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

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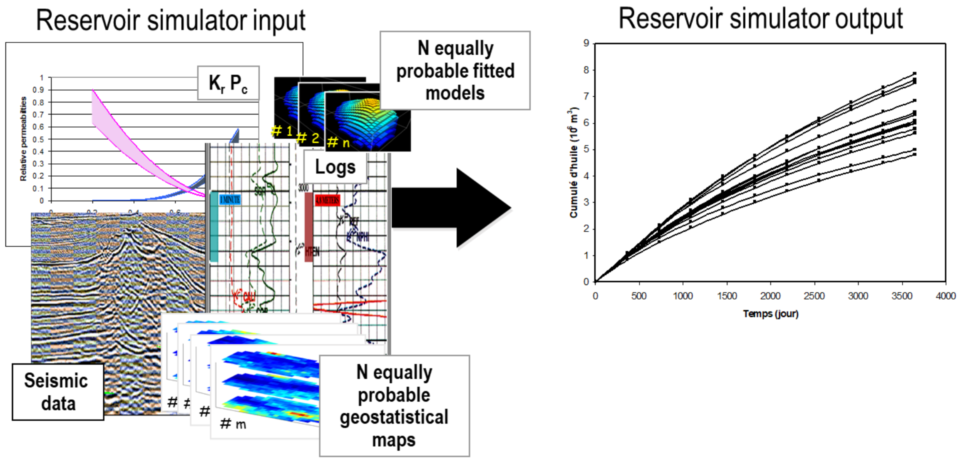
Motivation & Problem

Motivation

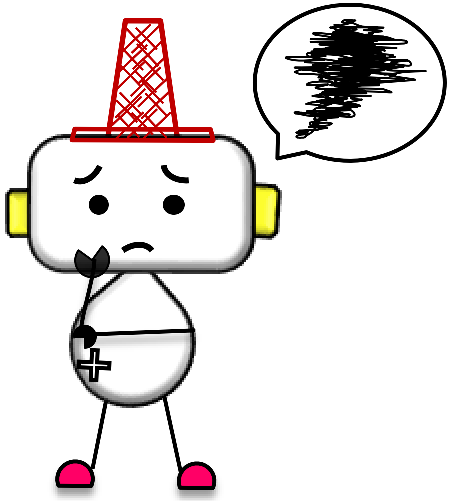
- Recognize high CAPEX development plan
- Necessity to quantify uncertainty of reservoir in multiple realization to make better and more accurate decision



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

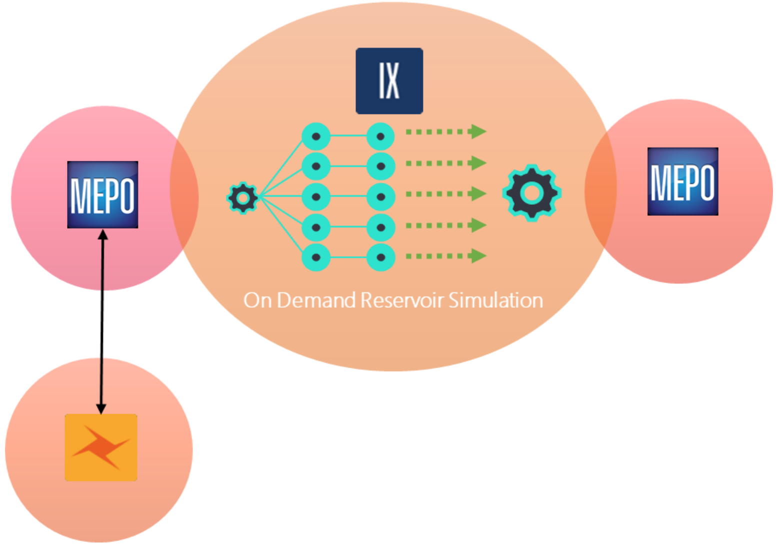
- Petrel, IX and MEPO
- Scalable and elastic computing resource
- Utilizing enough license and CPU in Cloud
- Handling multiple realization
- Deriving multiple equivalent history matched models
- Uncertainty quantification and operational optimization

Our needs

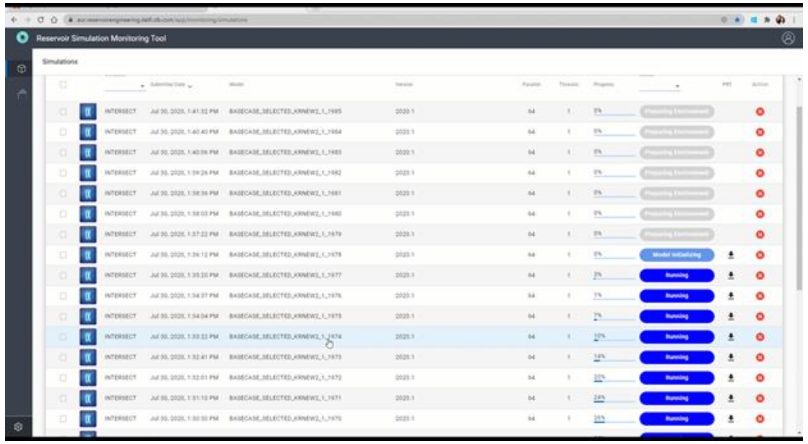
- No intention to purchase additional PC and/or software
- Not committed to do this PJT for long term (6 months at most)
- Easy to use remotely
- Low Cost

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

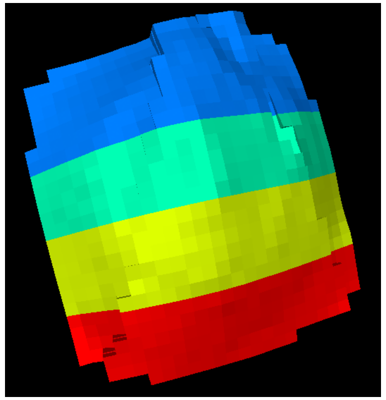


PTS: Petrotechnical Suite, ODRS: On Demand Reservoir Simulation

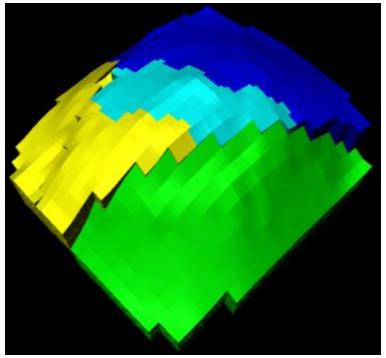
Why INTERSECT?

- 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

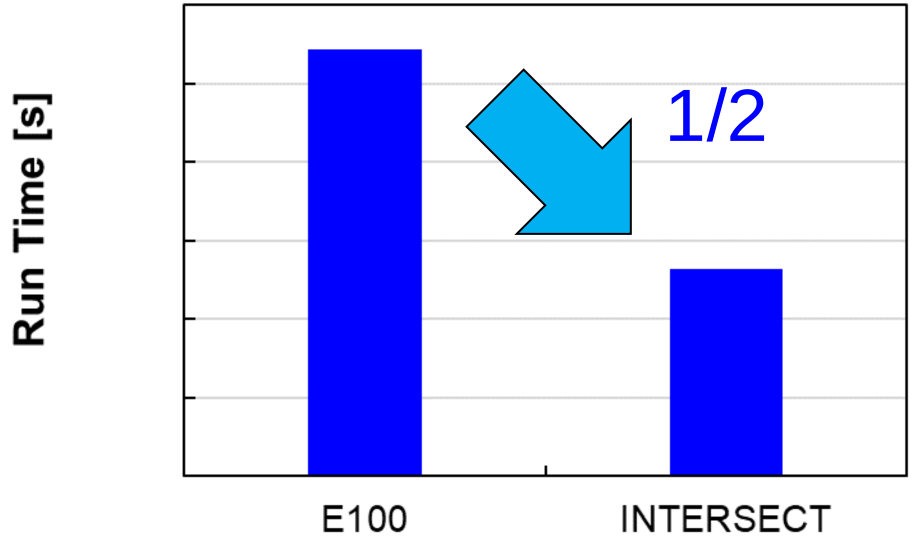
Efficient parallel processing in IX



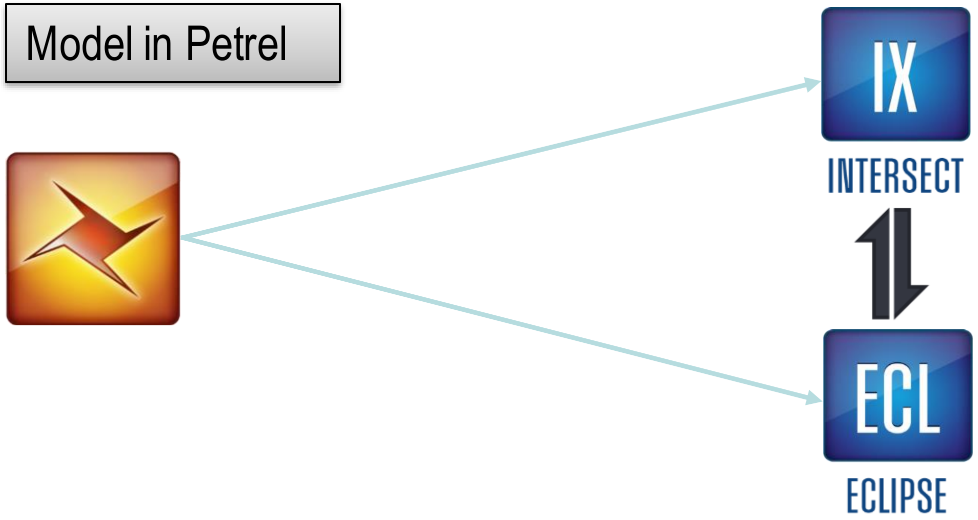
ECLIPSE partition



INTERSECT partition (Intelligent partitioning)



Model in Petrel

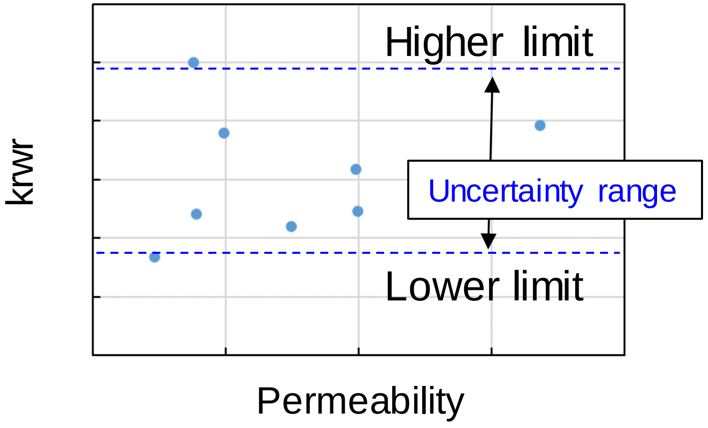


Comparison of simulation time in DELFI
- IX vs. ECL
- IX with different number of paralllel

Applied Workflow

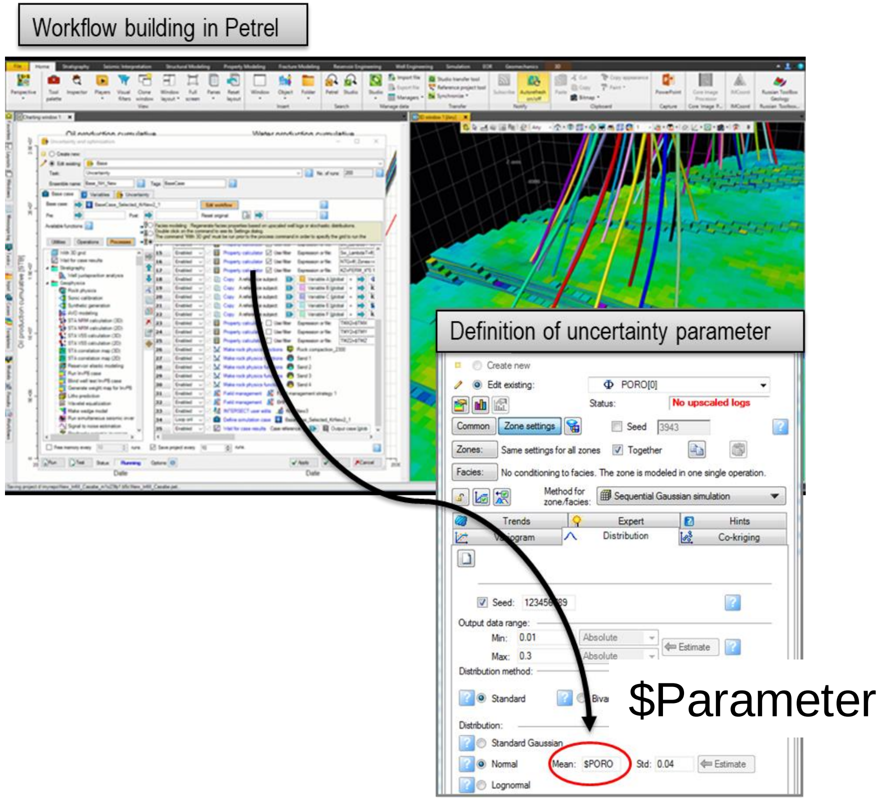
1. Data Review

To detect the appropriate the uncertainty range



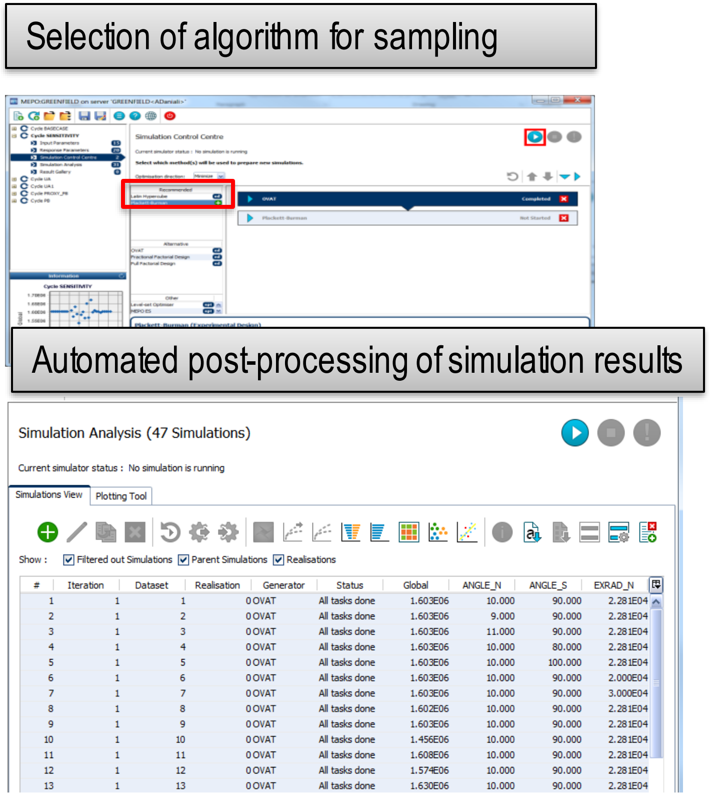
2. Uncertainty parameter definition in Petrel

To utilize a strong pre-processing functionalities in Petrel



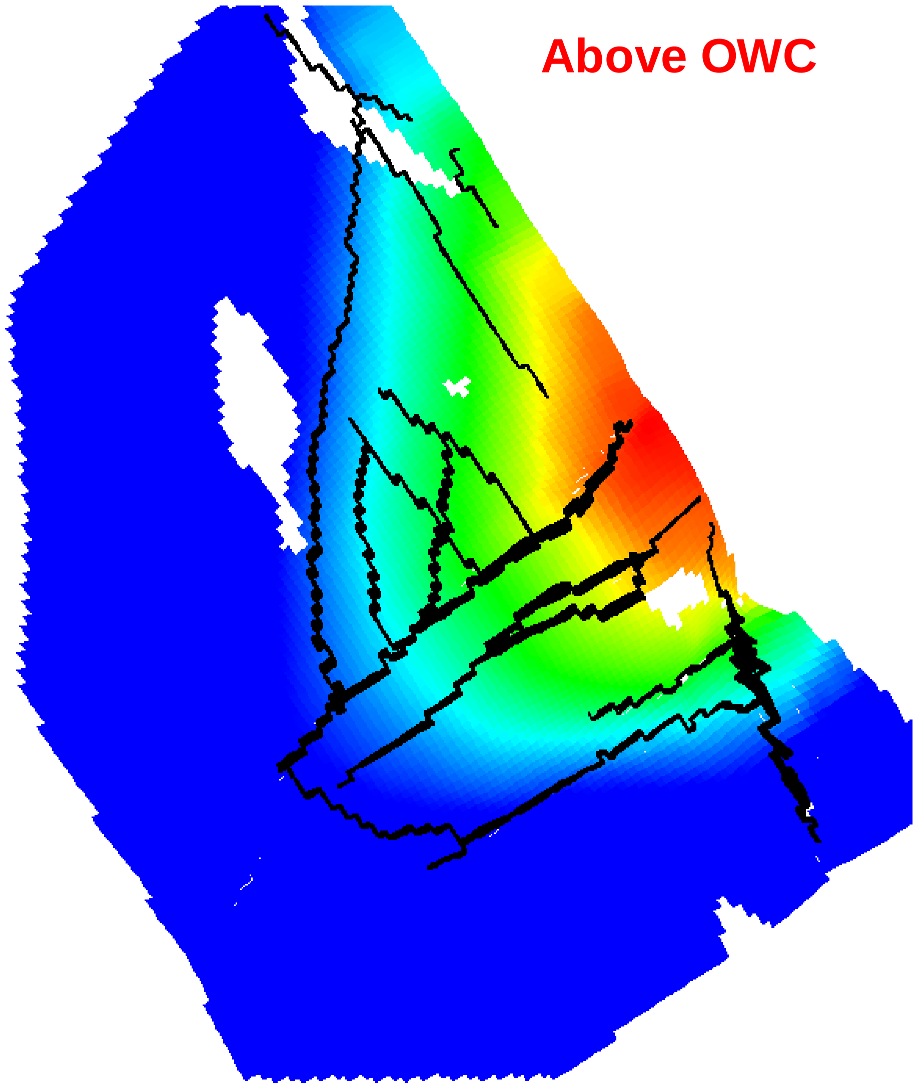
3. Assisted History matching (AHM) with MEPO

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



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

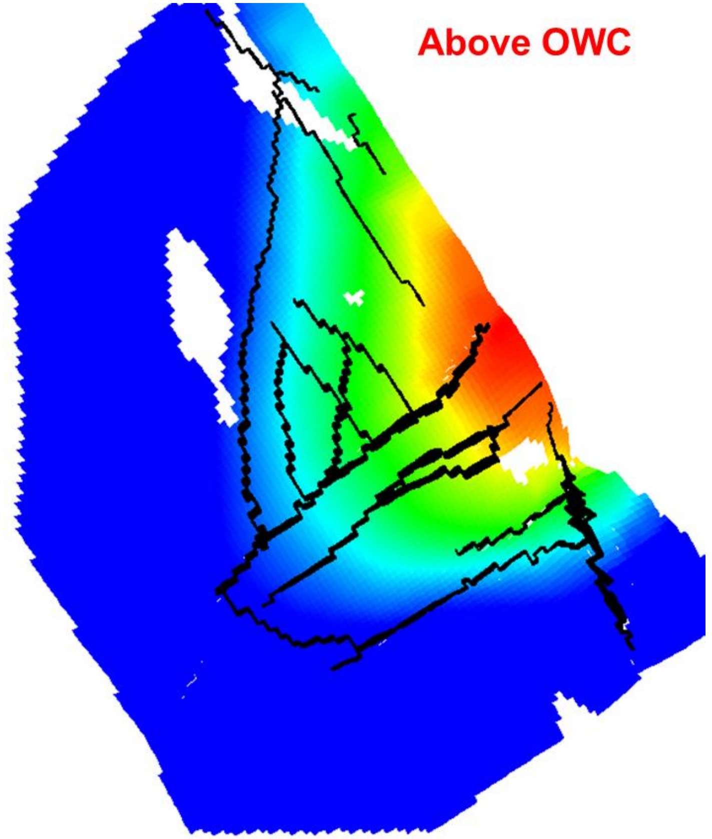
Objective Function

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	• End point and curvature of relative permeability curves (Swcr, Sorw, krwr, Nw, Now) • Rock compressibility (Cp) • Lower and upper limits were set based on core data
OOWC	2	• Set Upper and Lower OOWC of the target reservoir • Lower (HKW) and Upper (LKO) limits were set respectively
Aquifer Volume	2	• Set Upper / Lower AQVOL multiplier of the target reservoir • Lower and upper limits were set to the ratio of 2~20 times against HCPV
Fault Transmissibility	15	• Lower and upper limit set to 0.0001 ~ 1.0
Sum	25	

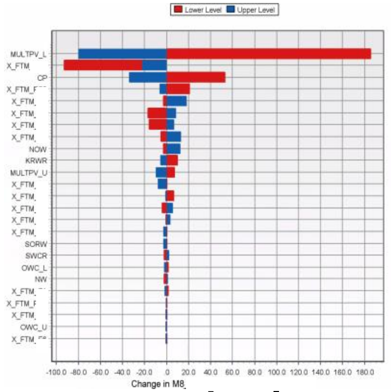


Phased Approach to History Matching

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
SWCR	-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	-0.083	-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

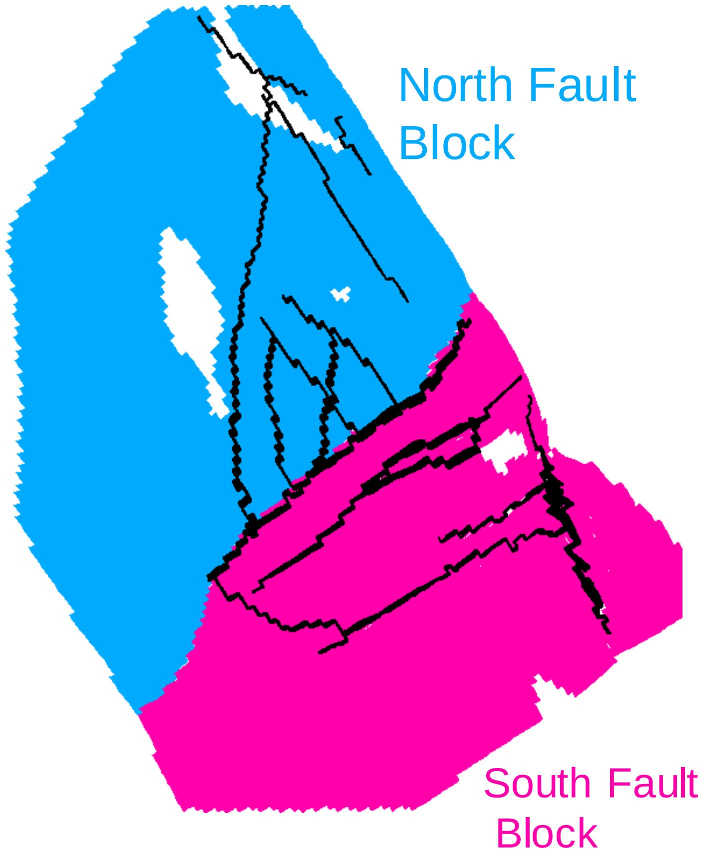
2. History Matching with GA (Genetic Algorithm)

a. Shut-in BHP at North Fault Block wells

b. Shut-in BHP at South Fault Block wells

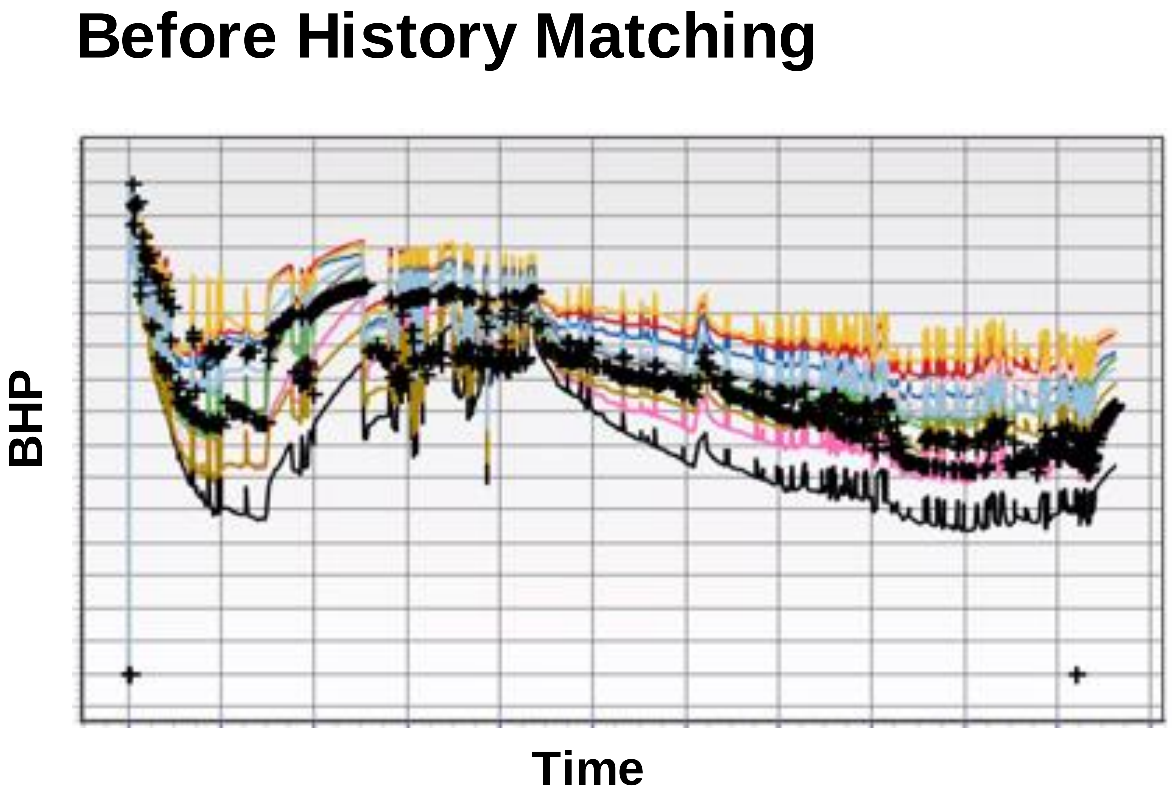
c. Water Cut at Well A

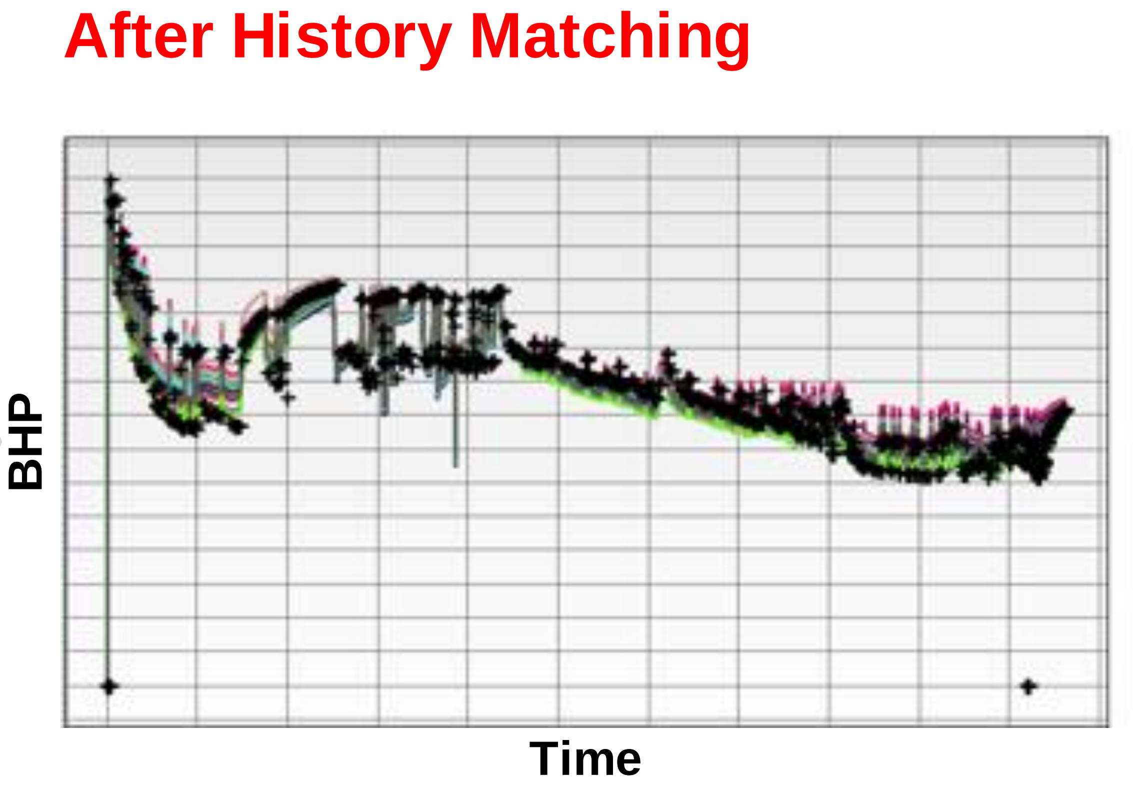
Narrow down the range of uncertain parameters in a sequentially manner



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)

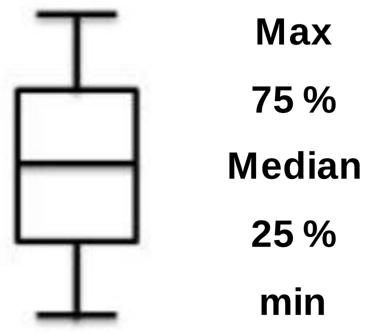




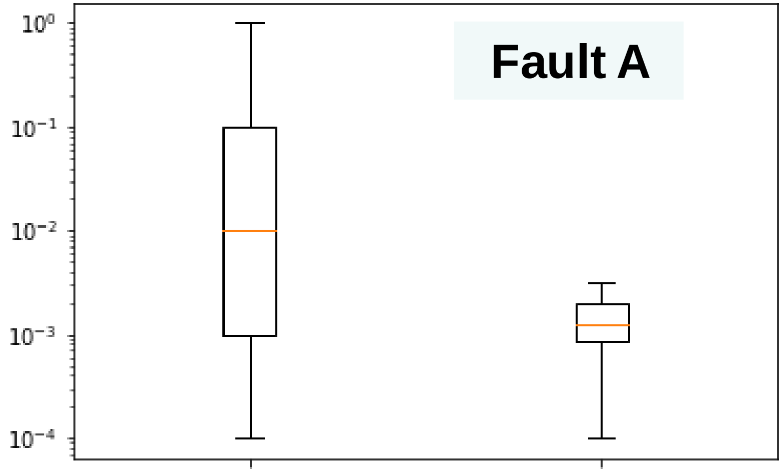
Completed all 3 HM tasks within 3.5 months and acquired the total of 90 high quality history matching models for the 3 Low / Mid / High cases

Change in uncertainty range of each parameter before and after HM

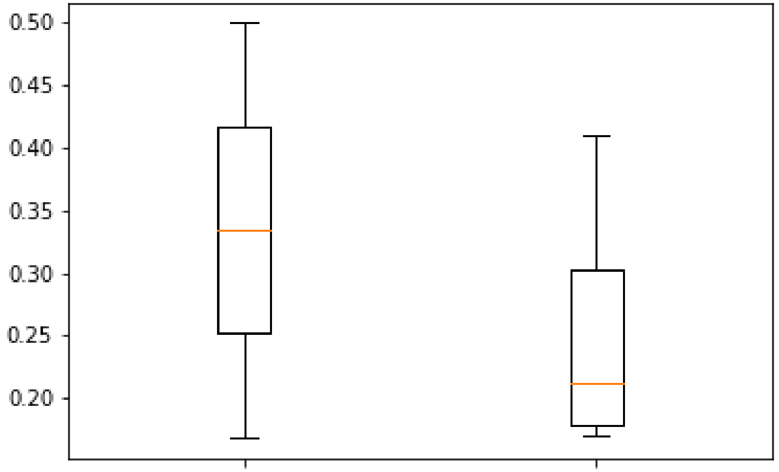
How to read box-and-whicker diagram



Fault Transmissibility



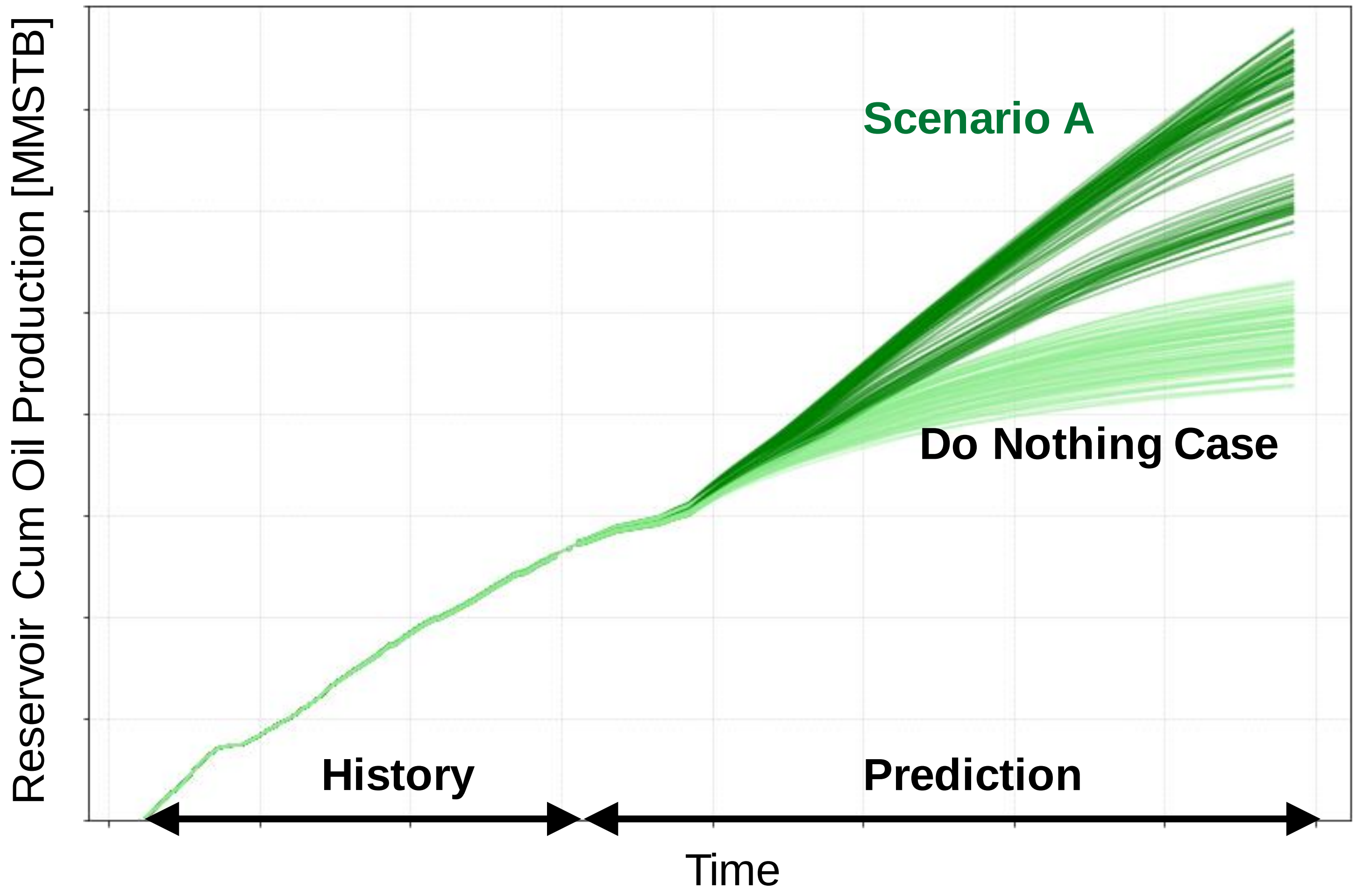
KRWR

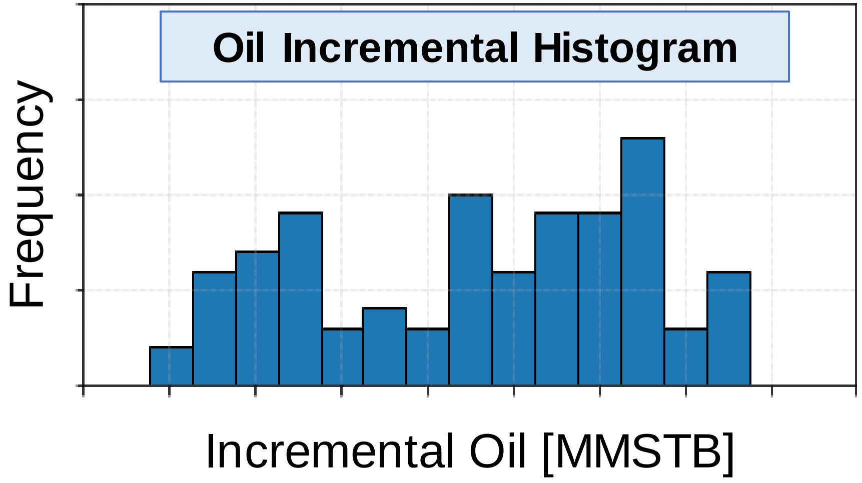


- **Uncertainty parameter mainly on <u>pressure:</u> Range has been narrowed down successfully**
- **Uncertainty parameter mainly on <u>water cut:</u> Range has not changed drastically**

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.