Opus Terra™
Optimization & Uncertainty Solutions

Terra 3E SAS

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Outline

- Opus Terra™ toolbox
- Example of Petrel* workflows
  - History Matching
  - Optimization
  - Uncertainties
- PUNQ-S3
  - Presentation
    - Geological description
    - Dynamic data
  - Geological modeling
  - History Matching
  - Prediction
  - Conclusion

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Opus Terra™ Toolbox

- At the Interface between Petrel and Eclipse

- To help in:
  - Integrating dynamical data in the geological model
  - History matching
  - Uncertainty assessment of production forecasts
  - Optimization of well placement, perforation locations, flow rates, etc.

Opus Terra™ Toolbox

- Toolbox contains plug-ins for Petrel*
  - Sirenn™ : Simulator Reservoir Neural Network
    - Neural networks have been developed to reproduce complex physical phenomena
    - Neural networks are very well adapted to represent nonlinear phenomena
  - Glhis™ : Global History Matching (CMA-ES)
    - CMA-ES has been recognized as one of the most powerful continuous optimization algorithms on benchmark problems (Hansen et al., 2010) and real-world problems
- These tools are fully integrated in Petrel*

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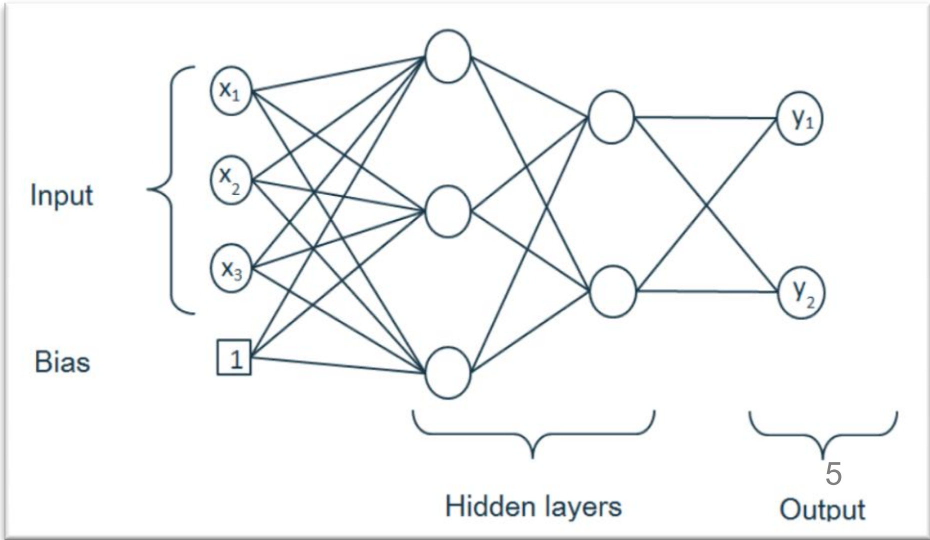
Sirenn™ : Simulator Reservoir Neural Network

- Tool for optimization and uncertainty in Petrel *
- Sirenn = A Neural Network to « Replace » the Reservoir Simulator

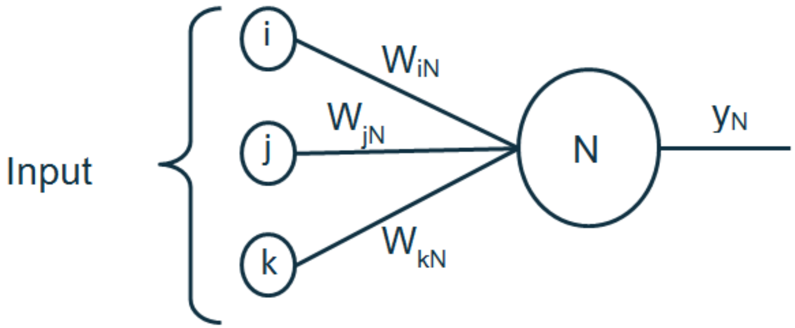
- Neural networks have been developed to reproduce complex physical phenomena
  - Aerospace: pilot flight simulation, etc..
  - Defense: missile guidance, etc..

- Neural network design
  - Network architecture
  - Learning base
  - Learning method



Sirenn™ : Simulator Reservoir Neural Network

- A neuron



$$y_N = f\left(\theta_0 + \sum_{i=1}^{n_{input}} w_{iN} x_i\right)$$

  - f : transfert function (e.g. sigmoide). The output varies continuously but not linearly as the input changes

- The creation of a neural network needs to have a learning data
  - Examples as representative as possible of the problem to reproduce

$$\begin{array}{ccccccc} & \text{Input} & & & \text{Output} & \\ x_1^1 & x_2^1 & x_3^1 & \longrightarrow & y_1^1 & y_2^1 \\ x_1^2 & x_2^2 & x_3^2 & \longrightarrow & y_1^2 & y_2^2 \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ x_1^N & x_2^N & x_3^N & \longrightarrow & y_1^N & y_2^N \end{array}$$

- Learning phase calculate the weight of the network

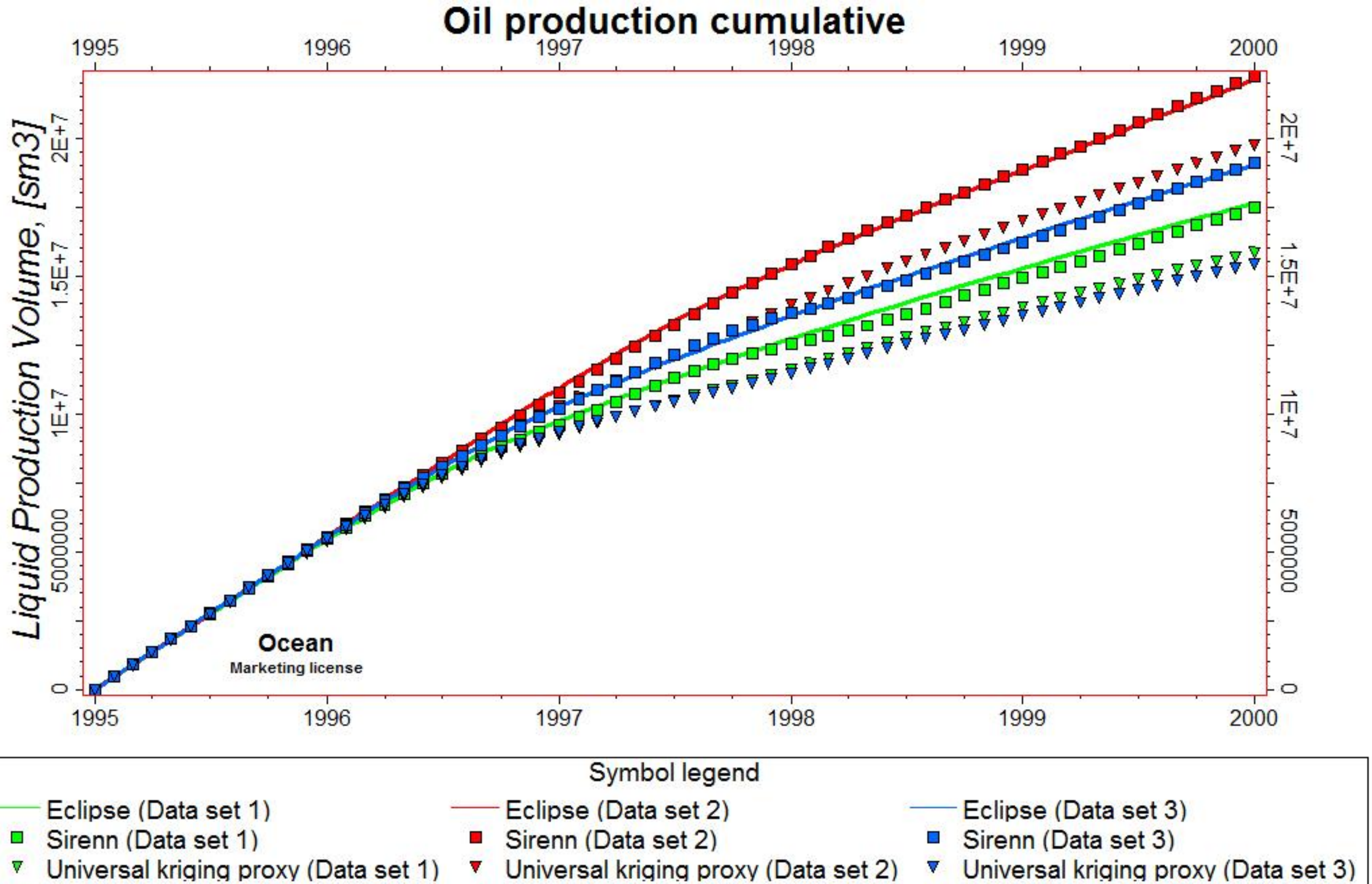
Sirenn™ : Simulator Reservoir Neural Network

- Neural networks are not widely used in reservoir simulation

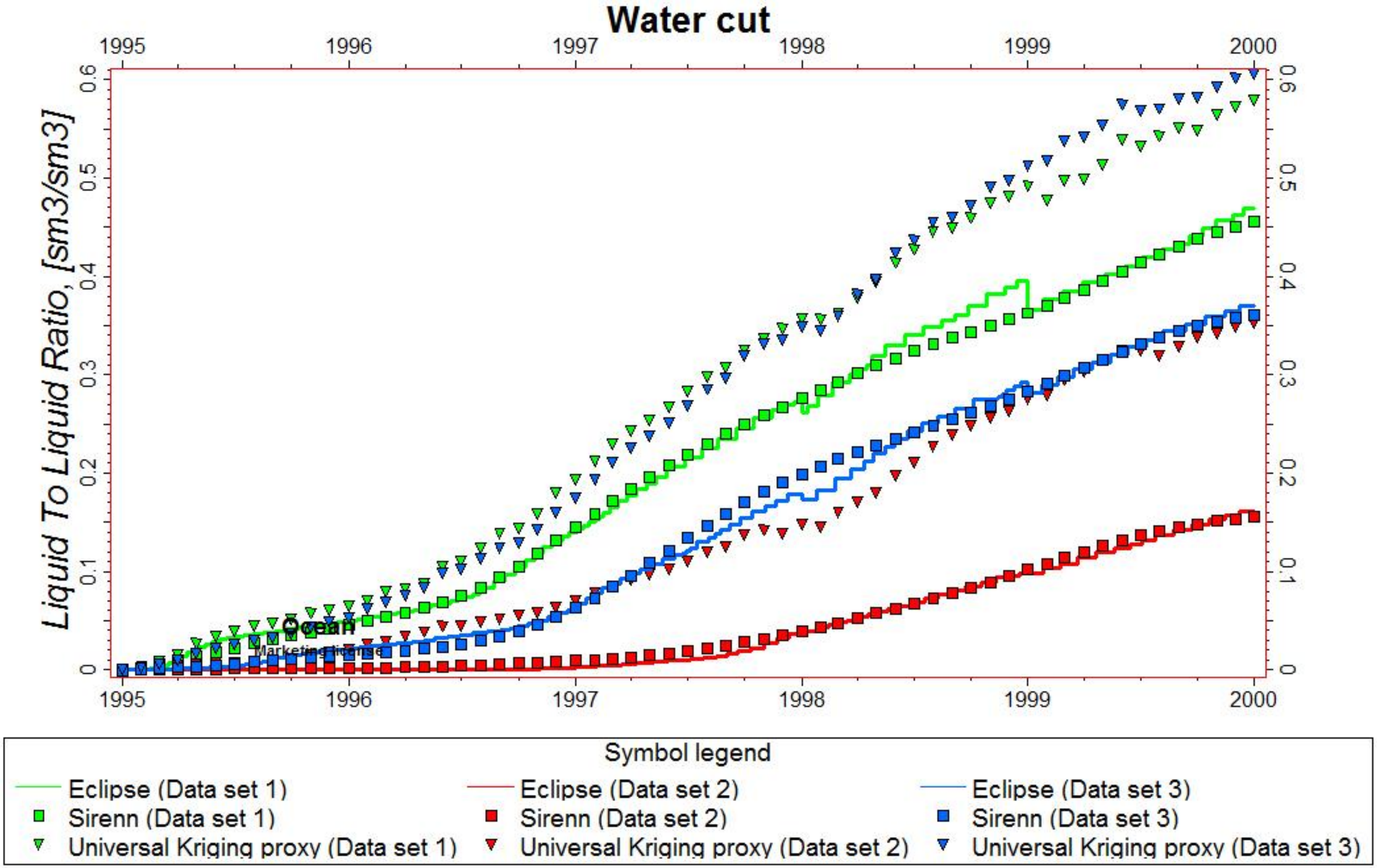
- Unlike conventional approaches, neural networks
  - Represent and reproduce complex physical phenomena
  - Require a limited number of simulations

- Gives better results than polynomials
- Gives better results than kriging

Sirenn™ : Example



Sirenn™ : Example



Sirenn™ : <u>Si</u>mulator <u>Re</u>servoir <u>N</u>eural <u>N</u>etwork

- Sirenn™ is very well adapted to represent nonlinear phenomena

- Sirenn™ allows bypassing time consuming reservoir simulations
  - Inverse problems : History matching - Optimization
  - Sensitivity analysis
  - Uncertainty analysis

Glhis™ : Global History Matching

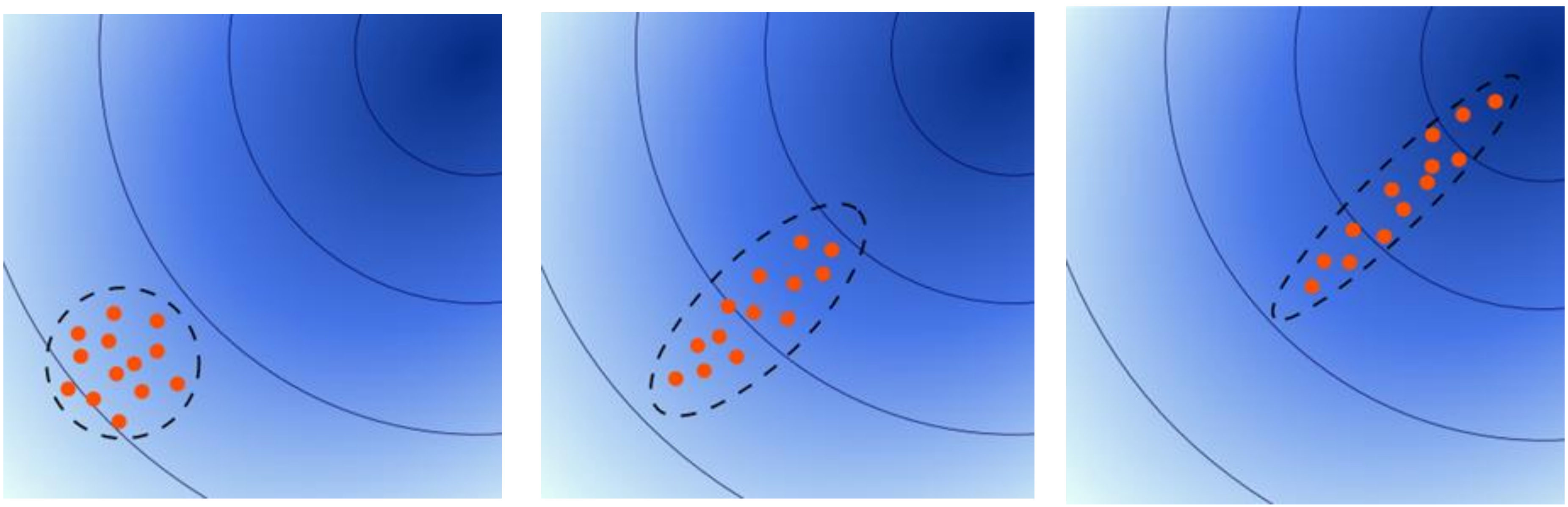
- The CMA-ES (Covariance Matrix Adaptation Evolution Strategy) is an evolutionary algorithm for difficult non-linear non-convex optimization problems

- Typically applied to optimization problems with a large number of parameters (hundred)

- Should be applied, if derivative based methods, e.g. quasi-Newton BFGS or conjugate gradient, fail due to a rugged search landscape:
  - discontinuities,
  - sharp bends or ridges,
  - noise,
  - local optima, etc.

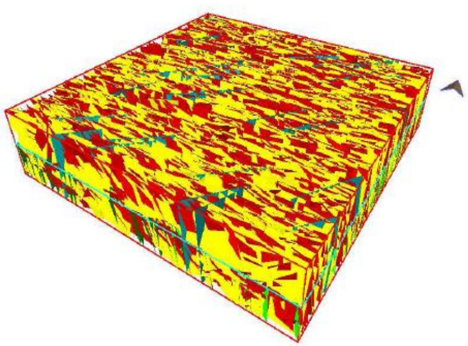
Glhis™ : Global History Matching

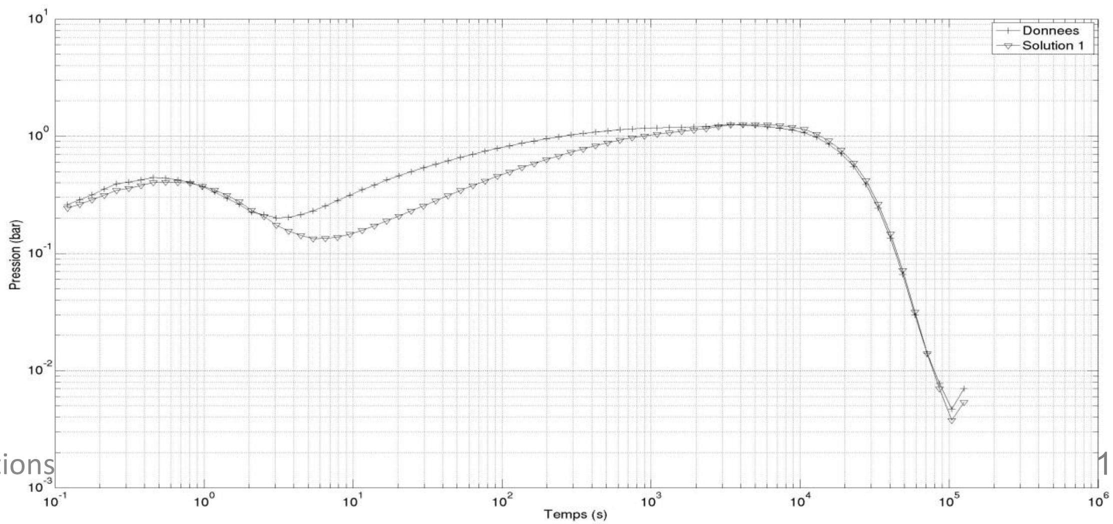
- The CMA-ES does not require a tedious parameter tuning for its application



Glhis™ : Global History Matching

- Applications of the CMA-ES
  - Well test inversion in fractured porous media
    - Bruyelle, J., Lange, A. - Automated characterization of fracture conductivities from well tests inversion. SPE EUROPEC/ EAGE annual conference and exhibition, SPE 121172 (2009)
    - Bruyelle, J. – Modélisation Inverse de l'Ecoulement en Milieux Poreux Fracturés, Université de Rennes 1, 2010. (Ref. IFP 61 791).
    - 19 parameters : fracture density, length, aperture, conductivity





- Applications of the CMA-ES
  - Well placement optimization
    - Bouzarkouna, Z., Ding, D.Y., Auger, A. - Using Evolution Strategy with Meta–models for Well Placement Optimization. 12th European Conference on the Mathematics of Oil Recovery (ECMOR XII). EAGE (2010)

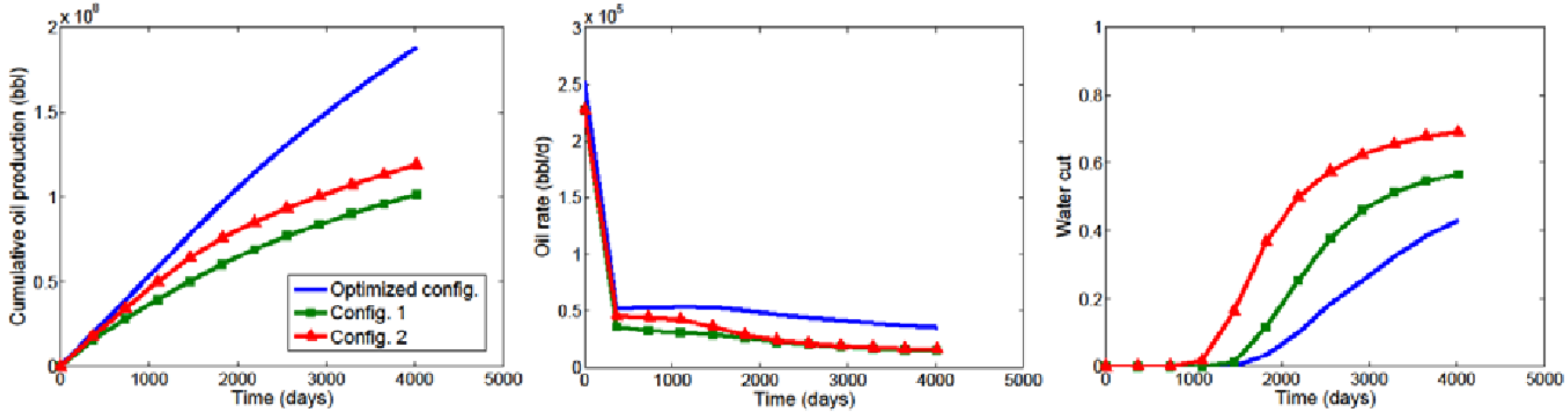


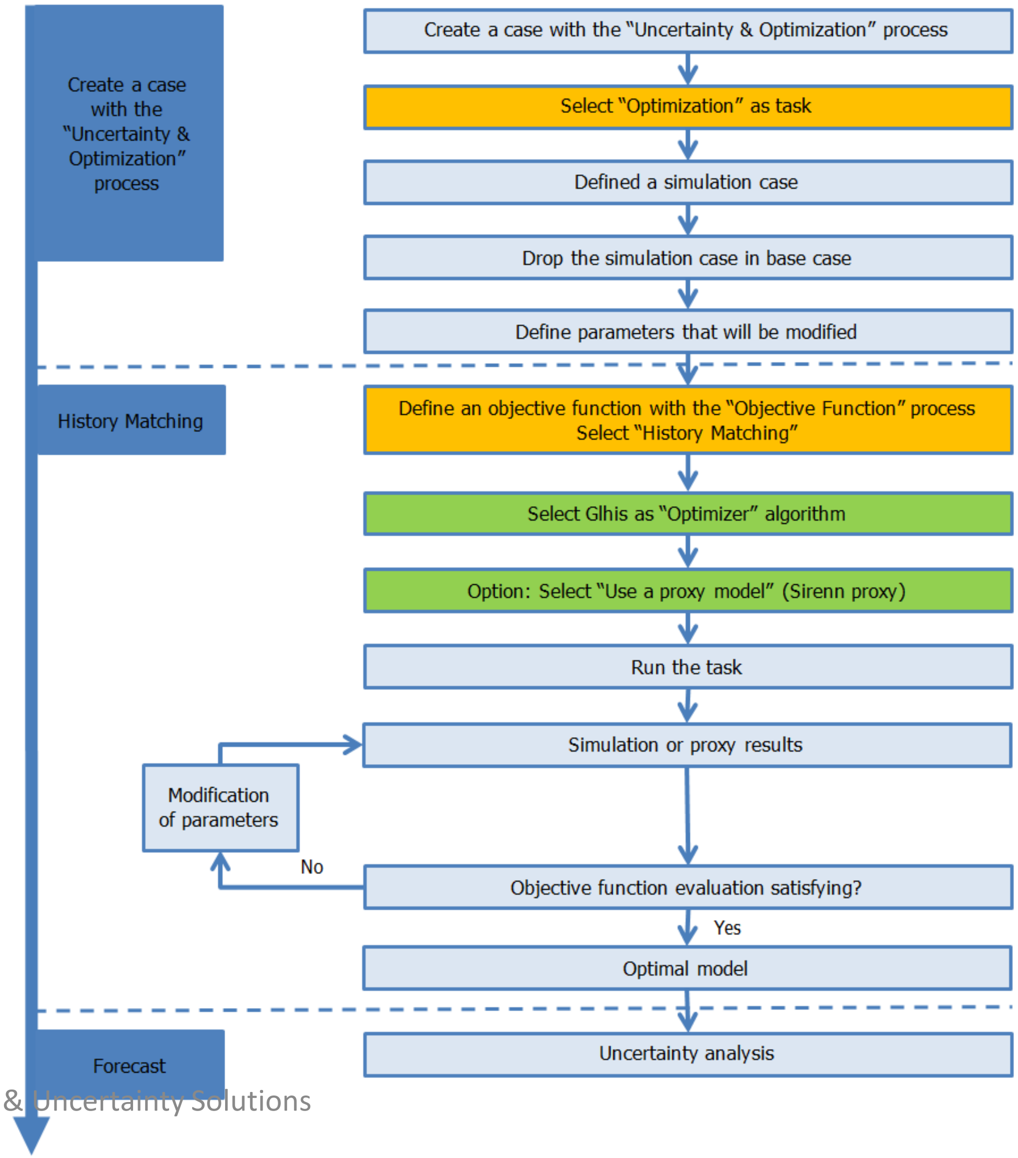
Fig. 10: Production curves for an optimized solution using CMA-ES with meta-models (*optimized config.*) and 2 engineer's proposed configurations (*config.1* and *config.2*).

Glhis™ : Global History Matching

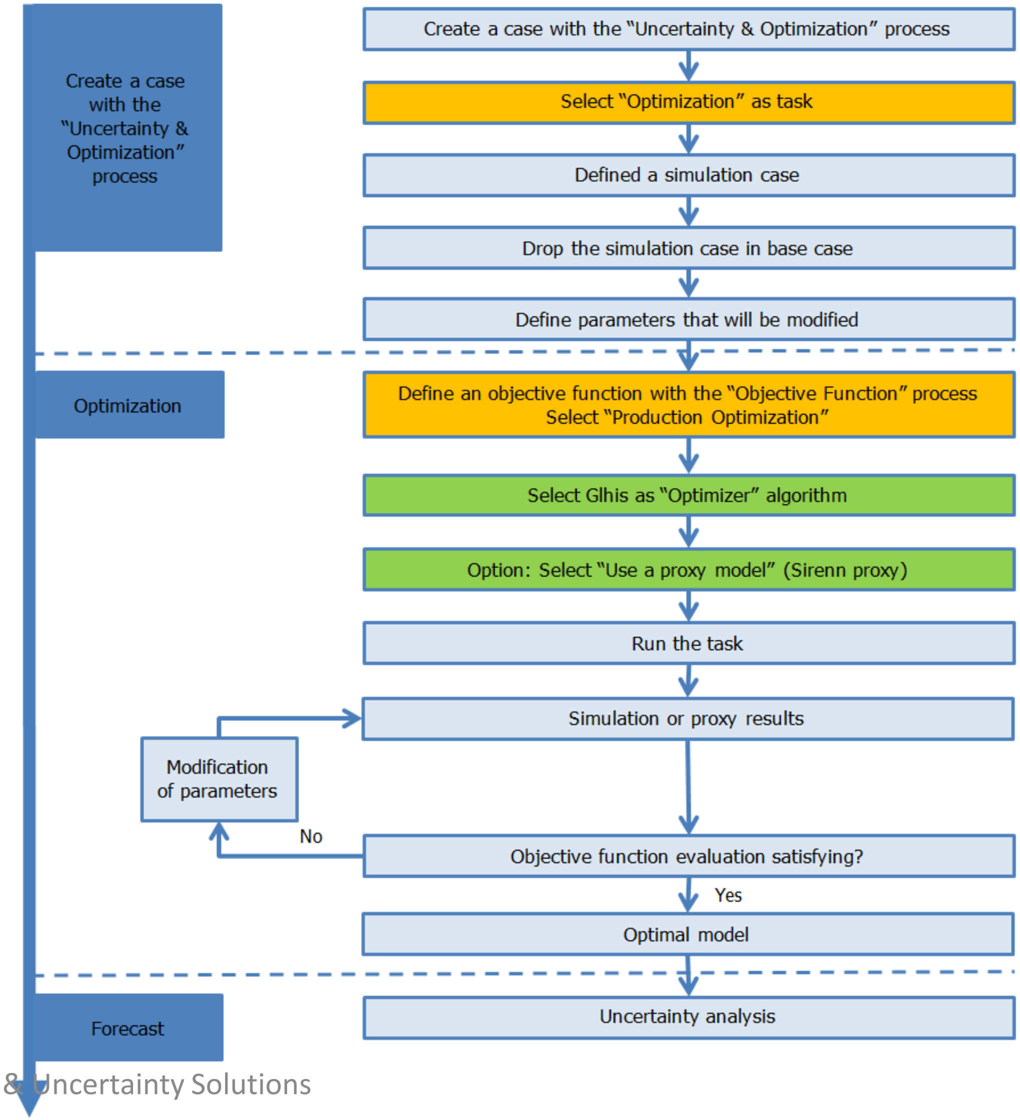
- CMA-ES has been recognized as one of the most powerful continuous optimization algorithms on benchmark problems (Hansen et al., 2010) and real-world problems

- This method is useful for the problem with many parameters (more than 10) to find an « optimal » answer

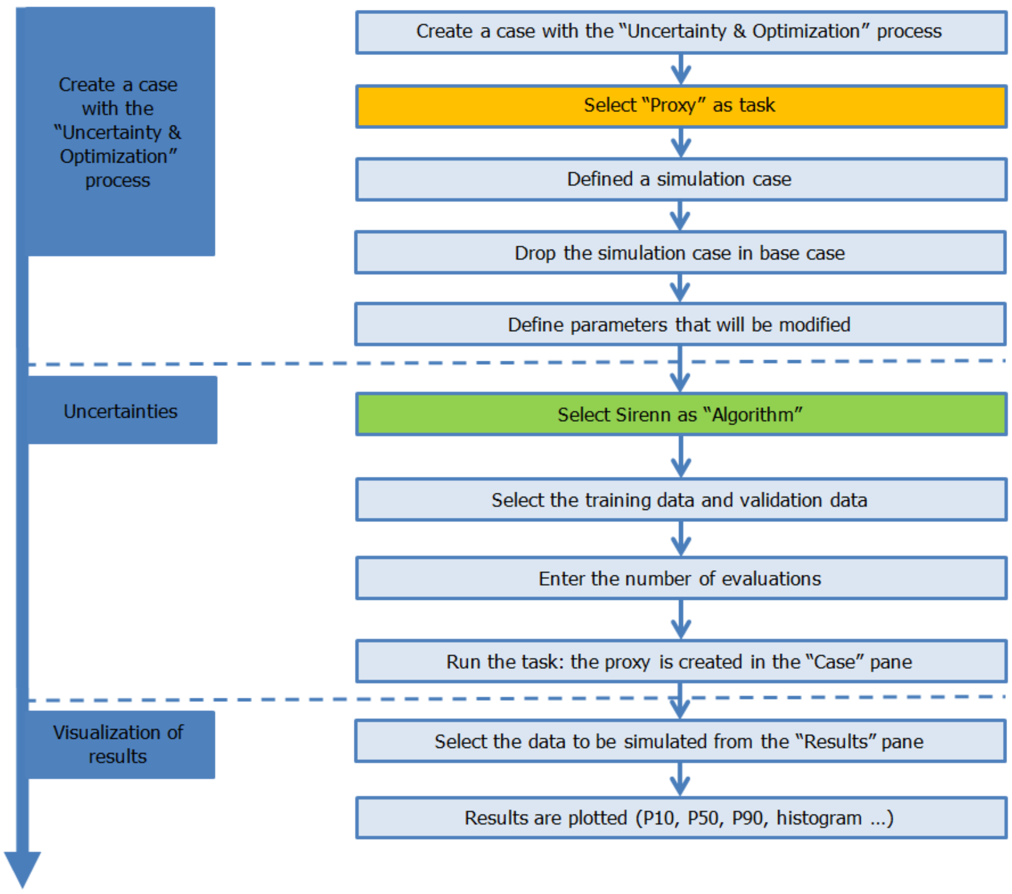
Example of Petrel Workflows – History Matching



Example of Petrel Workflows – Optimization

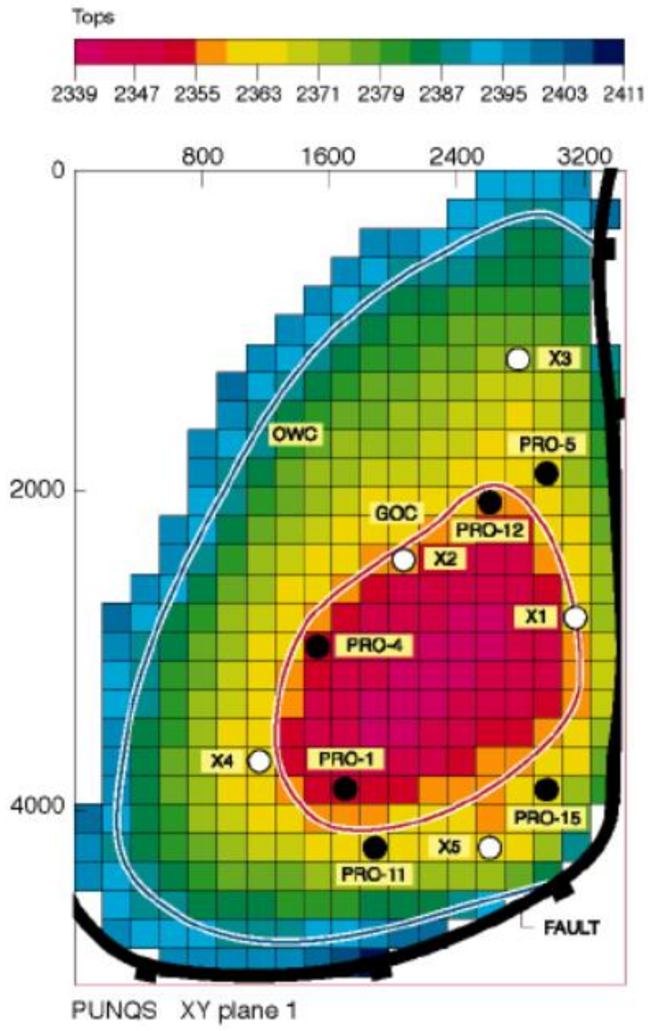


Example of Petrel Workflows – Uncertainties



PUNQ-S3

- The PUNQ-S3 case has been taken from a reservoir engineering study on a real field performed by Elf Exploration Production.
- It was qualified as a small-size industrial reservoir engineering model.
- http://www3.imperial.ac.uk/earthscienceandengineering/research/perm/punq-s3model



PUNQ-S3 – Geological Description

- Layers 1, 3, and 5 have linear streaks of high-porous sands (phi > 20 %), with an azimuth somewhere between 110 and 170 degrees SE. These sand streaks of about 800 m wide are embedded in a low porous shale matrix (phi < 5 %).

- In layer 2 marine or lagoonal shales occur , in which distal mouthbar or distal lagoonal delta occur. They translate into a low-porous (phi < 5%), shaly sediment, with some irregular patches of somewhat higher porosity (phi > 5%).

- Layer 4 contains mouthbars or lagoonal deltas within lagoonal clays, so a flow unit is expected which consists of an intermediate porosity region (phi ~ 15%) with an approximate lobate shape embedded in a low-porosity matrix (phi < 5%). The lobate shape is usually expressed as an ellipse (ratio of the axes= 3:2) with the longest axis perpendicular to the paleocurrent (which is between 110 and 170 degrees SE).

PUNQ-S3 – Geological Description

- Expected sedimentary facies with estimates for width and spacing for major flow units for each layer

Layer	Facies	Width (m)	Spacing (m)
1	Channel Fill	800	2000 – 5000
2	Lagoonal Shale	-	-
3	Channel Fill	1000	2000 – 5000
4	Mouthbar	500 – 5000	10000
5	Channel Fill	2000	4000 – 10000

PUNQ-S3 – Geological Modeling

- The GM (Geological Model) has:
  - 19x28x5=2660 grid blocks,
  - with 1761 active

- Layer 1, 3 & 5 has two facies:
  - An high-porous sands (phi > 20 %);
  - A low porous shale matrix (phi < 5 %)
  - GM = adaptive channel modeling using the geological description & the hard observed data

PUNQ-S3 – Geological Modeling

- Layer 2 has two facies:
  - A low porous shaly sediment (phi < 5%);
  - A high porous shaly sediment (phi > 5 %).
  - GM = ellipses as body shape modeling using the geological description & the hard observed data.

- Layer 4 has two facies:
  - An intermediate porosity region (phi ~ 15%);
  - A low-porosity matrix (phi < 5%).
  - GM = ellipses as body shape using the geological description & the hard observed data.

PUNQ-S3 – Geological Modeling

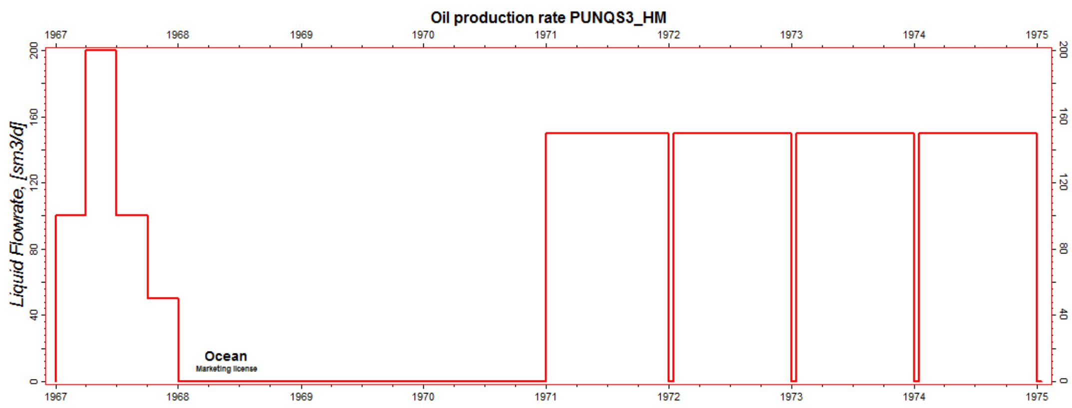
- The uncertain geological parameters of PUNQ-S3 are the porosities, the vertical & horizontal permeabilities

- The parameterization of PUNQ-S3 model is based on the geological description

- The constant properties are estimated for each facies
  - 18 parameters

PUNQ-S3 – History Matching

- Production scheduling inspired by the original model:
  - 1st year = extended well testing
  - Followed by 3 years shut-in period, before field production commences
  - Well testing year consists of 4 three-monthly production periods, each having its own production rate.
  - During field production, two weeks/year used for each well to do a shut-in test to collect shut-in pressure data
  - Wells operate under production constraint. After falling below a limiting bottom hole pressure, they will switch to BHP-constraint.



PUNQ-S3 – History Matching

- Data points used in history matching

Date	PRO-1			PRO-4			PRO-5			PRO-11			PRO-12			PRO-15		
	BHP	GOR	WC	BHP	GOR	WC	BHP	GOR	WC	BHP	GOR	WC	BHP	GOR	WC	BHP	GOR	WC
1.01	224.0			225.2			228.7			219.3			231.0			217.1		
91	211.7			210.6			222.9			202.7			218.7			193.5		
182	215.6			216.6			223.4			208.4			220.8			209.0		
274	219.6			224.4			230.0			219.1			224.7			216.8		
366	226.3			229.5			230.7			228.4			229.8			228.1		
1461	233.2			234.2			235.9			235.3			234.6			234.6		
1642		72.6																
1826	201.0	135		190.4			215.7	63.6		203.8	67.2		209.1	67		191.1	63.7	
1840	222.2			224.5			226.5			225.1			225.4			223.4		
1841					82.1													
2008		191.7			165.3													
2192	190.6			177.7			207.2	62.5		194.4	59.1		200.5	74.5		181.3	56.3	
2206	215.4			217.9			220.0			218.8			219.6			217.2		
2373		147.1			106													
2557	184.4			170.7			202.6	62.5		186.0	62.4		197.2	67.8		175.9	58.1	
2571	210.8			213.4			215.7			213.3			215.5			212.2		
2572												0						
2738		190.1			74.8							0.022						
2922	178.5		0	167.8		0	196.4	59.9	0.002	169.9	65.2	0.098	195.7	76.4	0	170.0	49.8	0
2936	206.1			210.3			212.4			208.9			212.4			208.1		
Sigma	3	34	0.2	3	21	0.2	3	6.2	0.2	3	6.3	0.2	3	7	0.2	3	5.7	0.2

PUNQ-S3 – History Matching

- Objective function

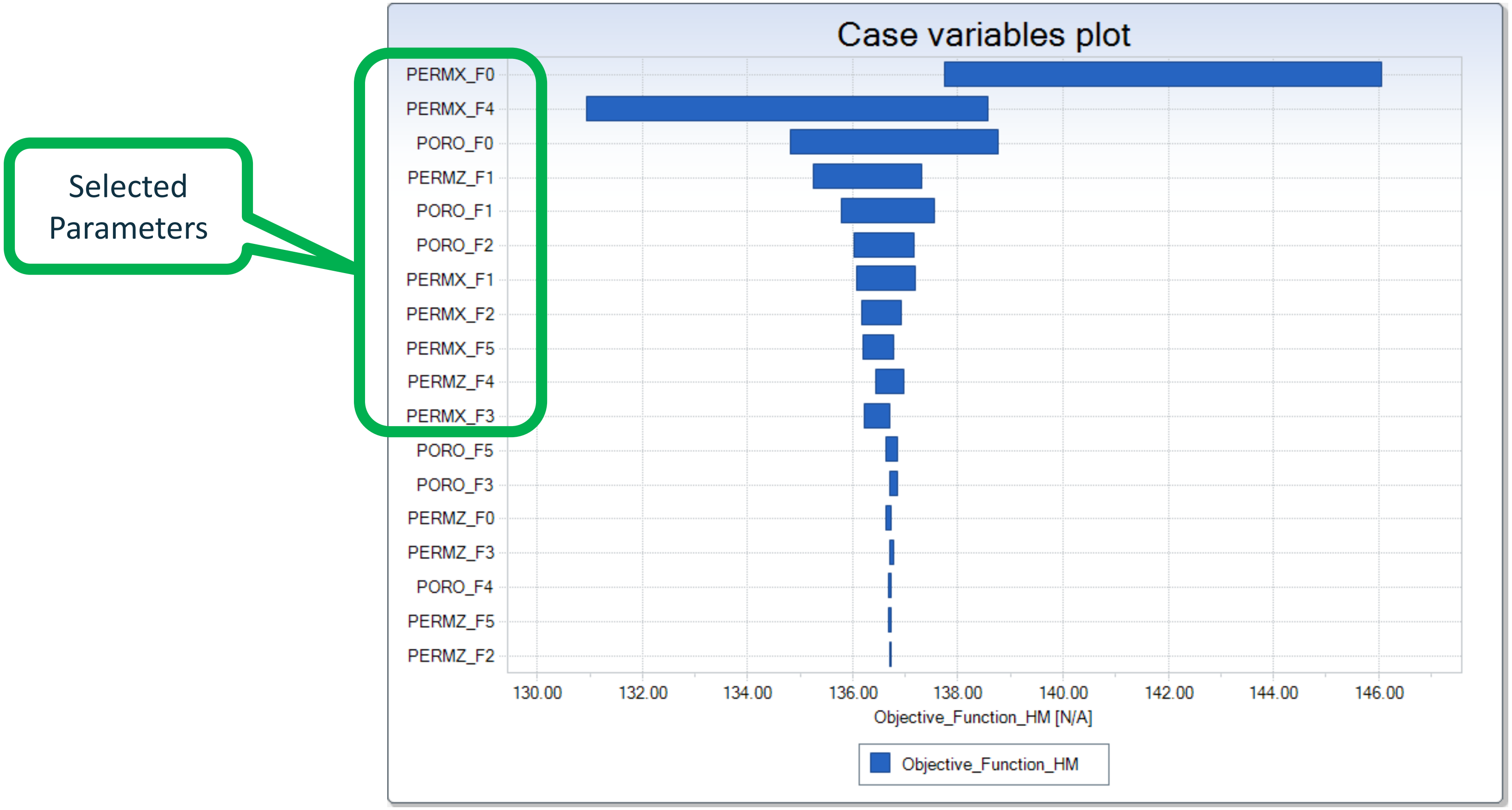
$$J(\theta) = \sqrt{\frac{\sum_{i=1}^{N_w} \sum_{j=1}^{N_{p_i}} \sum_{k=1}^{N_{t_{ij}}} w_{ijk} \left(\frac{D_{ij}(t^k) - S_{ij}(t^k, \theta)}{\sigma_{ij}} \right)^2}{\sqrt{\sum_{i=1}^{N_w} \sum_{j=1}^{N_{p_i}} \sum_{k=1}^{N_{t_{ij}}} w_{ijk}}}}$$

  - N_w is the number of wells
  - N_{p_i} is the number of production data type for the well i
  - $N_{t_{ij}}$ is the number of production data report times for the well i and the production data type j.

- For a parameter sample θ, observed data $D_{ij}(t^k)$ are compared with simulated data $S_{ij}(t^k, \theta)$ at time step t^k with

PUNQ-S3 – History Matching

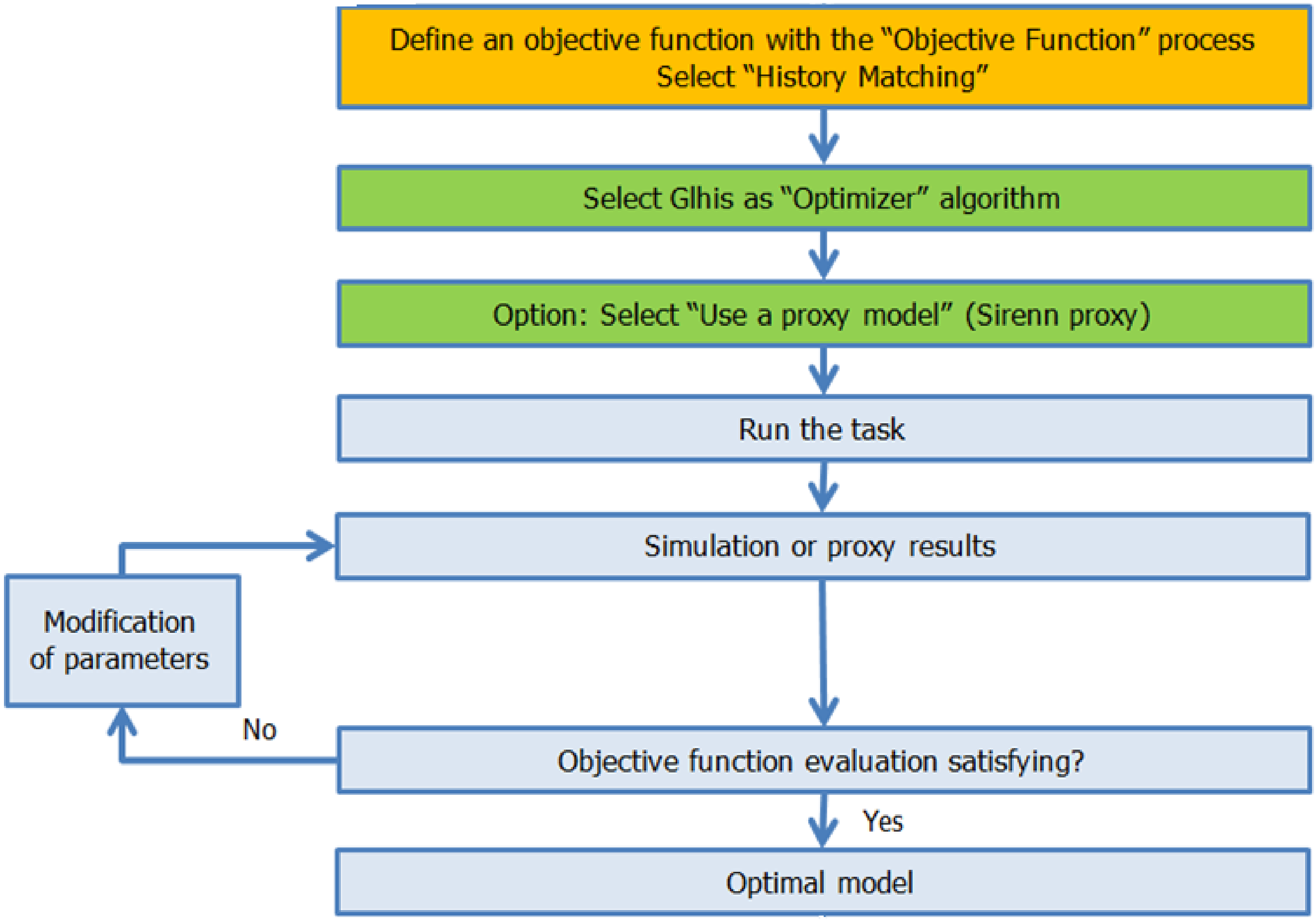
- Sensitivity analysis by variable
  - Equal spacing sampler: 4 simulations by variable = 72 simulations.



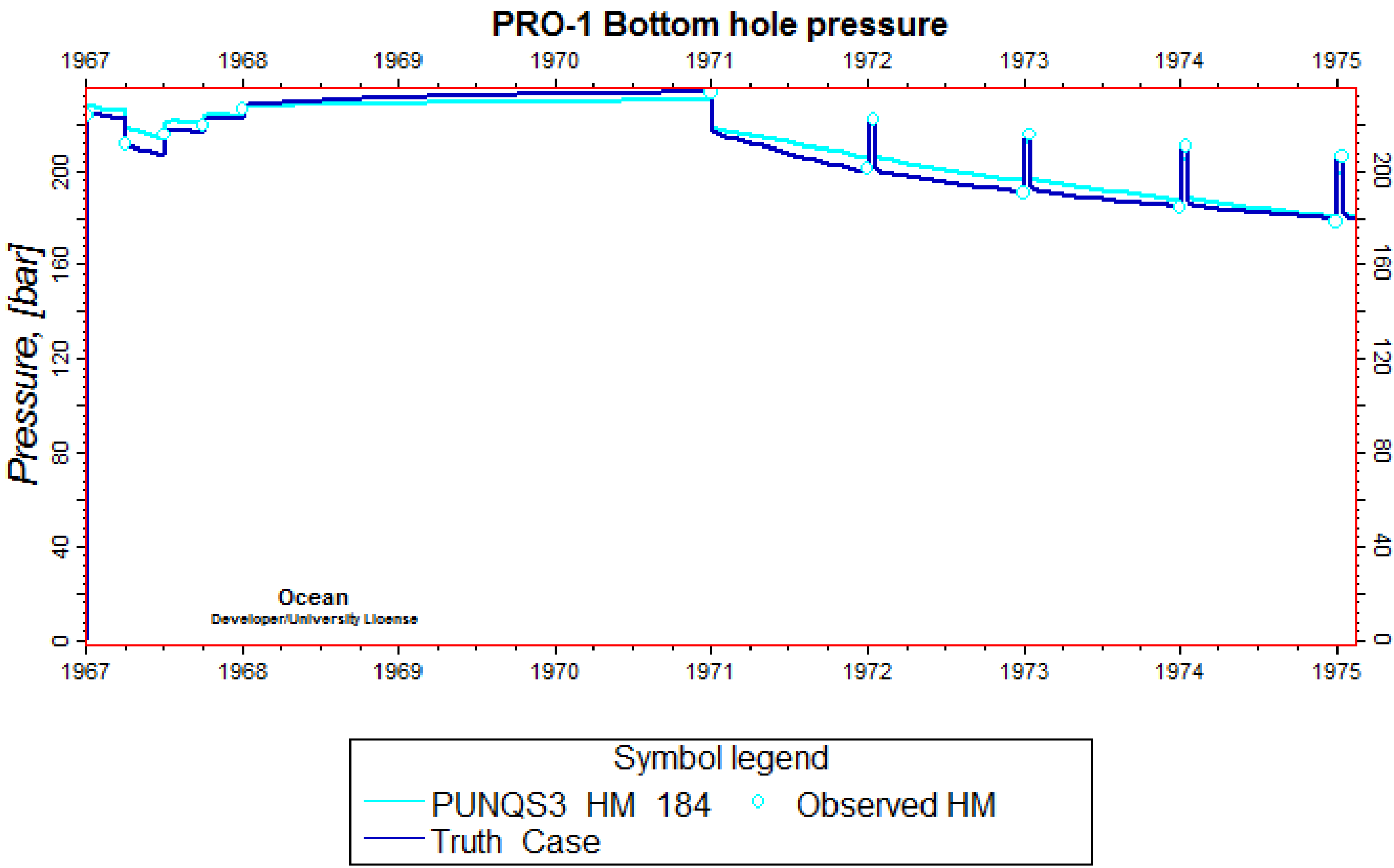
PUNQ-S3 – History Matching

- Proxy model of the objective function with Sirenn™
  - Training data
    - Experimental design : Fractionnal factorial sampler : 32 simulations + central point.
    - Simulation performed for sensitivity analysis : 72 simulations
- Minimization of the objective function with Glhis™ using the Sirenn™ proxy

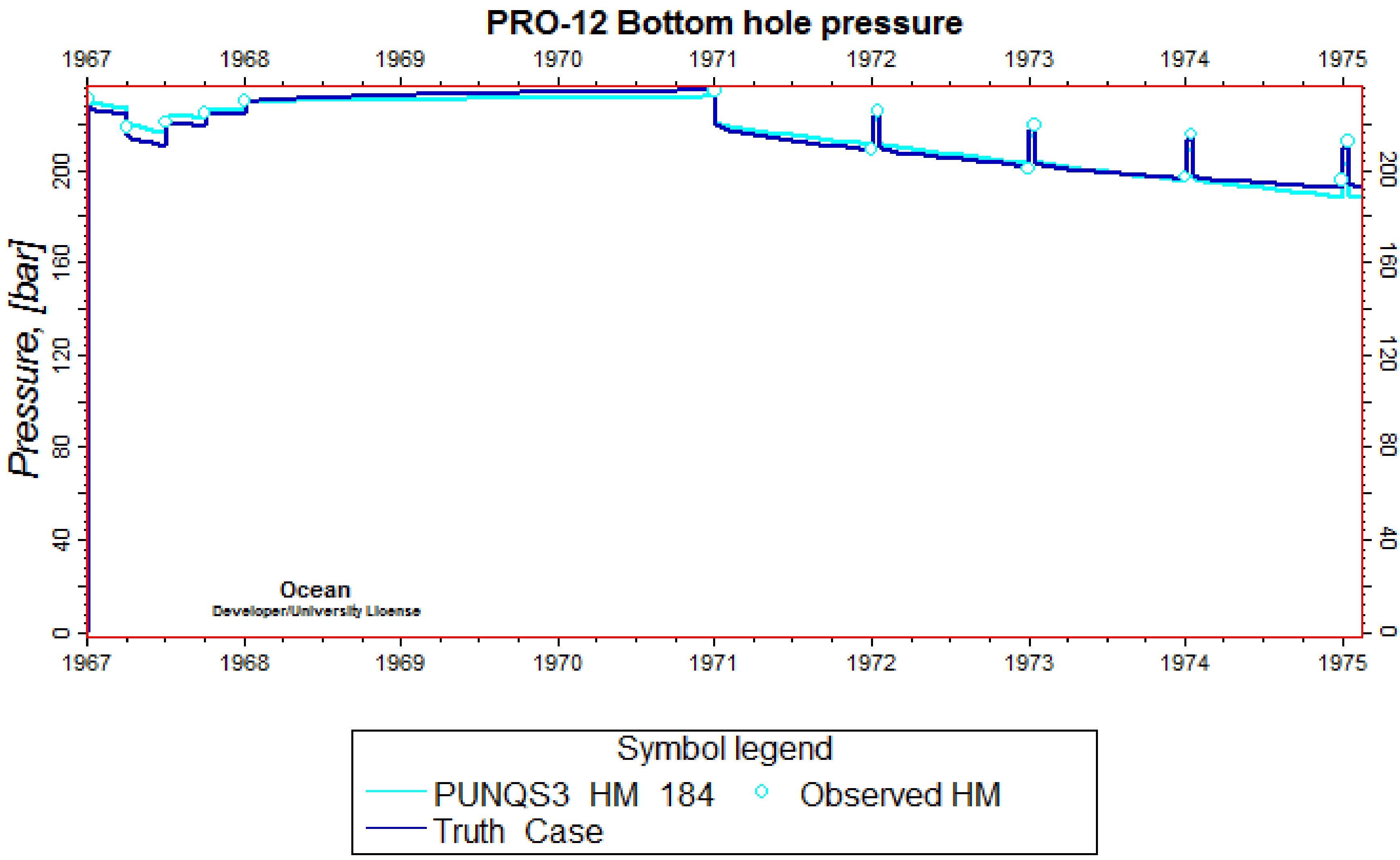
PUNQ-S3 – History Matching



PUNQ-S3 – History Matching Results



PUNQ-S3 – History Matching Results



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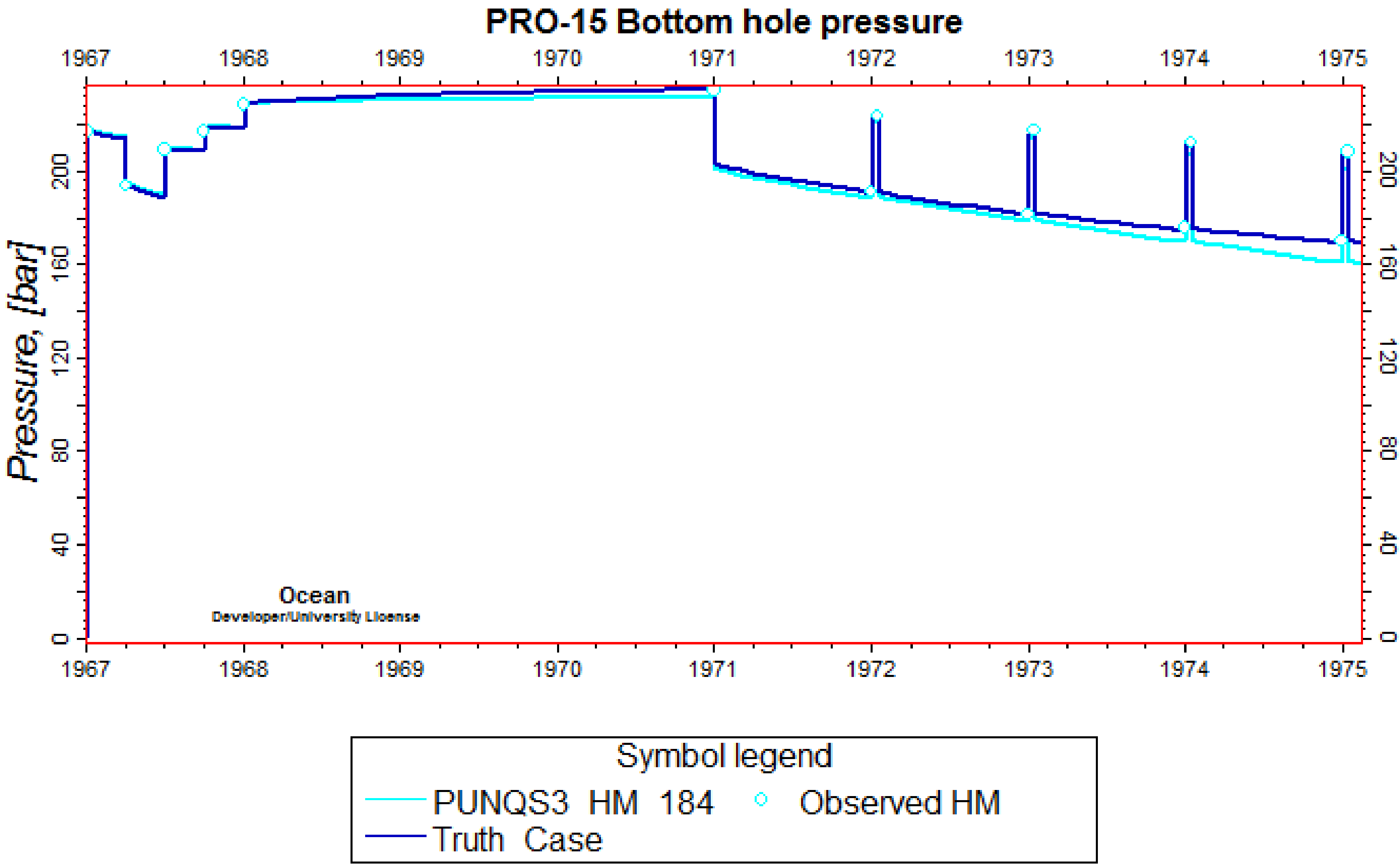
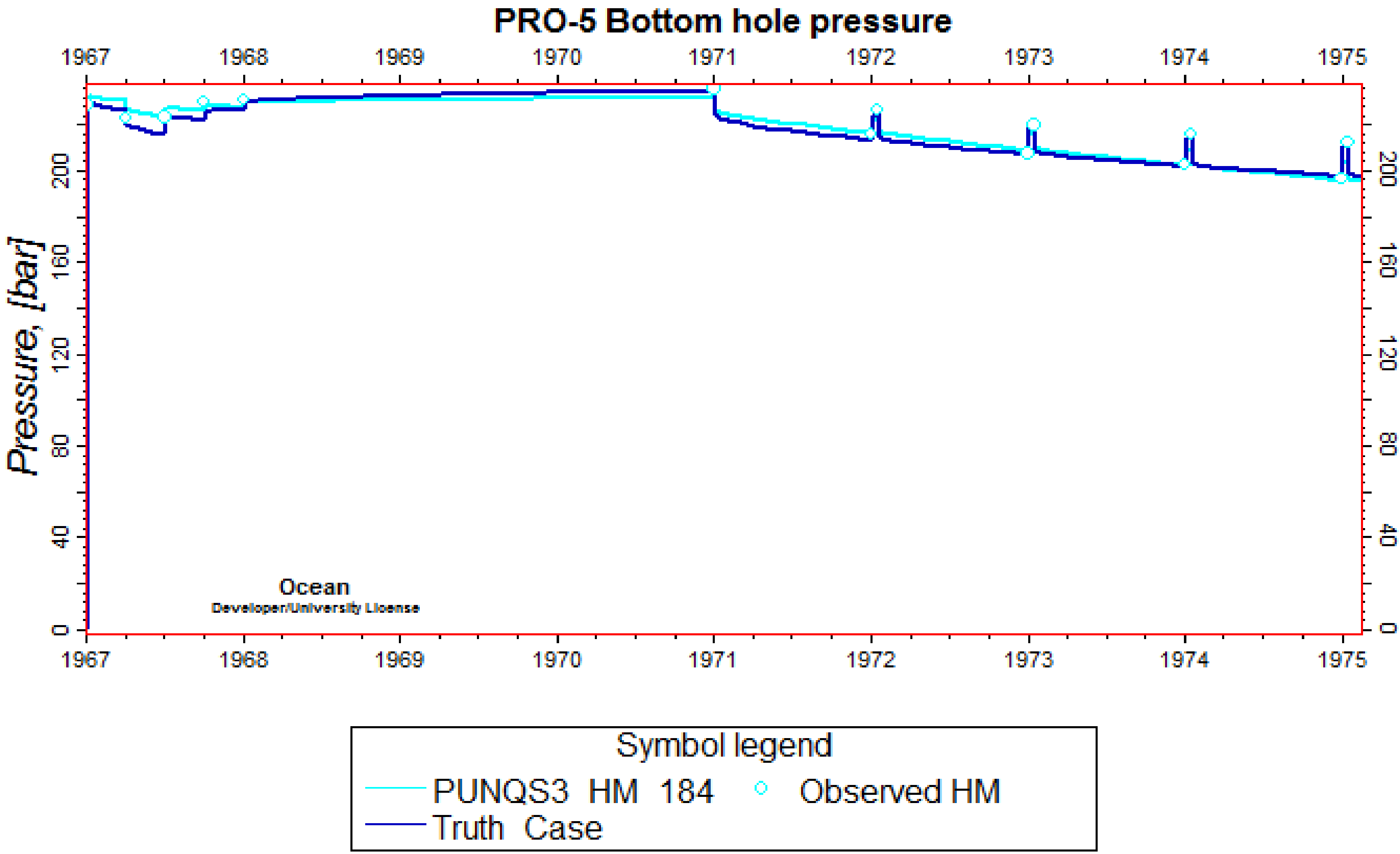


PUNQ-S3 – History Matching Results



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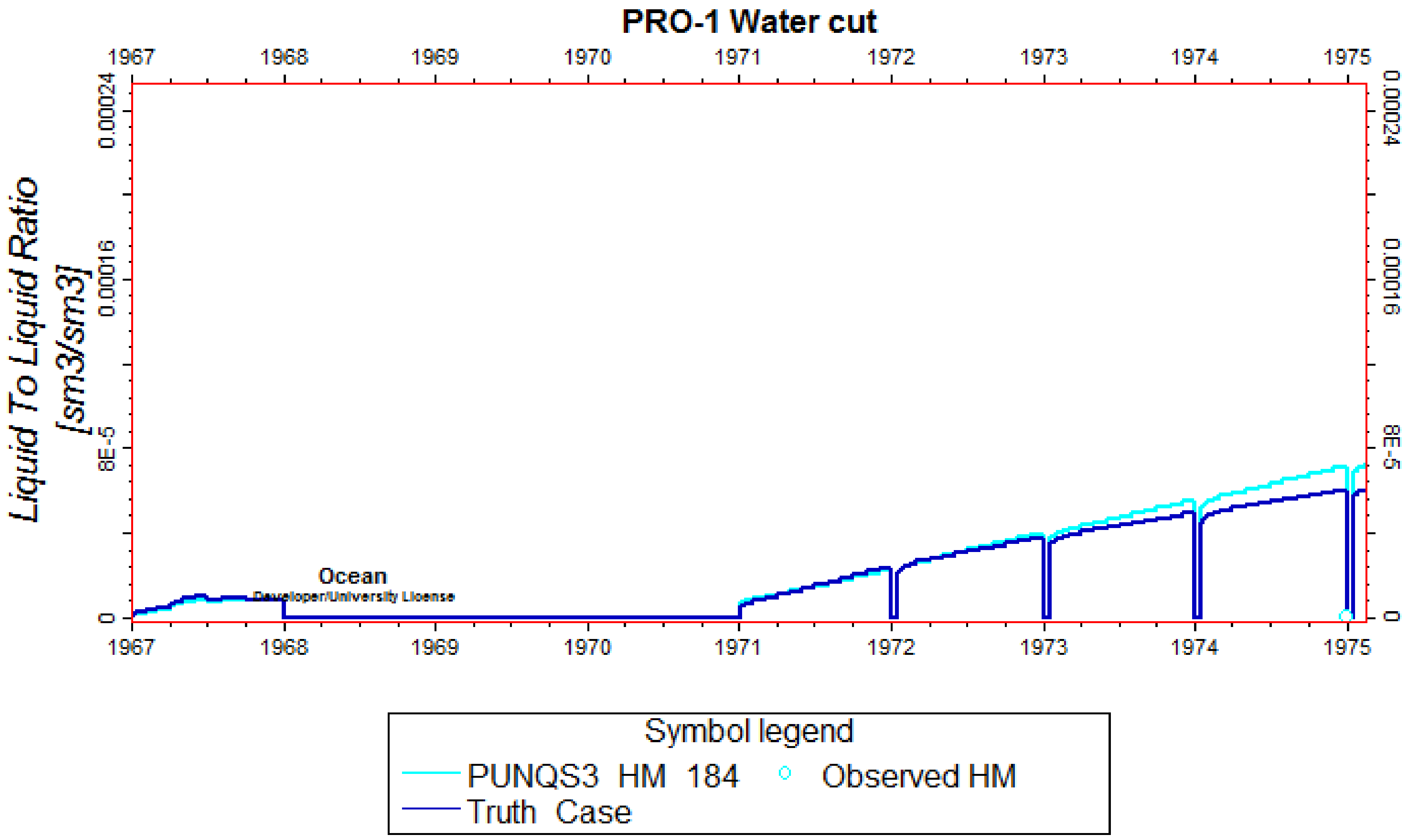
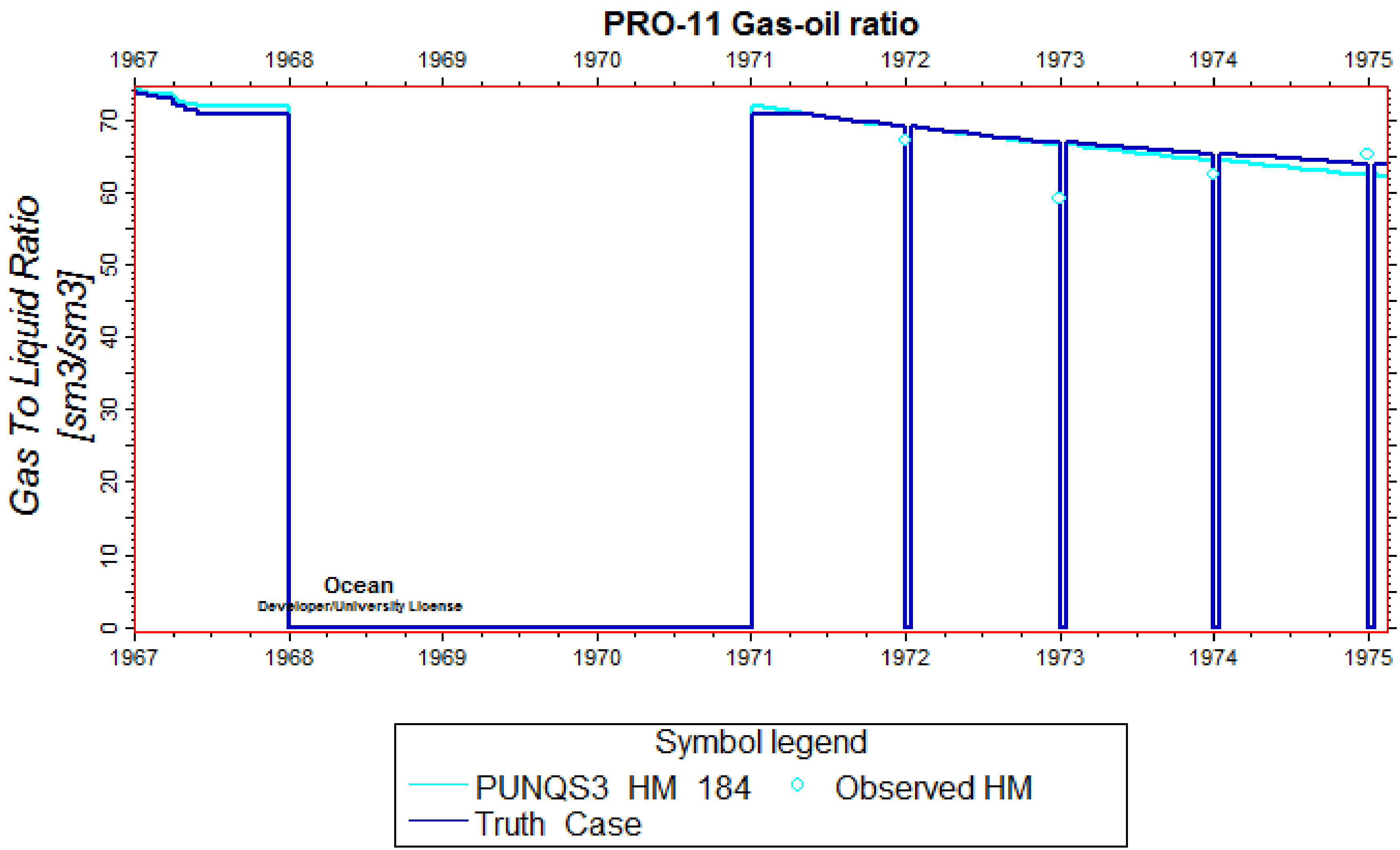
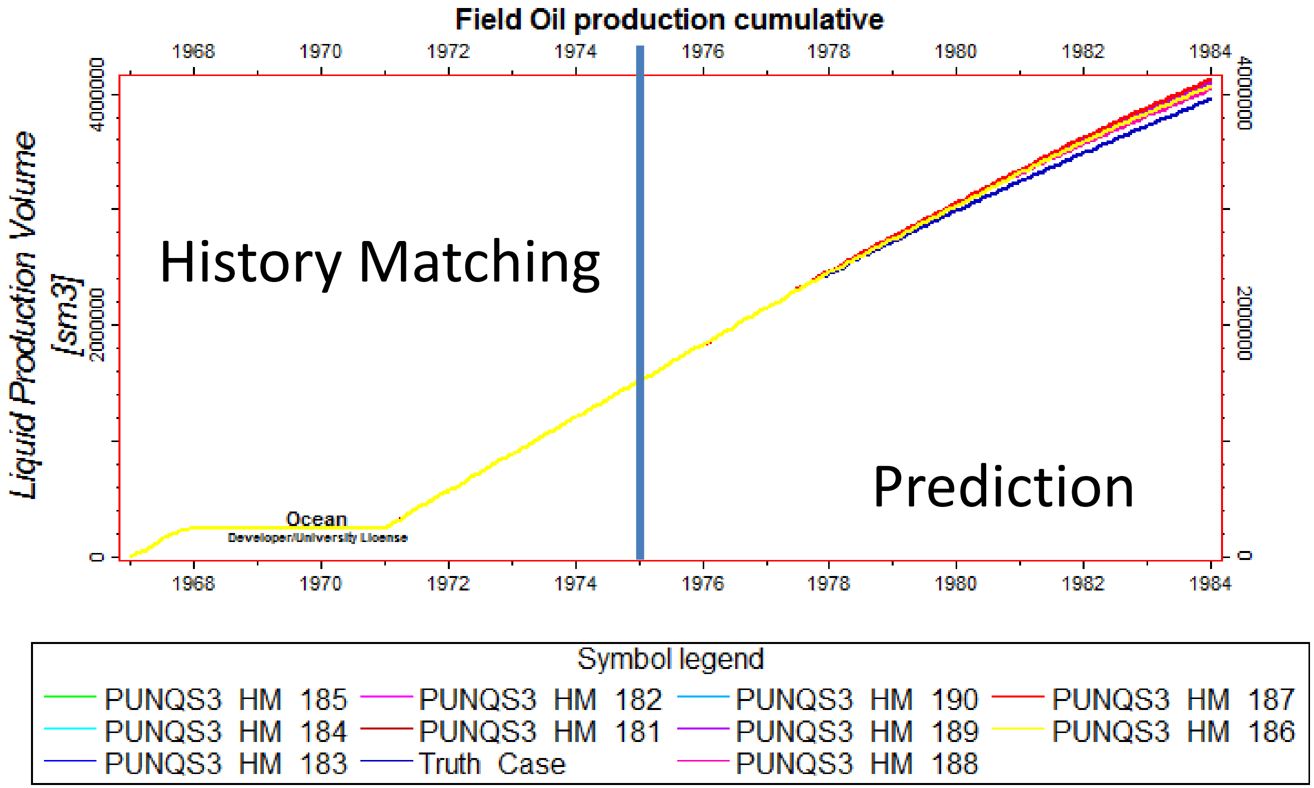


PUNQ-S3 – History Matching Results



PUNQ-S3 - Prediction

- The next step consists to predict the ultimate recovery after 16.5 years.
- Prediction obtains with 10 different solutions.



PUNQ-S3 - Conclusion

- Opus Terra™ allows to:
  - Build a proxy of the objective function with a minimal number of simulations
  - Perform a global optimization

- The different solutions fit the observed data (Pressure, Water-cut and Gas-oil ratio)

- The predictions of differents solutions are very close to the truth case.

Conclusions

- Opus Terra™ plug-ins are fully integrated in Petrel*
  - Complements existing tools in Petrel*
  - Ability to use any Petrel* modeling parameter in the workflow "Uncertainty and Optimization"

- Additional Opus Terra™ modules planned for 2013
  - EnKF, gradient based methods (BFGS …)
  - Global sensitivity analysis (Sobol, Morris …)
  - Automatically generated report

- Price : 24 000 $ / year

* Mark of Schlumberger

Useful Links

- Opus Terra™
  - Ocean Store: http://www.ocean.slb.com/Pages/Product.aspx?category=all&cat=Ocean&id=POTA-B1
  - Leaflet: http://www.terra3e.com/Docs/OpusTerra_Leaflet.pdf
  - Tutorial: http://terra3e.com/Docs/OpusTerra.avi
- PUNQ-S3:
  - Imperial College: http://www3.imperial.ac.uk/earthscienceandengineering/research/perm/punq-s3model
- CMA-ES :
  - Wikipedia: http://en.wikipedia.org/wiki/CMA-ES
- Other products:
  - VolTerra™: http://www.ocean.slb.com/Pages/Product.aspx?category=all&cat=Ocean&id=PVTE-B1
  - Scenarium™: http://www.ocean.slb.com/Pages/Product.aspx?category=all&cat=Ocean&id=PSCN-B1
  - Sirenn™: http://www.ocean.slb.com/Pages/Product.aspx?category=all&cat=Ocean&id=PSRN-B1
  - Glhis™: http://www.ocean.slb.com/Pages/Product.aspx?category=all&cat=Ocean&id=PGLH-B1

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