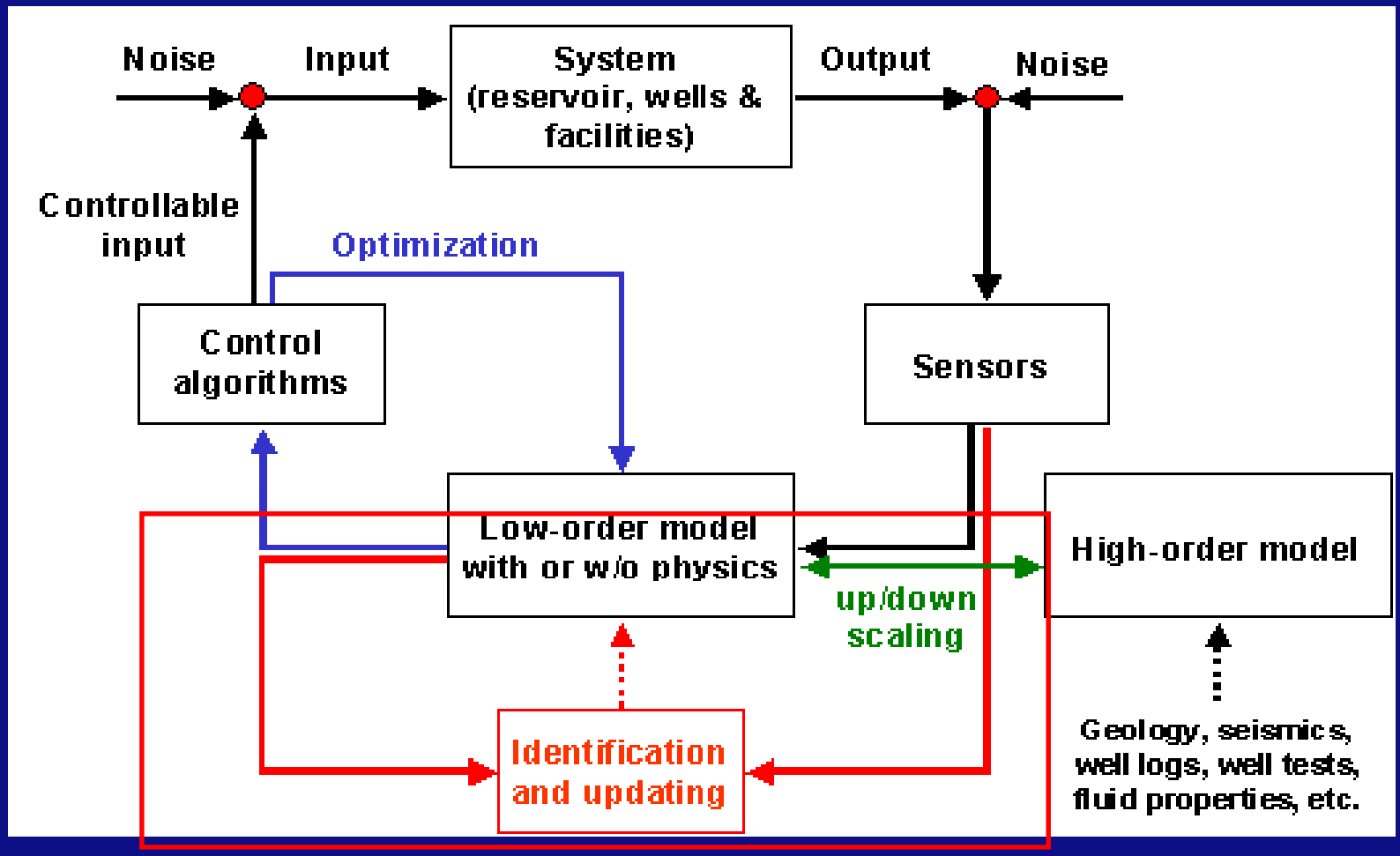


Reservoir management: water injection

- Water is injected to displace the oil towards the production well




Noise
Input
System
(reservoir, wells &
facilities)
Output
Noise
Controllable
input
Optimization
Control
algorithms
Sensors
Low-order model
with or w/o physics
High-order model
up/down
scaling
Identification
and updating
Geology, seismics,
well logs, well tests,
fluid properties, etc.

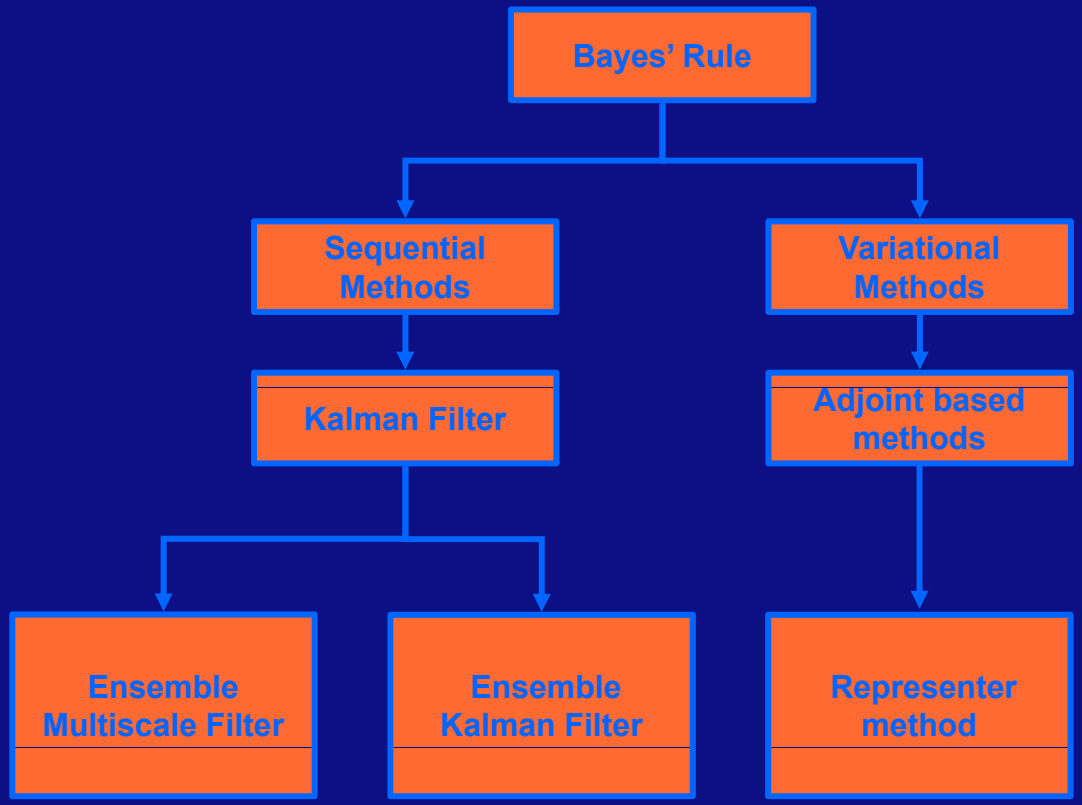

Noise
Input
System
(reservoir, wells &
facilities)
Output
Noise
Controllable
input
Optimization
Control
algorithms
Sensors
Low-order model
with or w/o physics
up/down
scaling
High-order model
Identification
and updating
Geology, seismics,
well logs, well tests,
fluid properties, etc.

history matching

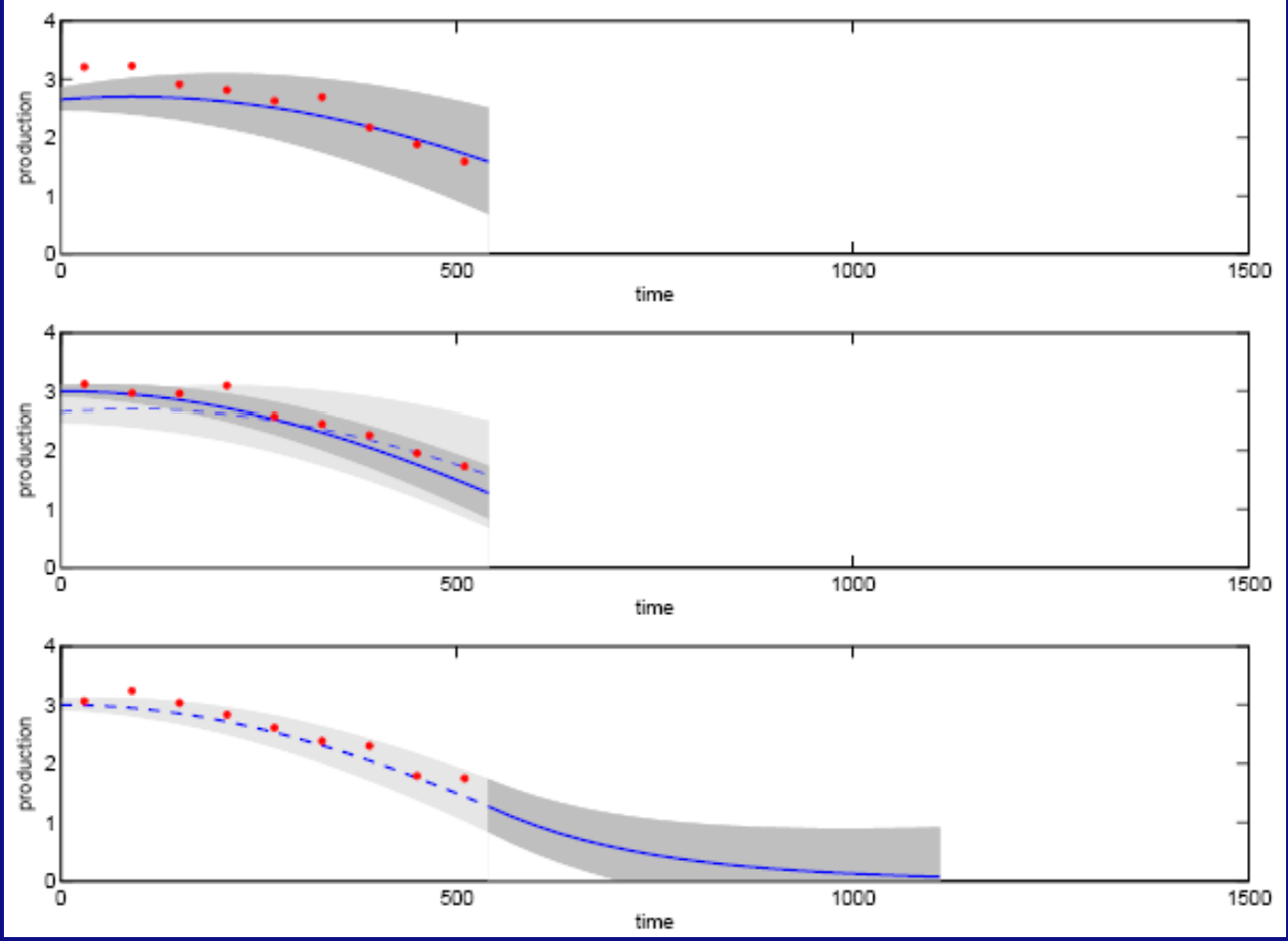
1. n. [Reservoir Characterization]
The act of adjusting a model of a reservoir until it closely reproduces the past behavior of a reservoir. [: : :] Once a model has
been history matched, it can be used to simulate future reservoir
behavior with a higher degree of condence, particularly if the adjustments are constrained by known geological properties in the
reservoir.

source: Schlumberger Oilfield Glossary.

Three examples of history matching

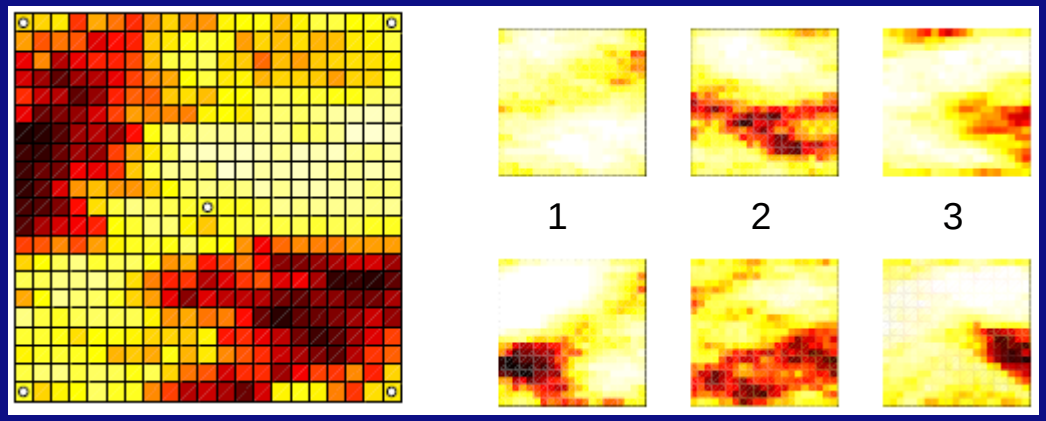


Purpose of History Matching



History Matching a 2D model with the Ensemble Kalman Filter

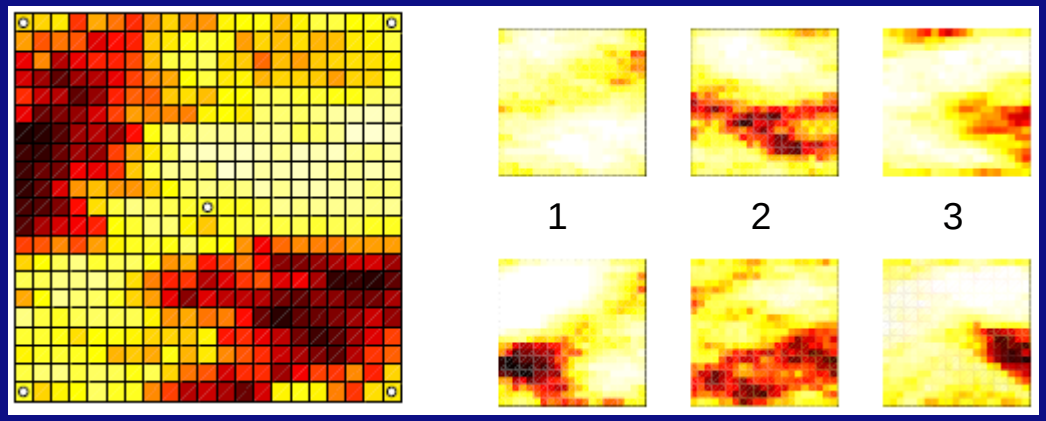
Experiments were performed with a 2D oil reservoir simulator (J.D. Jansen, TU Delft/Shell)



Uncertain parameter:
permeability

History Matching a 2D model with the Ensemble Kalman Filter

Experiments were performed with a 2D oil reservoir simulator (J.D. Jansen, TU Delft/Shell)



Uncertain parameter: permeability

Production data from producers and pressure from the injector were assimilated using the Ensemble Kalman Filter

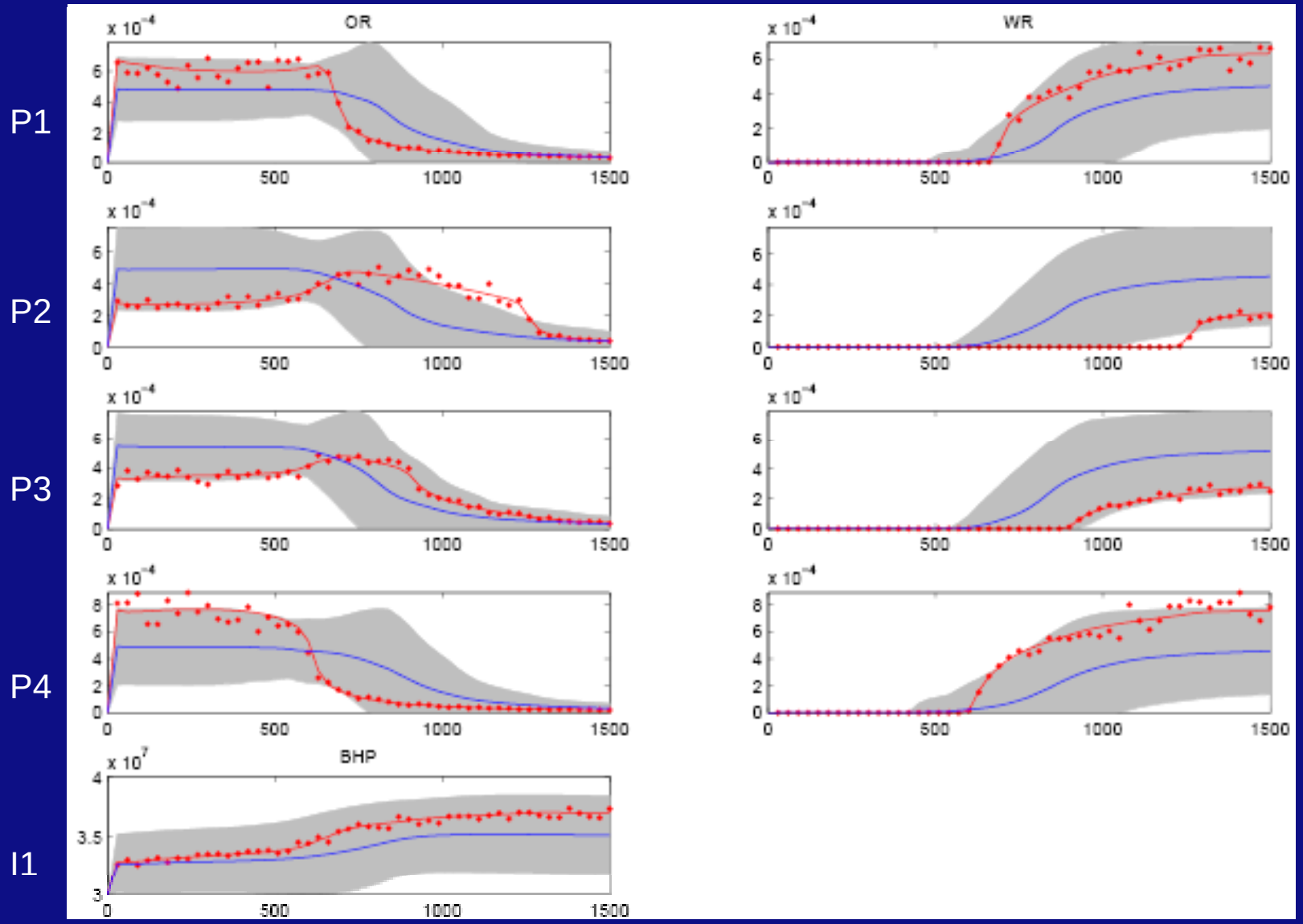
$$\mathbf{A} = [\mathbf{x}_1, \ldots, \mathbf{x}_N], \quad \mathbf{Y} = [\mathbf{y} + \mathbf{n}_1, \ldots, \mathbf{y} + \mathbf{n}_N]$$

$$\mathbf{P} = \frac{1}{N-1}\mathbf{A}'\mathbf{A}'^T, \qquad \text{where} \quad \mathbf{A}' = \mathbf{A} - \frac{1}{N}\sum_i \mathbf{x}_i$$

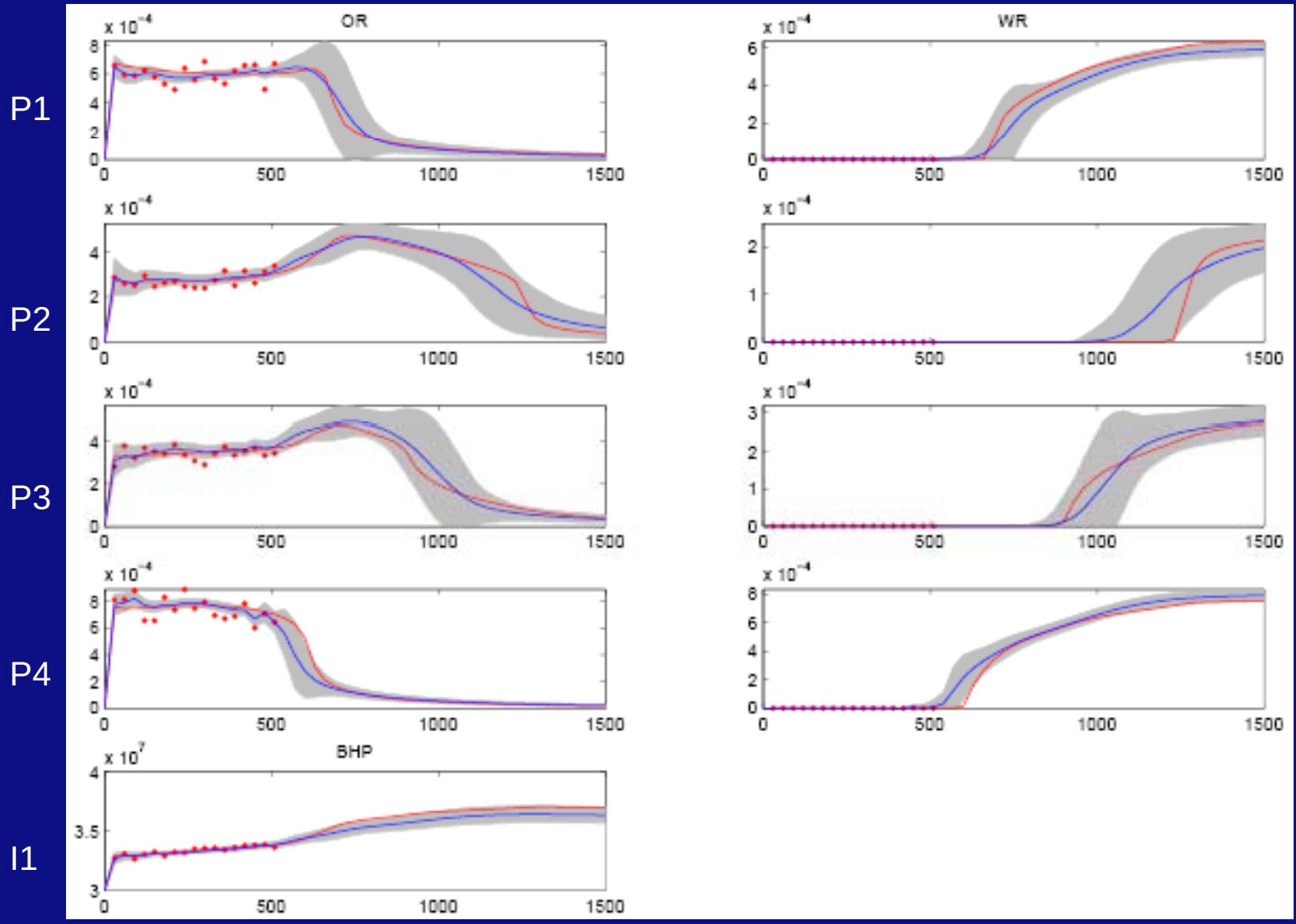
$$\mathbf{A}_a = \mathbf{A}_f + \mathbf{P}_f\mathbf{H}^T(\mathbf{H}\mathbf{P}_f\mathbf{H}^T + \mathbf{R})^{-1}(\mathbf{Y} - \mathbf{H}\mathbf{A}_f)$$

The added value of including additional saturation information in the history match procedure was determined on the basis of the quality of subsequent forecasts.

Experiments with a 2D reservoir model I. Unconstrained ensemble run



Experiments with a 2D reservoir model I. Production data only



Experiments with a 2D reservoir model II. Low accuracy seismic

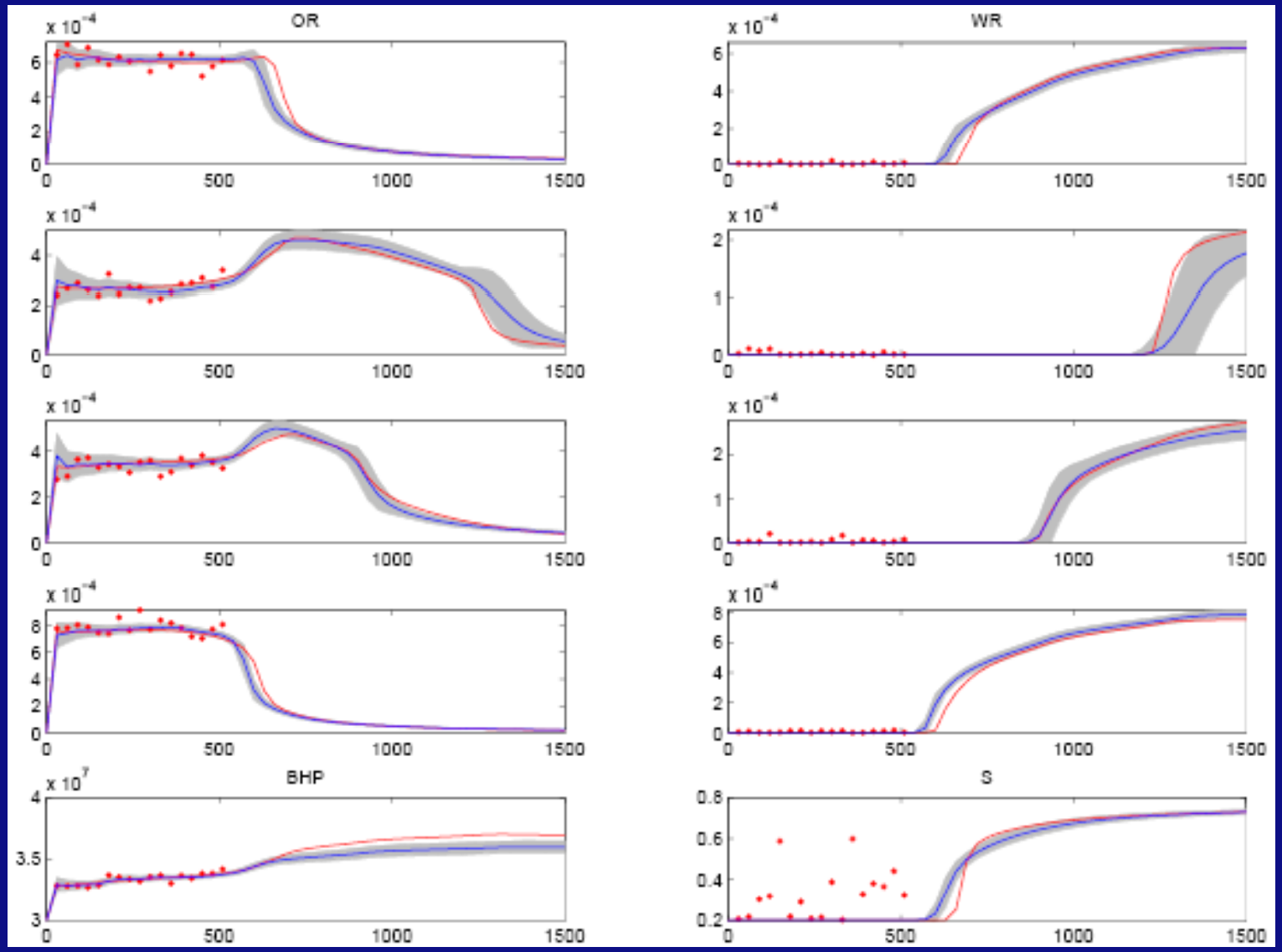
P1

P2

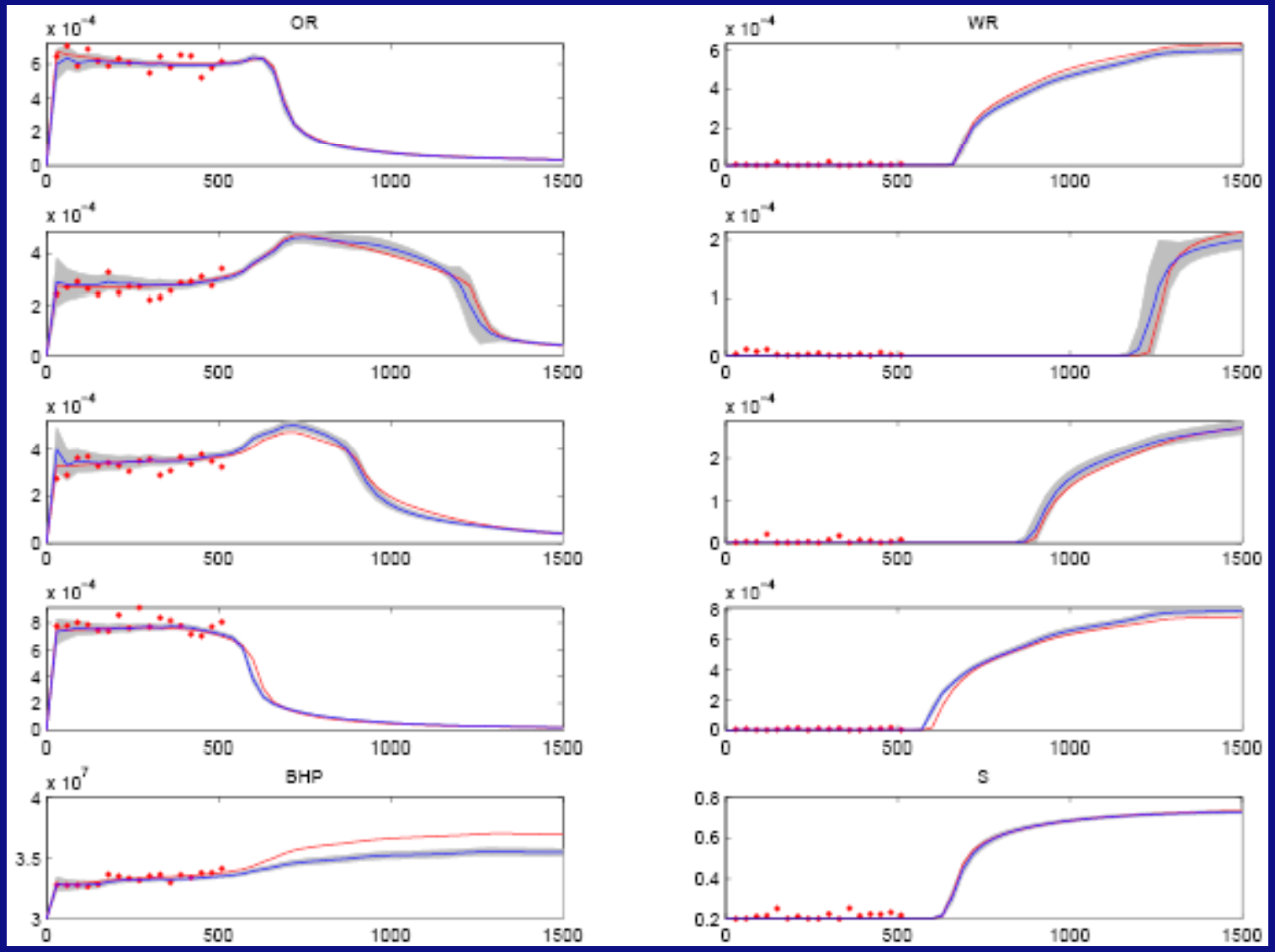
P3

P4

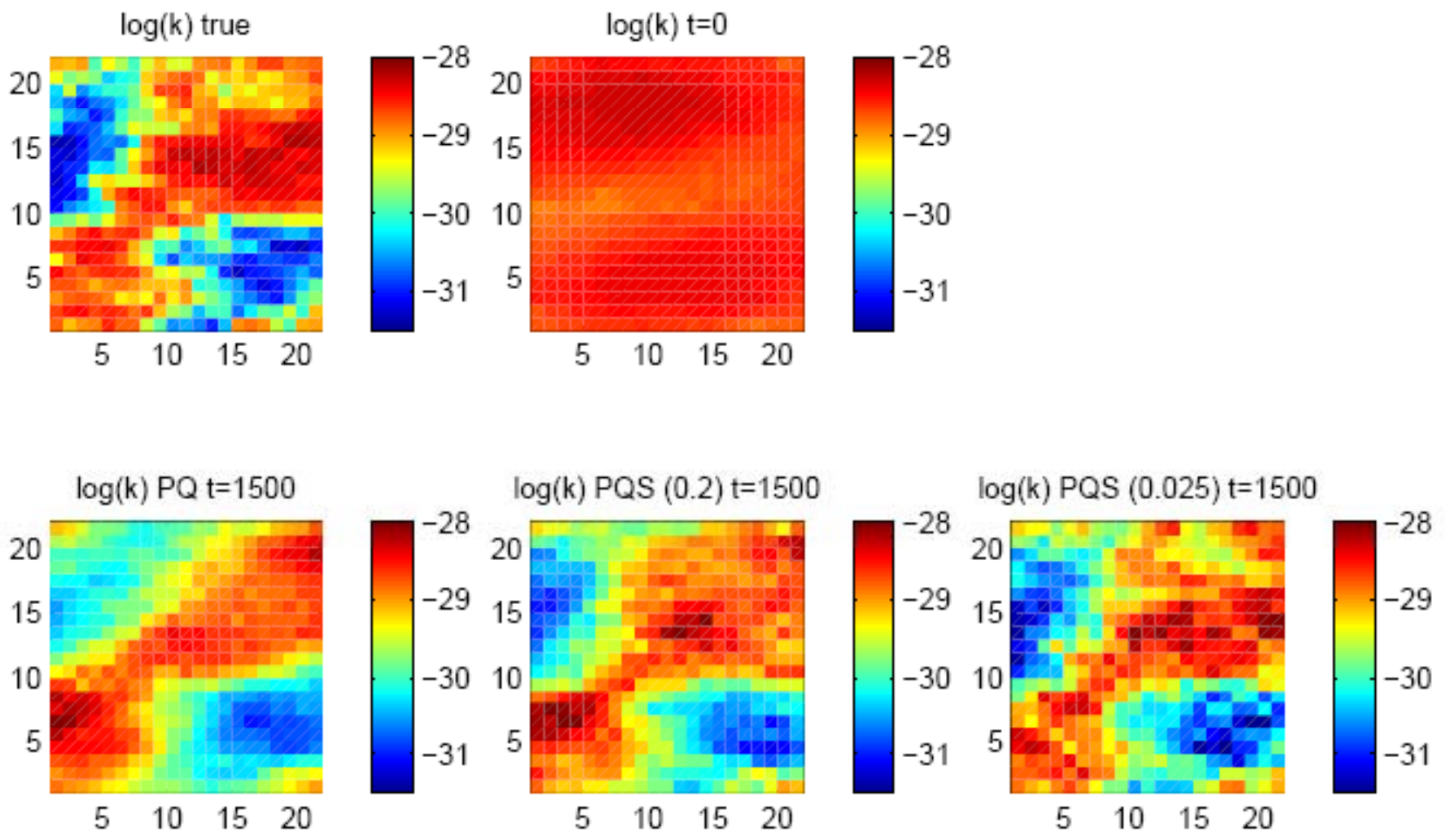
I1

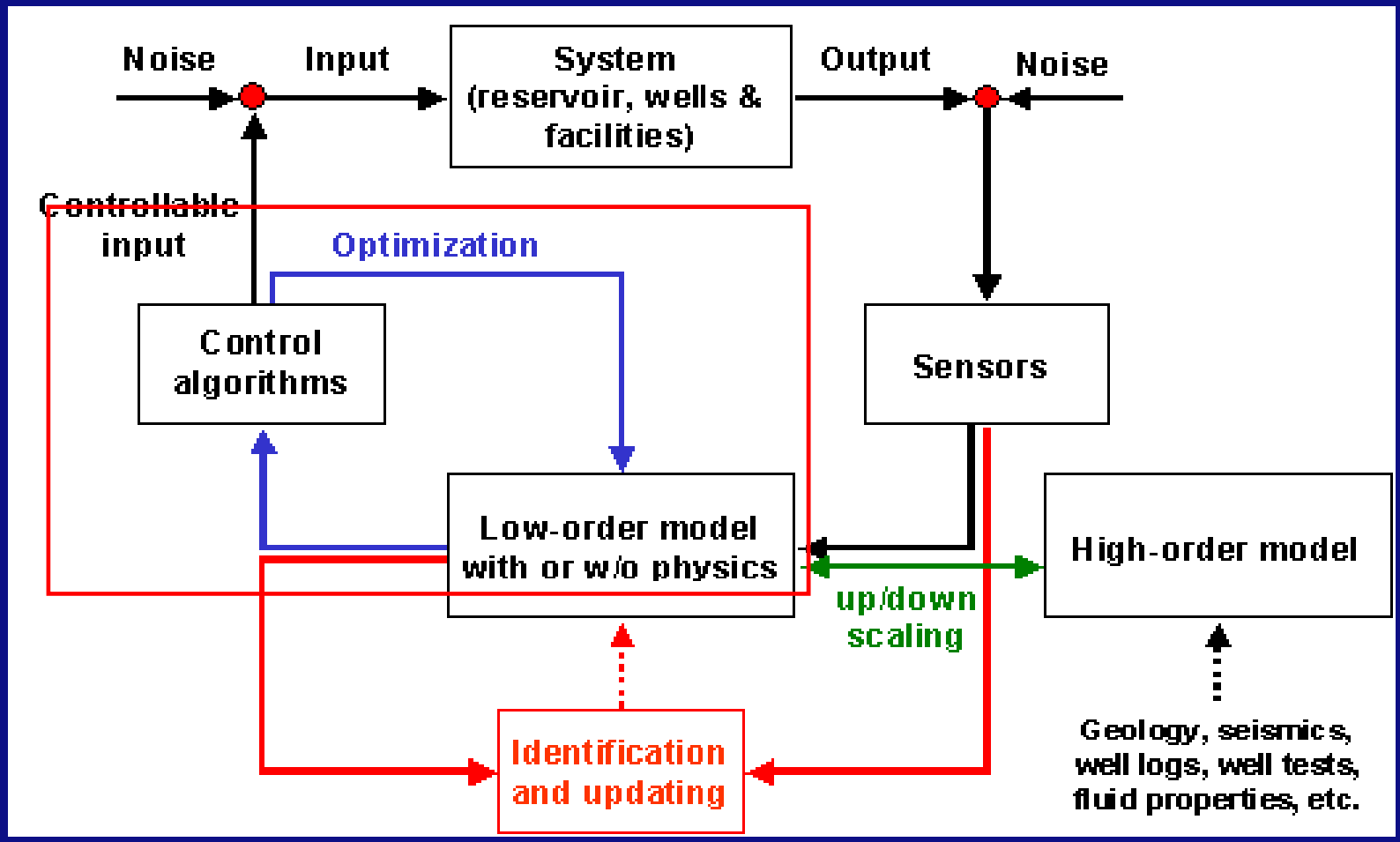


Experiments with a 2D reservoir model III. High accuracy seismic



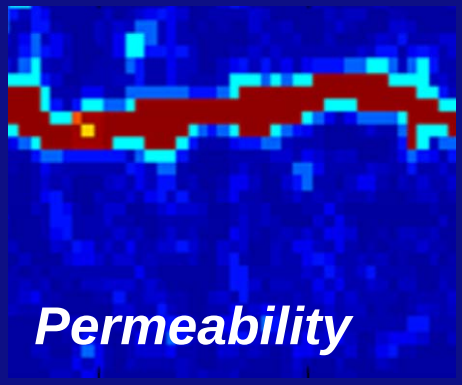
Estimation of permeability

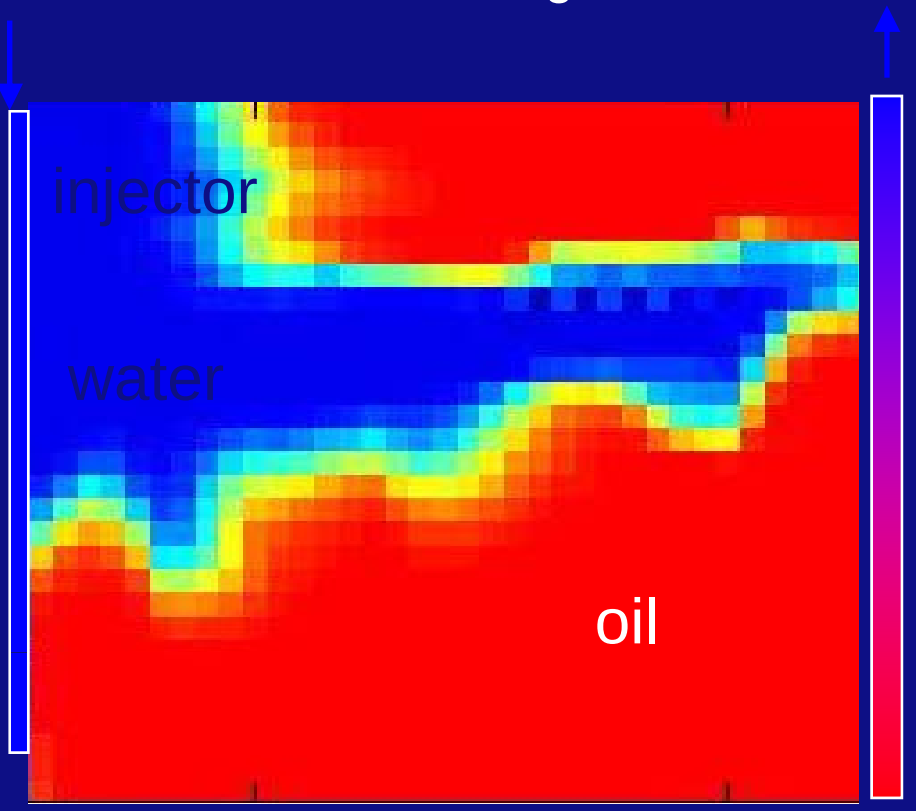


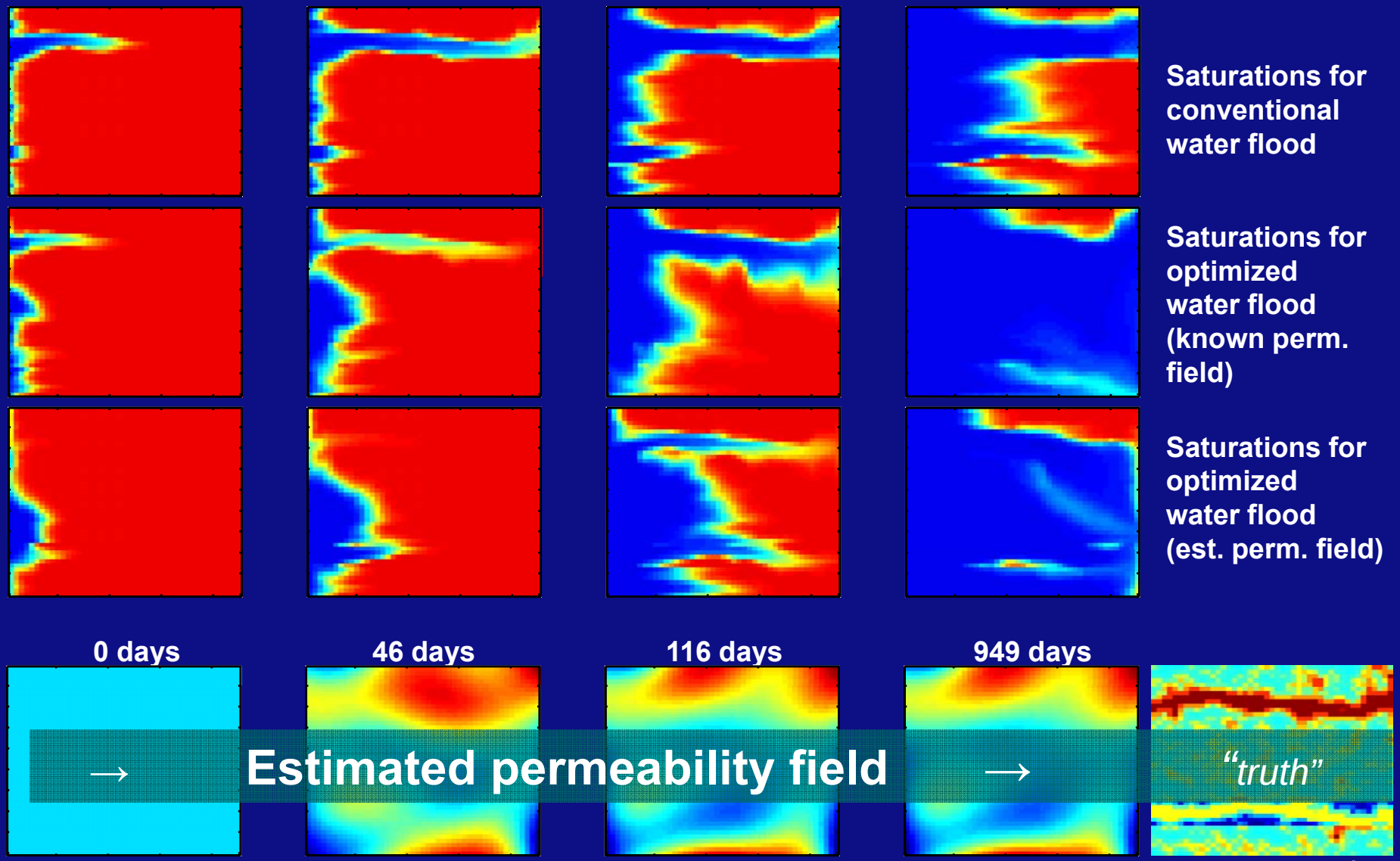

Noise
Input
System
(reservoir, wells &
facilities)
Output
Noise
Controllable
input
Optimization
Control
algorithms
Sensors
Low-order model
with or w/o physics
High-order model
up/down
scaling
Identification
and updating
Geology, seismics,
well logs, well tests,
fluid properties, etc.

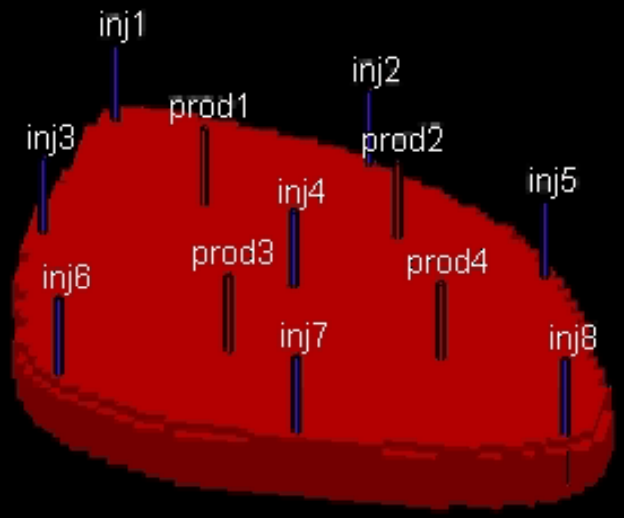
Reservoir management: water injection

- Early water breakthrough: the injected water often quickly finds its way to the producer due to reservoir heterogeneities

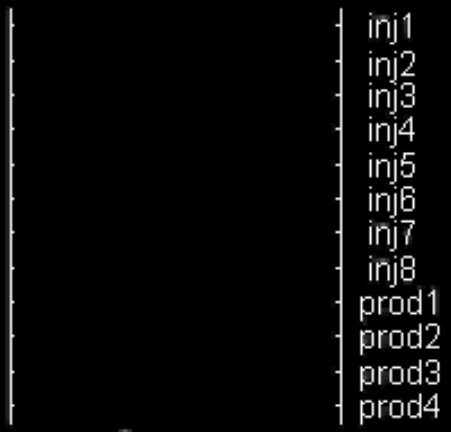





Saturations for conventional water flood
Saturations for optimized water flood (known perm. field)
Saturations for optimized water flood (est. perm. field)
0 days
46 days
116 days
949 days
→
Estimated permeability field
→
"truth"



Reactive Control

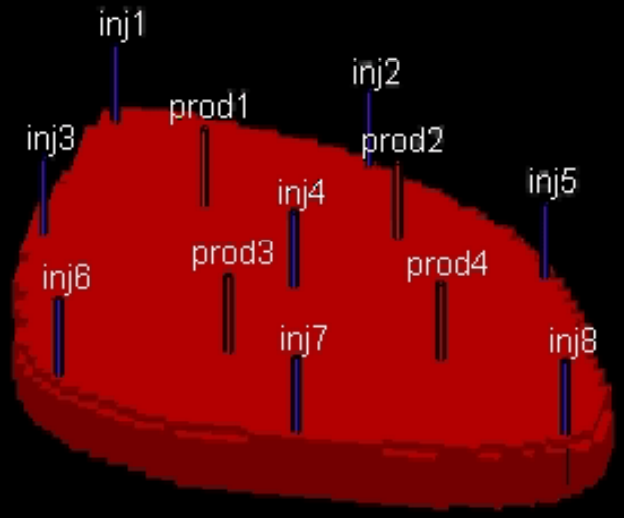


flow-rate

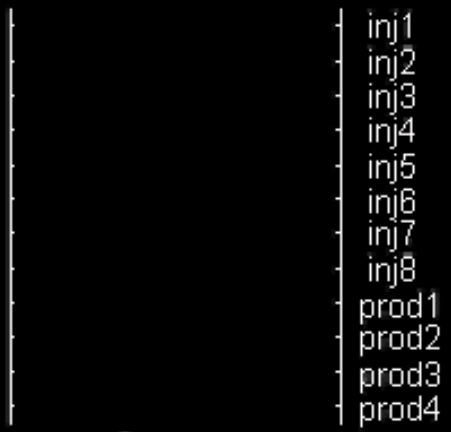
Cumulative Data

Oil Production: 0.00×10^6 *bbl*
Water Production: 0.00×10^6 *bbl*
Water Injection: 0.00×10^6 *bbl*

Revenue: 0.0 M$



Optimal Control



flow-rate

Cumulative Data

Oil Production: 0.00×10^6 *bbl*
Water Production: 0.00×10^6 *bbl*
Water Injection: 0.00×10^6 *bbl*

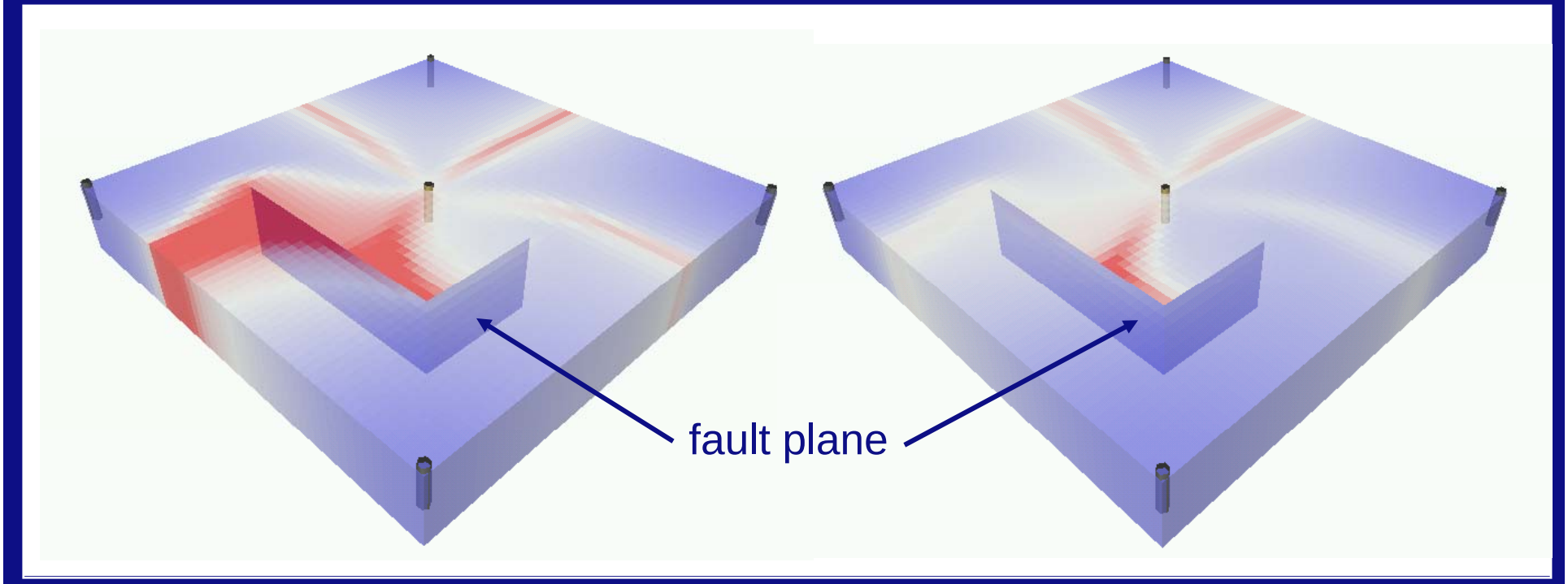
Revenue: 0.0 M$

time = 0.00 year

Model based optimization

- Example: sweep efficiency in water flooding case
  Method used: ensemble based robust well control optimization

residual oil saturation in a faulted reservoir

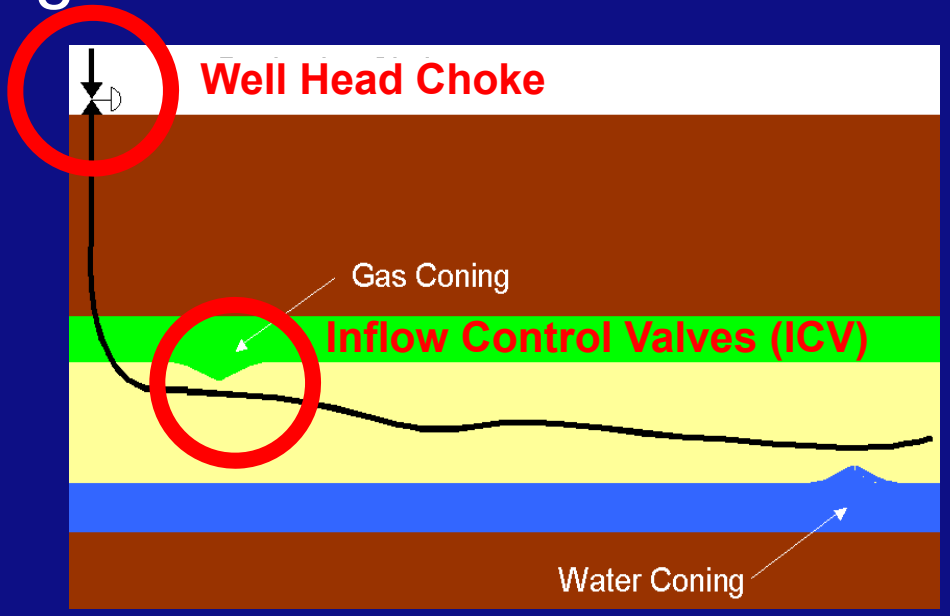


reference

optimal control

Thin oil rims

Gas coning control

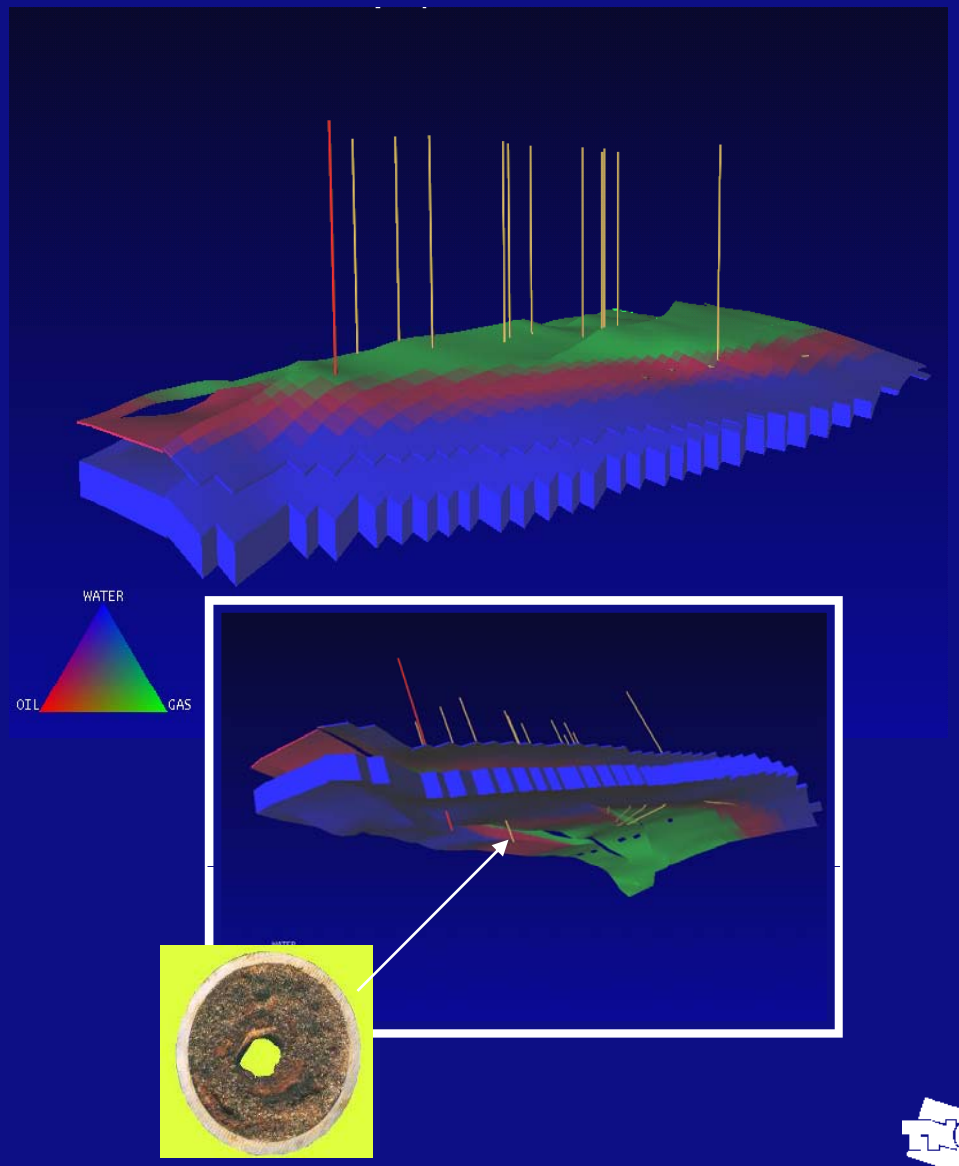


Problems due to dominant gas phase:

- May result in uneconomical production / flaring
- Damage topside equipment
- Decrease in reservoir drive

Gas Coning Control

- Asset with
  - Gas breakthrough
  - Wax deposition
  - Many wells need shut-in after two weeks
- Investigate use of well-head controllers to bring wells to continuous production

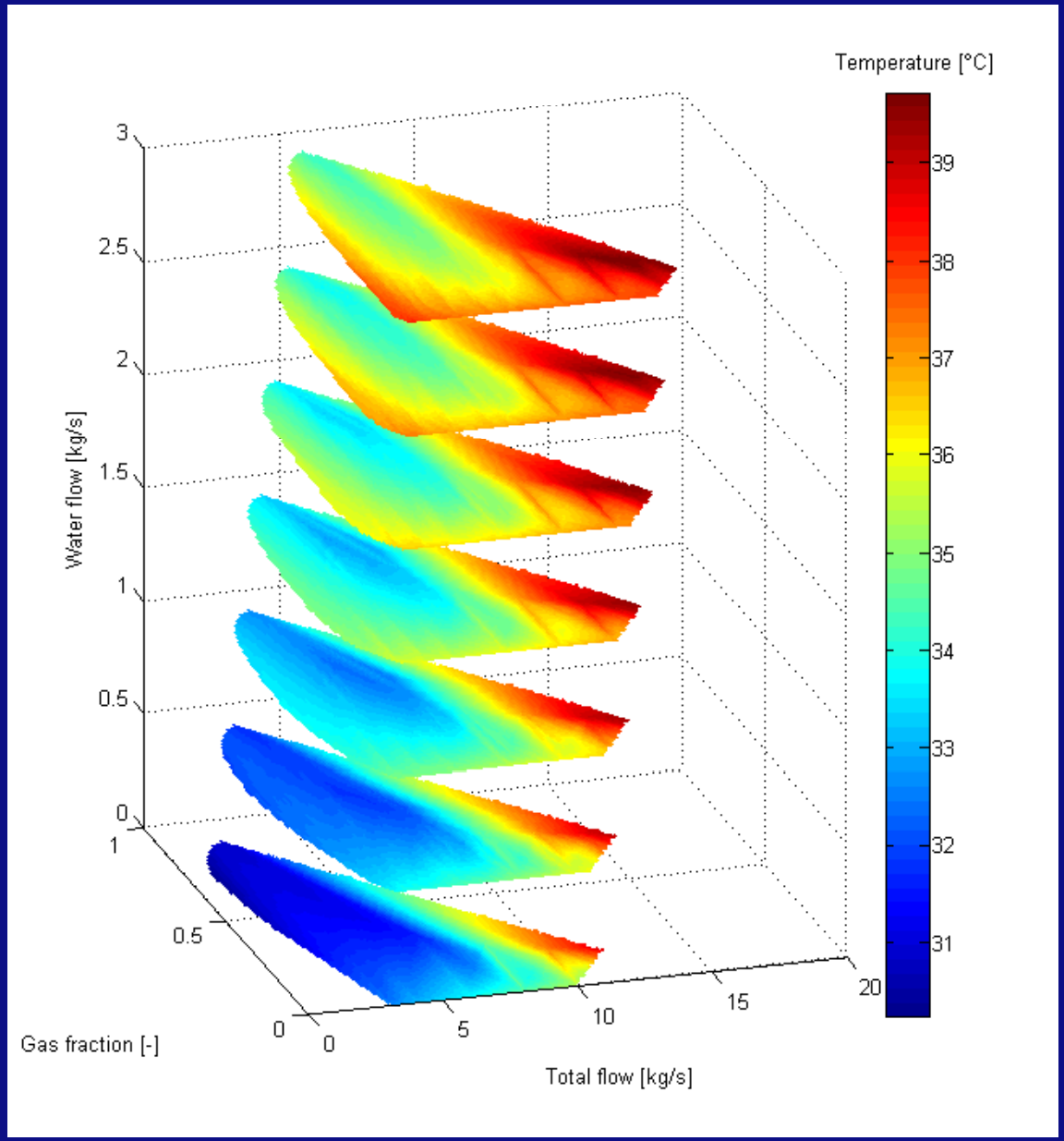


Approach

- well-reservoir model that tracks coning behavior, includes thermodynamic for waxing
- Validated on production data

Results

- Simulations show for what wells continuous closed loop production with flow controller is option
- Implementation (current): simulation model is used to improve time dependant tuning of controllers



Closed-Loop - Model-Driven - Real-Time
Production optimization - *Long-Time Wish*

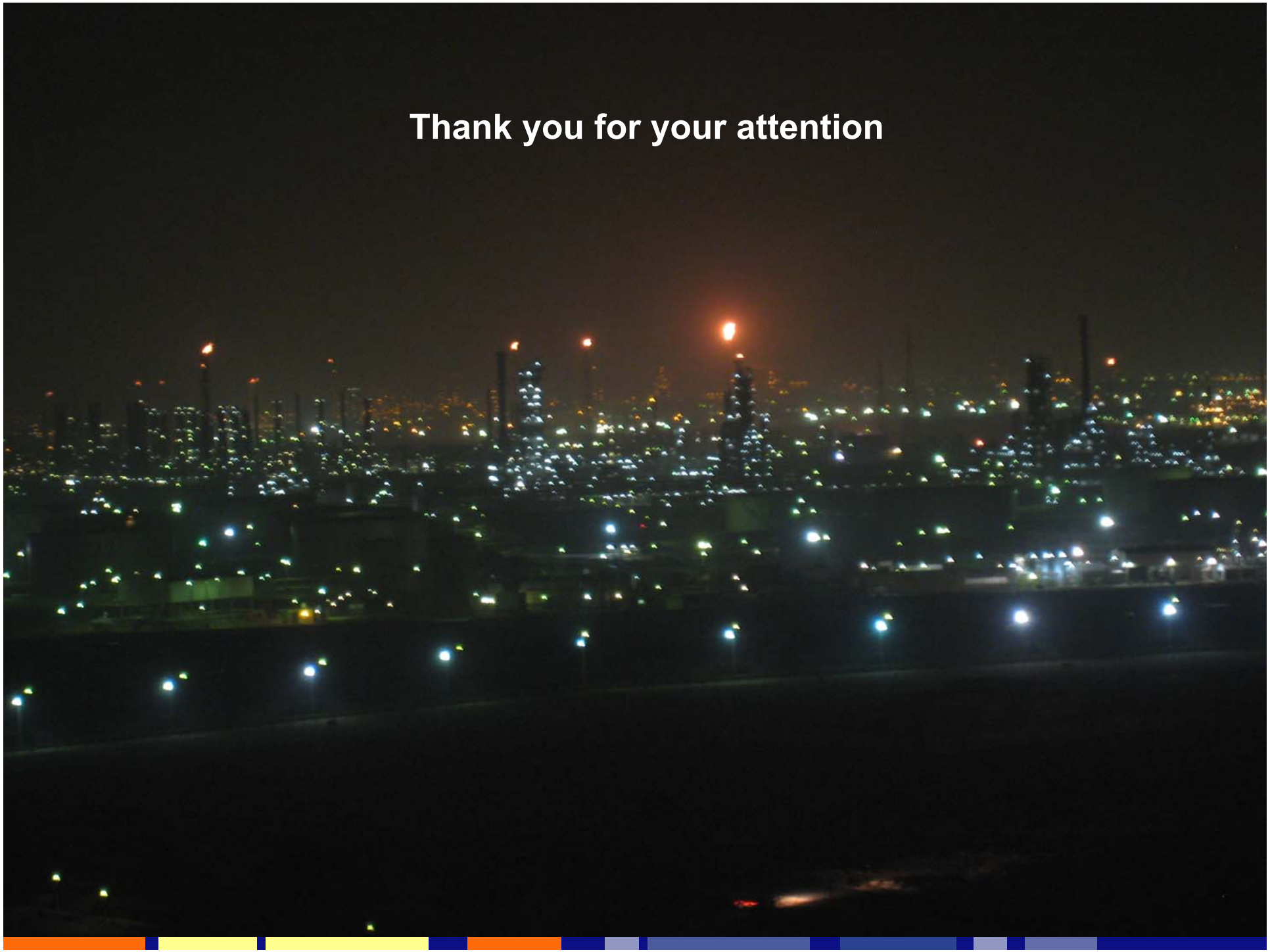
Closed loop reservoir management

- Focus on increasing sweeping efficiency

- Increasing the displacement of oil along swept streamlines

- Combination with EOR techniques

Viscosity of oil, brine or gas
Density & IFT


Thank you for your attention