

Agile uncertainty evaluation for field development with multiple high quality history matched models using DELFI PTS and INTERSECT

Schlumberger Digital Forum 2022

September 20-22 | KKL Luzern, Switzerland

Daiki Watanabe and Yuta Tosuji



JX Nippon Oil & Gas Exploration Corporation

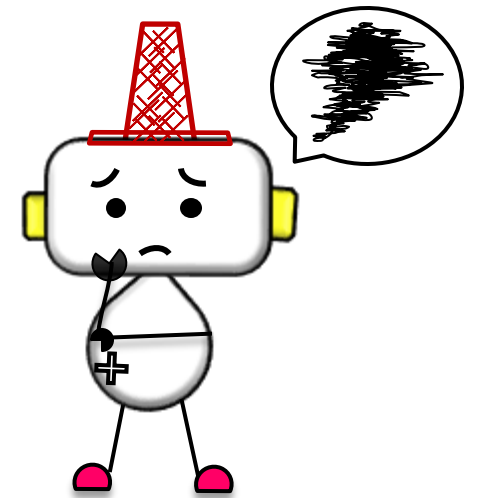
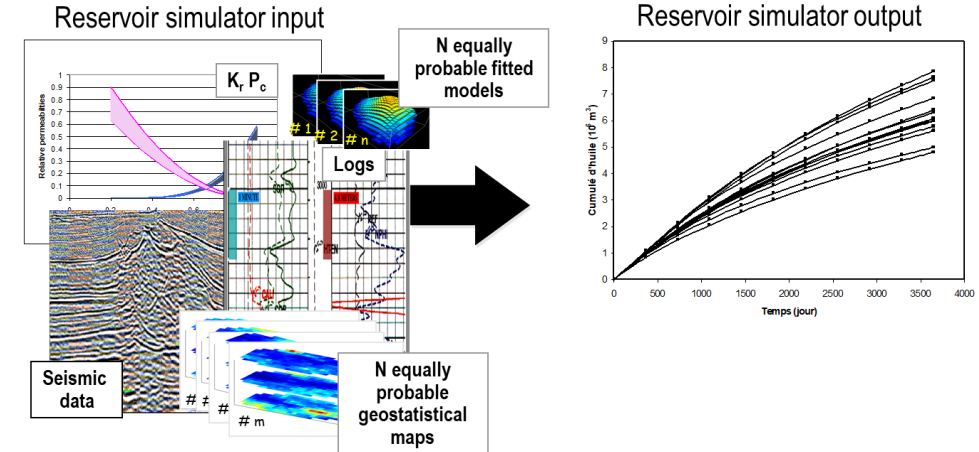
Motivation & Problem

Motivation

- Recognize high CAPEX development plan
- Necessity to quantify uncertainty of reservoir in multiple realization to make better and more accurate decision

Problems

- Huge efforts on history matching even in a single model
 - Numerous uncertainty parameters in static/dynamic models
 - Manual model creation and analysis
 - Serial run of simulation due to insufficient number of simulators
- Limited resource due to OBO PJT with low working Interest
 - Manpower (RE: 2 G&G:1, only 1 RE is dedicated to this PJT)
 - Timeframe: 5 months
 - Software & Hardware (conflict with other PJTs)



How can we mitigate these problems? → DELFI has solved them.

Why DELFI PTS?

DELFI PTS and ODRS

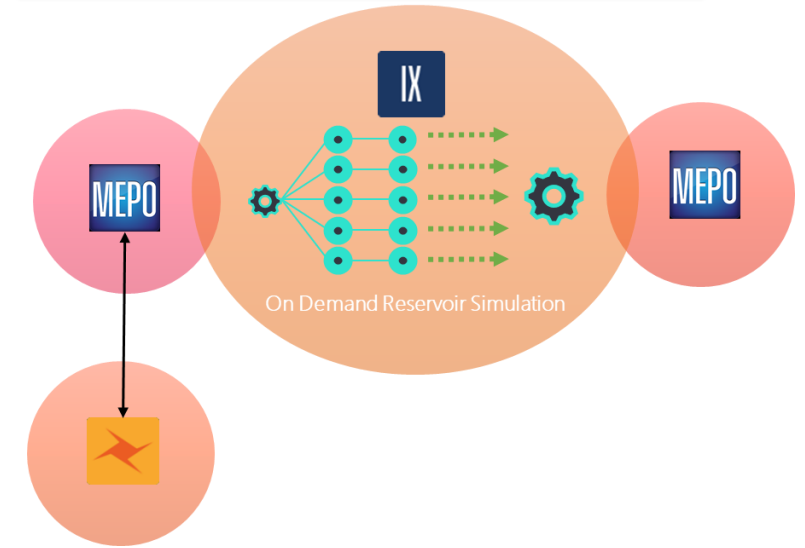
- Petrel, IX and MEPO
- Scalable and elastic computing resource
- Utilizing enough license and CPU in Cloud
- Handling multiple realization
- Deriving multiple equivalent history matched models
- Uncertainty quantification and operational optimization

Our needs

- No intention to purchase additional PC and/or software
- Not committed to do this PJT for long term (6 months at most)
- Easy to use remotely
- Low Cost

Everything we need is in DELFI PTS
Cost Effective compared to lease option

Application of linked workflow in DELFI



Running simulation concurrently & Monitoring status in Reservoir Simulation Monitoring Tool

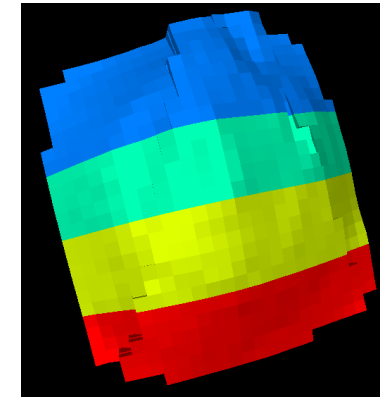
Name	Version	Progress	Status
INTERSECT Jul 30, 2020, 1:41:22 PM BASECASE_SELECTED_ARNEW_L_1988	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:41:40 PM BASECASE_SELECTED_ARNEW_L_1984	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:42:06 PM BASECASE_SELECTED_ARNEW_L_1985	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:54:26 PM BASECASE_SELECTED_ARNEW_L_1982	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:56:36 PM BASECASE_SELECTED_ARNEW_L_1981	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:58:03 PM BASECASE_SELECTED_ARNEW_L_1986	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:57:23 PM BASECASE_SELECTED_ARNEW_L_1979	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:56:12 PM BASECASE_SELECTED_ARNEW_L_1978	0000.1	0%	Monitoring
INTERSECT Jul 30, 2020, 1:56:20 PM BASECASE_SELECTED_ARNEW_L_1977	0000.1	2%	Monitoring
INTERSECT Jul 30, 2020, 1:56:37 PM BASECASE_SELECTED_ARNEW_L_1976	0000.1	1%	Monitoring
INTERSECT Jul 30, 2020, 1:56:34 PM BASECASE_SELECTED_ARNEW_L_1975	0000.1	2%	Monitoring
INTERSECT Jul 30, 2020, 1:56:22 PM BASECASE_SELECTED_ARNEW_L_1974	0000.1	20%	Monitoring
INTERSECT Jul 30, 2020, 1:52:41 PM BASECASE_SELECTED_ARNEW_L_1973	0000.1	1%	Monitoring
INTERSECT Jul 30, 2020, 1:52:01 PM BASECASE_SELECTED_ARNEW_L_1972	0000.1	1%	Monitoring
INTERSECT Jul 30, 2020, 1:51:10 PM BASECASE_SELECTED_ARNEW_L_1971	0000.1	22%	Monitoring
INTERSECT Jul 30, 2020, 1:50:50 PM BASECASE_SELECTED_ARNEW_L_1970	0000.1	22%	Monitoring

PTS: Petrotechnical Suite, ODRS: On Demand Reservoir Simulation

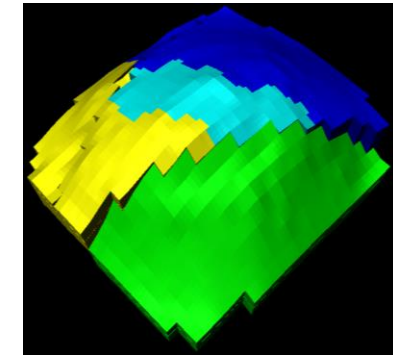
Why INTERSECT?

- Efficient parallel processing in IX
 - 3D domain partitioning
 - Partition based on main transmissibility contrasts
 - Load balanced is optimized
- Simulation time of IX is 1/2 of that of ECL
- Easy migration from E100 to INTERSECT
- **Cost & time saving** with high performance simulator, IX

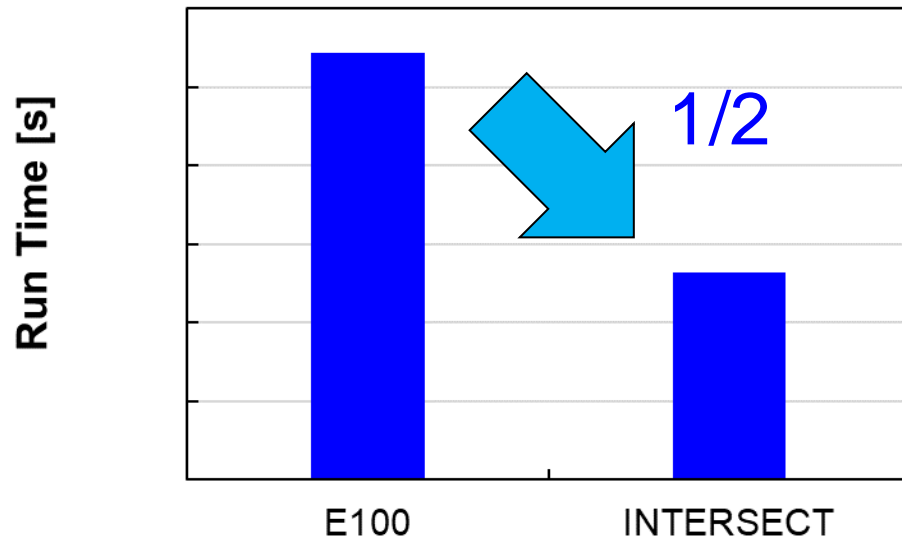
Efficient parallel processing in IX



ECLIPSE partition



INTERSECT partition
(Intelligent partitioning)



Model in Petrel



INTERSECT



ECLIPSE

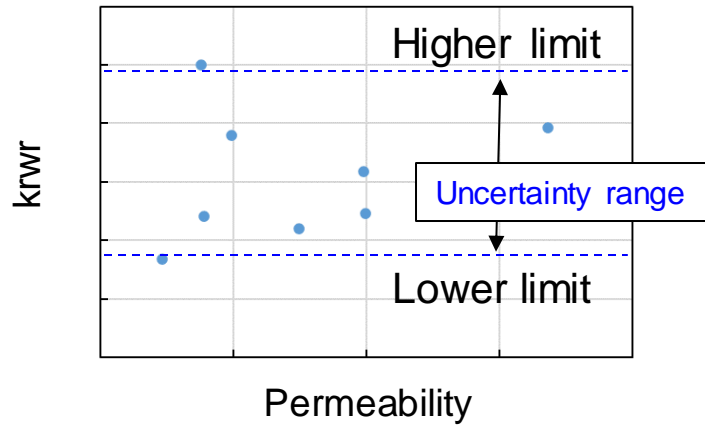
Comparison of simulation time in DELFI

- IX vs. ECL
- IX with different number of parallel

Applied Workflow

1. Data Review

To detect the appropriate the uncertainty range



2. Uncertainty parameter definition in Petrel

To utilize a strong pre-processing functionalities in Petrel

Workflow building in Petrel

The screenshot shows the Petrel software interface. On the left, a 'Workflow building in Petrel' window displays a list of tasks. On the right, a 3D geological model is visible. A callout box titled 'Definition of uncertainty parameter' is overlaid on the interface, showing a configuration window for a parameter named '\$PORO'. The 'Mean' is set to '\$PORO' and the 'Std.' is 0.04. A large '\$Parameter' label is placed next to the 'Mean' field.

3. Assisted History matching (AHM) with MEPO

To utilize the efficient sampling & optimization algorithm and powerful post-processing

Selection of algorithm for sampling

The screenshot shows the MEPO software interface, specifically the 'Simulation Control Centre'. A red box highlights the 'Algorithm' selection dropdown menu, which is currently set to 'MCMC'.

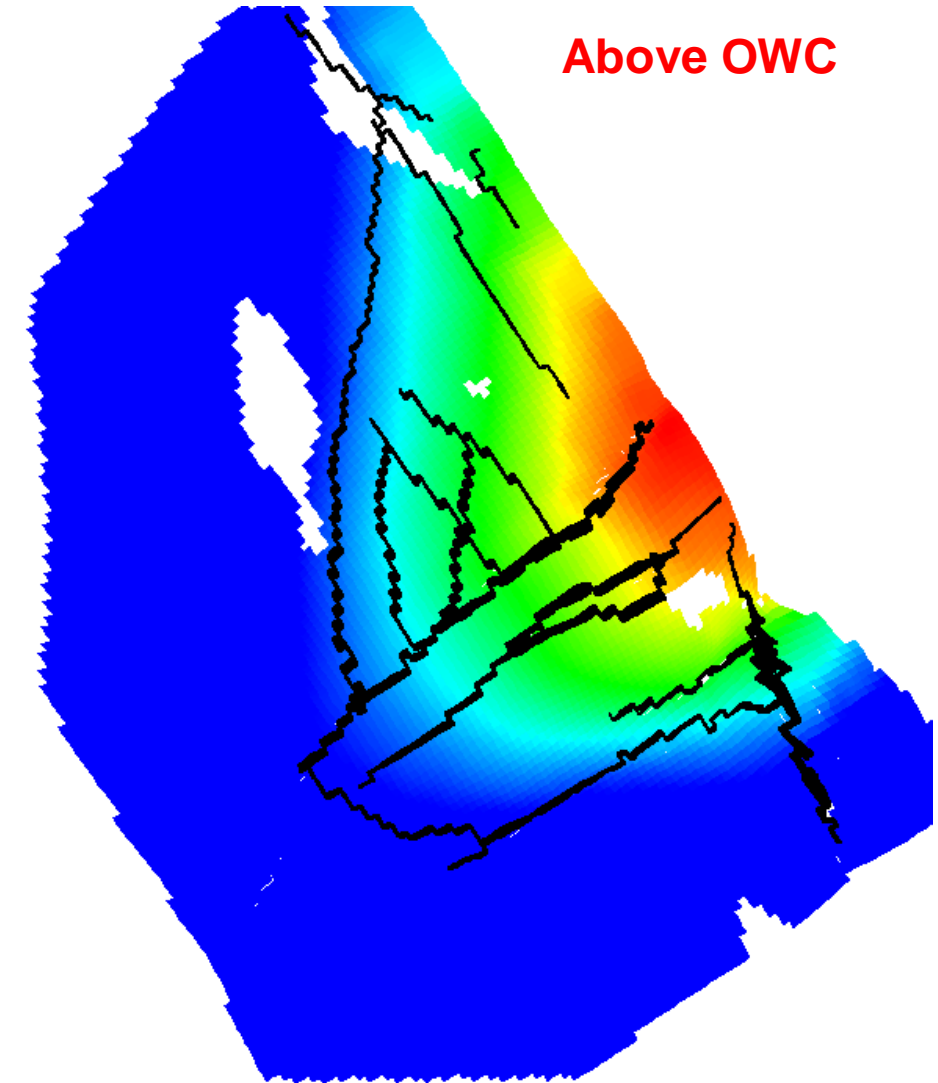
Automated post-processing of simulation results

The screenshot shows the 'Simulation Analysis (47 Simulations)' window. It displays a table of simulation results. The table has columns for Iteration, Dataset, Realisation, Generator, Status, Global, ANGLE_N, ANGLE_S, and EXRAD_N. The first 13 rows are shown, all with a status of 'All tasks done'.

#	Iteration	Dataset	Realisation	Generator	Status	Global	ANGLE_N	ANGLE_S	EXRAD_N
1	1	1	0	O VAT	All tasks done	1.603E06	10.000	90.000	2.281E04
2	1	2	0	O VAT	All tasks done	1.603E06	9.000	90.000	2.281E04
3	1	3	0	O VAT	All tasks done	1.603E06	11.000	90.000	2.281E04
4	1	4	0	O VAT	All tasks done	1.603E06	10.000	80.000	2.281E04
5	1	5	0	O VAT	All tasks done	1.603E06	10.000	100.000	2.281E04
6	1	6	0	O VAT	All tasks done	1.603E06	10.000	90.000	2.000E04
7	1	7	0	O VAT	All tasks done	1.603E06	10.000	90.000	3.000E04
8	1	8	0	O VAT	All tasks done	1.602E06	10.000	90.000	2.281E04
9	1	9	0	O VAT	All tasks done	1.603E06	10.000	90.000	2.281E04
10	1	10	0	O VAT	All tasks done	1.456E06	10.000	90.000	2.281E04
11	1	11	0	O VAT	All tasks done	1.608E06	10.000	90.000	2.281E04
12	1	12	0	O VAT	All tasks done	1.574E06	10.000	90.000	2.281E04
13	1	13	0	O VAT	All tasks done	1.630E06	10.000	90.000	2.281E04

Reservoir Description

- Deep water & Deep sandstone reservoir High P & High T
- Faulted 3-way dip closure against a salt stock feeder
- Many faults based on seismic data
- Favorable sand quality: intermediate porosity, high permeability
- Black Oil; Highly undersaturated oil
- Low Aquifer influx
- More than 10 years production history
- Number of producers: 7



Objective Function & Uncertainty Parameter

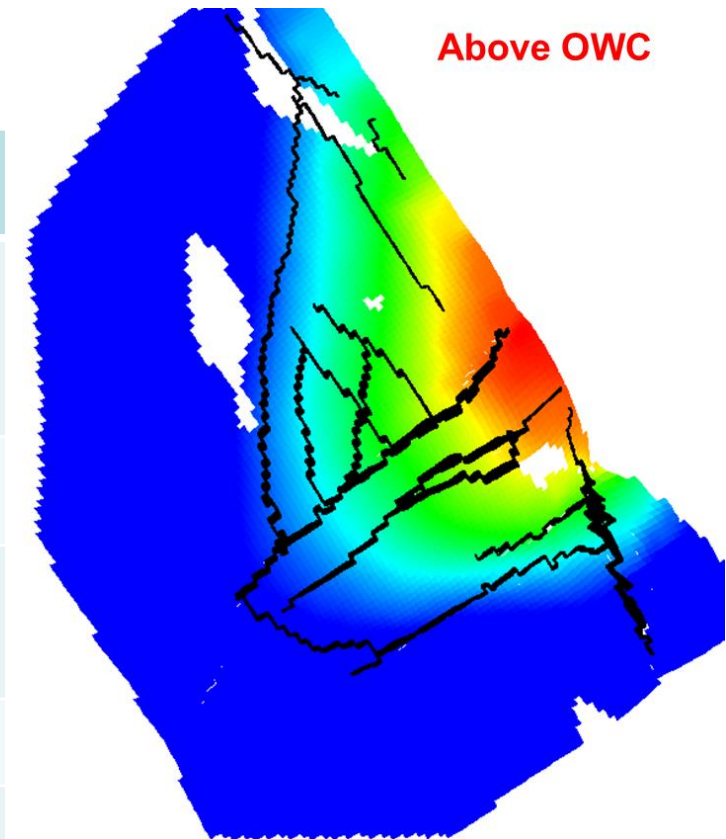
Objective Function

Control the well with liquid constraint and try to match the following parameter

1. Shut-in BHP (Highest Priority)
2. FBHP
3. Water Cut

Uncertainty Parameter matrix

Uncertainty parameter	Quantity	Content
Rock properties	6	<ul style="list-style-type: none">• End point and curvature of relative permeability curves (Swcr, Sorw, krwr, Nw, Now)• Rock compressibility (Cp)• Lower and upper limits were <u>set based on core data</u>
OOWC	2	<ul style="list-style-type: none">• Set Upper and Lower OOWC of the target reservoir• <u>Lower (HKW) and Upper (LKO) limits were set respectively</u>
Aquifer Volume	2	<ul style="list-style-type: none">• Set Upper / Lower AQVOL multiplier of the target reservoir• Lower and upper limits were set to the <u>ratio of 2~20 times against HCPV</u>
Fault Transmissibility	15	<ul style="list-style-type: none">• Lower and upper limit set to <u>0.0001 ~ 1.0</u>
Sum	25	

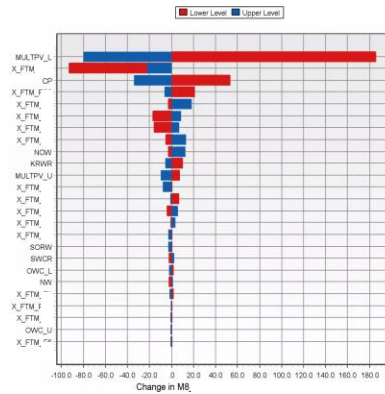


Phased Approach to History Matching

1. Sensitivity Analysis: OVAT (One Variable At Time) and Latin Hypercube sampling

To detect the high sensitivity parameter on each well's BHP

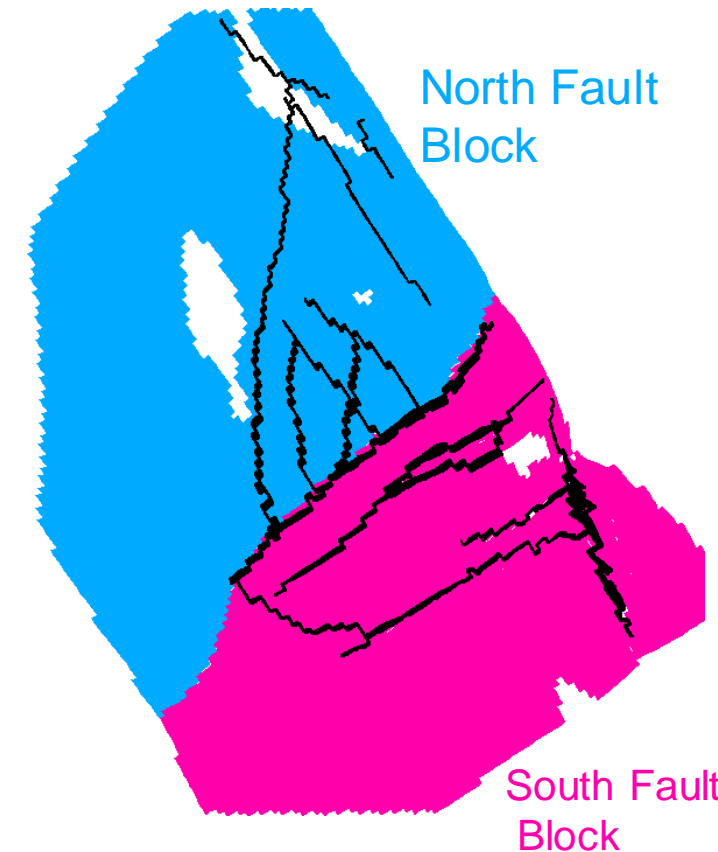
To obtain the good parameter sets as starting simulation run for optimization



Tornado Plot

	BHP at well A	BHP at well B	BHP at well C	BHP at well D	BHP at well E
CP	0.073	0.082	-0.041	-0.007	-0.035
KRWR	0.167	0.077	0.065	-0.079	0.026
MULTPV_L	0.393	0.370	-0.576	0.093	-0.497
MULTPV_U	0.083	0.176	-0.095	0.011	-0.202
NOW	-0.157	-0.086	-0.102	0.042	0.017
NW	0.021	-0.003	-0.064	-0.007	0.025
OWC_L	-0.013	0.023	-0.086	0.005	-0.108
OWC_U	-0.103	-0.089	0.044	-0.025	0.050
SORW	0.067	0.006	0.014	-0.071	0.017
SWGR	-0.089	-0.049	-0.006	0.056	0.034
X_FTM	0.083	0.038	-0.197	-0.049	-0.380
X_FTM	0.022	-0.013	0.041	-0.050	0.059
X_FTM	-0.050	-0.062	0.161	-0.085	-0.002
X_FTM	0.008	-0.005	-0.078	0.041	-0.054
X_FTM	0.032	0.083	-0.085	-0.112	-0.142
X_FTM	-0.010	0.041	0.039	0.052	-0.014
X_FTM	0.285	0.106	0.084	-0.049	-0.028
X_FTM	0.181	-0.024	0.193	0.021	0.038
X_FTM	0.027	0.057	-0.003	0.035	0.033
X_FTM	0.129	0.116	0.142	0.025	0.118
X_FTM	0.023	0.027	-0.115	-0.003	-0.106
X_FTM	0.046	0.009	0.266	-0.009	0.259
X_FTM	0.305	0.430	0.306	-0.145	-0.418

Correlation Matrix



2. History Matching with GA (Genetic Algorithm)

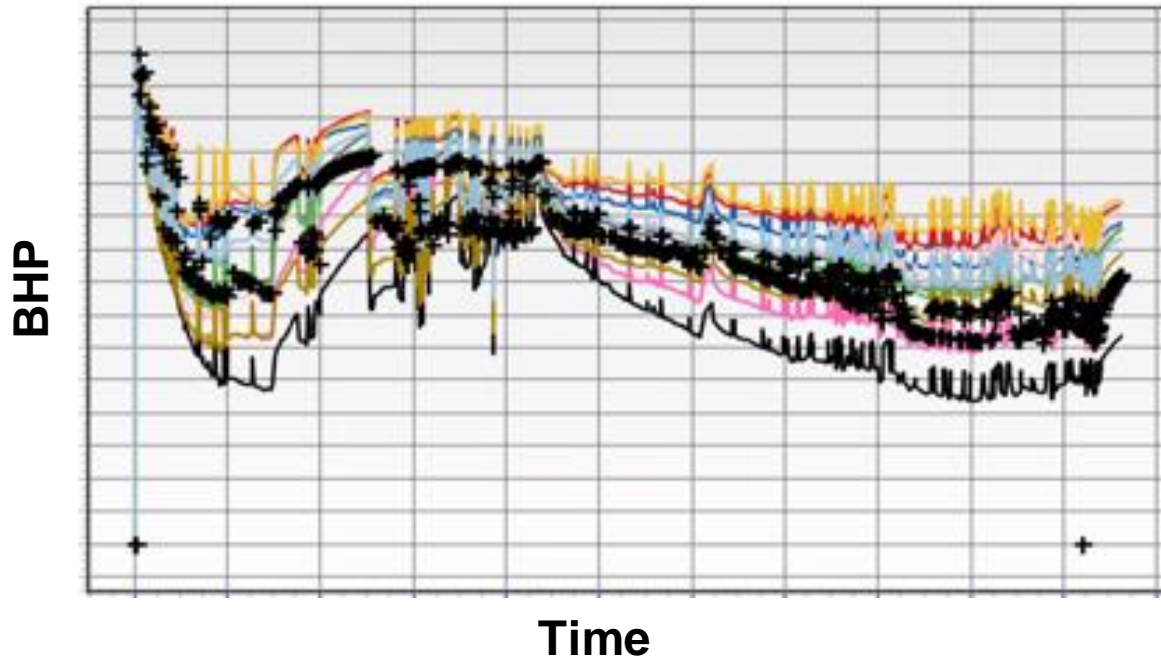
- Shut-in BHP at North Fault Block wells
- Shut-in BHP at South Fault Block wells
- Water Cut at Well A

Narrow down the range of uncertain parameters in a sequentially manner

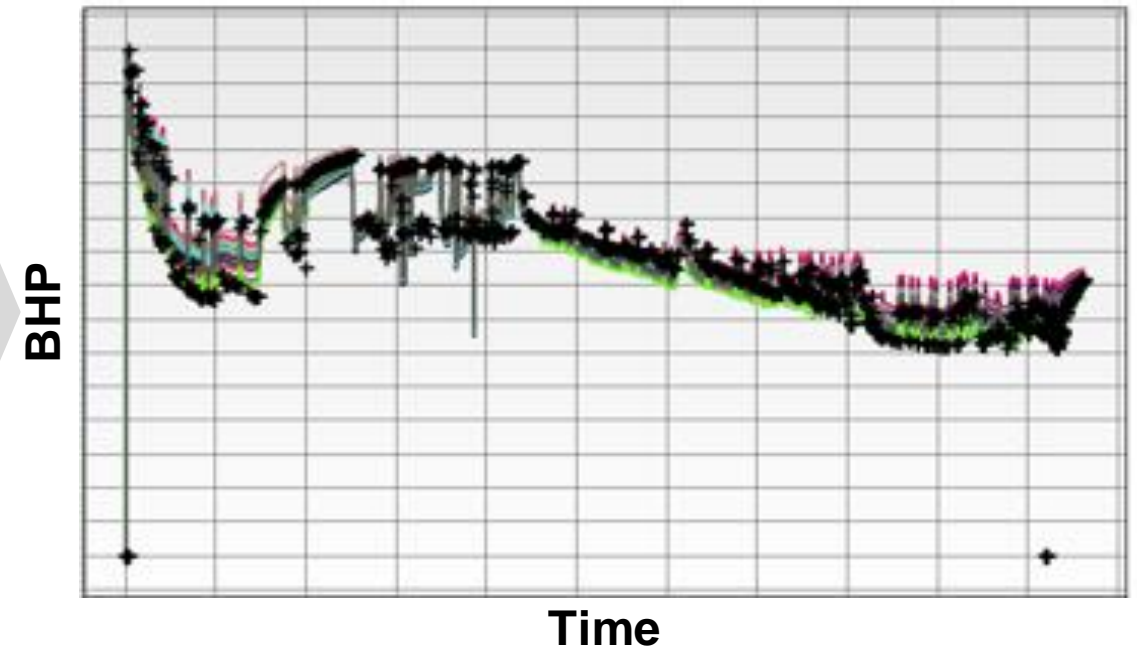
History Matching Results

- Tune the uncertainty parameters in the phased approach to minimize the mismatch with GA
- Conduct 1,500 – 2,000 simulation per each Low / Mid / High OOIP static model (25 runs concurrently)

Before History Matching



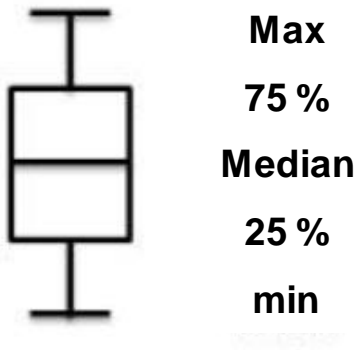
After History Matching



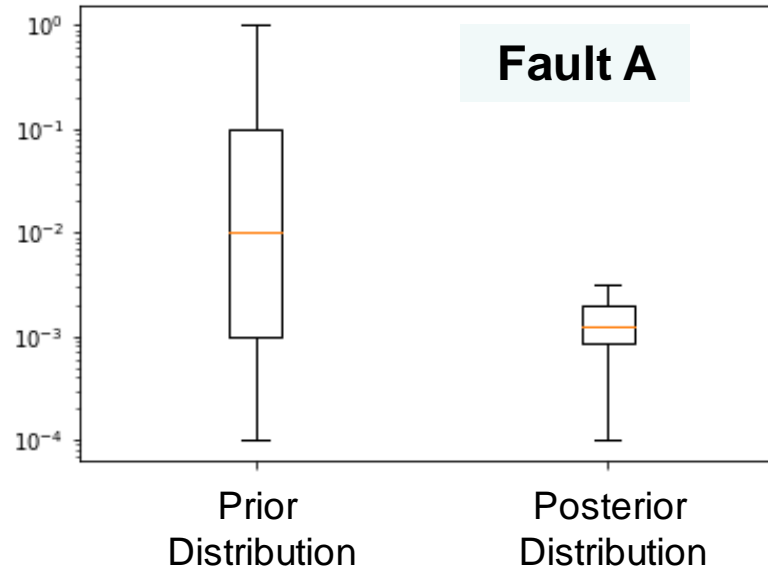
Completed all 3 HM tasks within 3.5 months and acquired the total of 90 high quality history matching models for the 3 Low / Mid / High cases

Change in uncertainty range of each parameter before and after HM

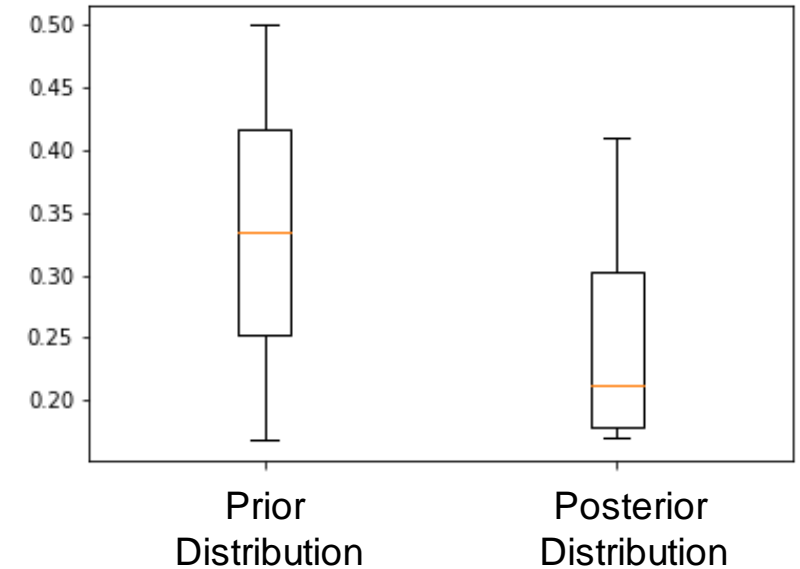
How to read
box-and-whisker diagram



Fault Transmissibility



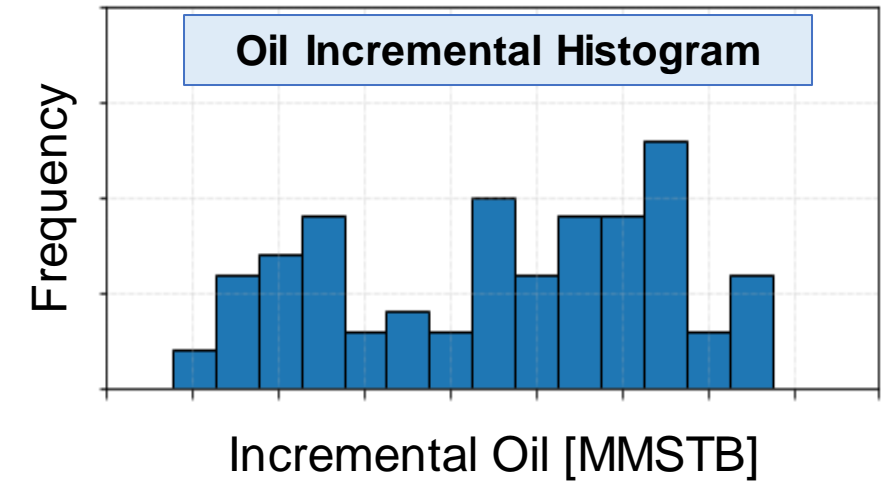
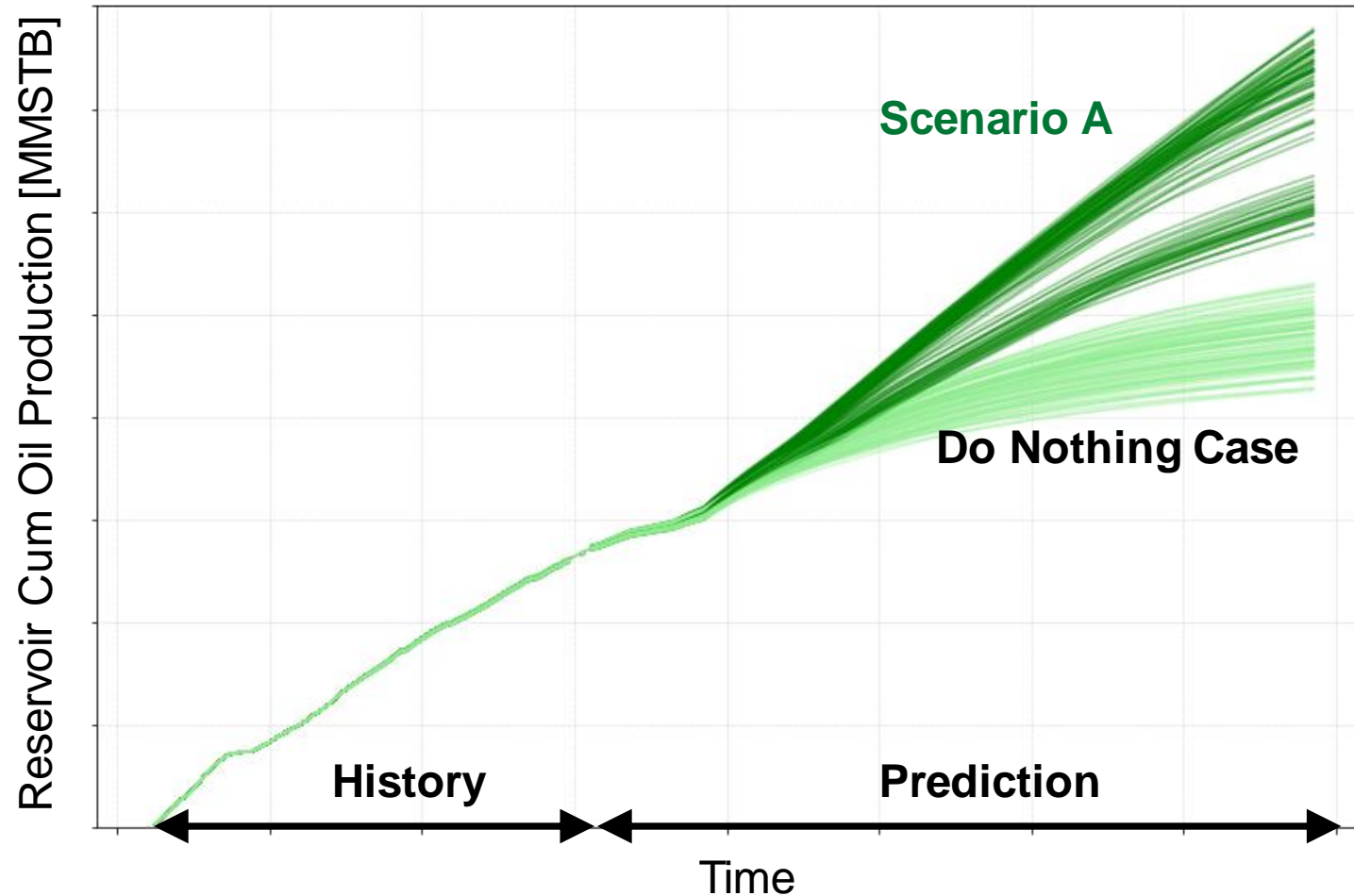
KRWR



- Uncertainty parameter mainly on pressure: Range has been narrowed down successfully
- Uncertainty parameter mainly on water cut: Range has not changed drastically

Uncertainty Quantification

- Multiple realization with high quality history matching was used for prediction
- Comparison between Do nothing case and additional development case (Scenario A)



Successfully quantify the uncertainty of incremental oil by additional development

Summary

- Successfully carried out the following tasks within the planned timeframe:
 - A total of 90 high quality history matching (HQHM) model is established for the 3 Low/Mid/High cases
 - Uncertainty quantifications for several additional development scenarios

Incredible improvement of work efficiency with the aids of DELFI PTS, INTERSECT and AHM in Petrel and MEPO

- DELFI and AHM is very powerful but more QC is required:
 - Do the uncertainty parameters change as expected?
 - Is the range of uncertainty parameter after AHM plausible?

History matching could be achieved more easily with AHM but the quality is not always good. We need to keep in mind that history matching is not the process of curve fitting but the process of reservoir understanding.