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Re-thinking the Goliat reservoir models:

History matching and identifying infill targets using an ensemble based method

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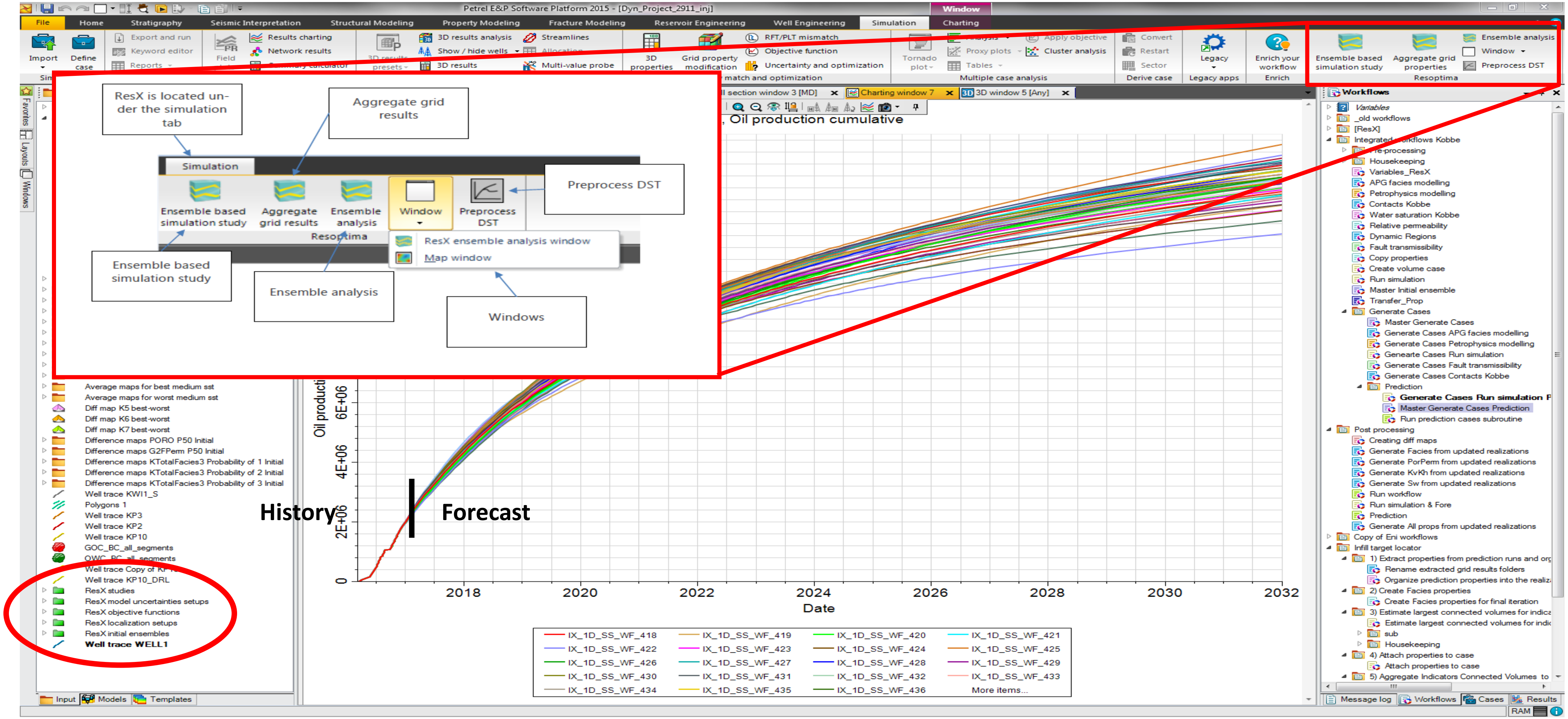
Agenda

- *Method*
- *History matching and forecasting results*
- *Identification of infill targets*
- *Conclusion and way forward*

METHOD

ResX as a plugin to Petrel



Ensemble modelling concept

- *ResX consistently conditions reservoir models to both static and dynamic data*
- *The ResX History Matching workflow includes updating of geological properties as well as dynamic parameters on cell by cell level*
- *Matching a full range of geological uncertainties, not just a base case*
- *Taking into account the effect of the subsurface uncertainties and generates P10, P50 and P90 statistical results*

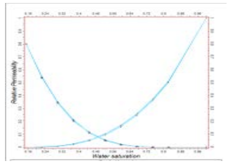
Ensemble-based reservoir modelling

Input

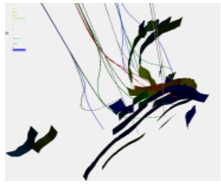
Well logs
Geological concept
Seismic data
Core data

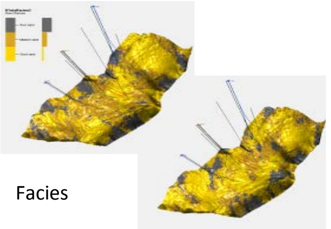
Reservoir modelling workflow

Relperm

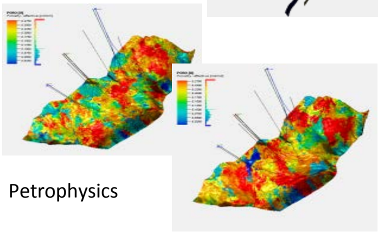


Faults





Facies



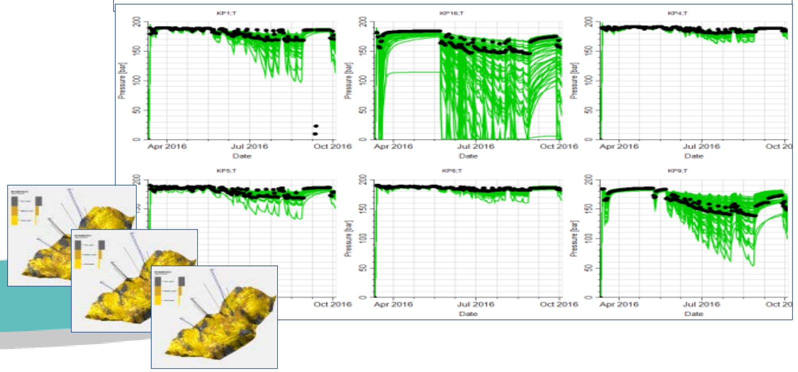
Petrophysics

ResX

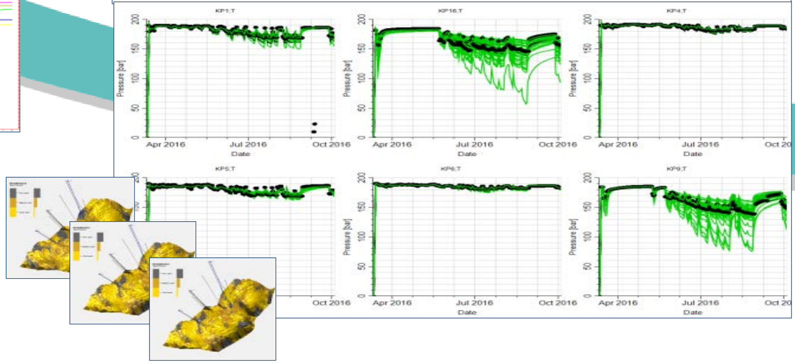
Geological uncertainties included:
- Structural
- Facies
- Petrophysical properties

Dynamic uncertainties included:
- Relative permeability
- Fault transmissibility
- OWC and GOC
- Well completion skin / PI multiplier

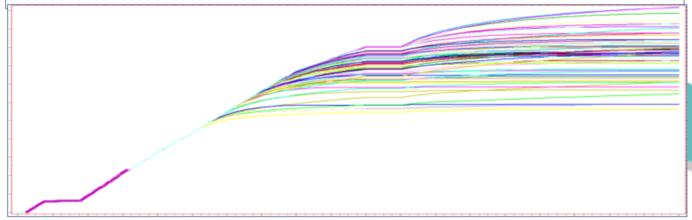
Initial models



History matched models



Forecasting and infill planning



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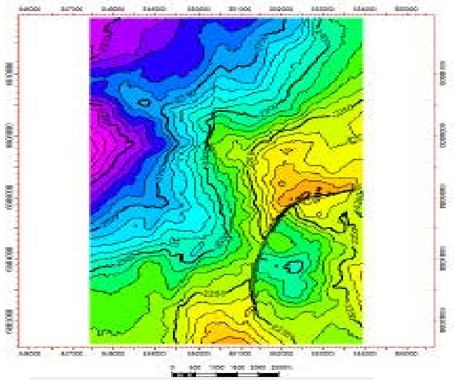
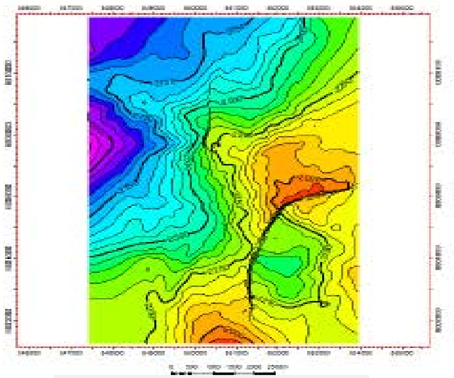
Structural uncertainty

TOP and BOTTOM maps are added a Gaussian random field

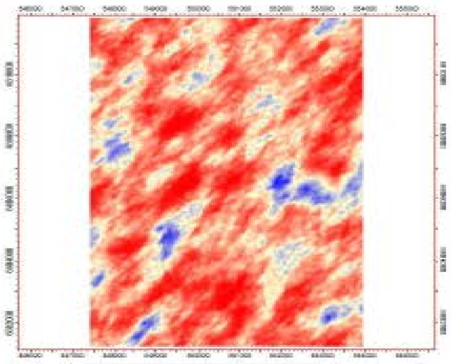
horizon/isochore = original + residual



Simulated Input Map

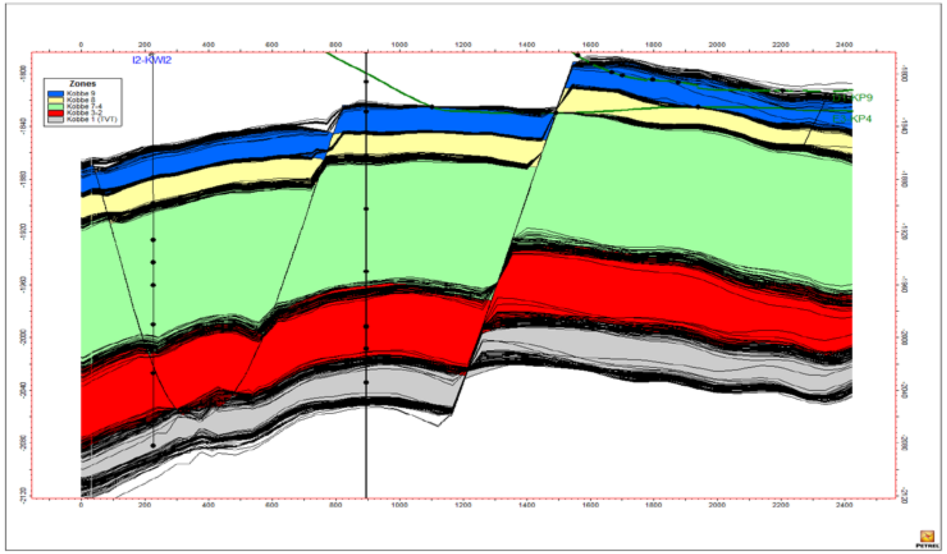


Original Input Map



Residual Field

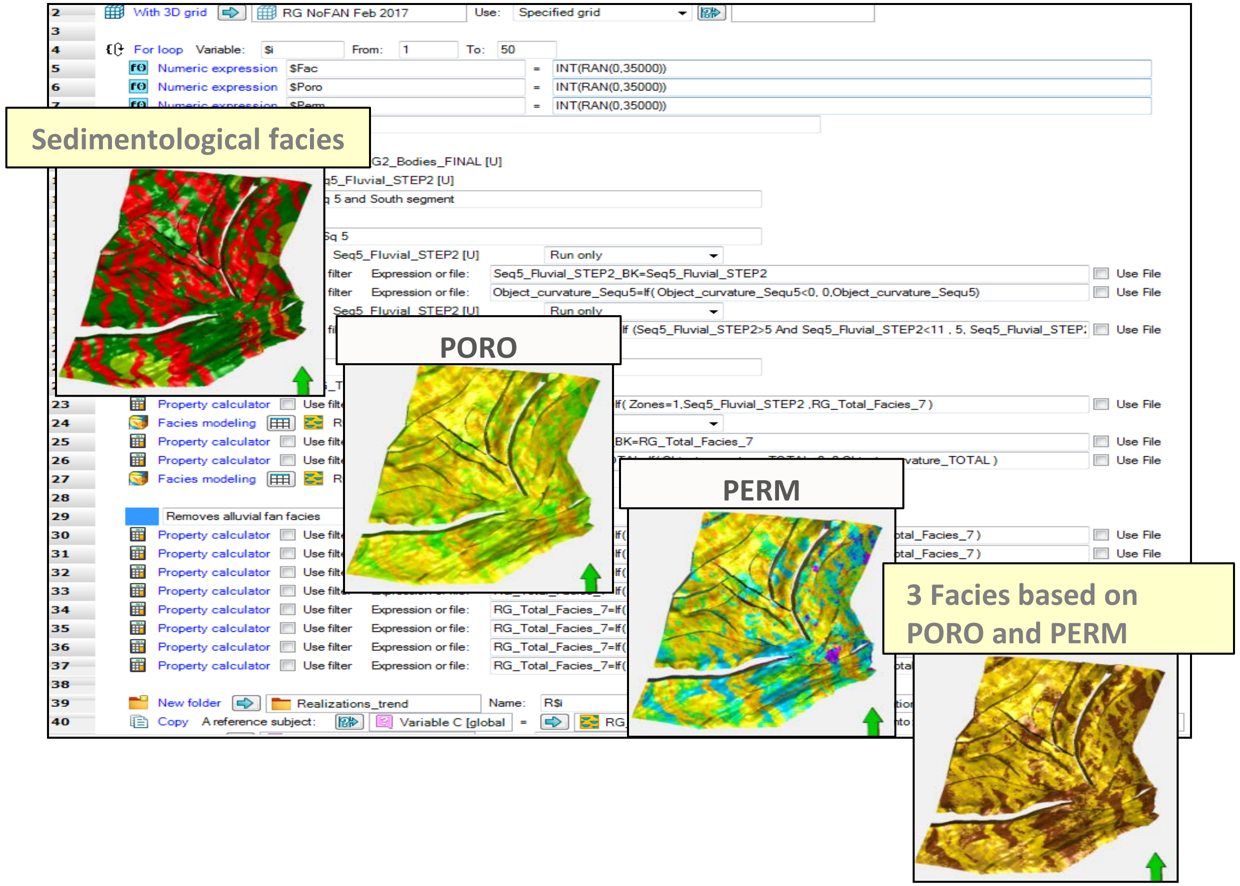
	Distribution	Mean	Std	Min	Max
$MeanRes	Truncated Normal	0	8	-15	15
$StdRes	Truncated Normal	3	2	0.5	8
$MajorRes	Truncated Normal	2000	1000	1000	4000
$Scalar	Truncated Normal	0.75	0.25	0.5	1
$AzimuthRes	Truncated Normal	-50	20	-90	-10
$MinorRes	$Major x Scalar				



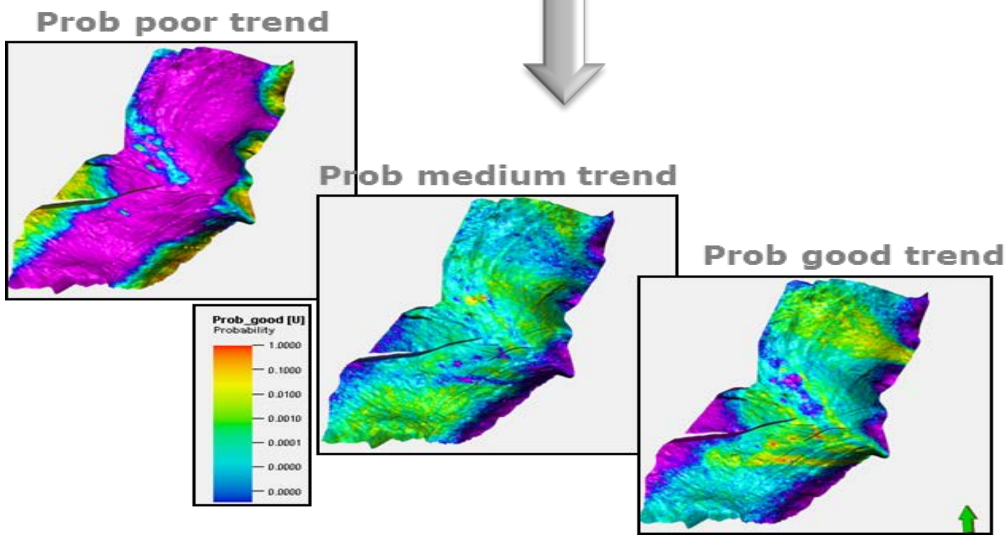
- *MEAN Residual accounts for the velocity model uncertainty*
- *STD residual accounts for the mapping uncertainty*
- *Distance from wells: 300 m*

Facies uncertainty (1/2)

Step 1: Creating facies trend maps from the geological conceptual model



1. *Running 50 realizations on original workflow (including sedimentological facies, porosity and permeability)*
2. *Aggregate the **three facies types based on rock quality index** into probability maps for each facies (poor, medium and good)*



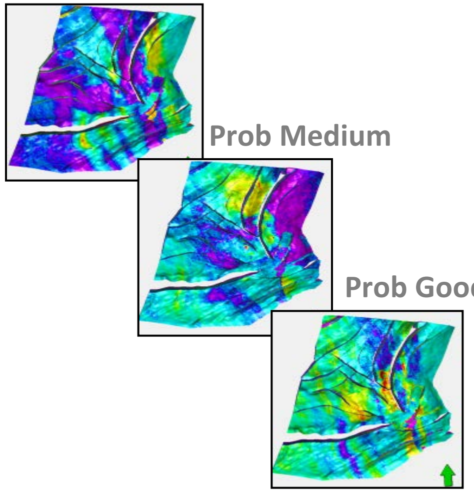
Facies uncertainty (2/2)

Step 2: Three facies types distributed using an ADAPTIVE PLURI-GAUSSIAN TECHNIQUE

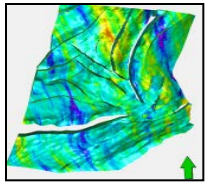
Prob Poor

Prob Medium

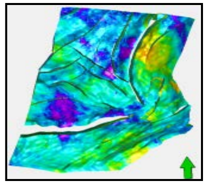
Prob Good

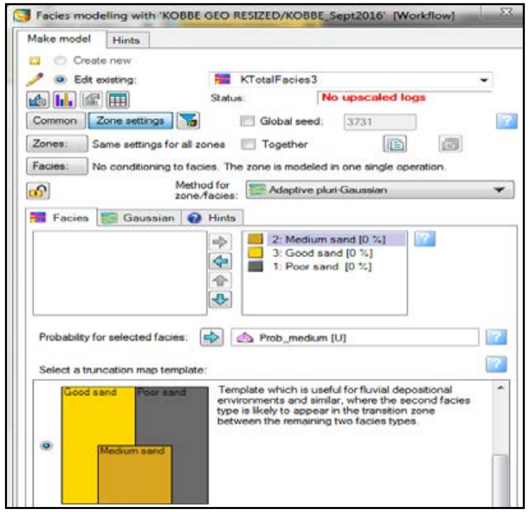


Gaussian Latent 1



Gaussian Latent 2





Facies Probability Maps

Probability for each facies resulting from a weighted compromise between well logs probabilities and geological conceptual model

Generate Gaussian (latent) variables

- Controls the spatial continuity of the generated facies realizations
- Enables conditioning facies realizations to dynamic data

Adaptive pluri-Gaussian simulation

Generate facies realizations honoring the conceptual model and the logs, and adding the Gaussian latent variables

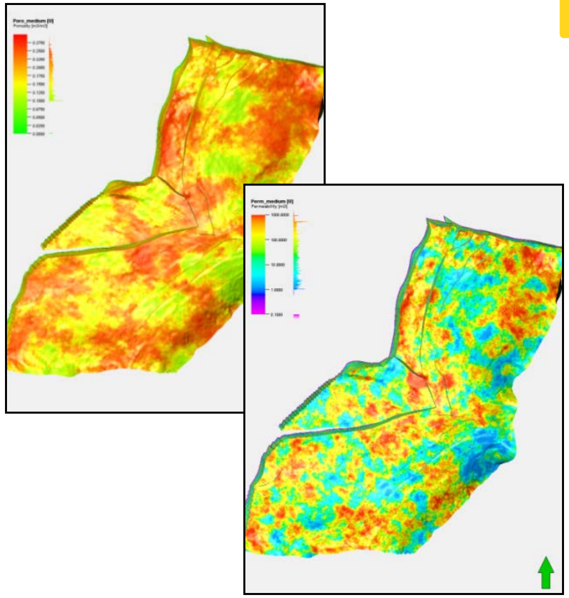
Ensemble based simulation study

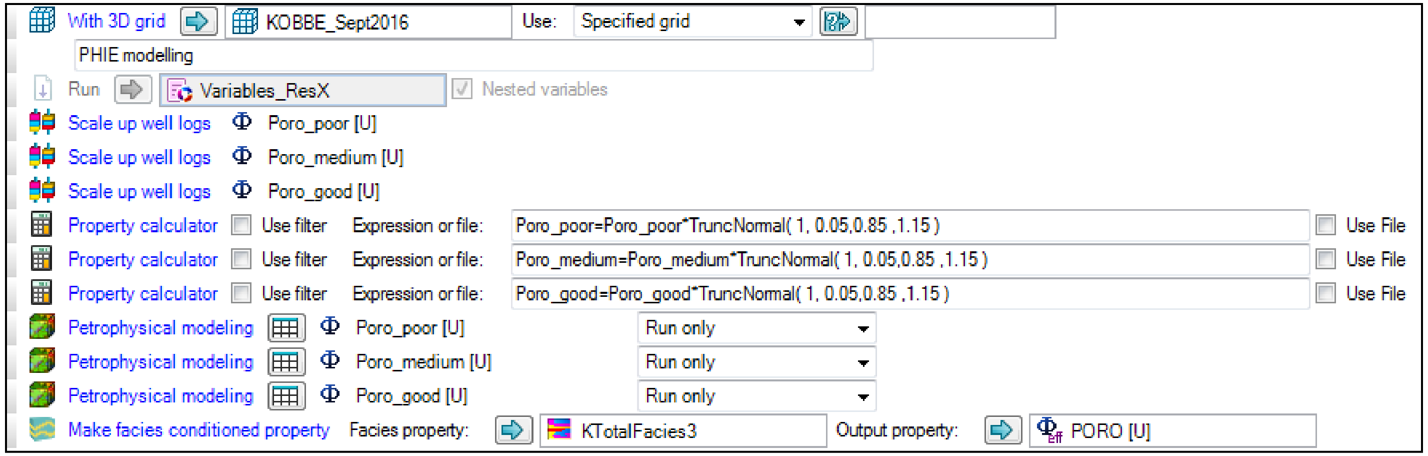
Latent (Gaussian) variables are updated by ResX to condition the generated facies realizations to dynamic data

Adaptive Pluri-Gaussian Technique Reference:
Sebacher, et al. (2013). A probabilistic parametrization for geological uncertainty estimation using the ensemble Kalman filter (EnKF), Computational Geosciences

Petrophysical uncertainty

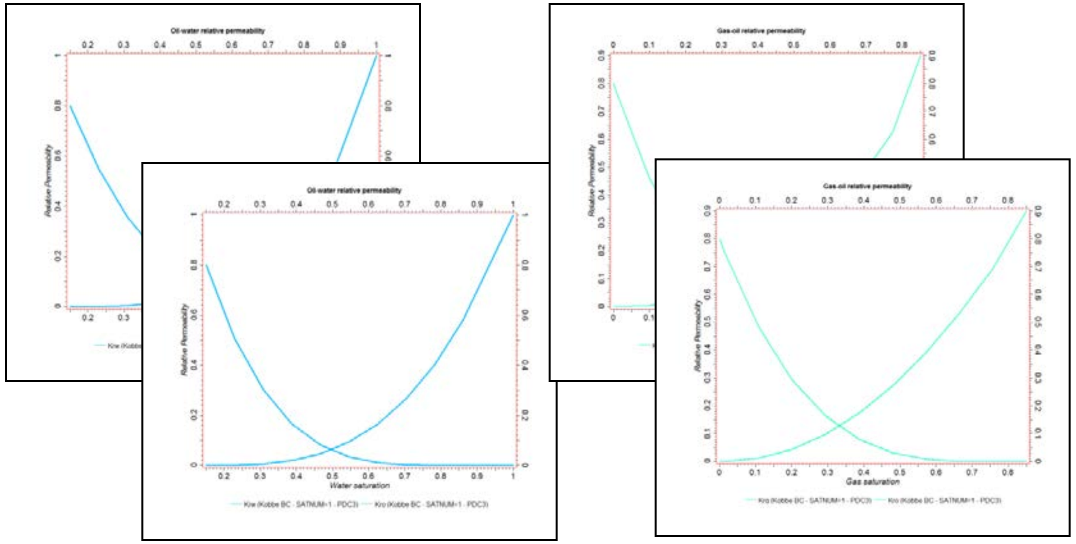
- *Porosity and permeability as a random pick of the log values for each facies plus truncated Gaussian multipliers*
- *Vertical permeability based on shale volume content or field analogues plus by truncated Gaussian multipliers*
- *Water Saturation based on J-functions and risked by variability ranges of the coefficients for each facies.*

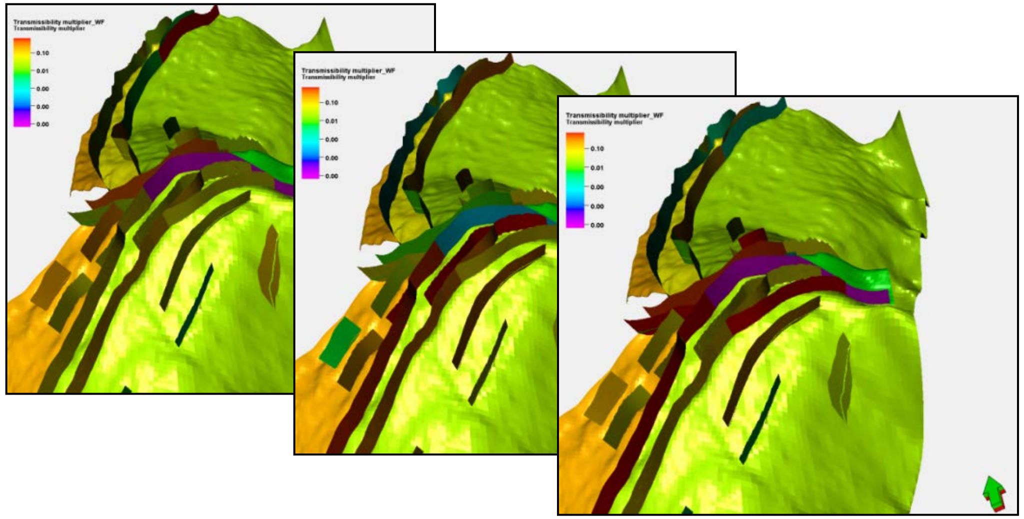




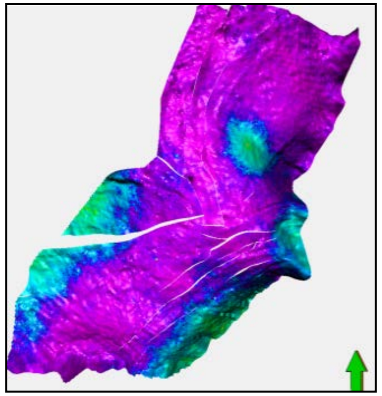
Dynamic uncertainty

- Relative Permeability
  - End point and Corey exponent uncertainty for both water/oil and gas/oil
- Fault Transmissibility
  - Transmissibility multipliers across faults
- OWC and GOC
- Completion skin / PI multiplier

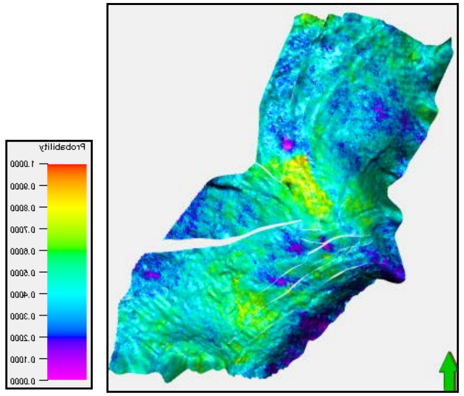




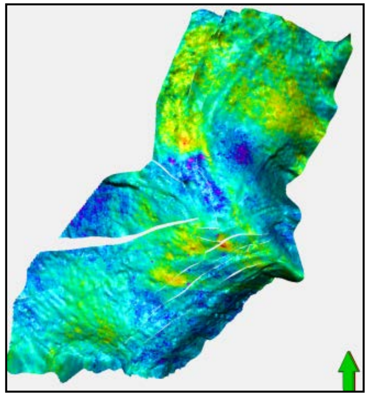
Aggregated properties – initial ensemble



Probability of shale

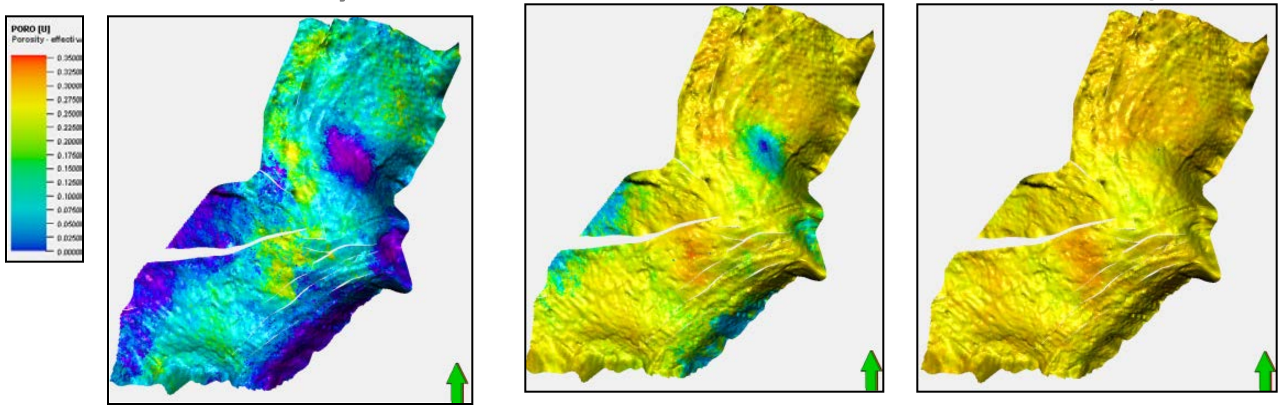


Probability of medium sand

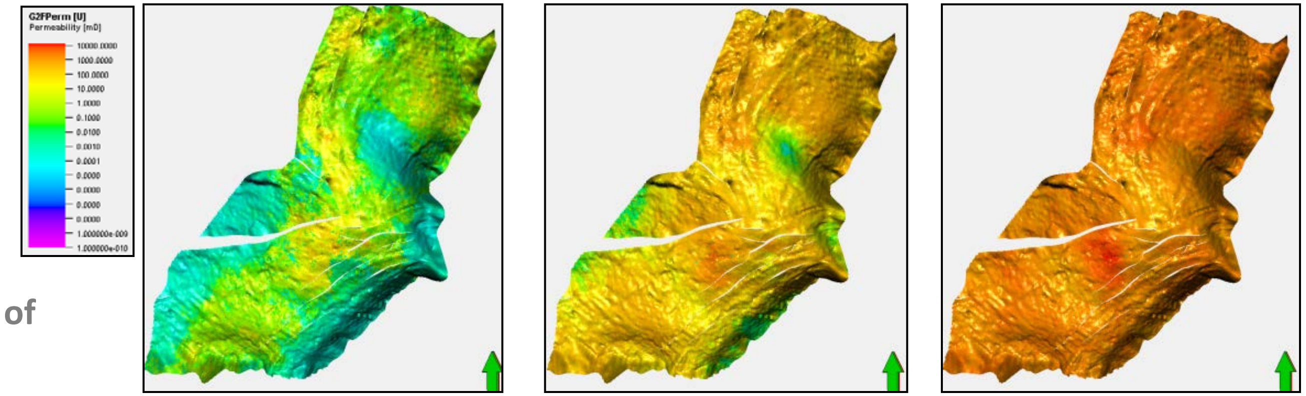


Probability of good sand

P10 Porosity P50 Porosity P90 Porosity

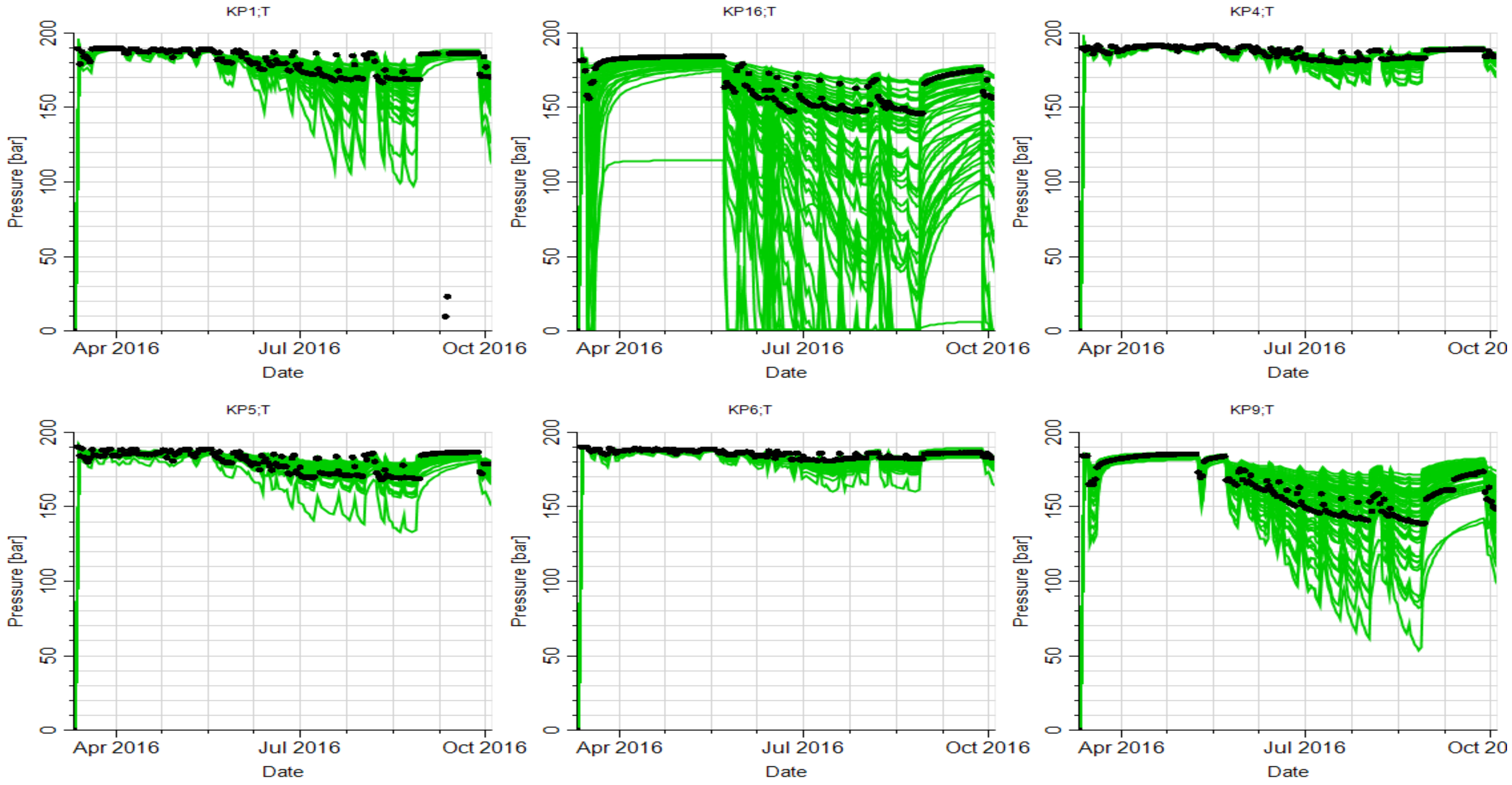


P10 Permeability P50 Permeability P90 Permeability



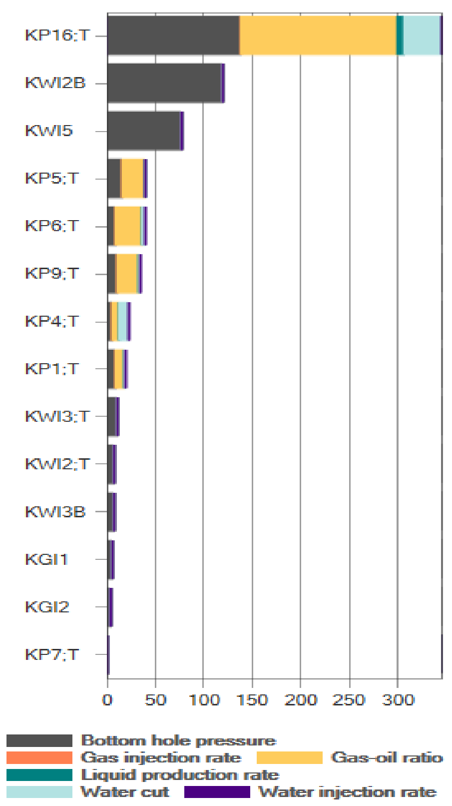
Initial ensemble coverage/variability check

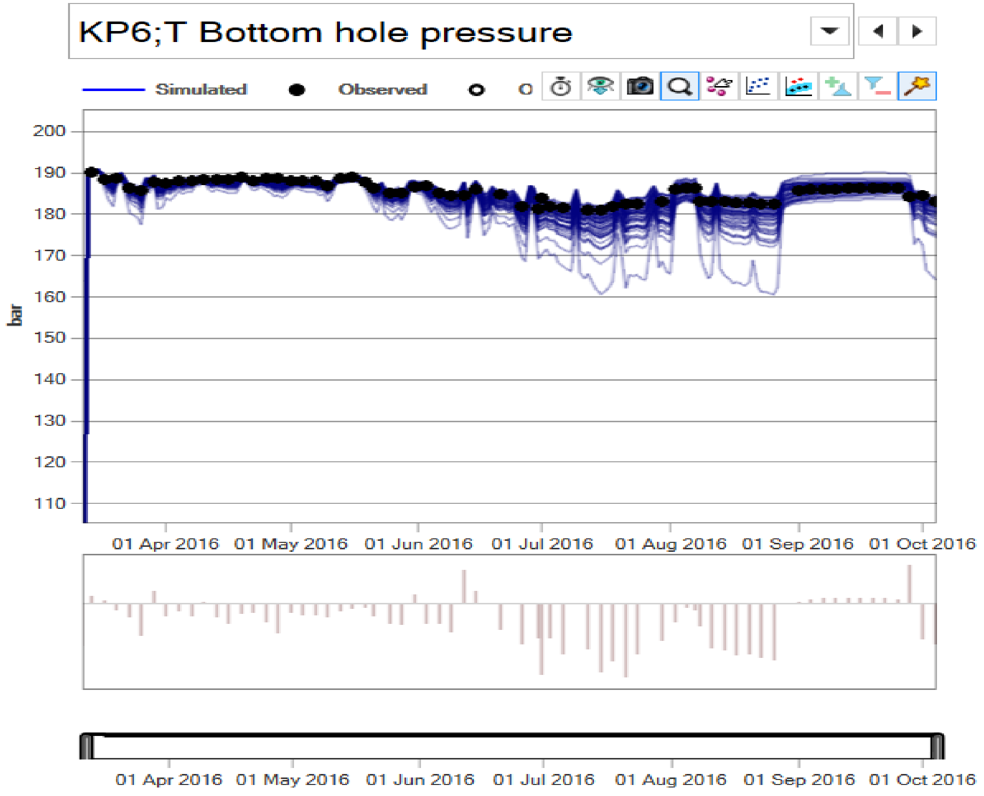
Bottom Hole Pressure



Definition of the objective function

- *Selection of production data to be part of the objective*
  - *Liquid production rate*
  - *Bottom hole pressure*
  - *GOR*
  - *WCT*
- *Specification of the tolerance*
  - *10 bar for pressure*
  - *10% for others*
- *Ensemble analysis process*
  - *Screening tool to analyze the initial ensemble*





Model uncertainties and localization

- *Specify the history matching variables and boundaries*
  - *facies probability*
  - *porosity & permeability*
  - *shale volume*
  - *fault transmissibility*
  - *relative permeability*
  - *well connection multipliers*

Grid properties | Scalars

Drag a field here to group by that field

Transfer property	Name	Passthrough	Minimum	Maximum	Unit	Transform	Comment
GaussianLatent1	GaussianLatent1		-3	2.99999		Linear	
GaussianLatent2	GaussianLatent2		-3	3		Linear	
Perm_good	Perm_good		0	19682.6	mD	Logarithmic	
Perm_medium	Perm_medium		0	1926.86	mD	Logarithmic	
Perm_poor	Perm_poor		0	3.0219	mD	Logarithmic	
Poro_good	Poro_good		0	0.404307	m3/m3	Linear	
Poro_medium	Poro_medium		0	0.309357	m3/m3	Linear	
Poro_poor	Poro_poor		0	0.113912	m3/m3	Linear	
Prob_good	Prob_good		0	1		Probability	
Prob_medium	Prob_medium		0	1		Probability	
Prob_poor	Prob_poor		0	1		Probability	
Vsh_good	Vsh_good		1.71866e-05	50	%	Linear	
Vsh_medium	Vsh_medium		1.5783e-05	90	%	Linear	
Vsh_poor	Vsh_poor		6.43546e-05	100	%	Linear	

- *Constrain the area of influence*
  - *radius around the wells*
  - *zones*
  - *segments*

Grid properties | Scalars

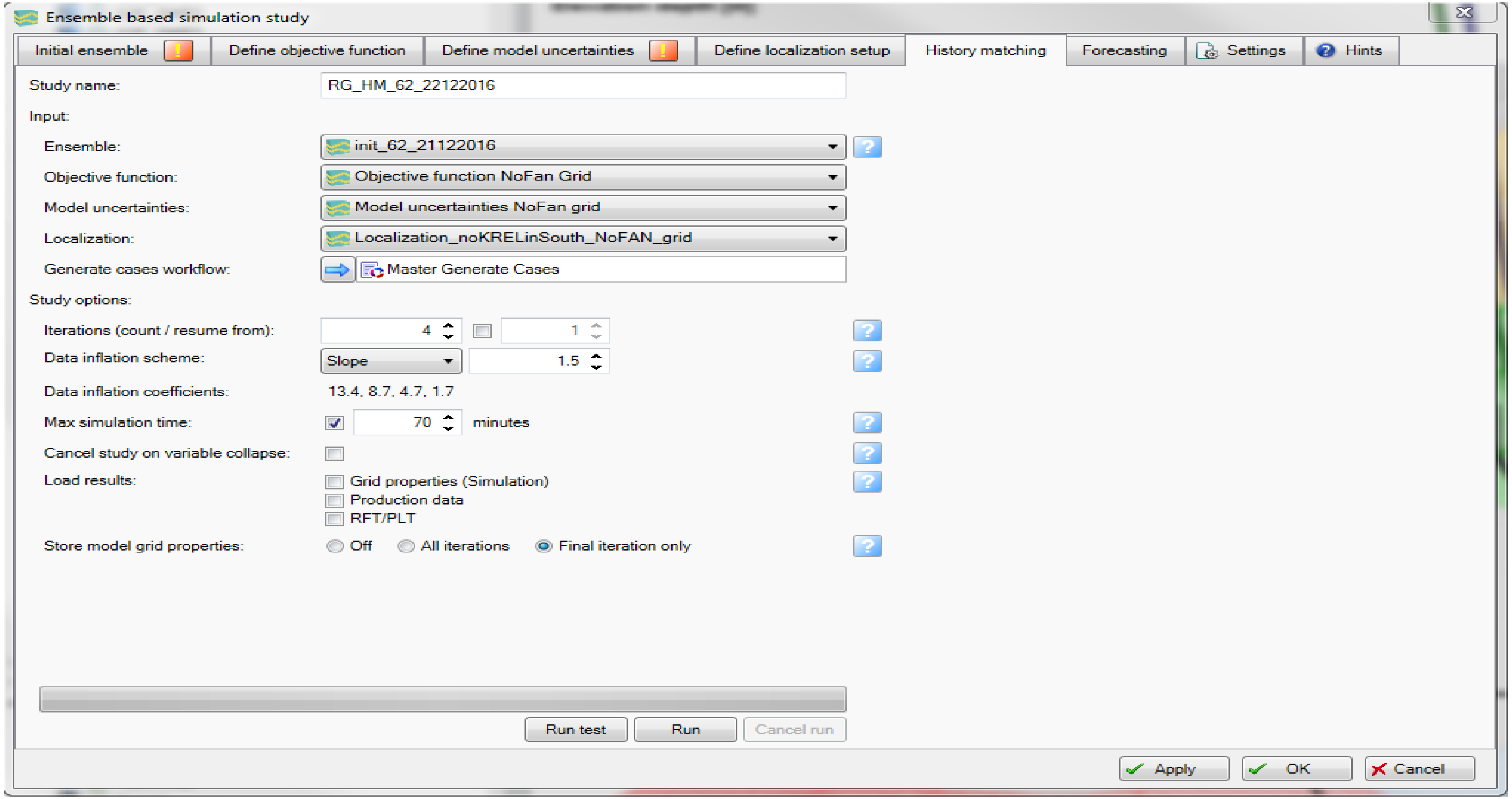
Drag a field here to group by that field

Identifier	Property	Type	GaussianLatent1	GaussianLatent2	Perm_good	Perm_me
KP16;T	Liquid production rate	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP1;T	Liquid production rate	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP4;T	Liquid production rate	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP5;T	Liquid production rate	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP6;T	Liquid production rate	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP9;T	Liquid production rate	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP16;T	Gas-oil ratio	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP1;T	Gas-oil ratio	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP4;T	Gas-oil ratio	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP5;T	Gas-oil ratio	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP6;T	Gas-oil ratio	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP9;T	Gas-oil ratio	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KGI1	Bottom hole pressure	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KGI2	Bottom hole pressure	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP16;T	Bottom hole pressure	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP1;T	Bottom hole pressure	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r
KP4;T	Bottom hole pressure	Production data	r=2000 m	r=2000 m	r=2000 m	r=2000 r

Values:
- Impact near well
- Radius: 2,000 m
- Near perforations only
- Impact all cells
- No impact
- Custom localization property
- Filter property
- Zones | Regions
  - 0: Kobbe 9
  - 1: Kobbe 8
  - 2: Kobbe 7
  - 3: Kobbe 6
  - 4: Kobbe 5
  - 5: Kobbe 4
  - 6: Kobbe 3
  - 7: Kobbe 2
  - 8: Kobbe 1

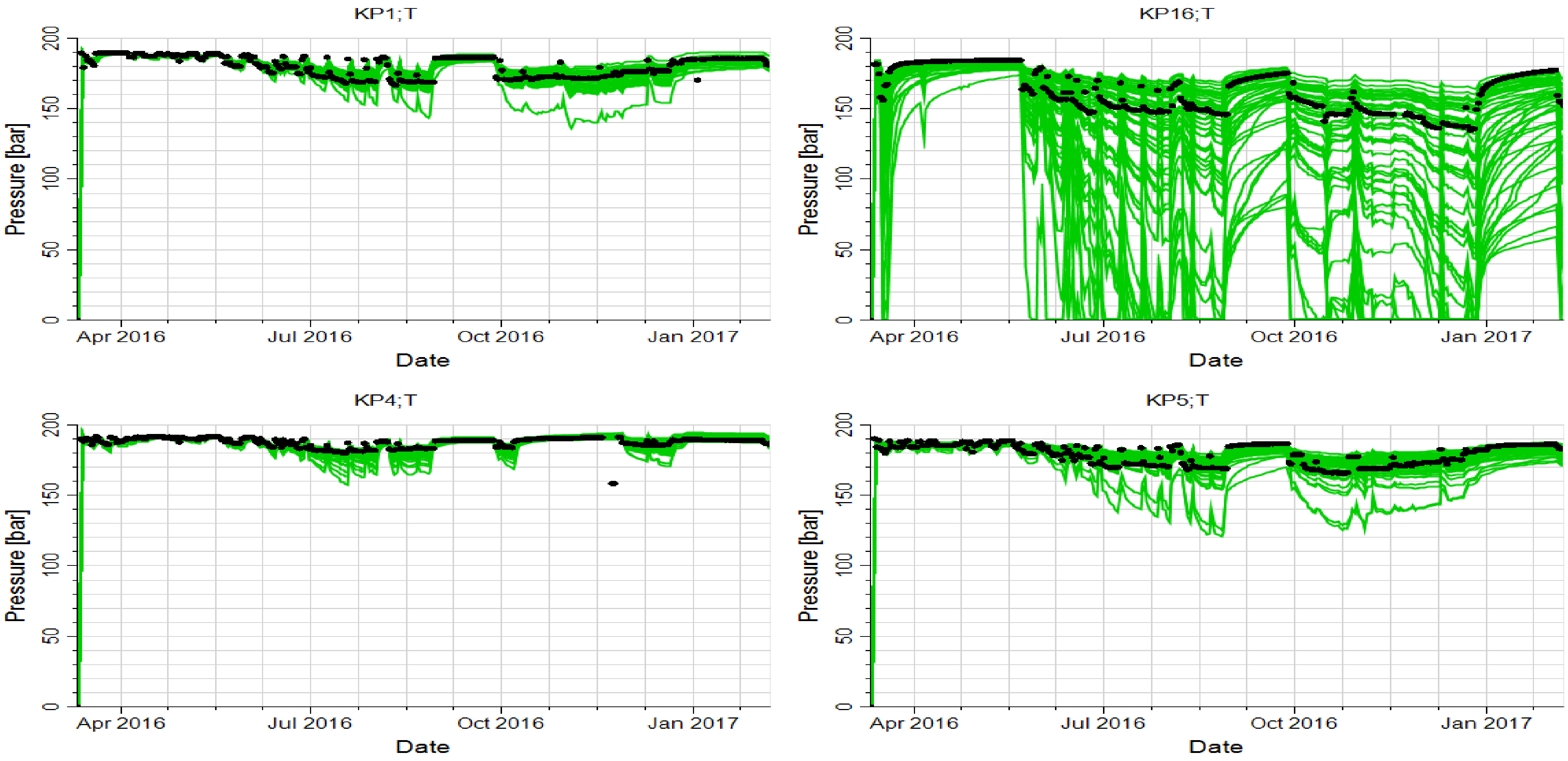
Apply | OK | Cancel

Data assimilation for history matching

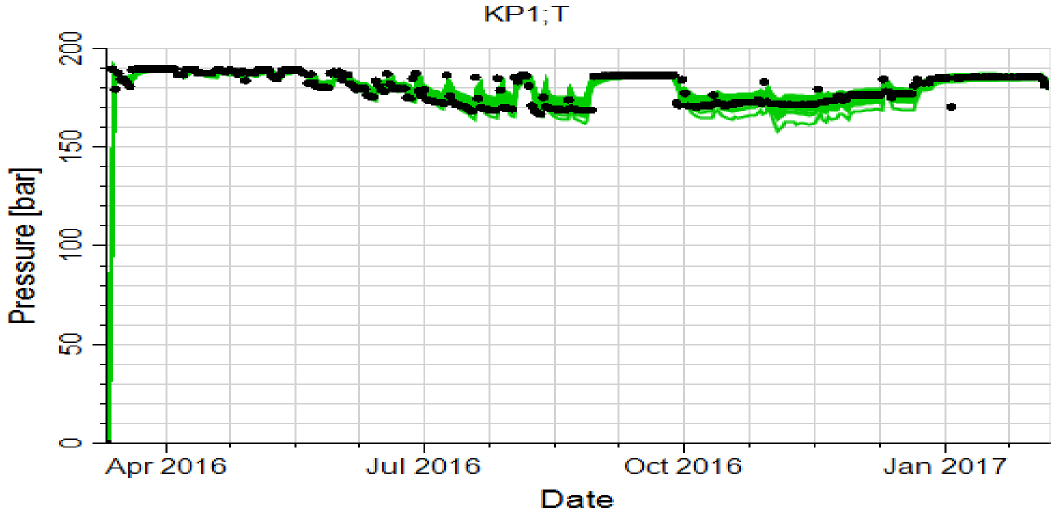


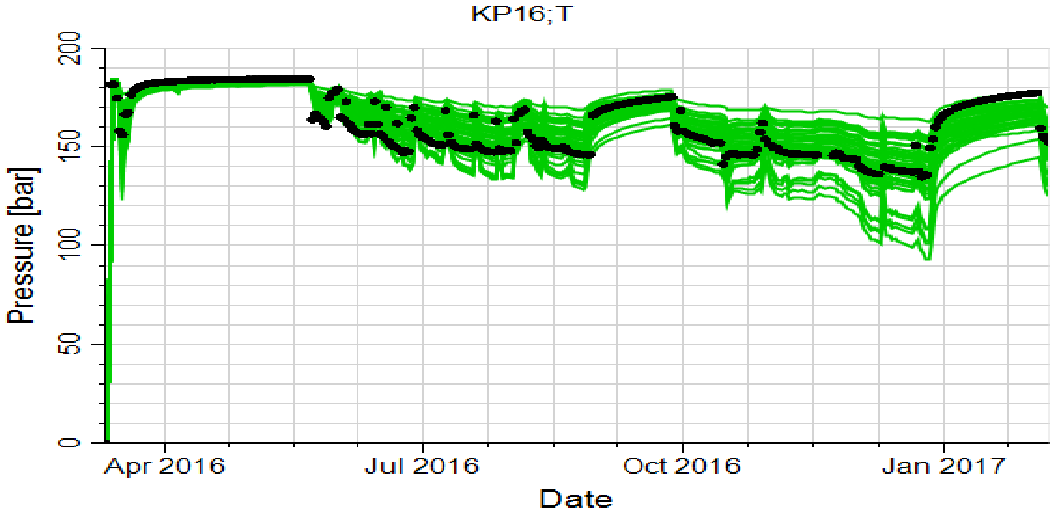
HISTORY MATCHING AND FORECASTING RESULTS

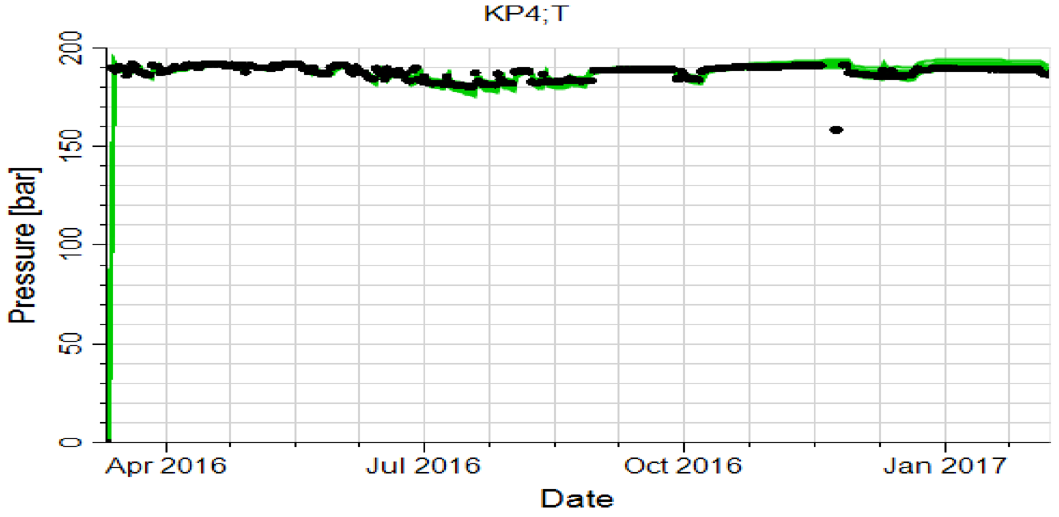
Initial ensemble - BHP

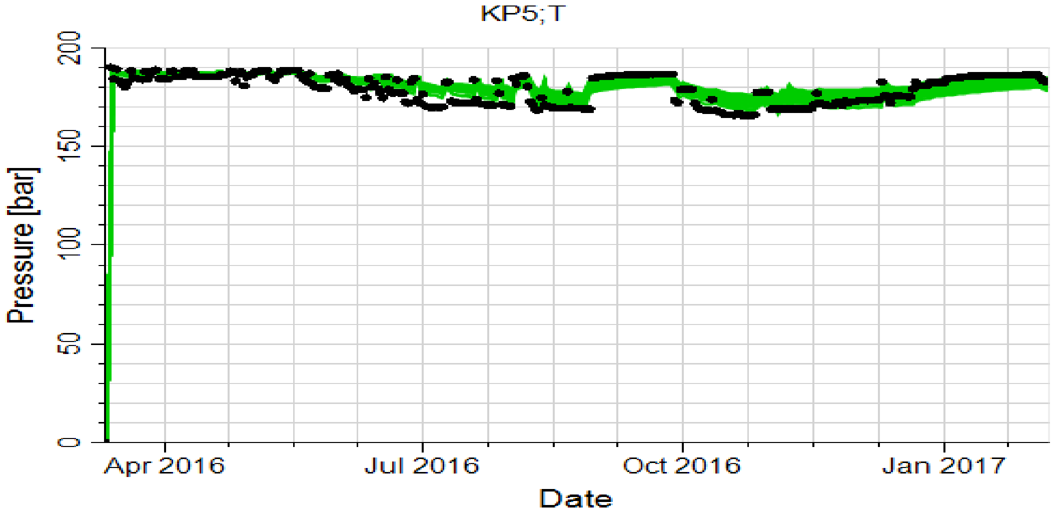


After history match - BHP

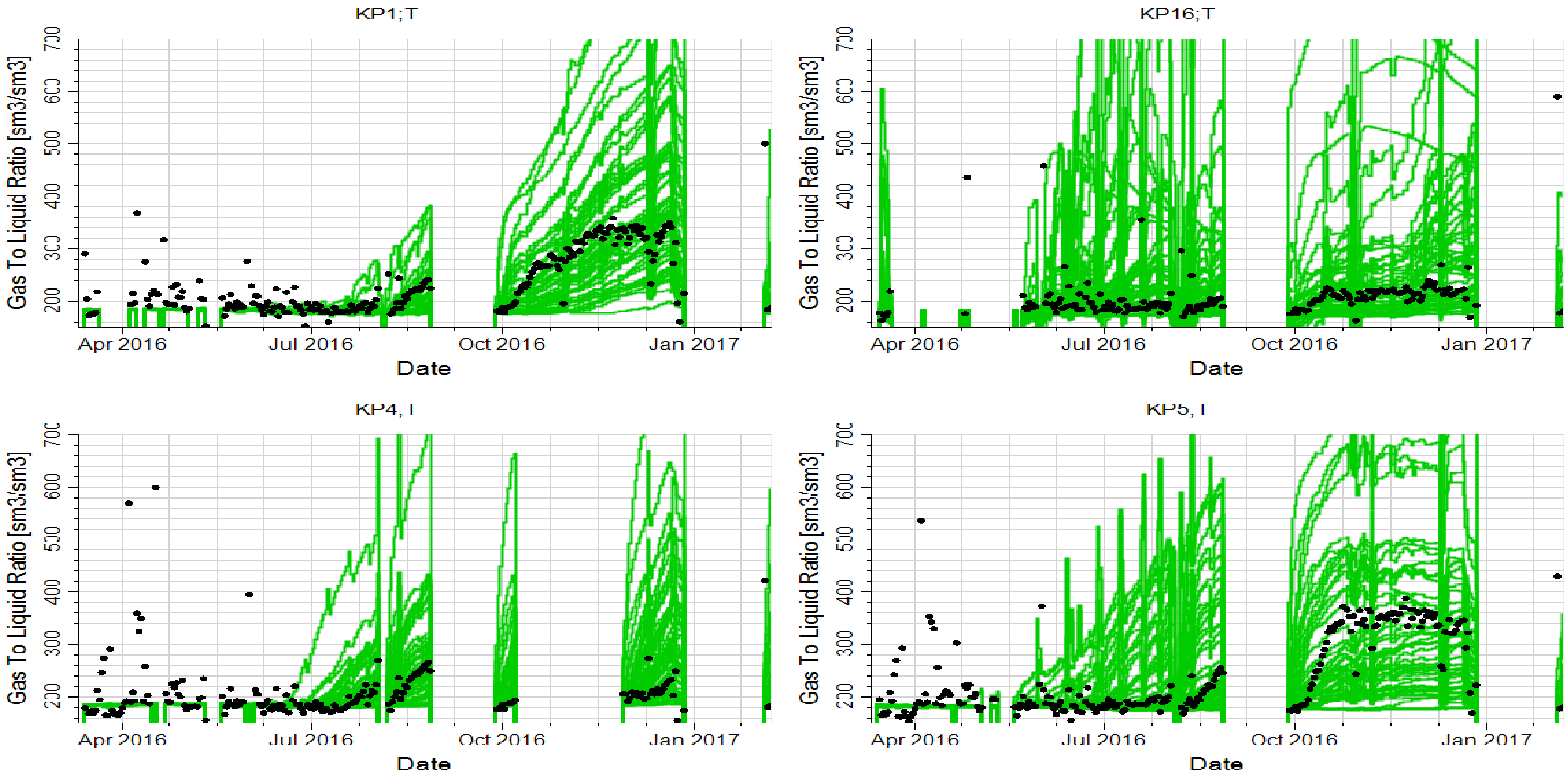








Initial ensemble - GOR



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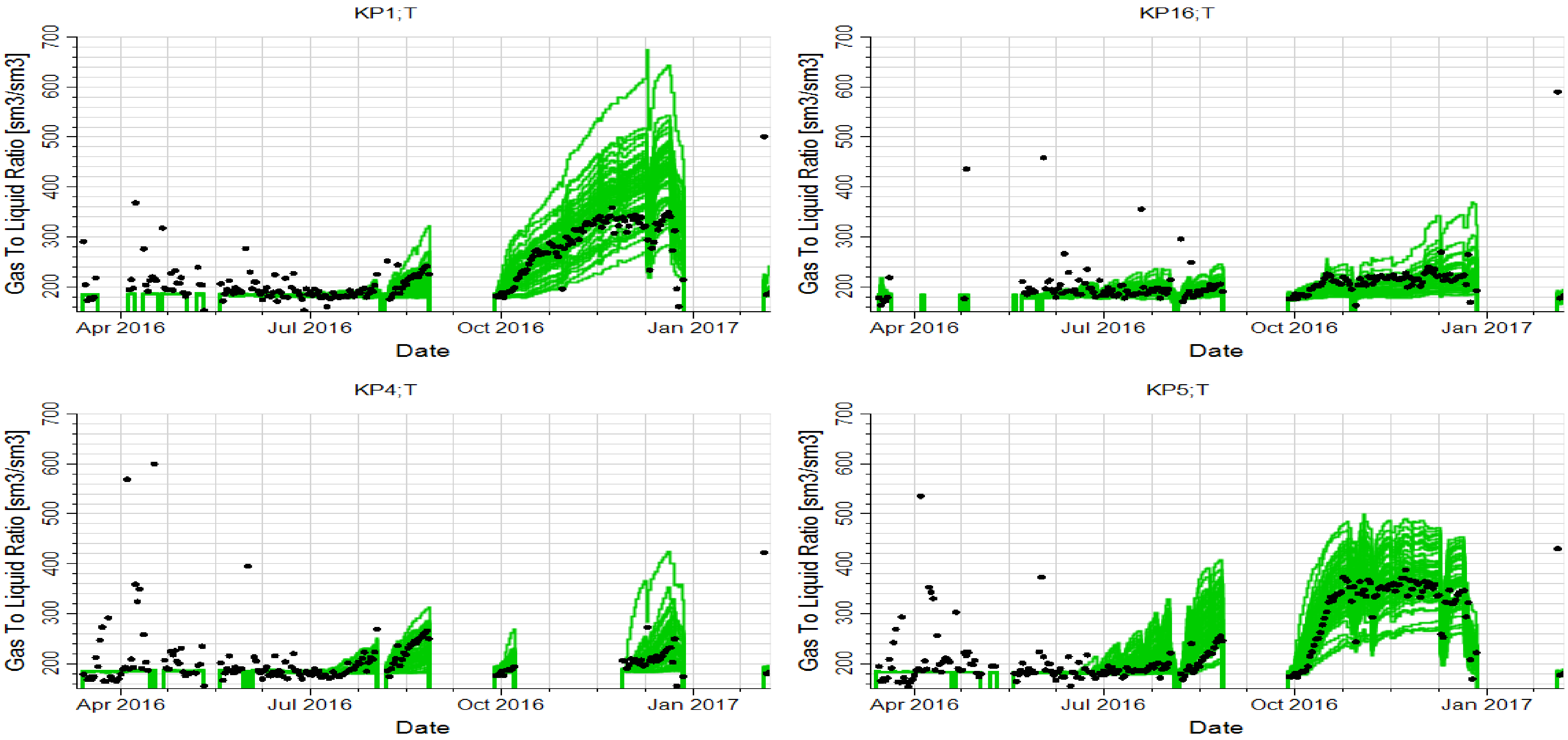
After history match - GOR



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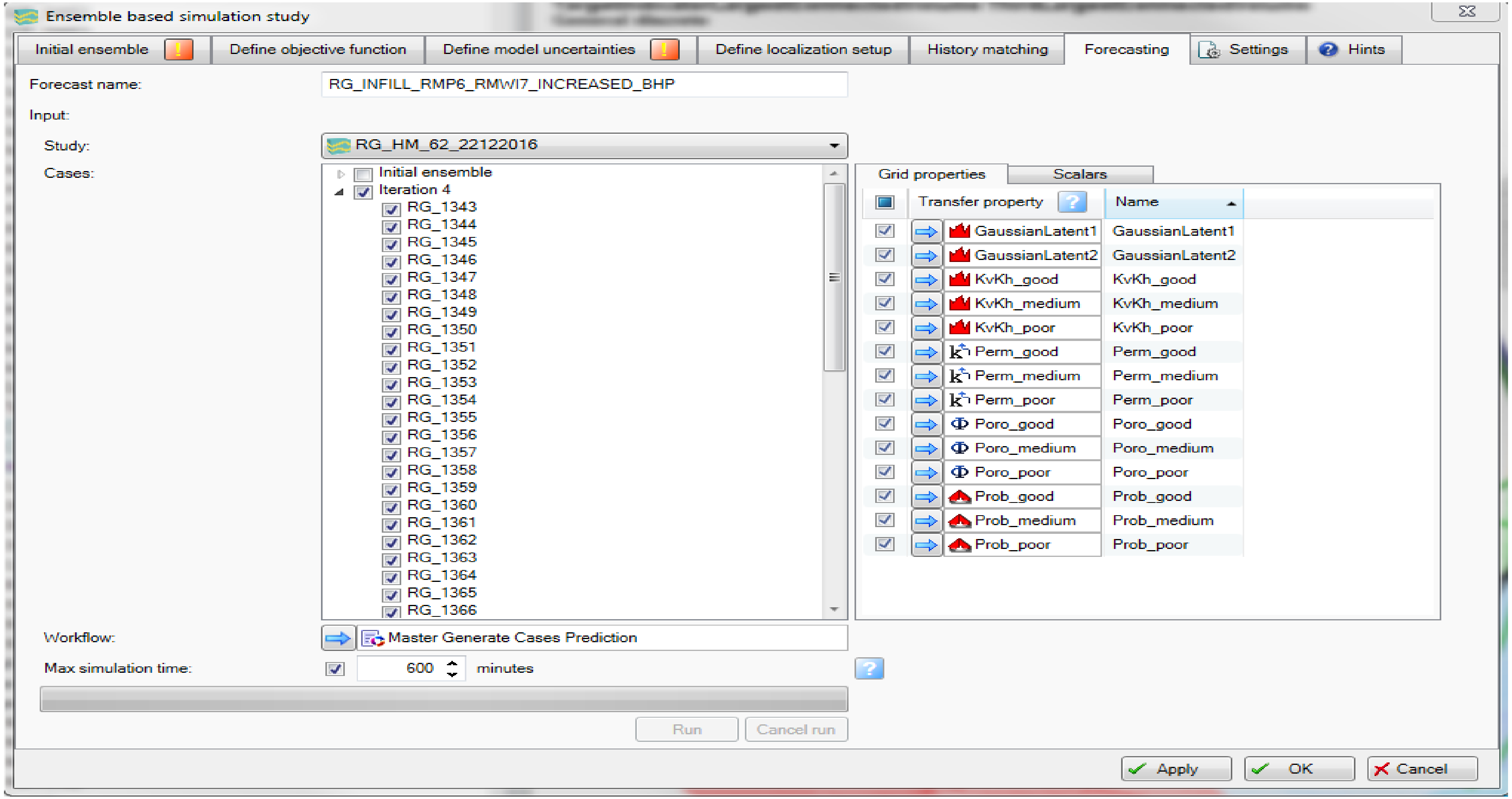
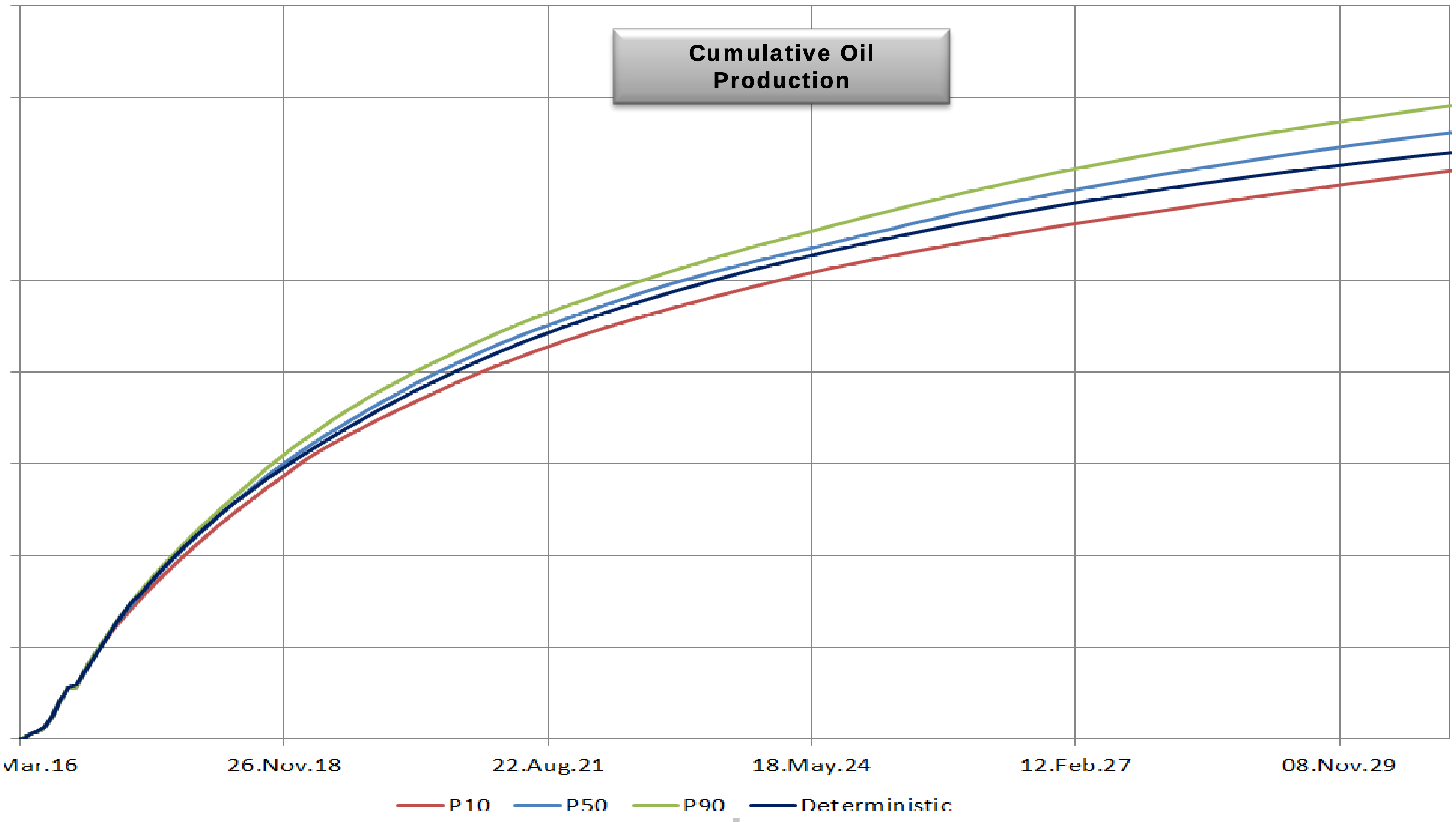
Forecasting set-up



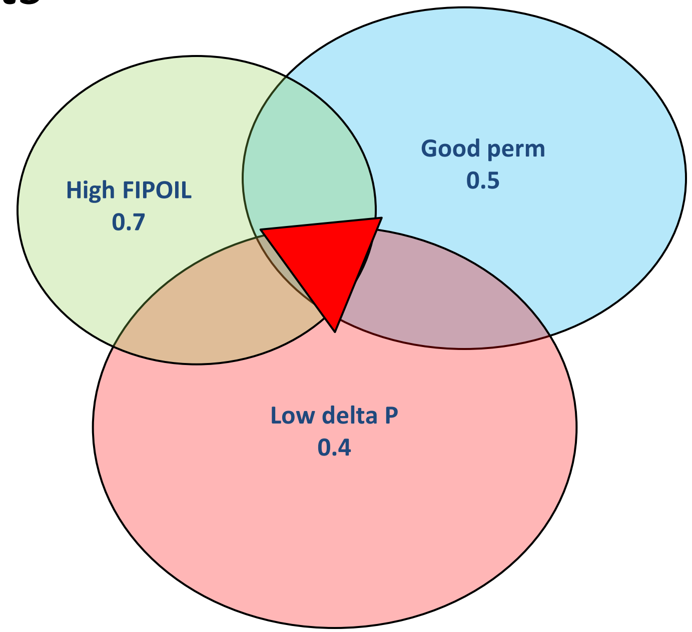
Ensemble forecast



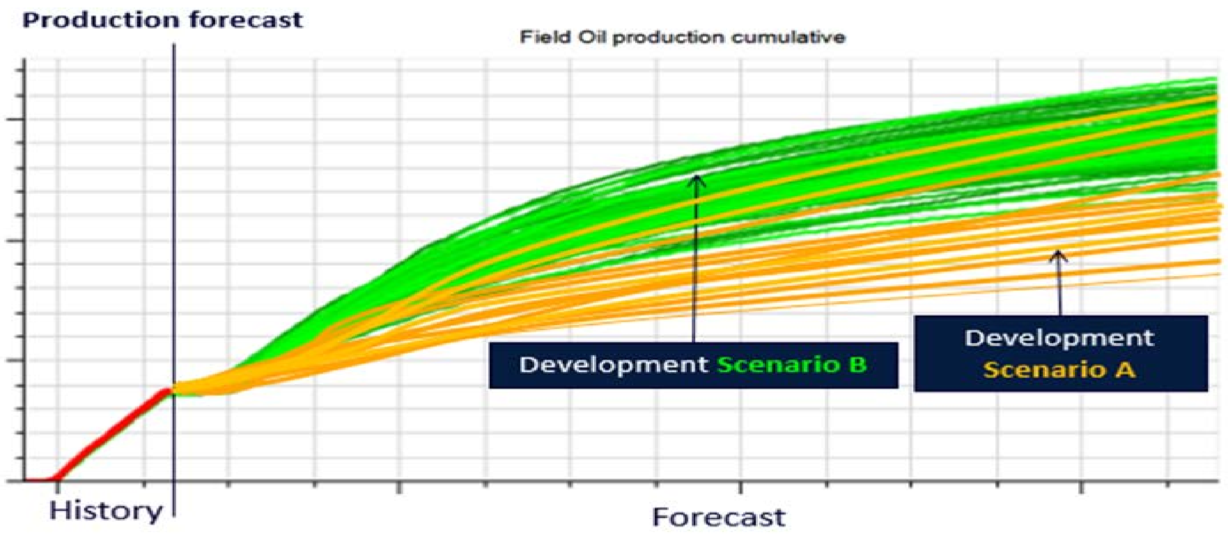
IDENTIFICATION OF INFILL TARGETS

Approach

- *Analyze the ensemble of models to identify robust infill targets*
  - *Identify **connected volumes** combining:*
    - *High probability of good perm sand*
    - *High probability of high in-place volumes*
    - *High probability of small pressure depletion*



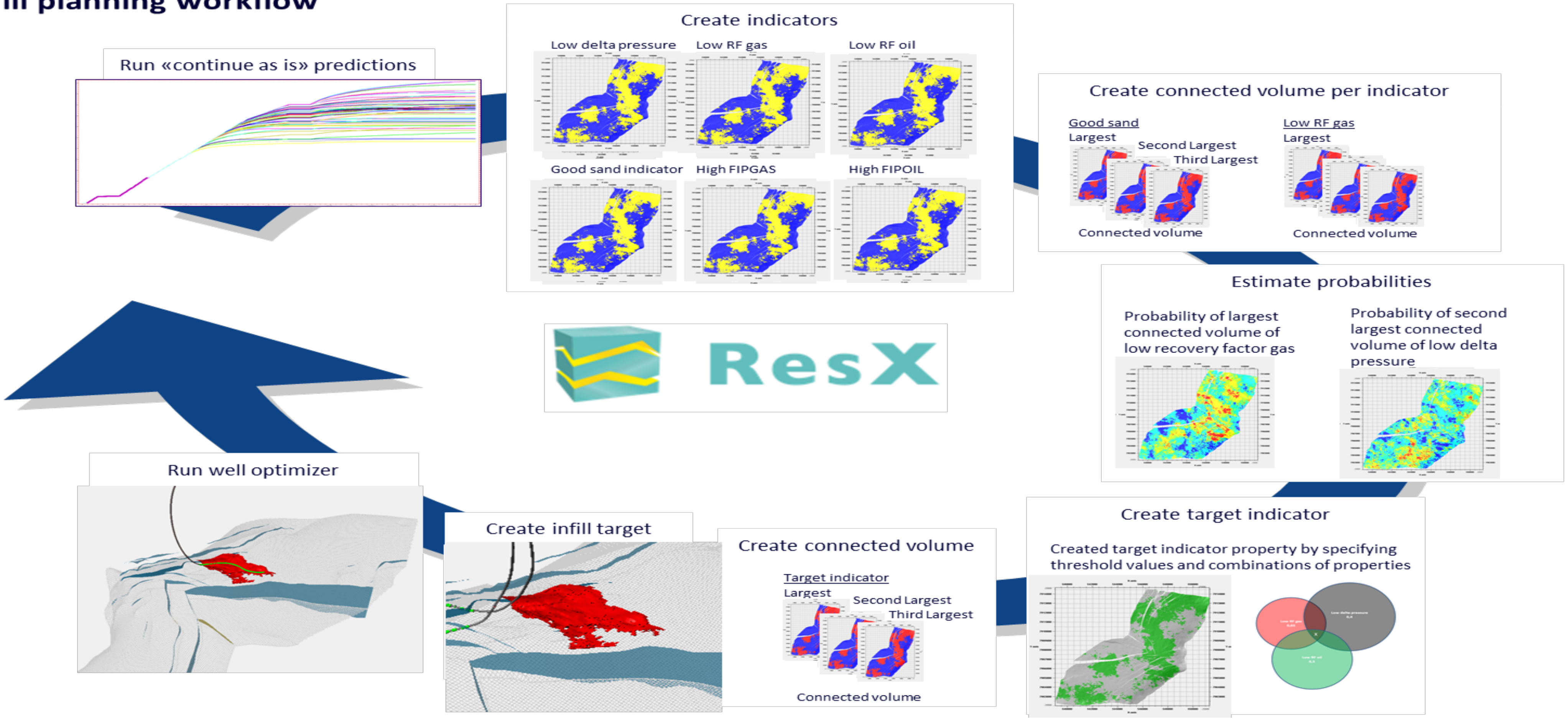
- *Evaluate the different development scenarios*



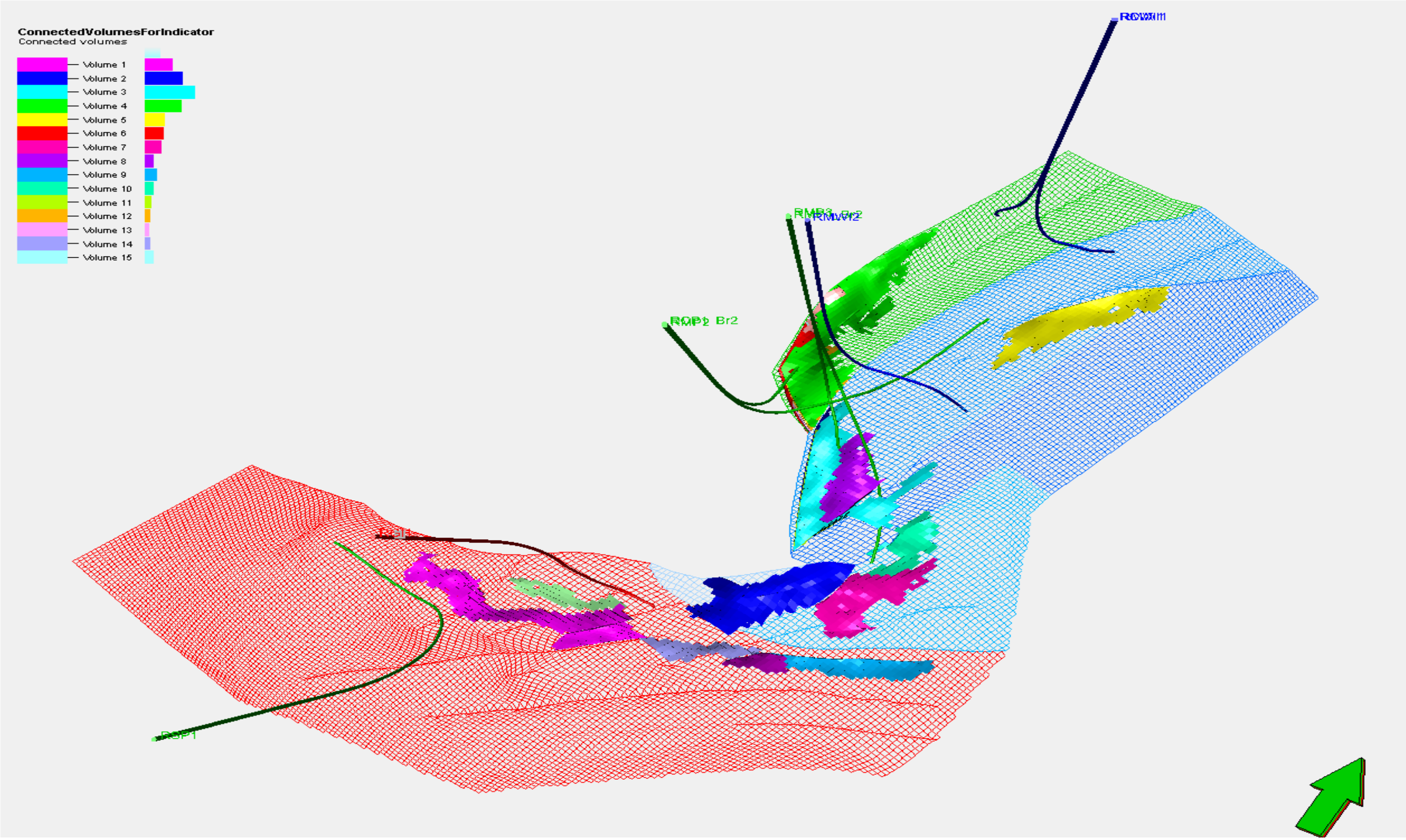
Infill planning workflow

History matching and robust infill drilling

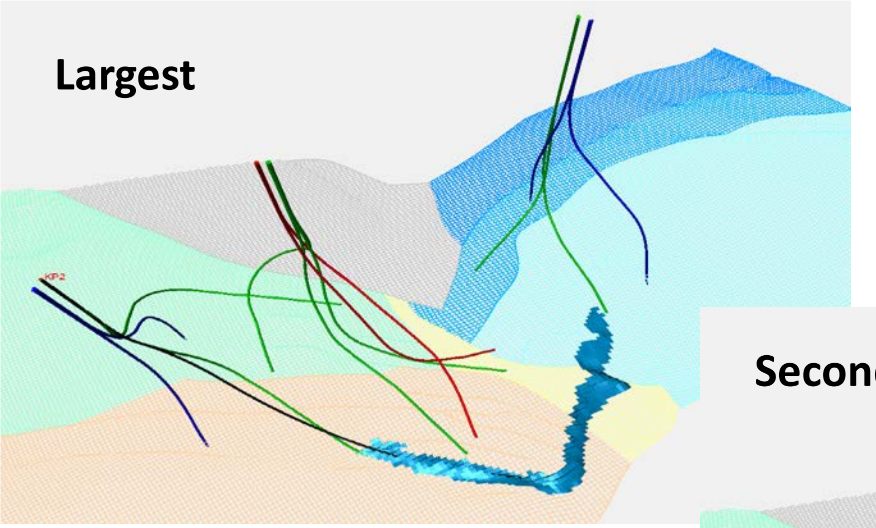
Robust infill planning workflow

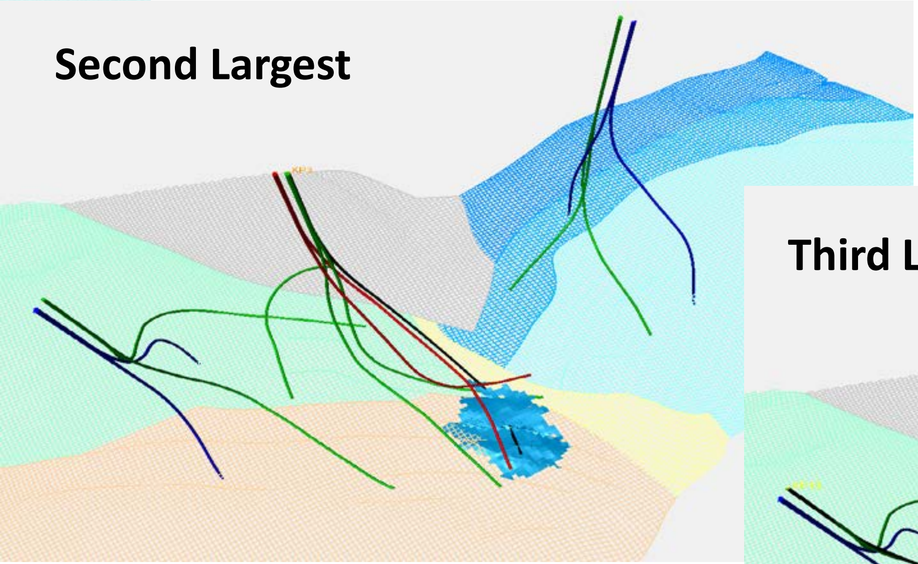


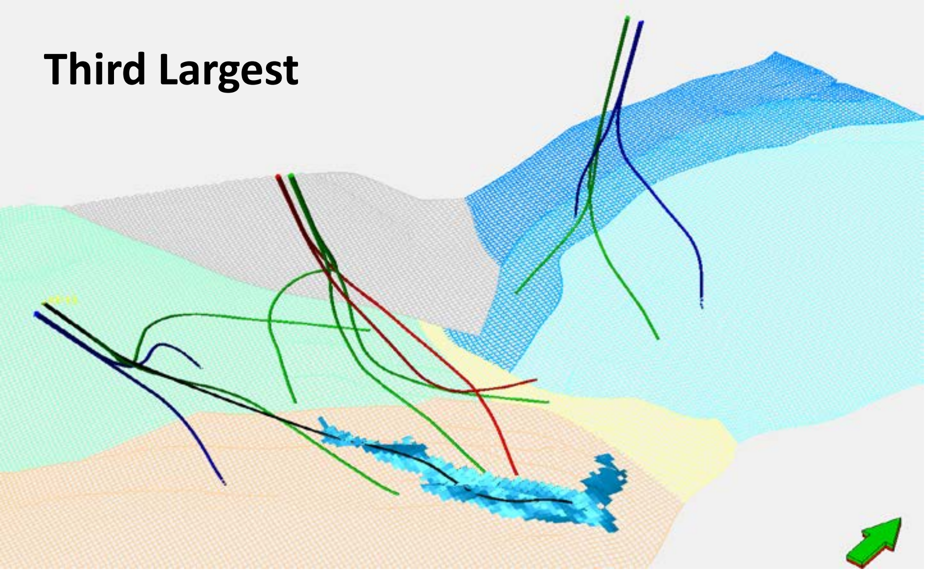
Connected volumes – Reservoir 1



Connected volumes - Reservoir 2







CONCLUSION

Conclusion and way forward

- *PROS*
  - *Close cooperation between the geologist and the engineer*
  - *Less constrained geological concept more adaptable to the observed dynamic data*
  - *The workflows are easily updated with the historical data*
  - *A better understanding of the residual uncertainty after history matching*
  - *Infill targets can be identified based on the prediction from the entire history matched ensemble*

- *CONS*
  - *The workflows create large models occupying a lot of disk space, and a lot of computing power is needed*
  - *Analysis of the data is time consuming*
  - *Software/computing infrastructure issues*

- *Way forward*
  - *Apply ResX for production optimisation*

THANK YOU!

Acknowledgements:

- *PL229 Licensees – Statoil Petroleum AS*
- *ResOptima*
- *Goliat Reservoir team, EniNorge*