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

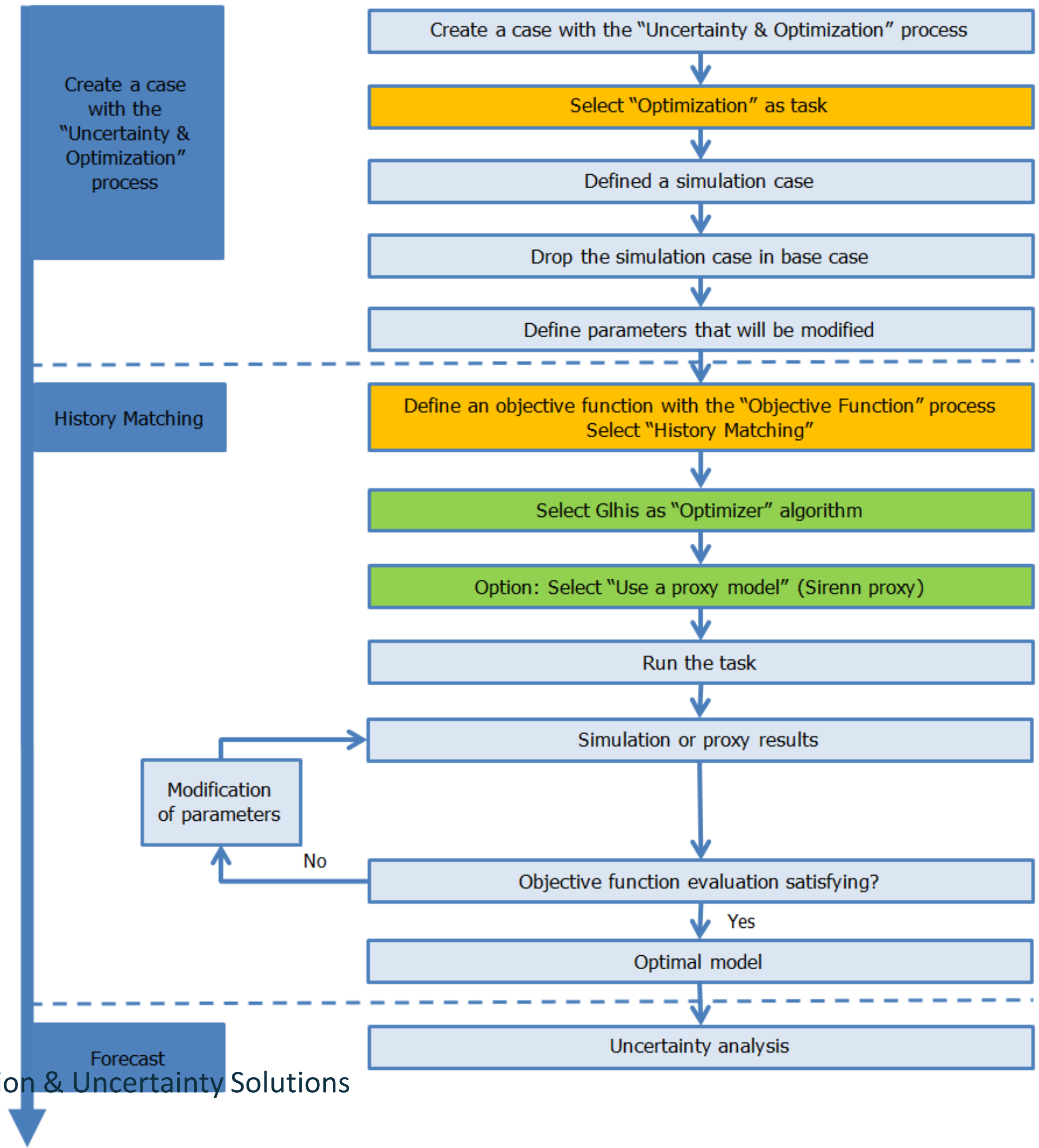
* Mark of Schlumberger

Opus Terra™ Toolbox

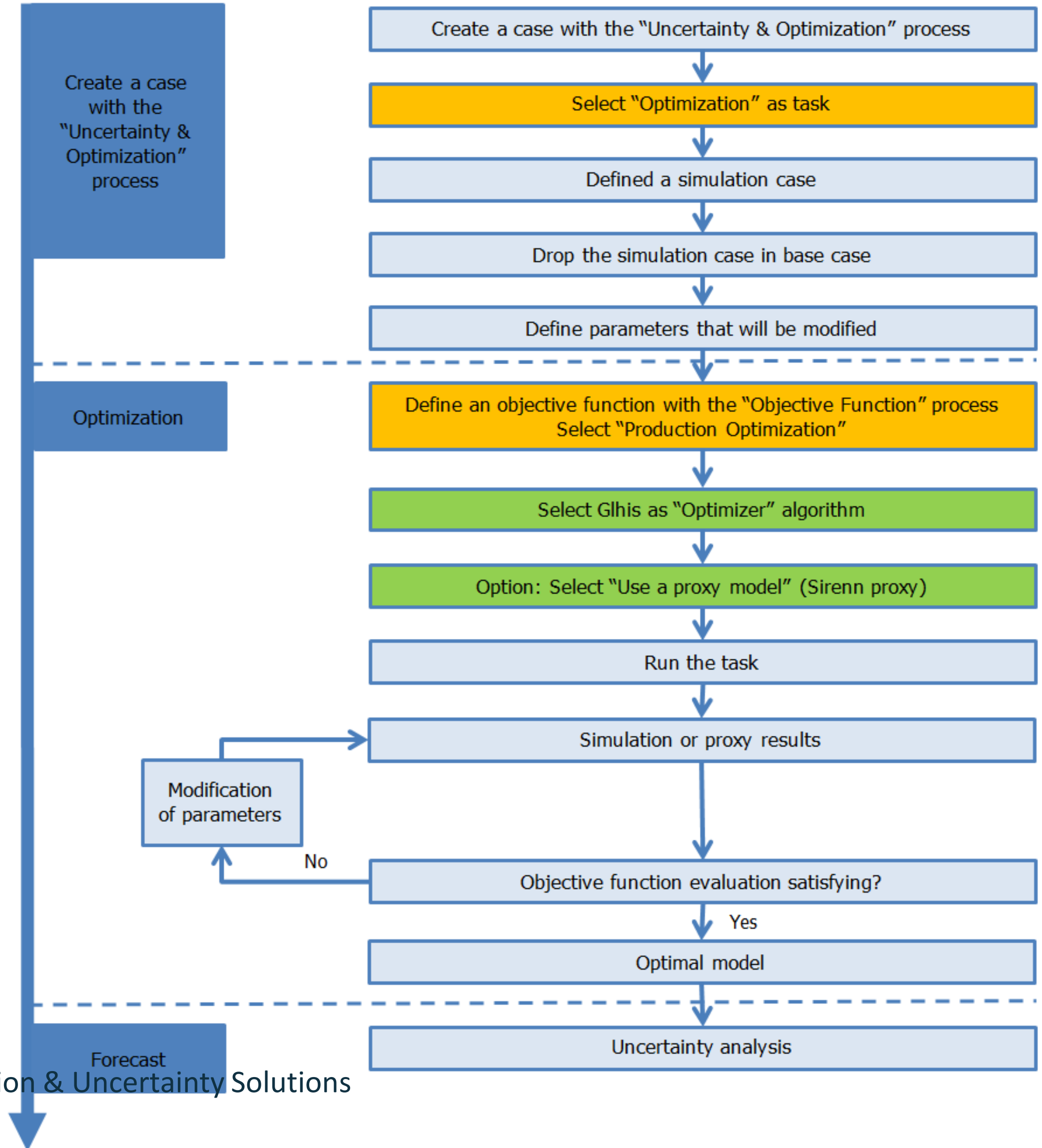
- Toolbox contains plug-ins for Petrel*
  - Glhis™ : Global History Matching (CMA-ES)
    - CMA-ES has been recognized as one of the most powerful continuous optimization algorithms on benchmark problems (Hansen et al., 2010) and real-world problems
  - Sirenn™ : Simulator Reservoir Neural Network
 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

* Mark of Schlumberger

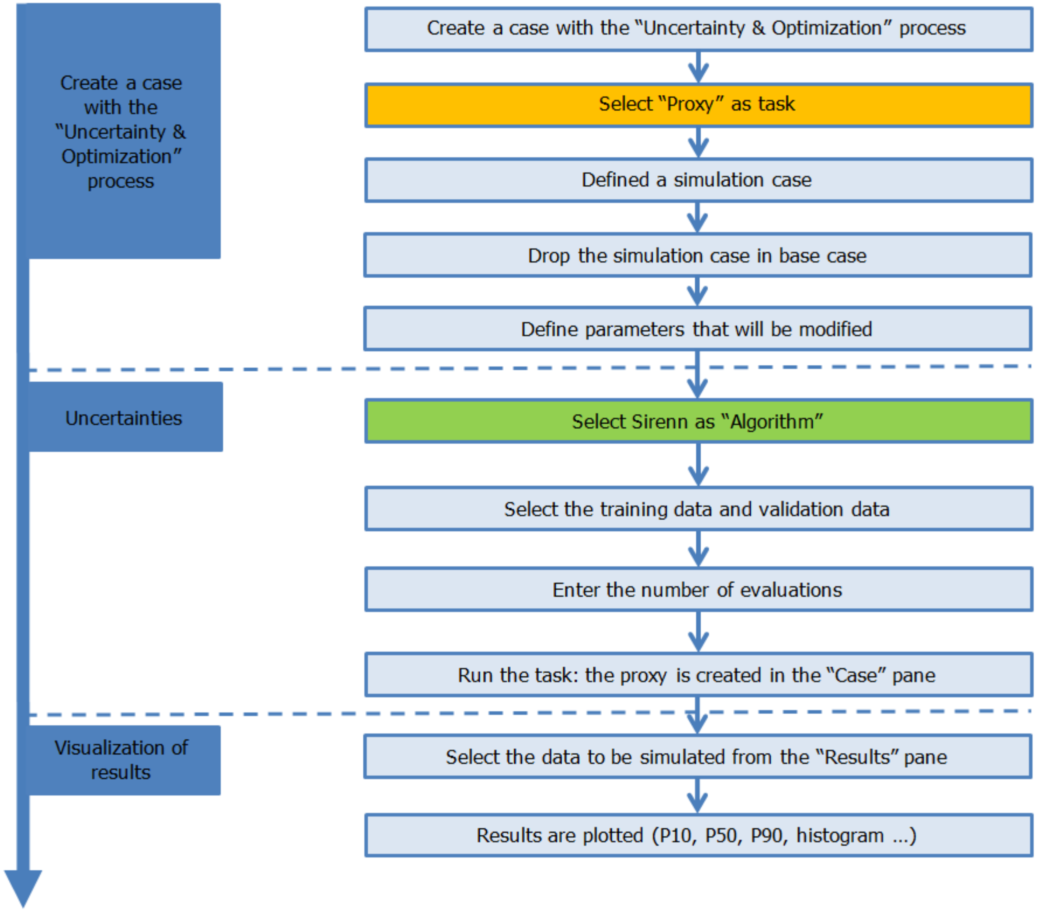
Example of Petrel Workflows – History Matching



Example of Petrel Workflows – Optimization



Example of Petrel Workflows – Uncertainties

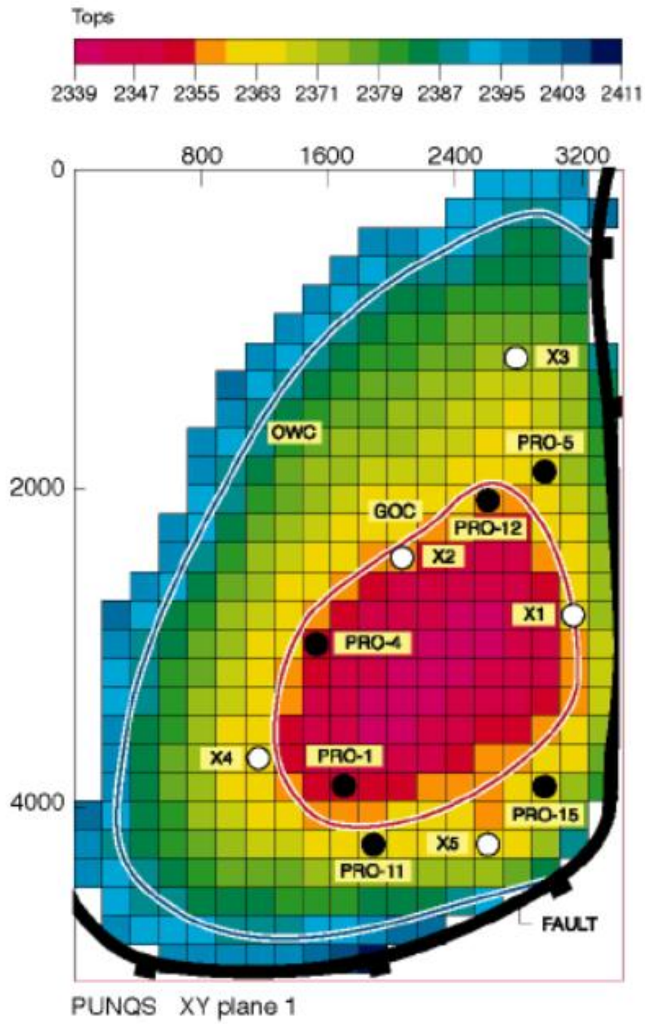


PUNQ-S3

- The PUNQ-S3 case has been taken from a reservoir engineering study on a real field performed Elf Exploration Production.

- It was qualified as a small-size industrial reservoir engineering model.

- The geological description is based on knowledge of the regional geology.



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 model contains 19x28x5 grid blocks, of which 1761 blocks are active.

- Layer 1, 3 and 5 : As describe in the geological description, we consider two facies:
  - An high-porous sands (phi > 20 %);
  - A low porous shale matrix (phi < 5 %).
  - The geological modeling was performed by using an adaptive channel modeling using the geological description and the hard observed data.

PUNQ-S3 – Geological Modeling

- Layer 2 : we consider two facies:
  - A low porous shaly sediment (phi < 5%);
  - A high porous shaly sediment (phi > 5 %).
  - The geological modeling was performed by using ellipses as body shape modeling using the geological description and the hard observed data.

- Layer 4 : we consider two facies:
  - An intermediate porosity region (phi ~ 15%);
  - A low-porosity matrix (phi < 5%).
  - The geological modeling was performed by using ellipses as body shape using the geological description and the hard observed data.

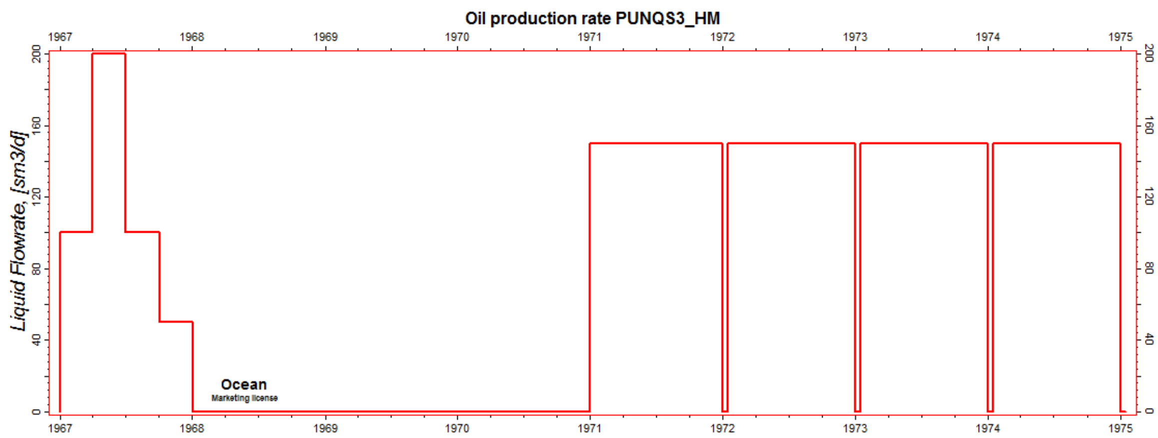
PUNQ-S3 – Geological Modeling

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

- The parameterization of PUNQ-S3 model is based on the geological description. We consider each facies, as describe in the previous section, and we estimates the constante properties for each facies: 18 parameters.

PUNQ-S3 – History Matching

- The production scheduling has been inspired by the original model
  - A first year of extended well testing, followed by a three year shut-in period, before field production commences. The well testing year consists of four three-monthly production periods, each having its own production rate.
  - During field production, two weeks of each year are used for each well to do a shut-in test to collect shut-in pressure data. The wells operate under production constraint. After falling below a limiting bottom hole pressure, they will switch to BHP-constraint.



PUNQ-S3 – History Matching

- Available 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

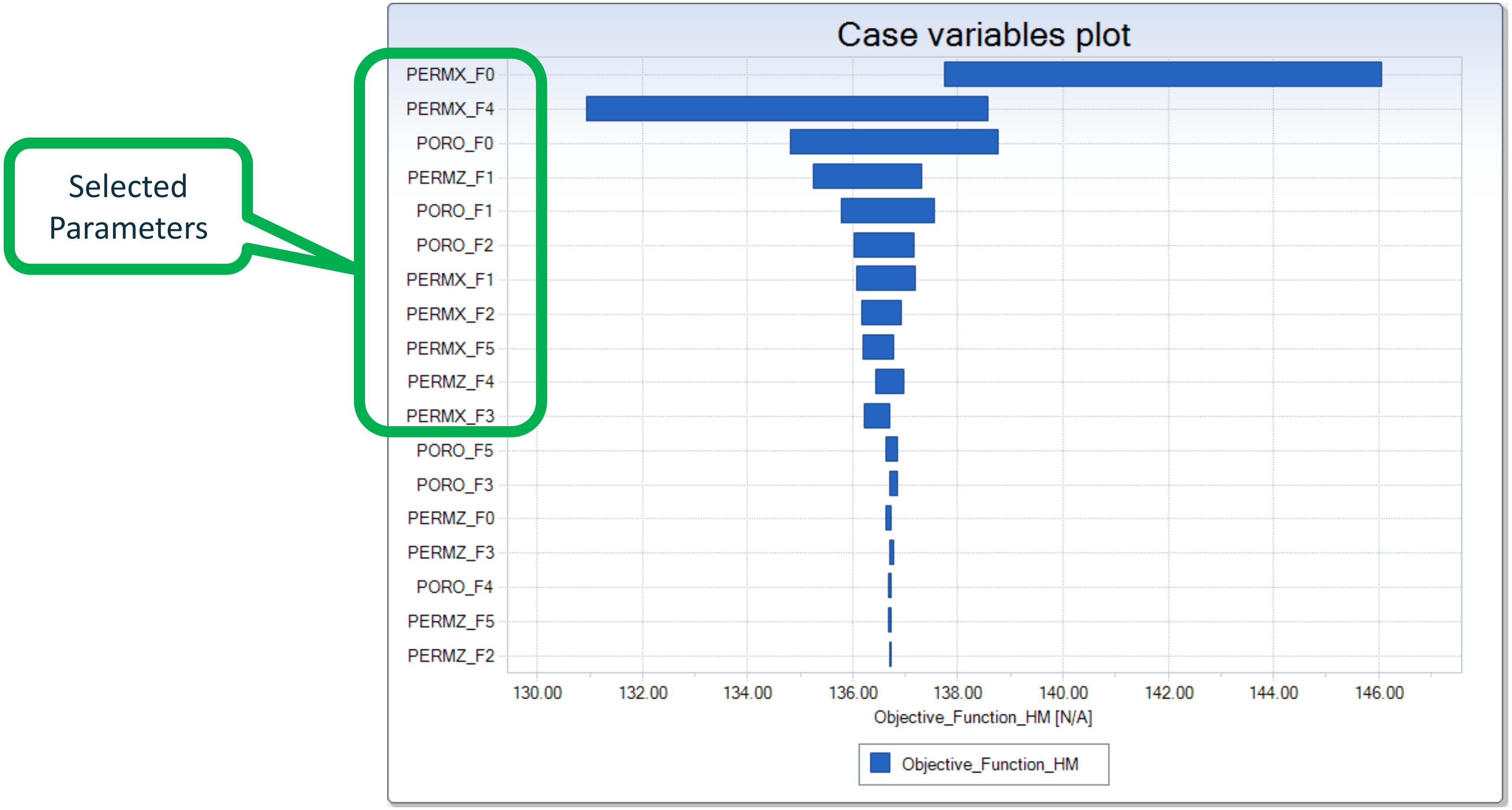
$$J(\theta) = \sqrt{\frac{\sum_{i=1}^{N_w}\sum_{j=1}^{N_{p_i}}\sum_{k=1}^{N_{t_{ij}}} w_{ijk}\left(\frac{D_{ij}(t^k) - S_{ij}(t^k,\theta)}{\sigma_{ij}}\right)^2}{\sqrt{\sum_{i=1}^{N_w}\sum_{j=1}^{N_{p_i}}\sum_{k=1}^{N_{t_{ij}}} w_{ijk}}}}$$

  - 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 a measure error σ_{ij} and a weight w_{ijk}.

PUNQ-S3 – History Matching

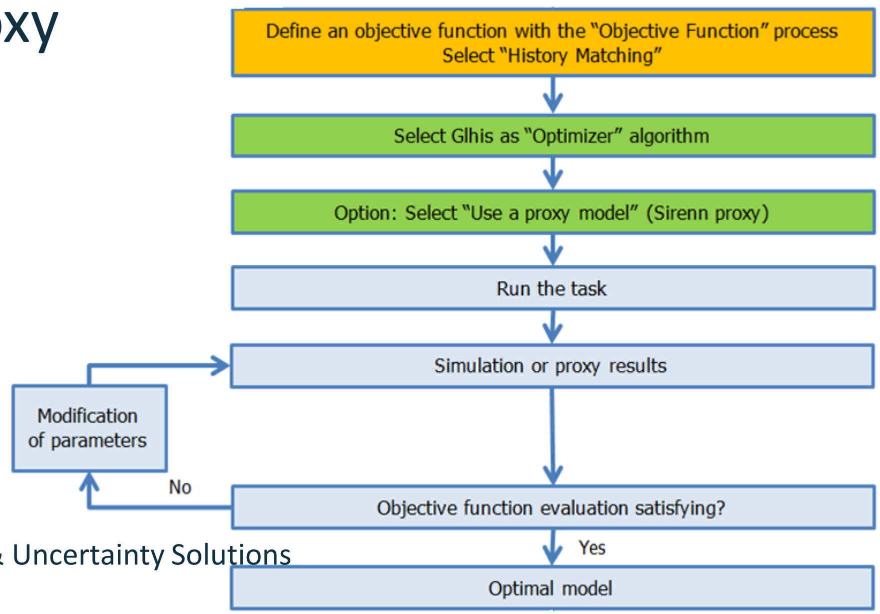
- Sensitivity analysis by variable
  - Equal spacing sampler: 4 simulations by variable = 72 simulations.



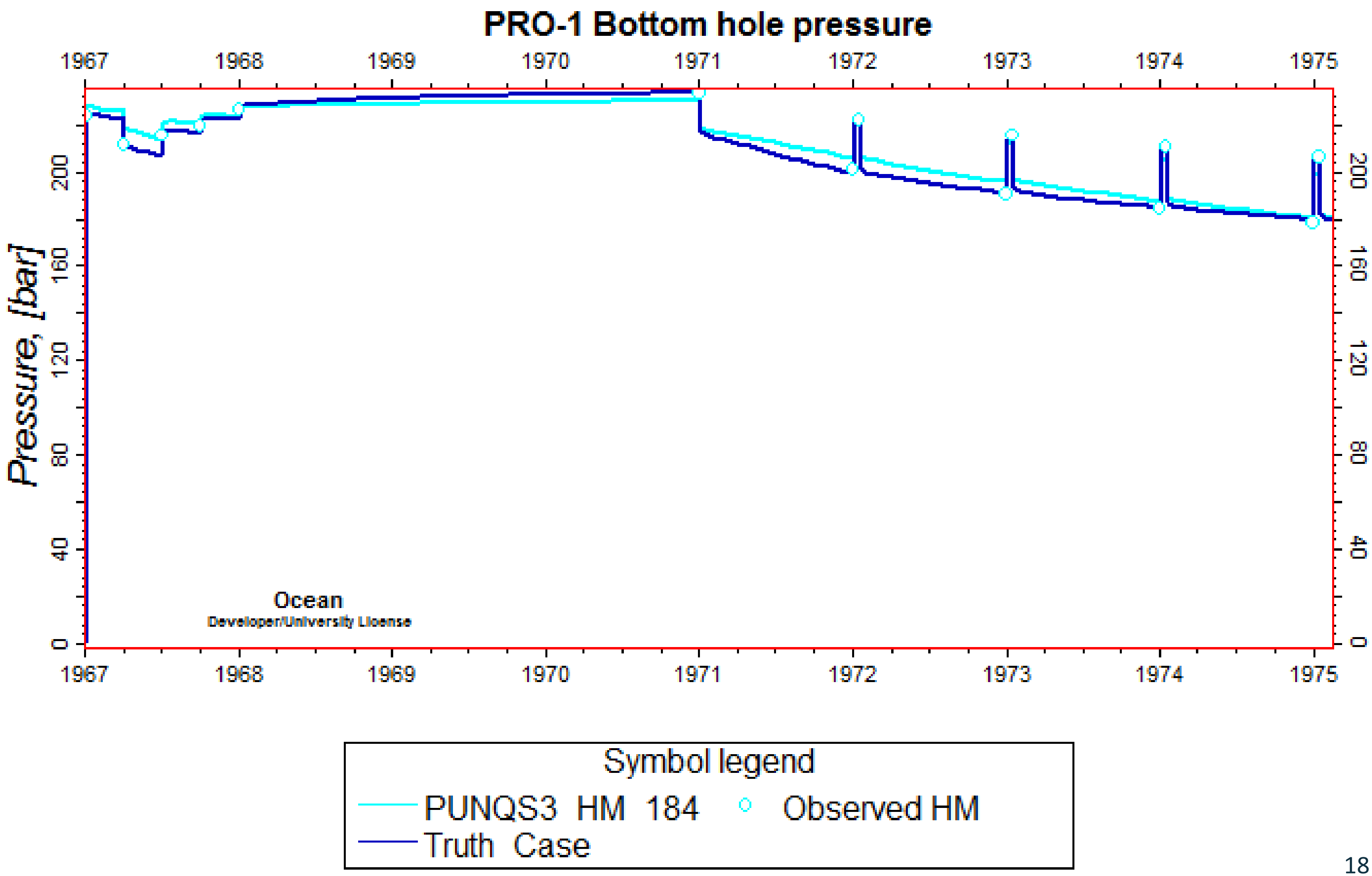
PUNQ-S3 – History Matching

- 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 Results



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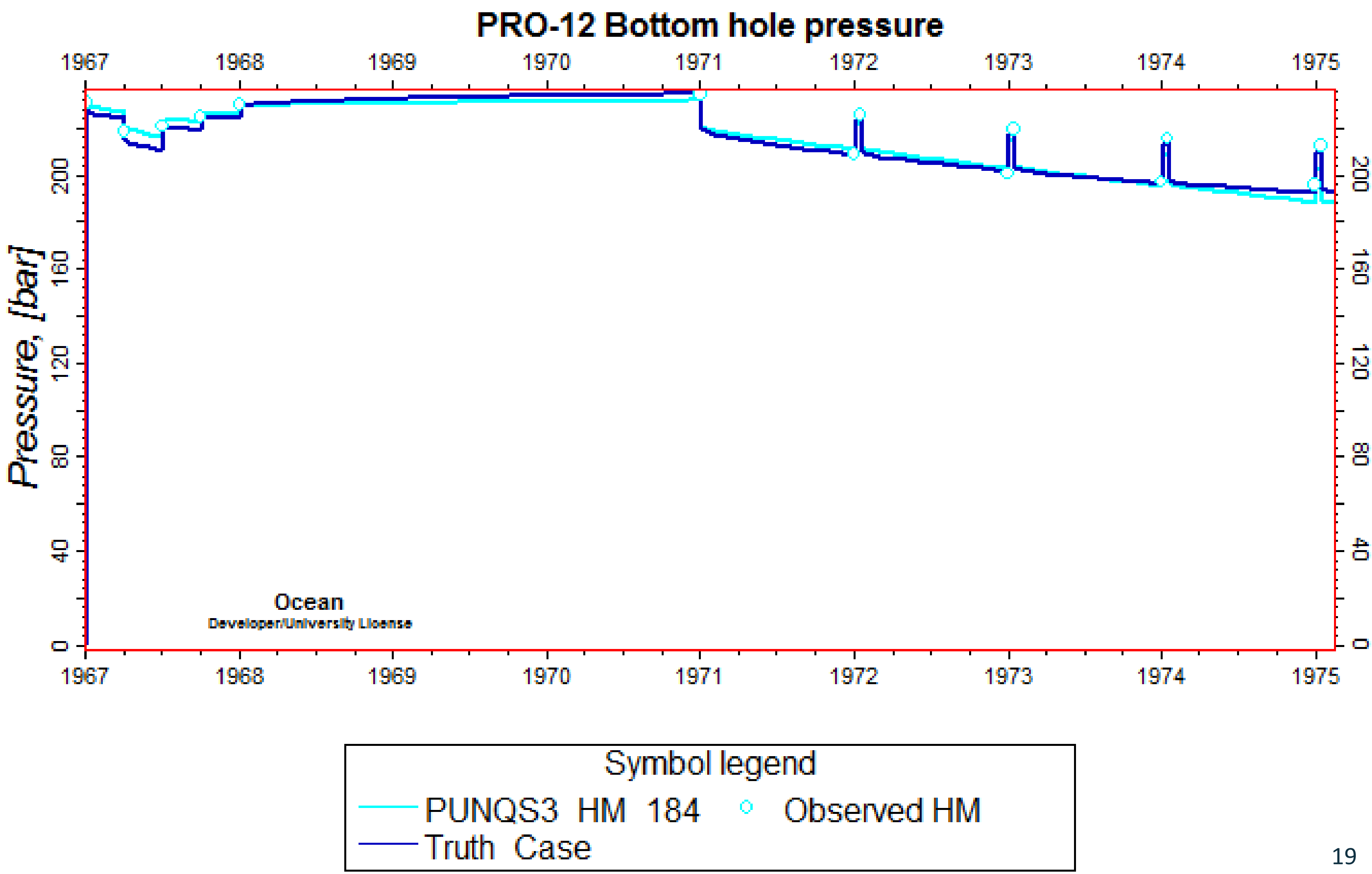

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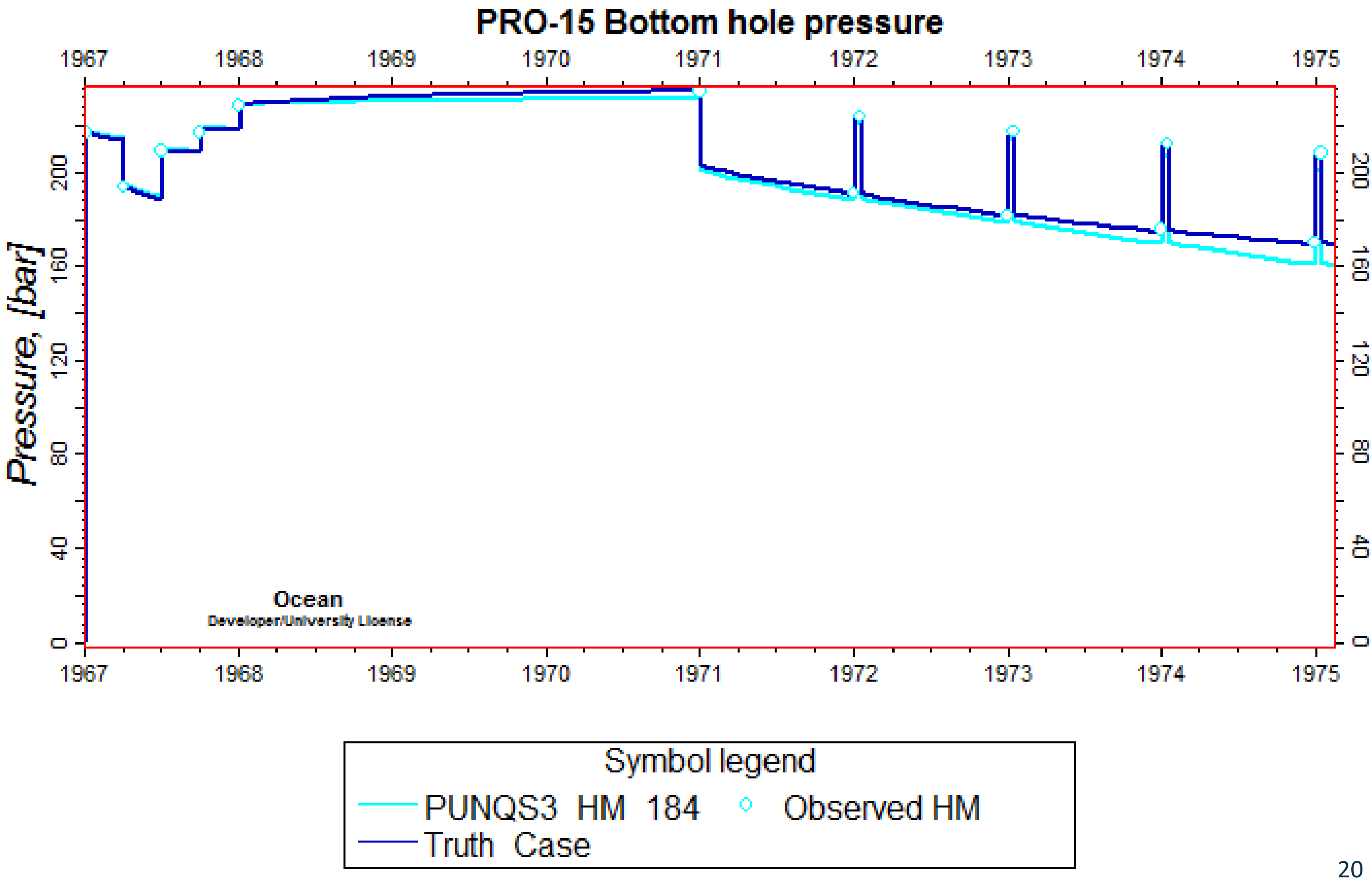

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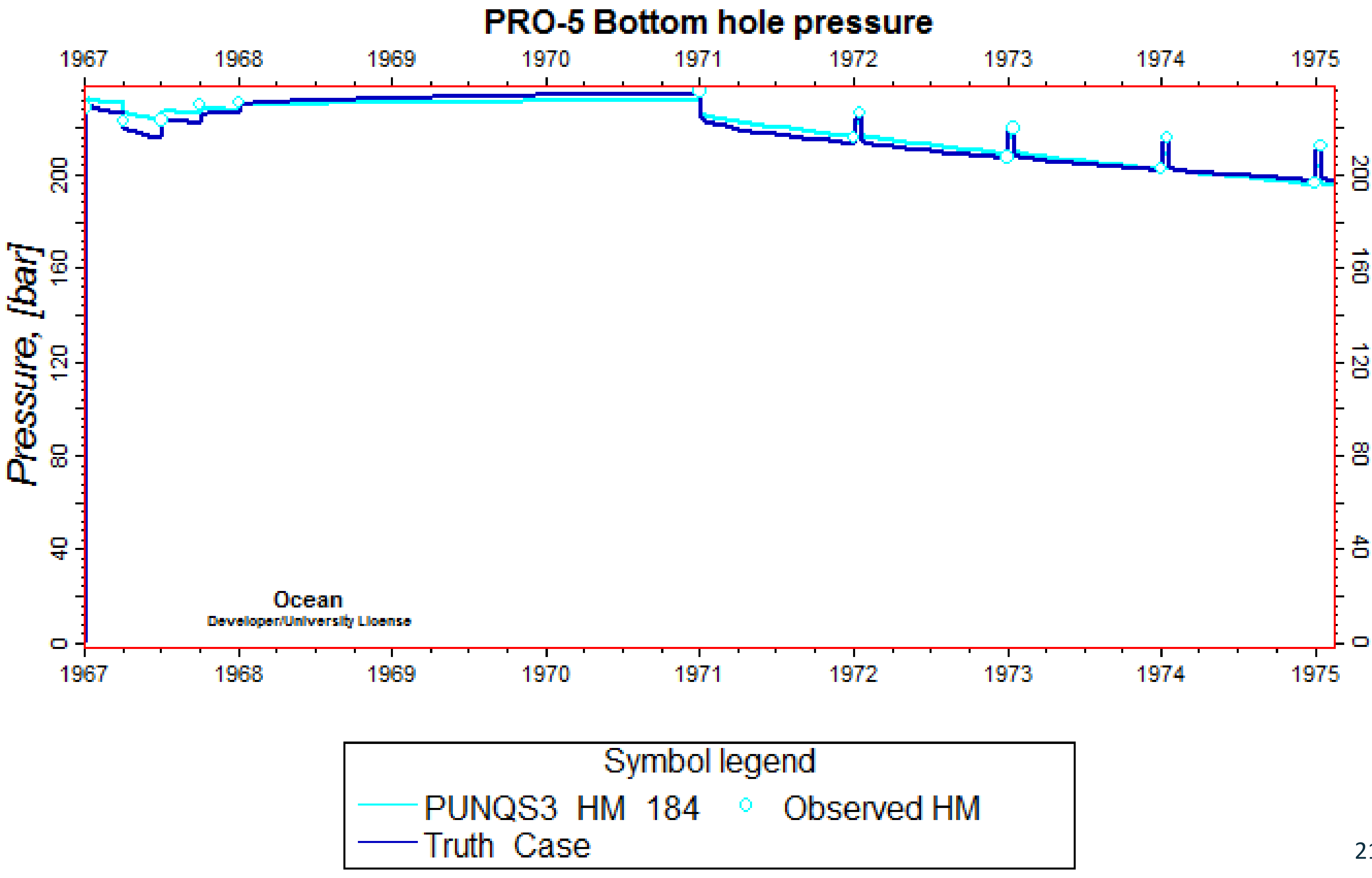

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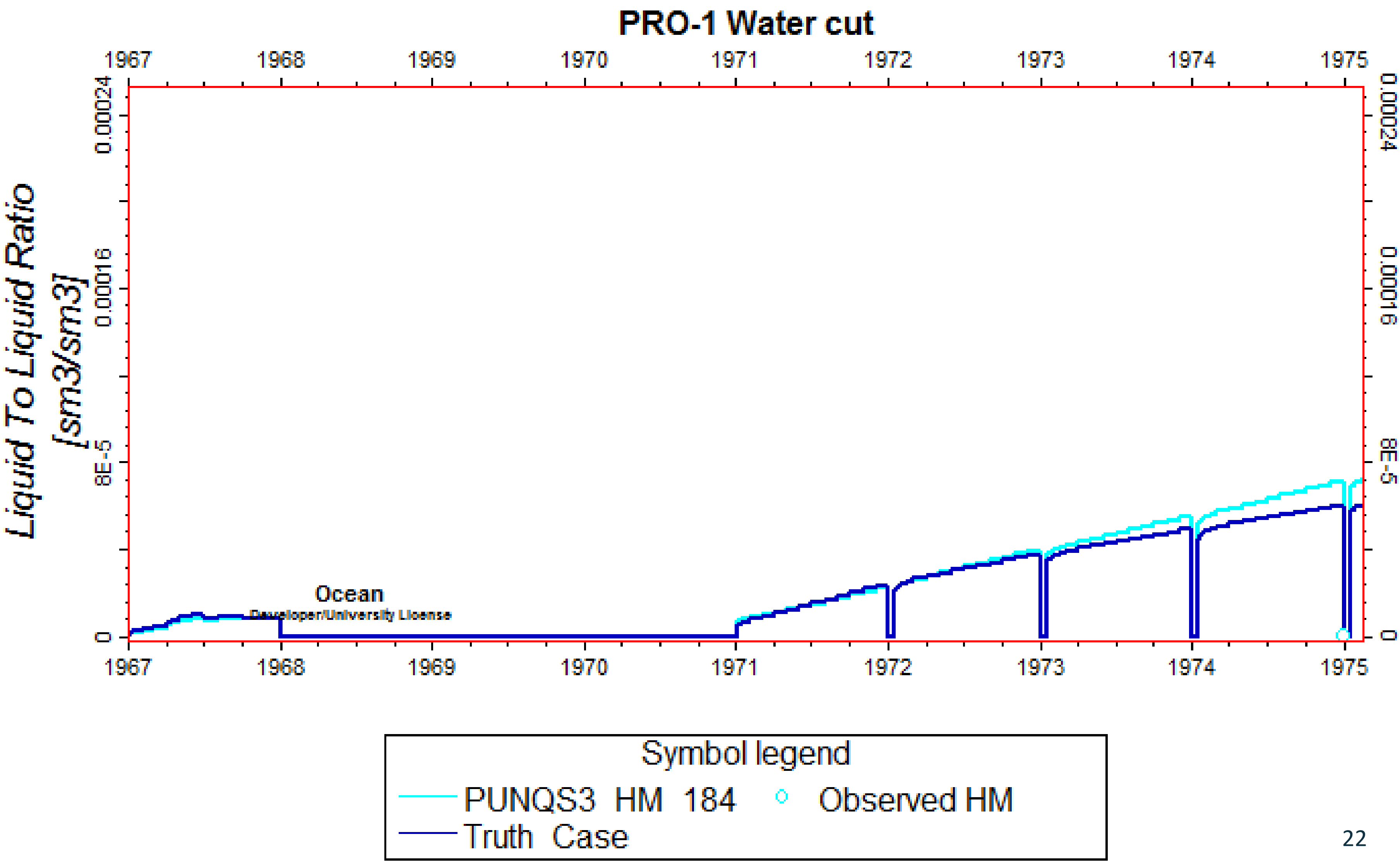

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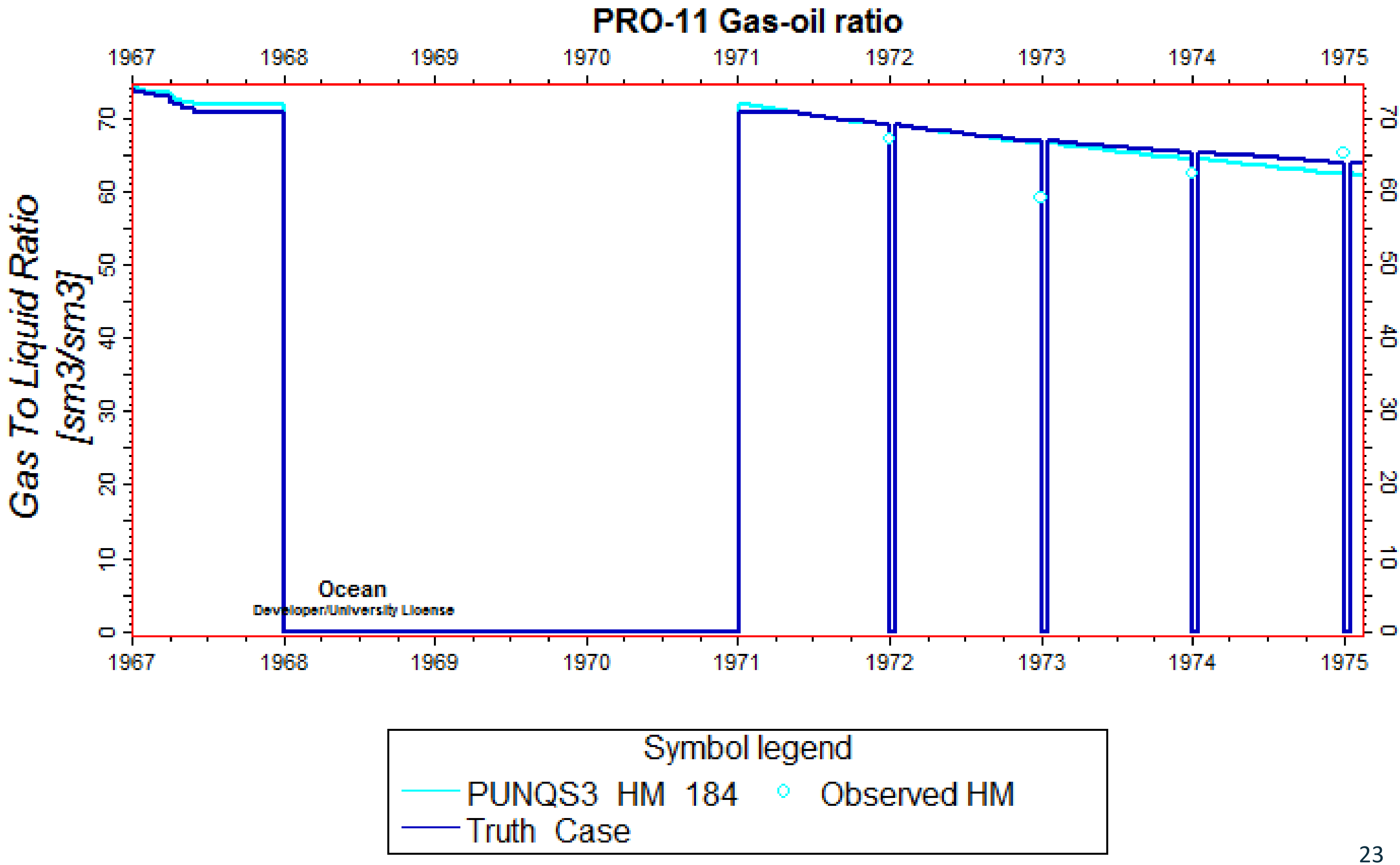
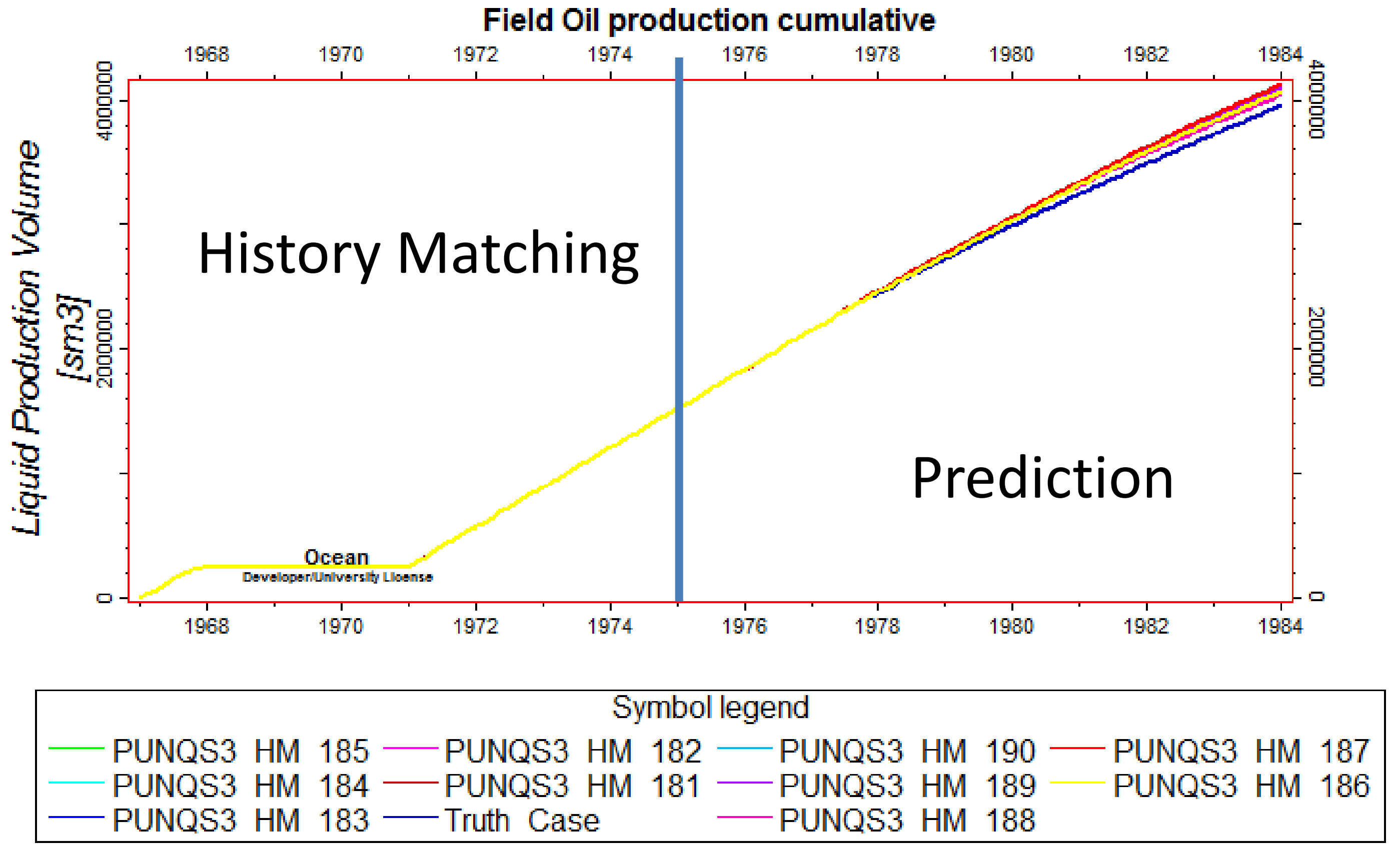


PUNQ-S3 - Prediction

- 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.

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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