



HISTORY MATCH WITH ENSEMBLE BASED METHODS : USE OF DISTANCE TO BOUNDARY PARAMETERIZATION TO ADDRESS UNCERTAINTY AND 4D SEISMIC OBSERVATION

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Total E&P UK - GRC

DISTANCE TO FACIES PARAMETERIZATION

- Facies are represented by discrete non-sortable values in the reservoir model.
- To be addressed by EnKF a re-parameterization scheme seems mandatory.
- Level set method to calculate the closest distance to the facies boundary was proposed by IRIS (SPE 143031 – 2011)

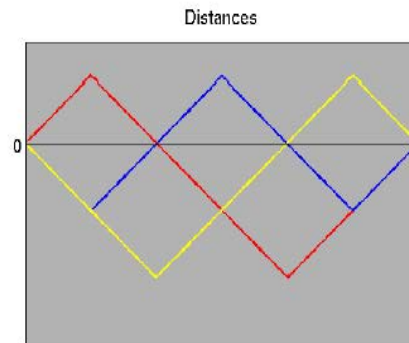
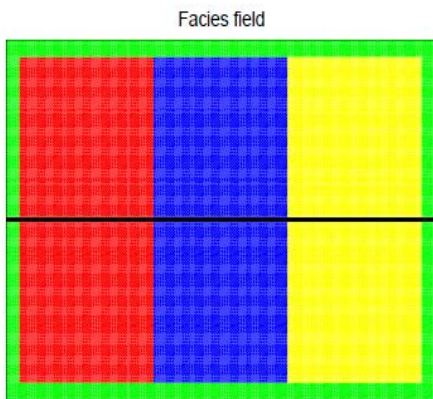
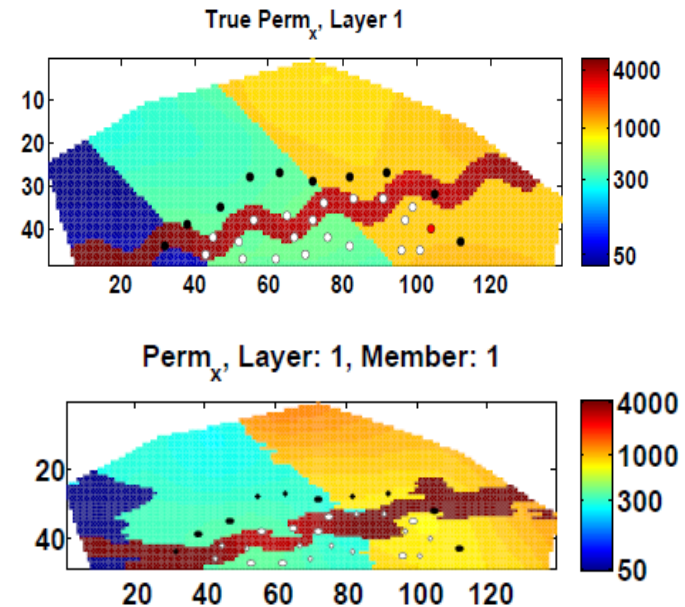
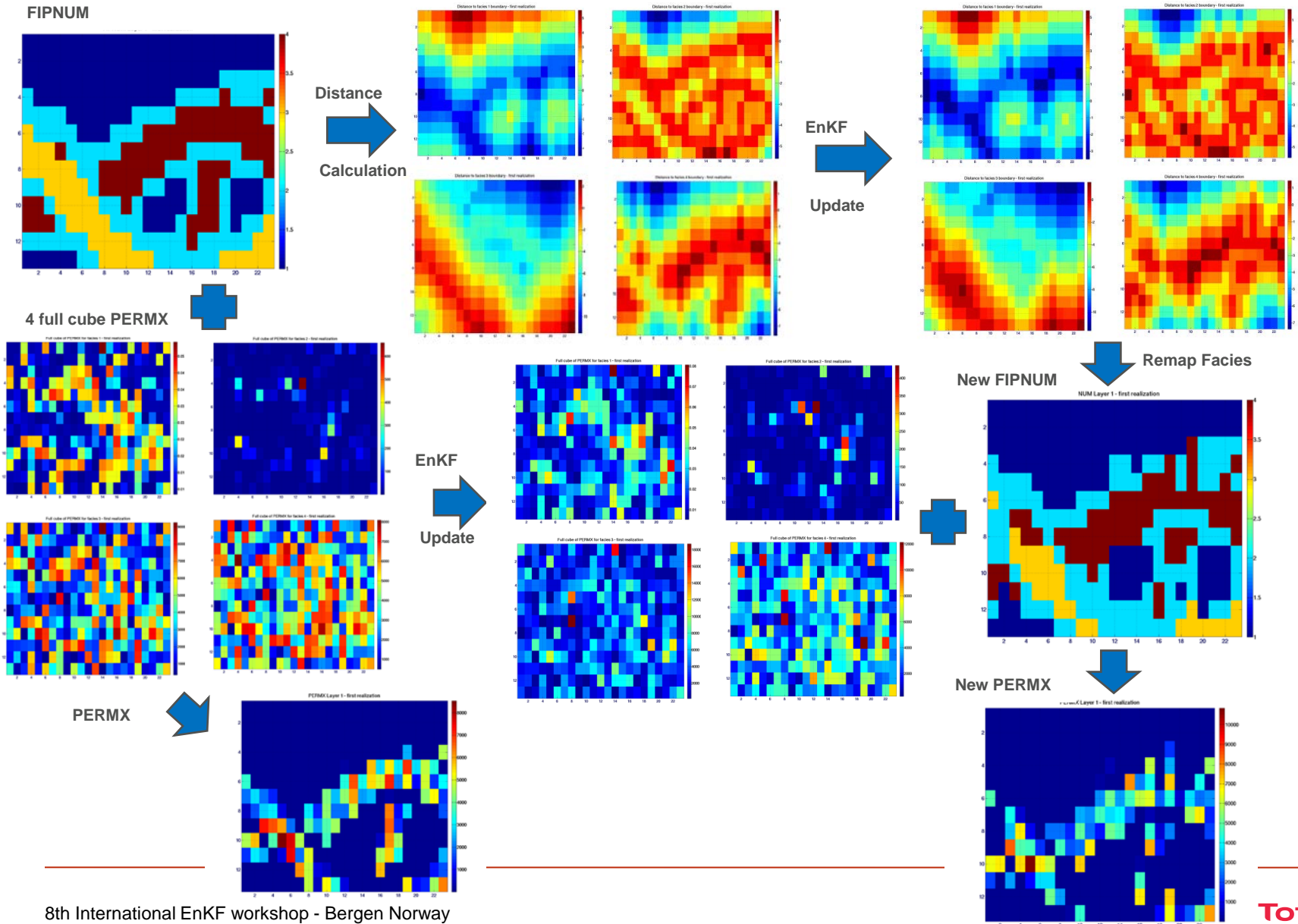


Figure 1: Example of distances (right) for a field with three facies types (left).



UPDATING FACIES BOUNDARIES – WORKFLOW



FIRST TEST CASE

Model dimensions: (13,23,20) , all cells are active

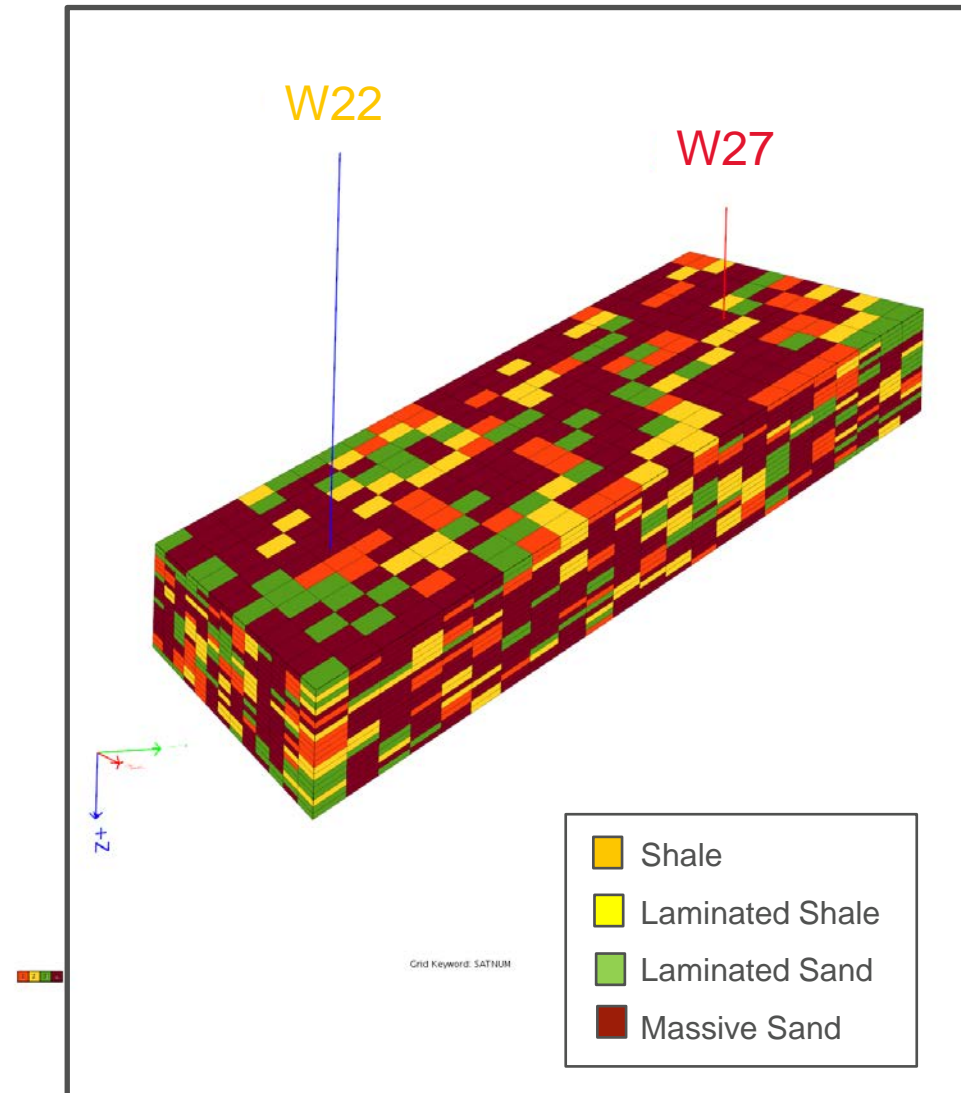
Two wells: W22: Water injector and W27 Producer

4 facies type : shale, laminated shale, laminated sand and massive sand

Uncertain parameters : PERMX/PERMY, PORO, NTG, PERMZ(using Kv/KH ratio), FIPNUM(facies distribution)

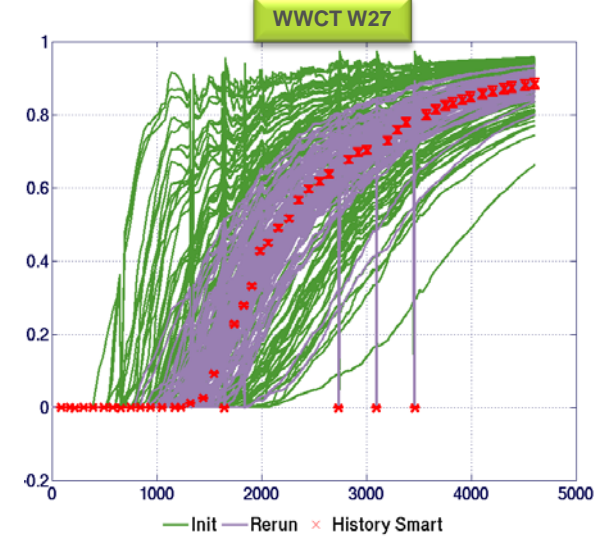
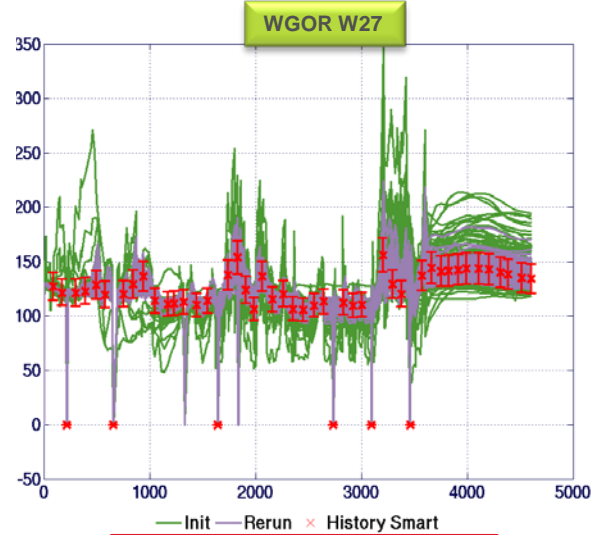
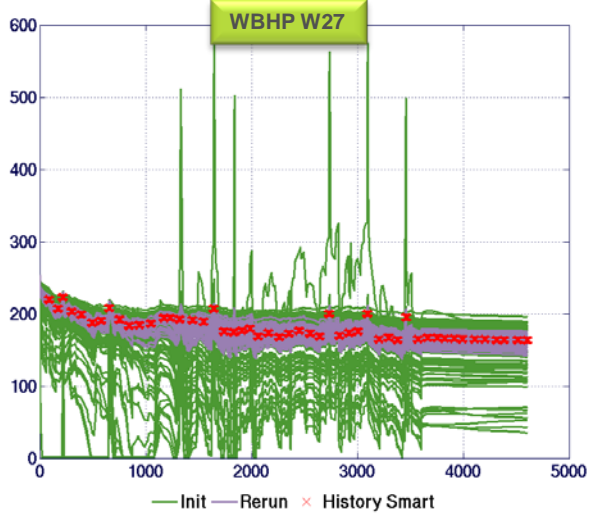
Initial Ensemble:

- 100 realizations of facies maps and properties (4 times for the full cube)
- Updated petro-physical values would be assigned to the model taking the updated Facies map into account.

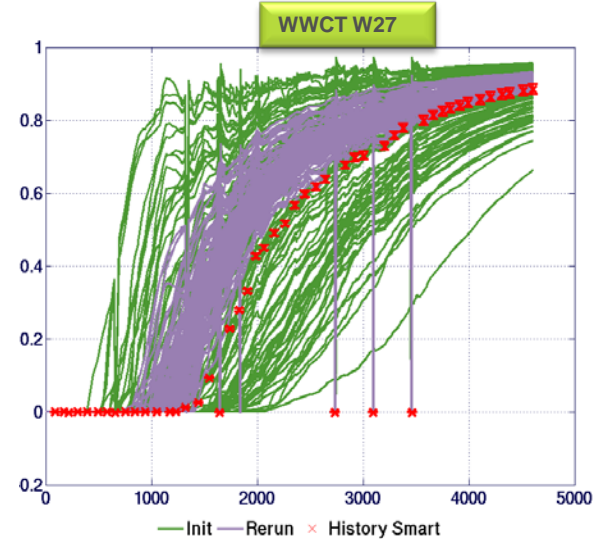
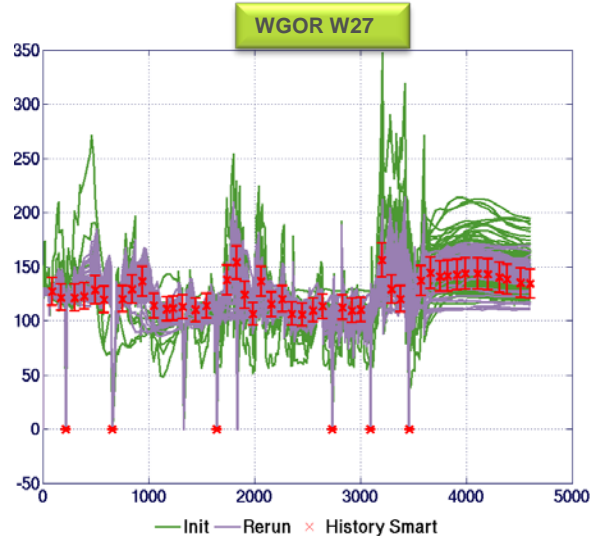
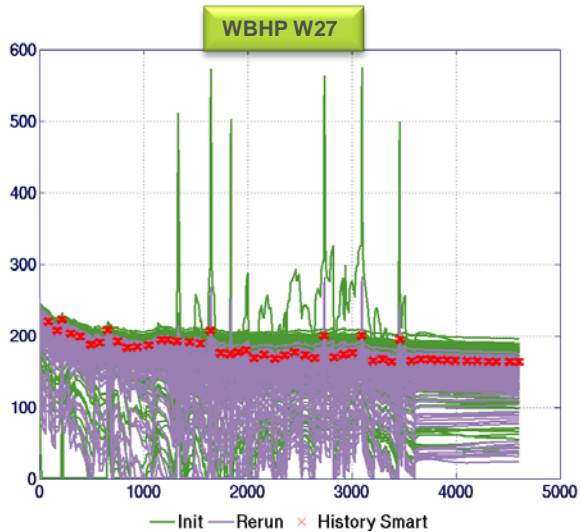


HISTORY MATCH RESULTS

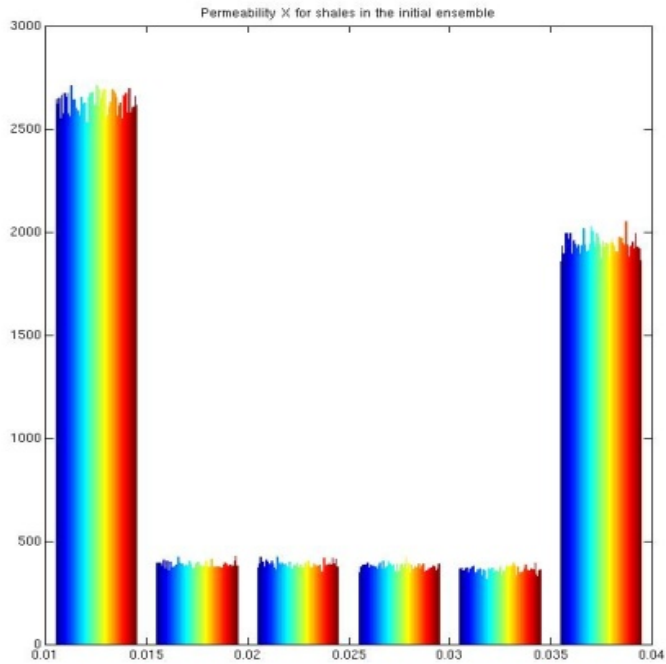
Updating FIPNUM



No FIPNUM Update

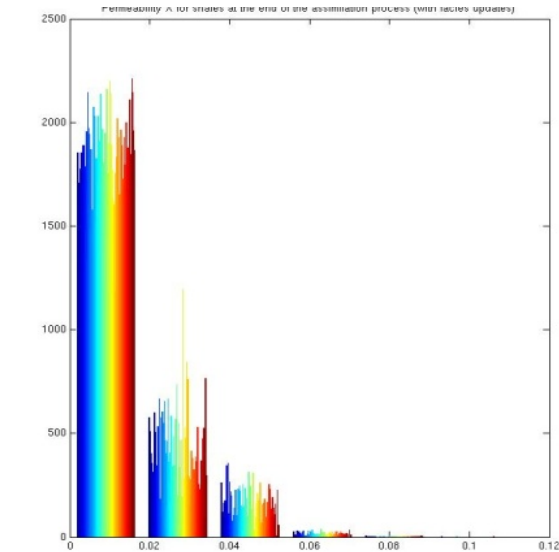
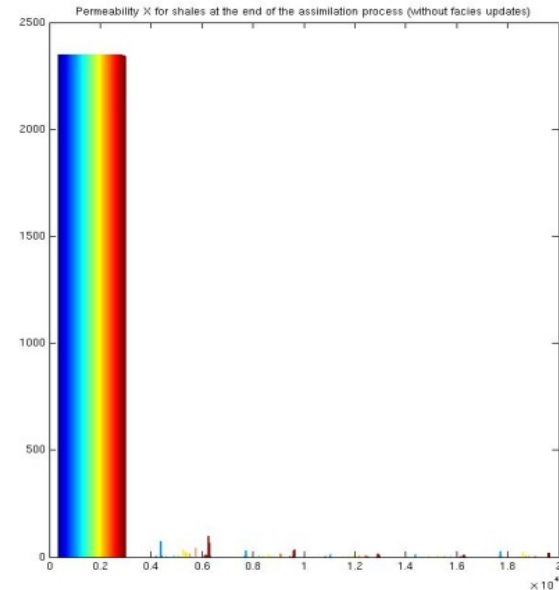


CHANGE IN PARAMETERS

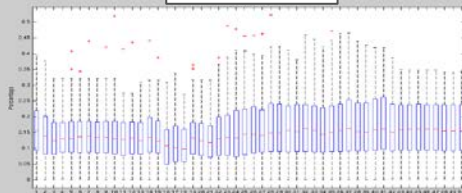


Just updating Properties

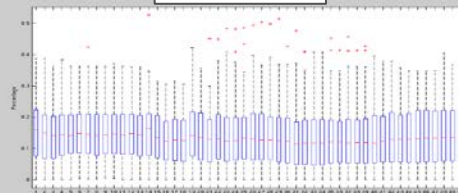
Updating FIPNUM and Properties



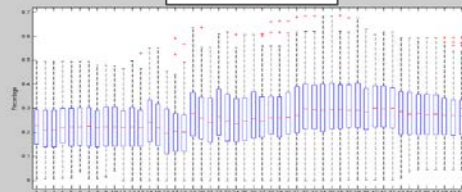
Facies 1



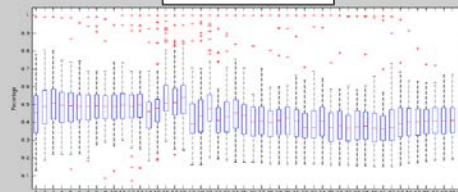
Facies 2



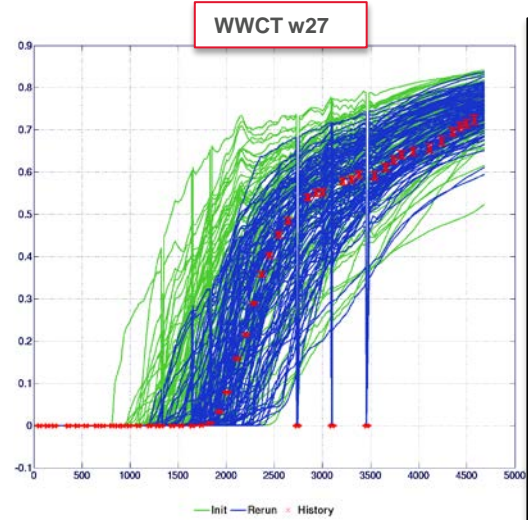
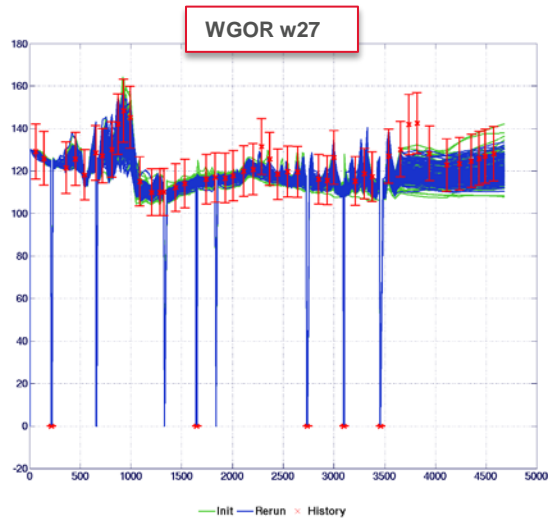
Facies 3



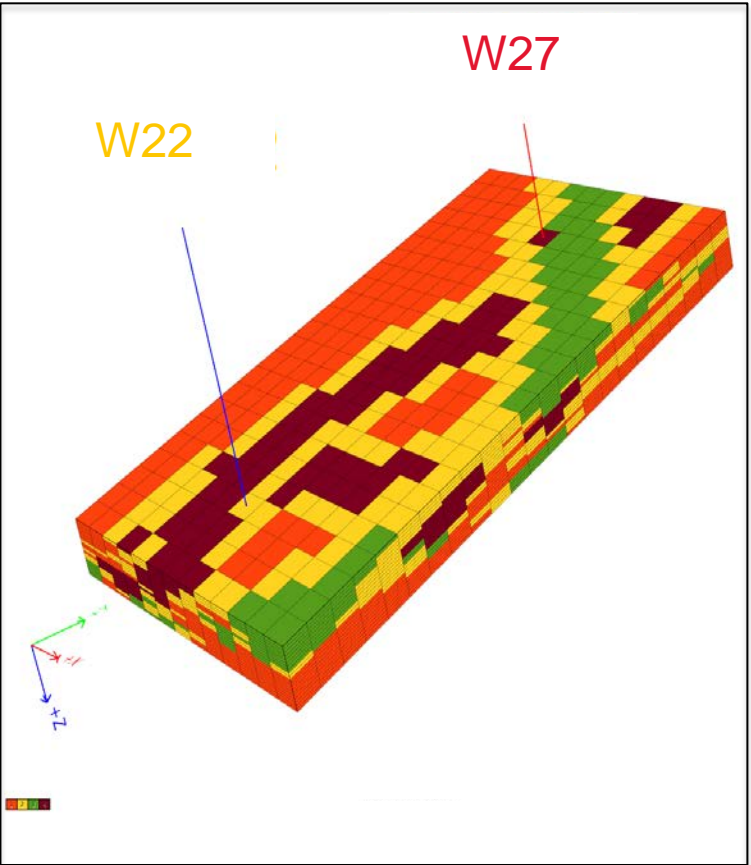
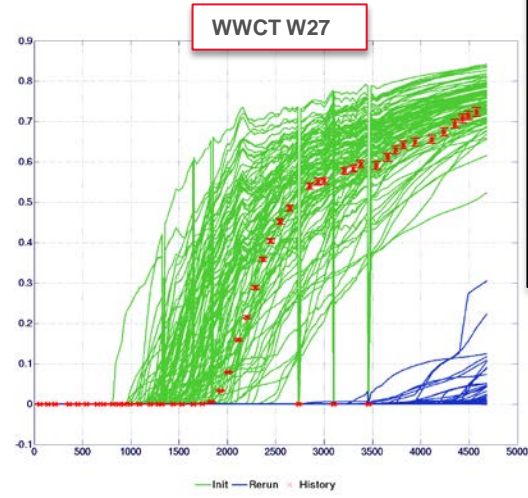
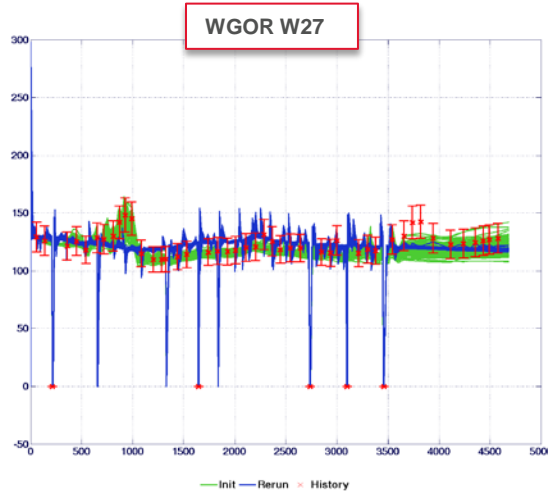
Facies 4



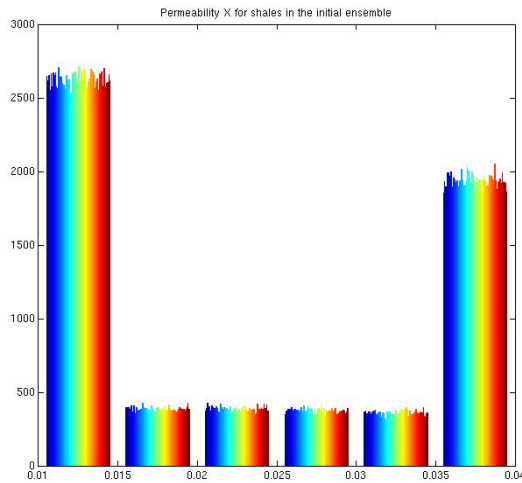
TEST ON CHANNELIZED MODEL



No FIPNUM Update

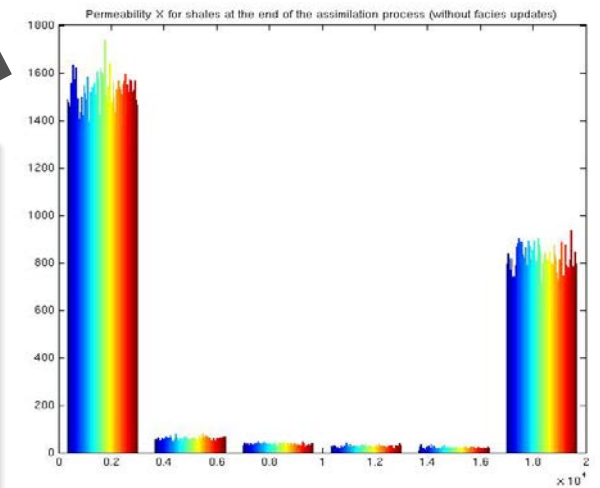
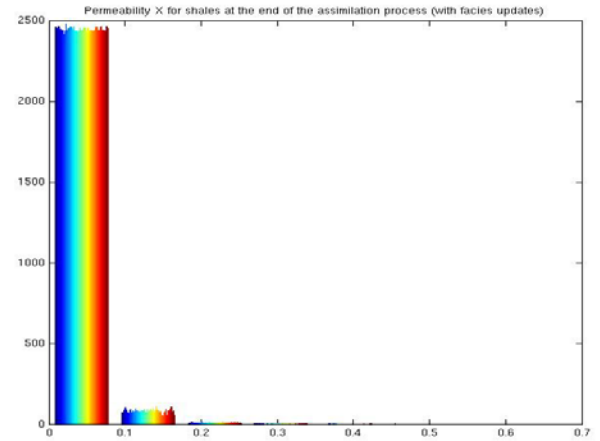


UPDATED PARAMETERS



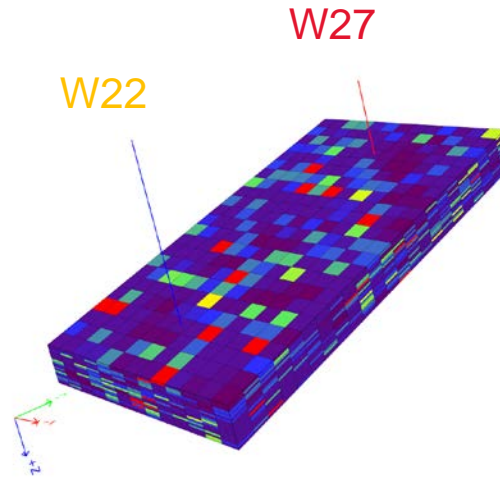
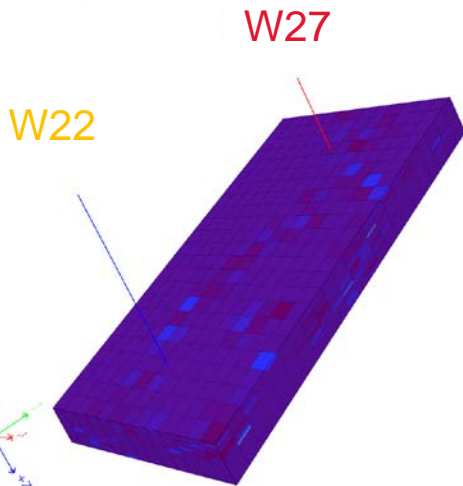
Updating FIPNUM
and Properties

Just updating
Properties



Updating Properties & FIPNUM

Just updating properties







Change in PERMX (mD) – Initial Vs Rerun

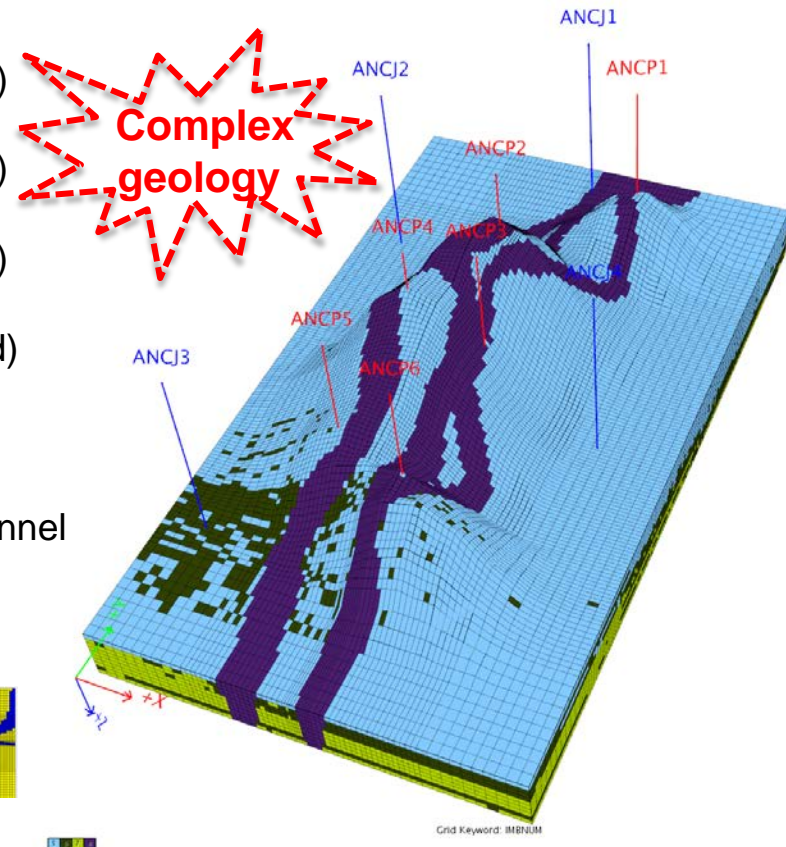
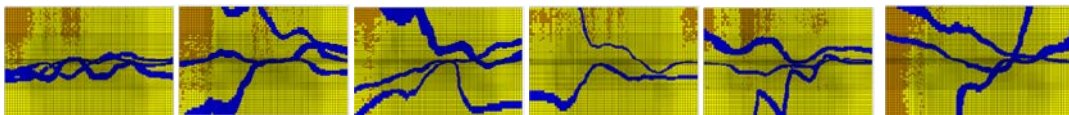


ANTICLINE – COMPLEX GEOLOGY

- Model dimensions: $X = 70$, $Y = 140$ and $Z = 10$
- 6 producer and 4 water injector (2 Producer and 1 injector penetrated in the channel)
- 4 facies type including the channel in the middle

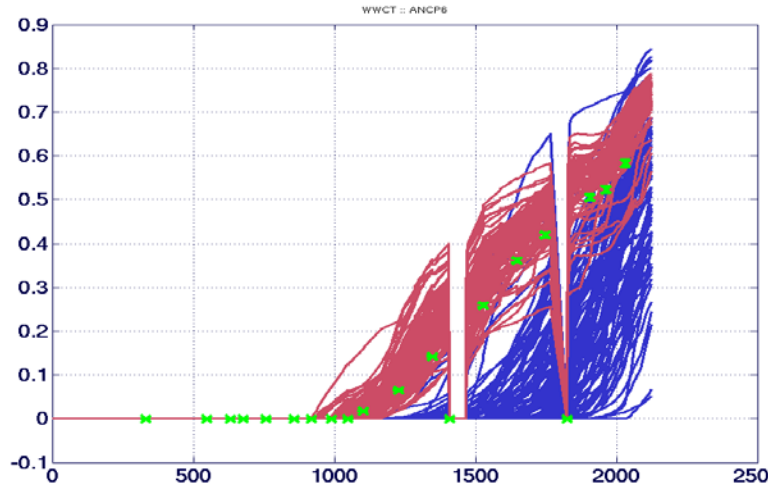
	K = 300 MD, NTG = 60% Poro = 15% (X correlated)
	K = 800 MD, NTG = 80% Poro = 17% (X correlated)
	K = 50 MD, NTG = 40% Poro = 10% (X correlated)
	K = 2000 MD, NTG = 80% Poro = 15% (X correlated)

- 2 x 4D survey, before and after water breakthrough
- Uncertainty in direction, widths, tortuosity and density of channel
- **Exercise objective: EnKF to find where the channel is**

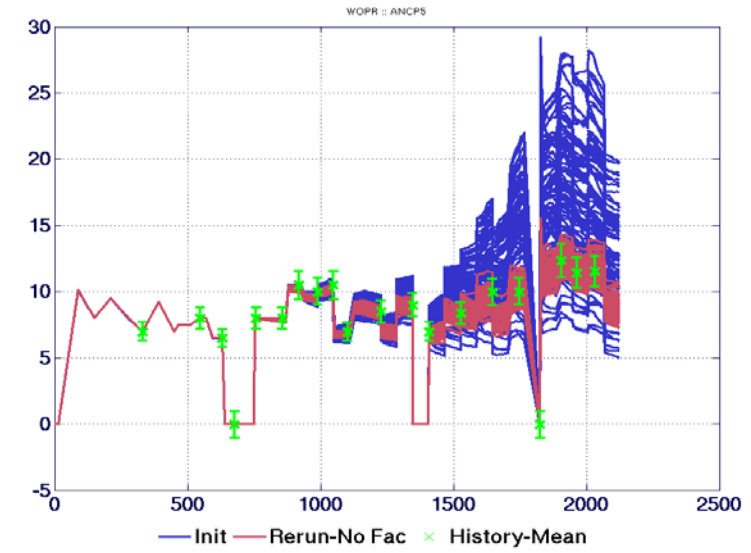
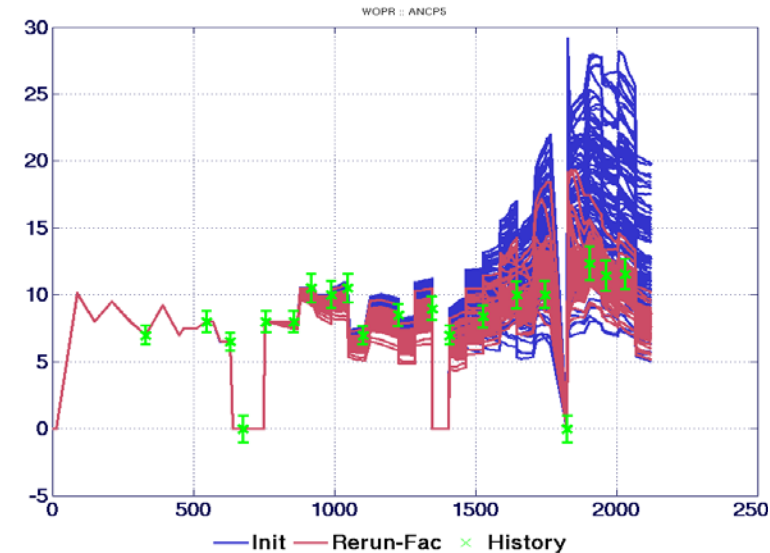
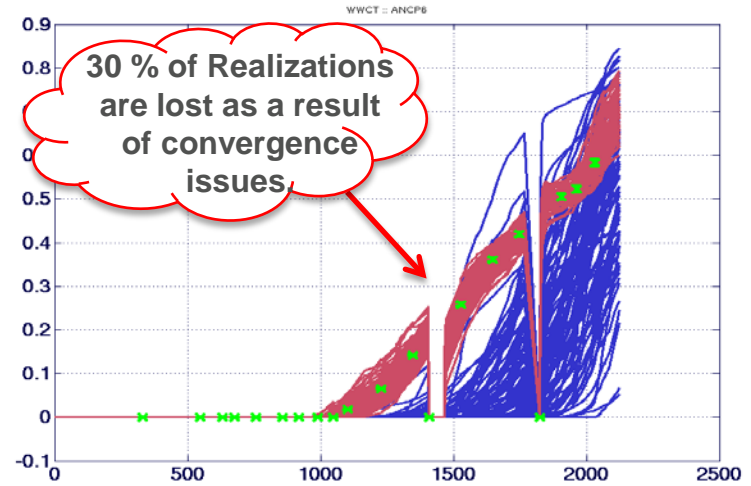


HISTORY MATCH RESULTS

With FIPNUM Update

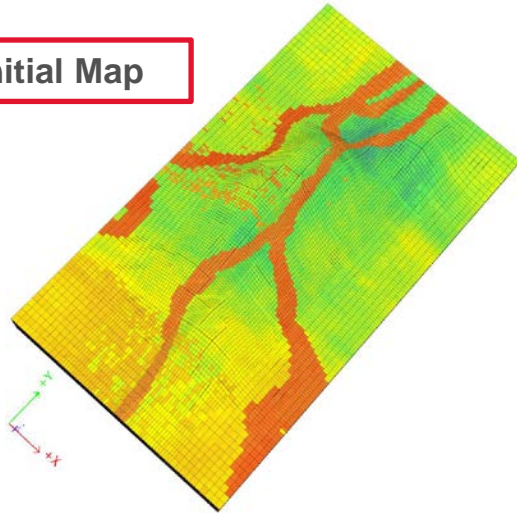


No FIPNUM Update

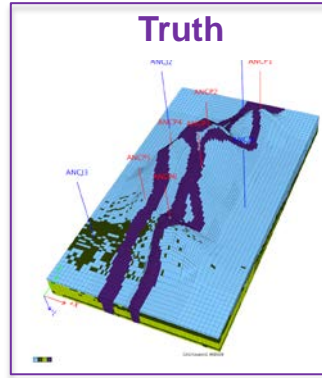


CHANGE IN THE PARAMETERS - PERMX

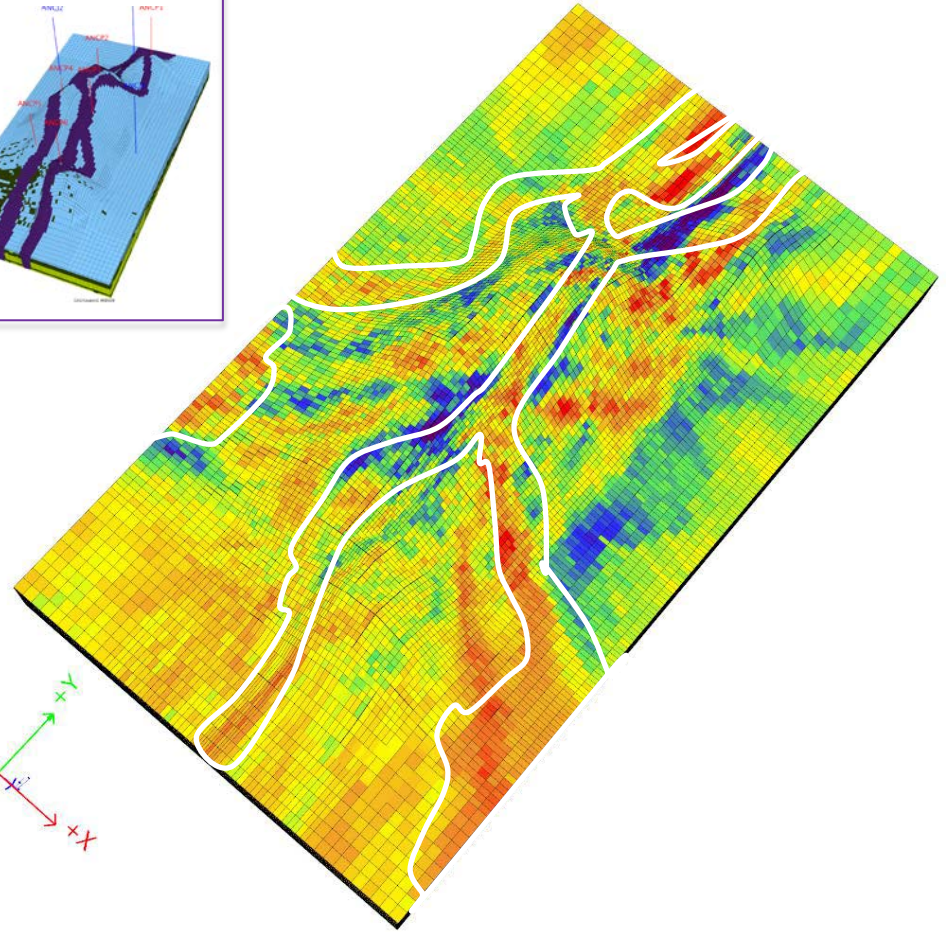
Initial Map



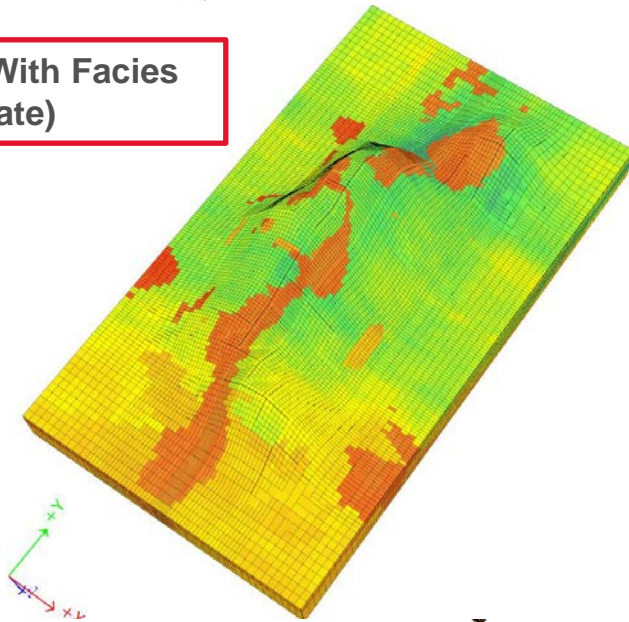
Truth



Final Map (No Facies Update)



Final Map (With Facies Update)



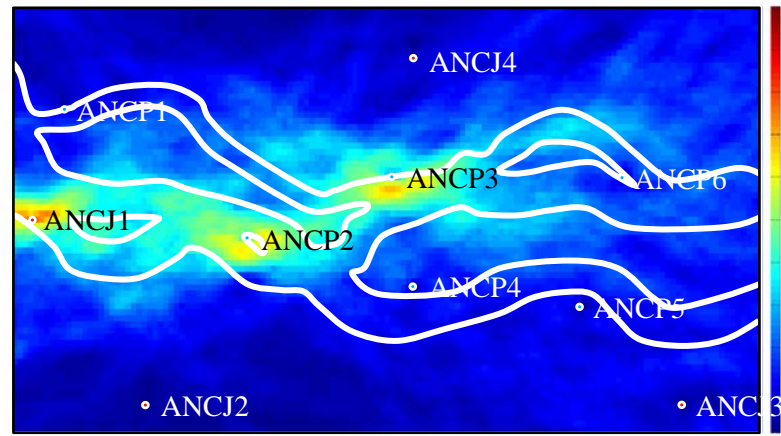
Grid Keyword: PERMX

0.010 0.1 1 10 100 1000 20000.0



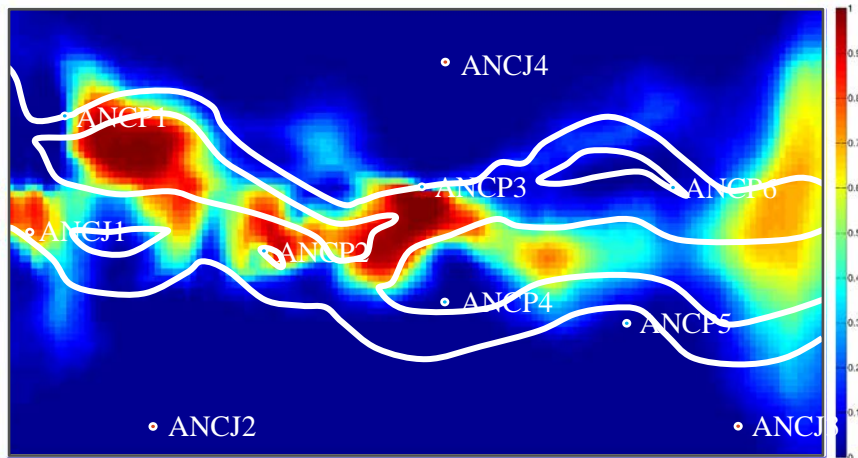
FACIES PROPORTION BEFORE AND AFTER ENKF

Prior Models

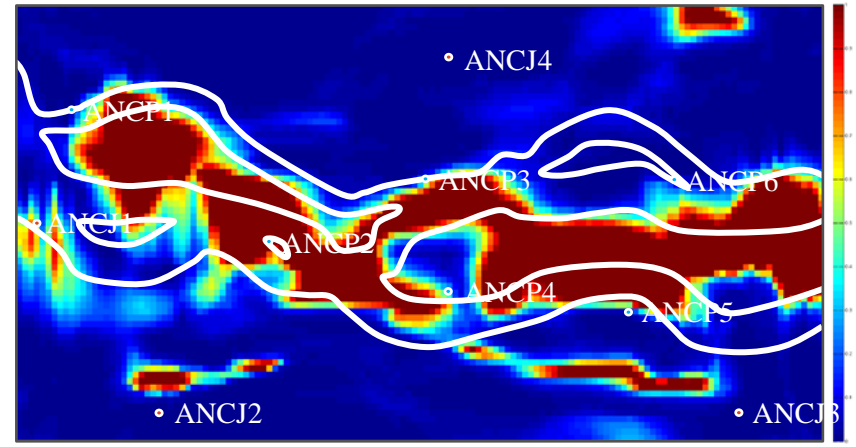


White outline = True location of channels

Posterior Models Distance to interface



Posterior Models Variogram normalized distance to facies

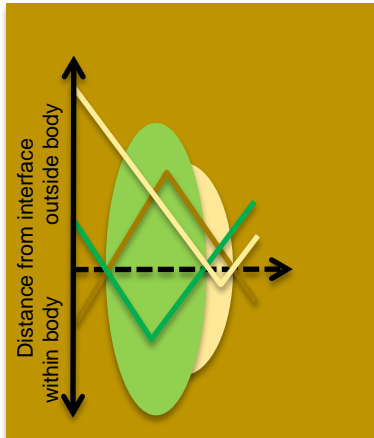


VARIOGRAM INFORMATION INTO DISTANCE CALCULATION

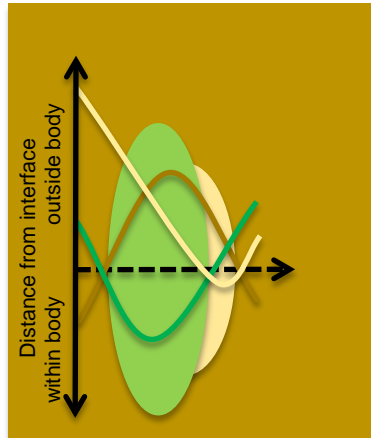
Using Variogram anisotropy and curvature to modify the distance calculation.

- Anisotropy to stretch the distance in the 3D space.
- Curvature is to normalize the distance and emphasis on the correlation length.

Original Idea



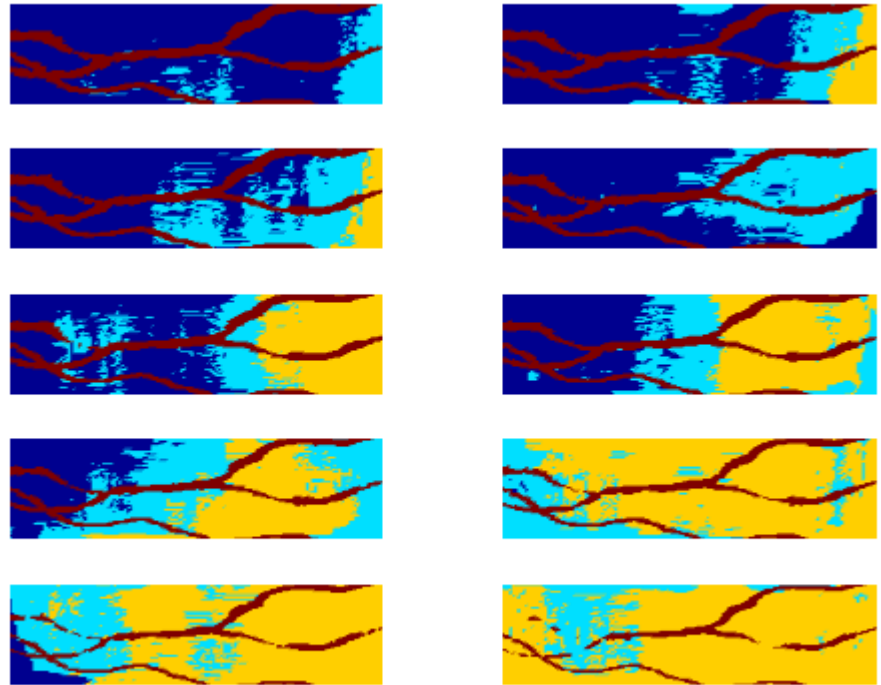
Today



Warning:

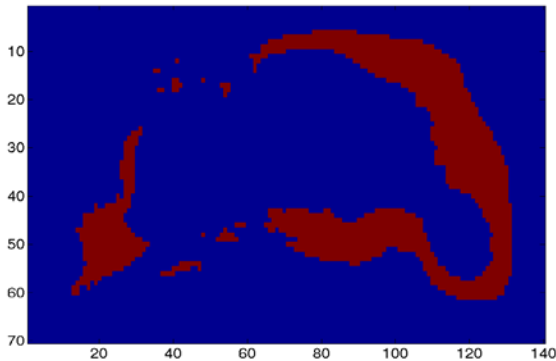
current implementation still statistically biased (toward equi-proportion), being corrected.

Facies map modification during assimilation steps

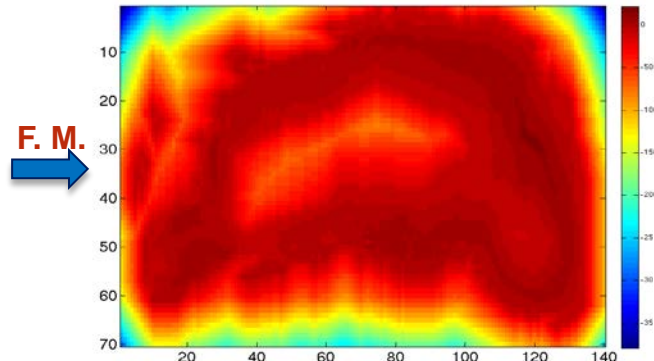


ASSIMILATION ON 4D SEISMIC OBSERVATIONS – WORKFLOW

Observed Front

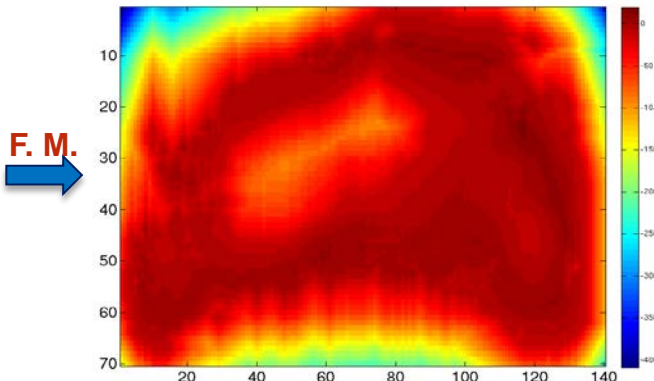
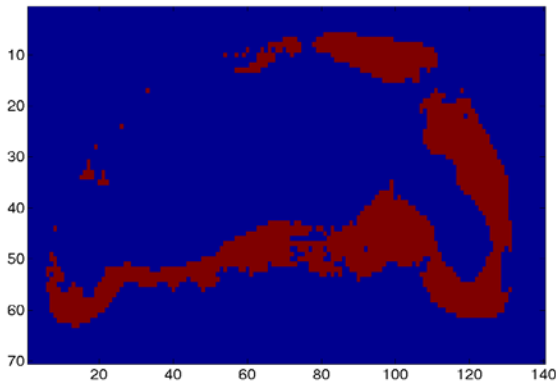


Distance to Front



F. M.

Simulated Front

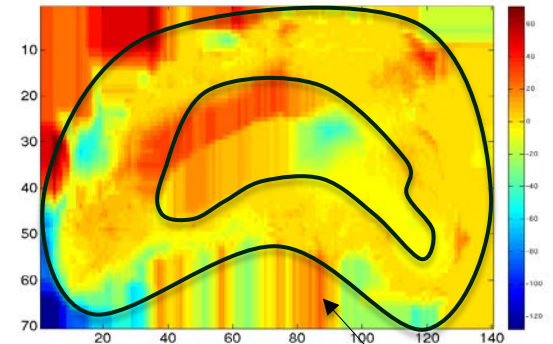


F. M.

Difference

Remark:
projection onto 1D space akin
to streamline parameterisation

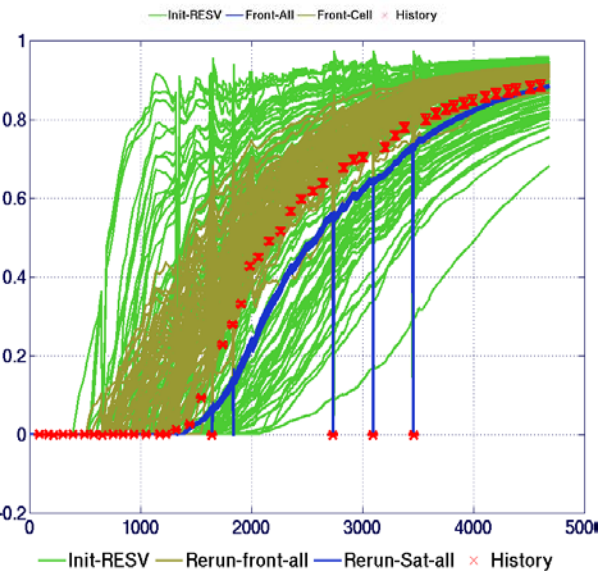
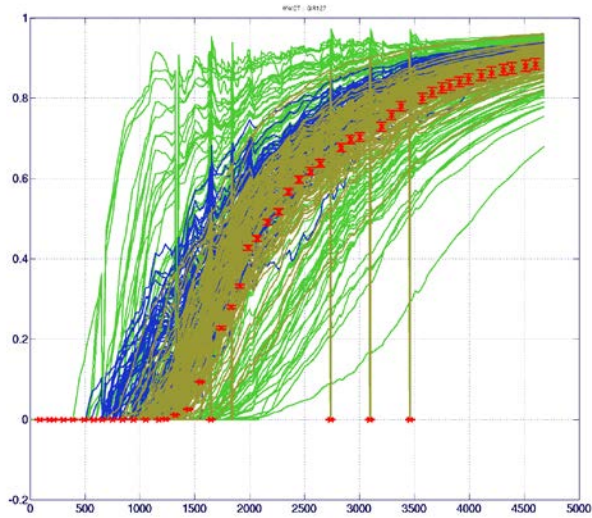
Hausdorff Distance to Front



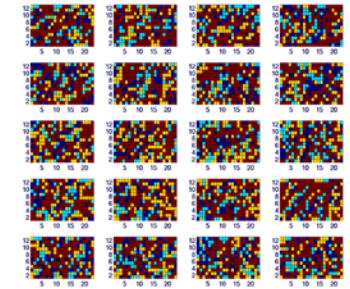
Minor error
introduced due to
low FMM order

Mismatch term to be used in
EnKF update equation

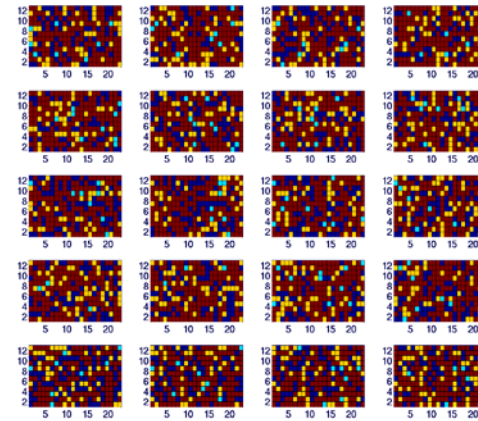
MATCH RESULTS – BENEFITS OF NEW APPROACH



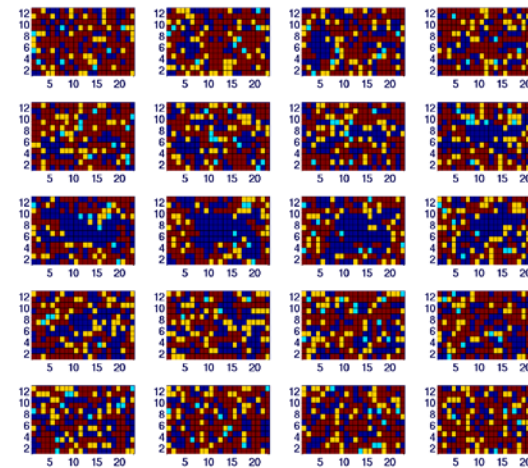
Reference map



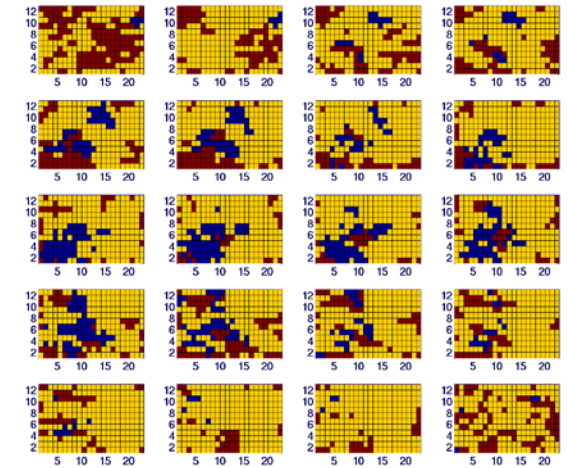
Initial map



Final map – Front Position



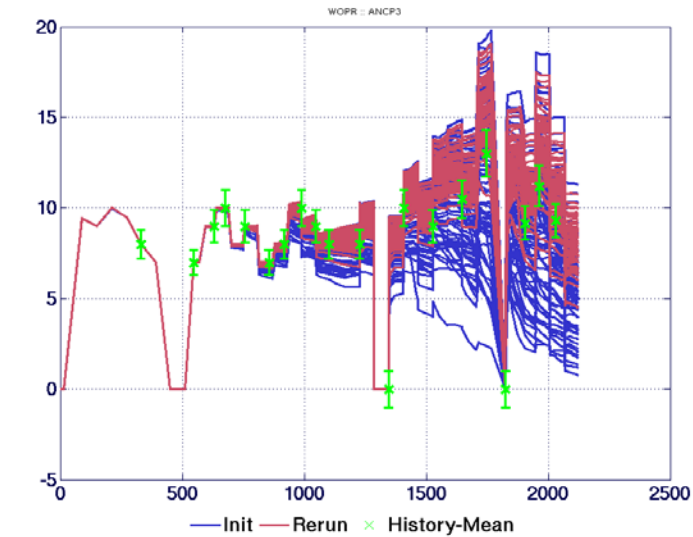
Final map – Cell Saturation



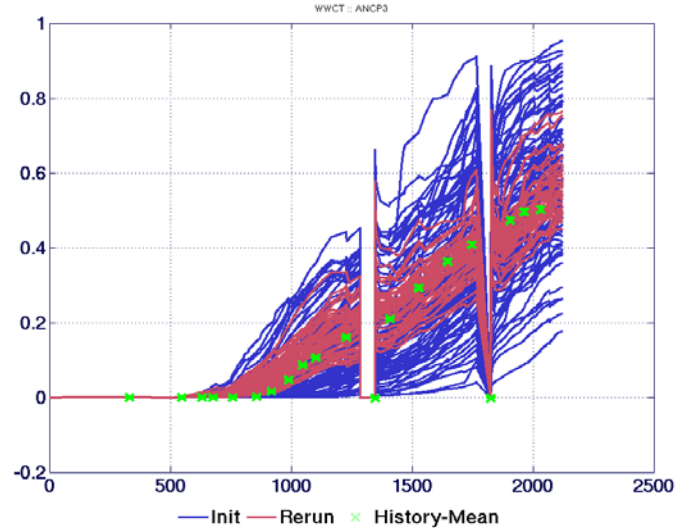
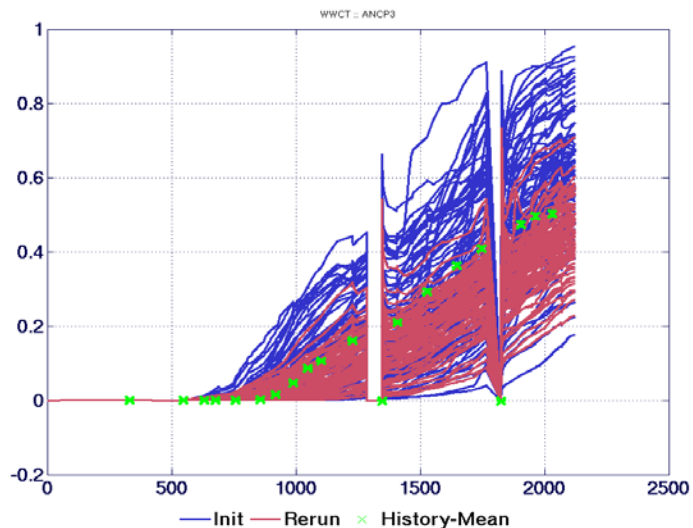
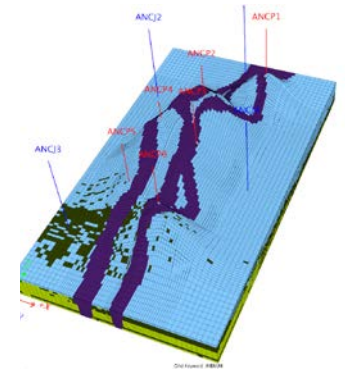
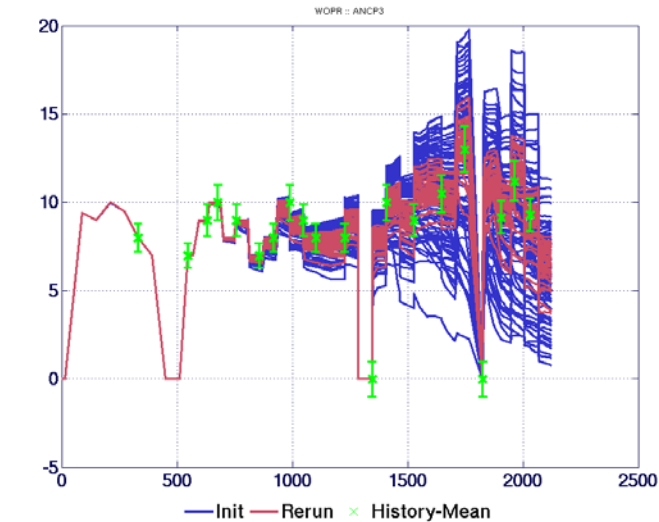
As for facies benefits are to be found more in respecting geology than obtaining match

MATCH RESULTS – BENEFITS FROM 4D ASSIMILATION

No 4D Assimilation

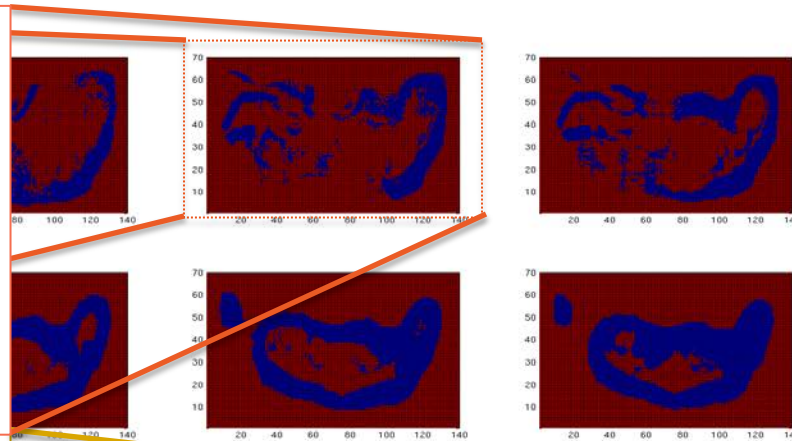
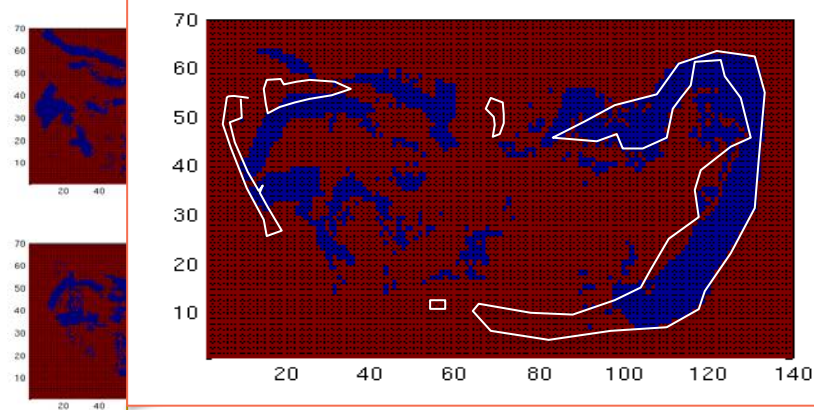


With 4D Assimilation

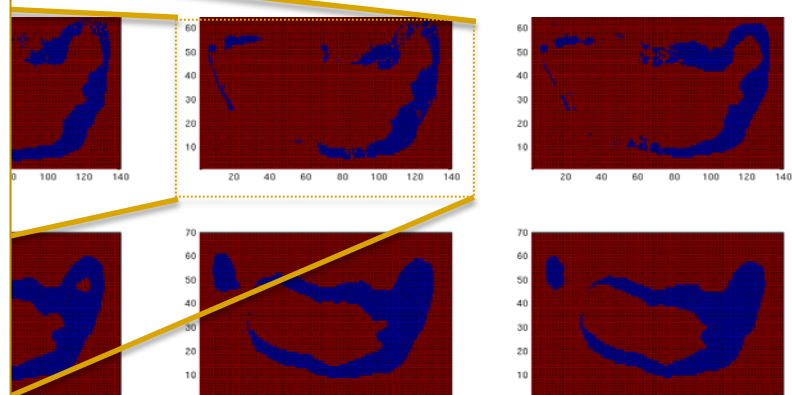
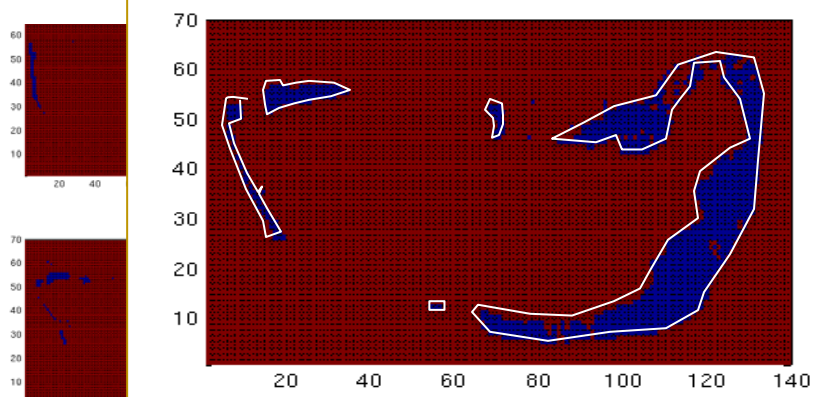


MATCHING 4D-DERIVED FRONT – 1 REALIZATION – NO VARIO. NORM.

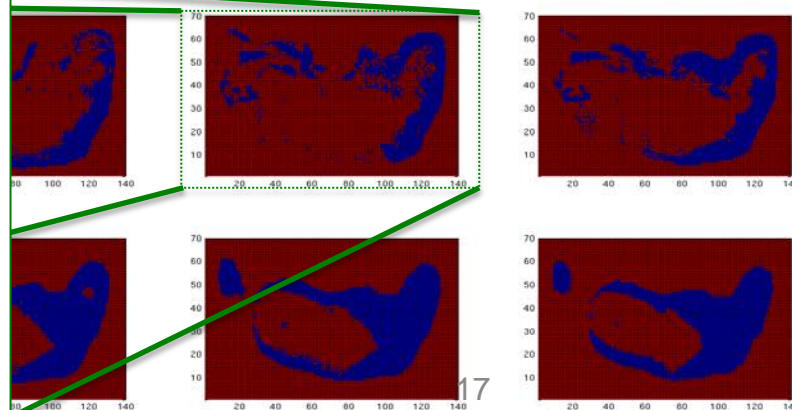
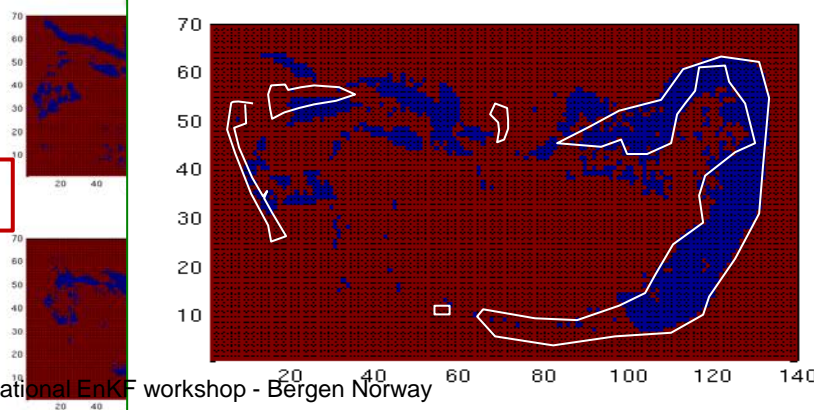
No 4D



Truth



With 4D

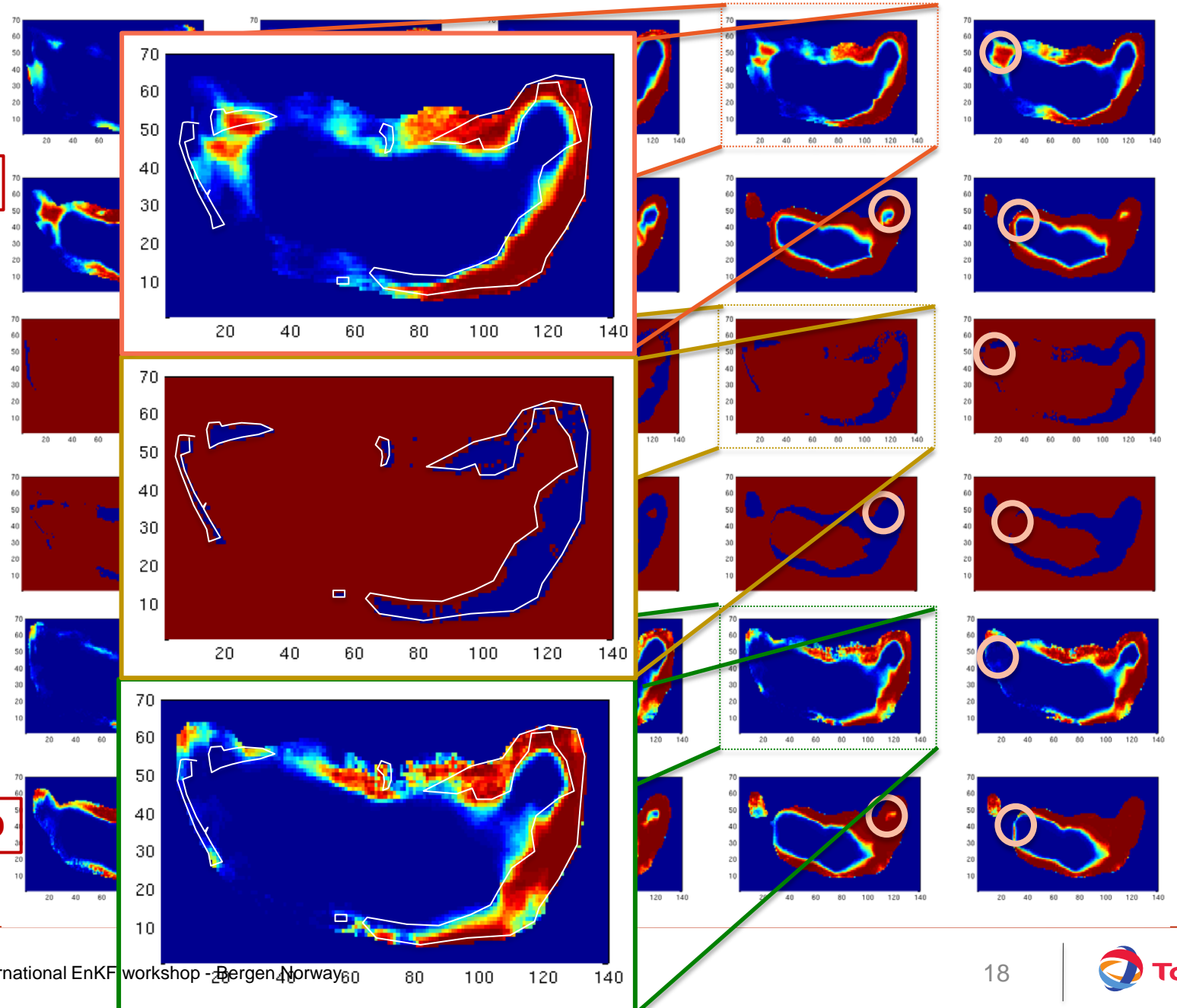


MATCHING 4D-DERIVED FRONT – ALL REALIZATIONS

No 4D

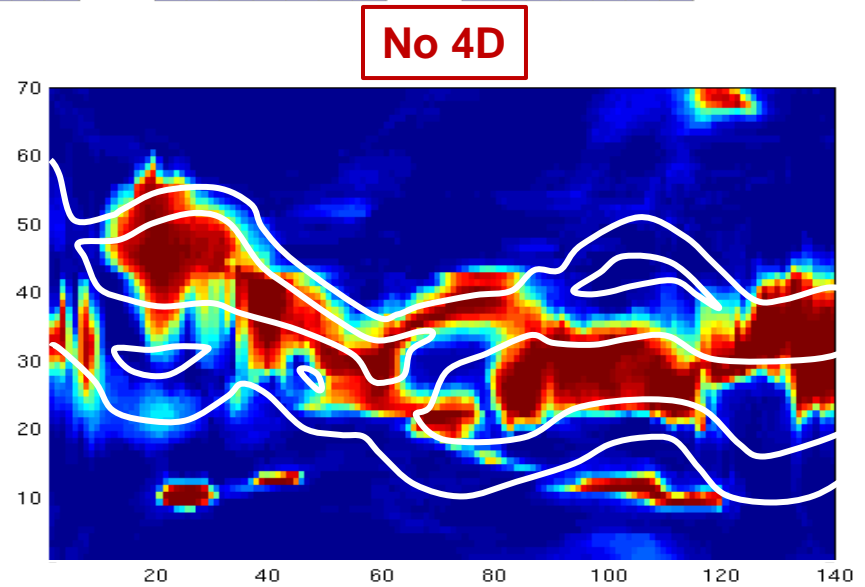
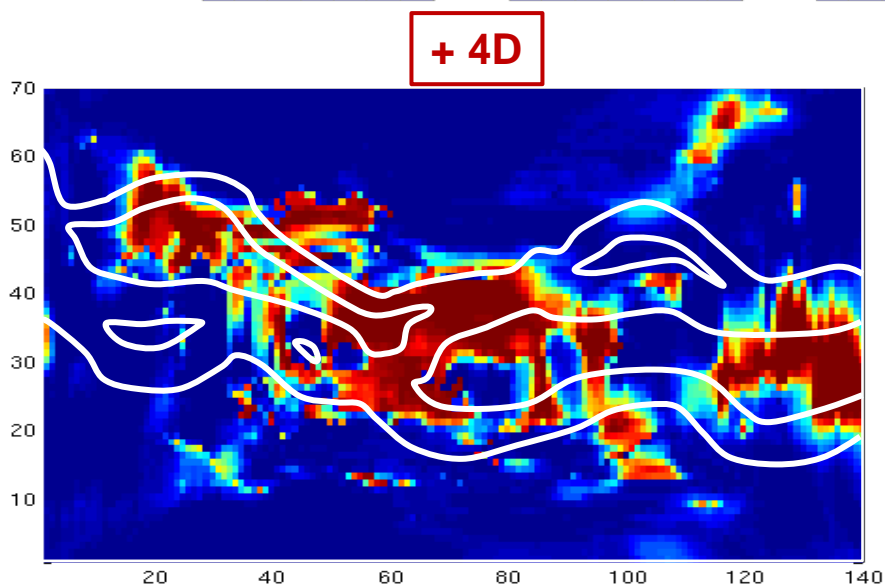
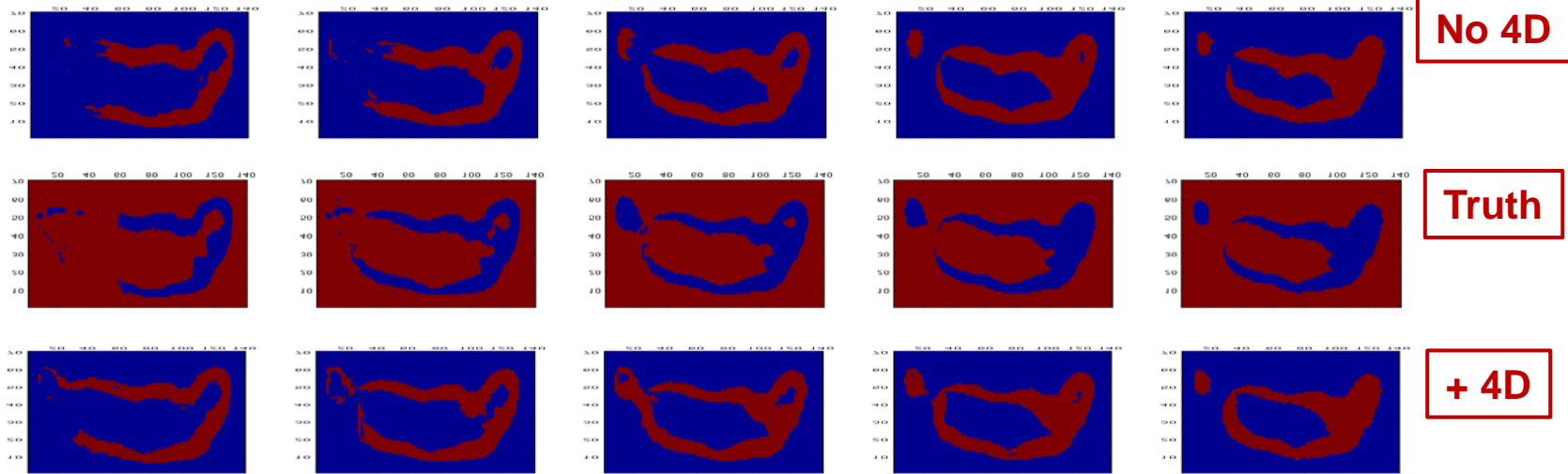
Truth

With 4D



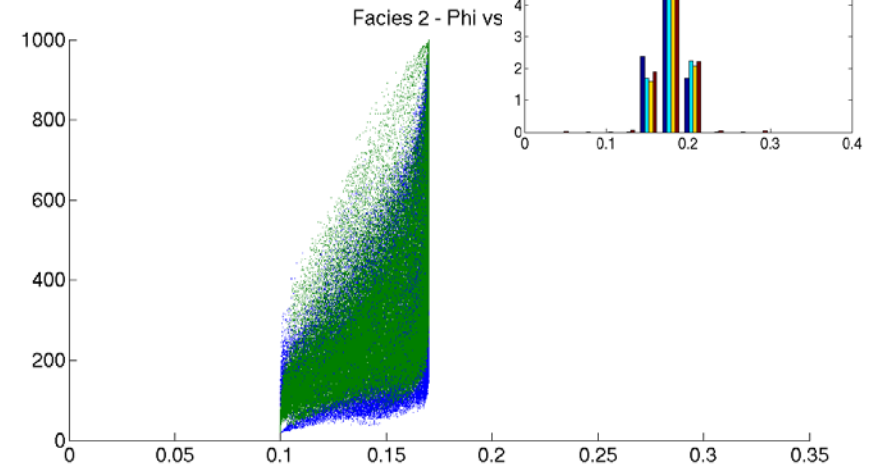
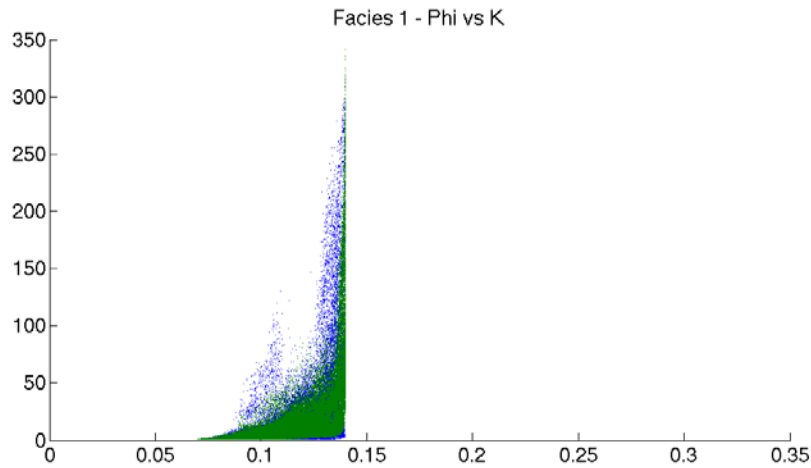
VARIOGRAM NORMALISATION: NOT MUCH DIFFERENT

Vario normalization of facies without 4D input, improves 4D forecast a lot. Improvement by adding vario normalized 4D is marginal / non existent.

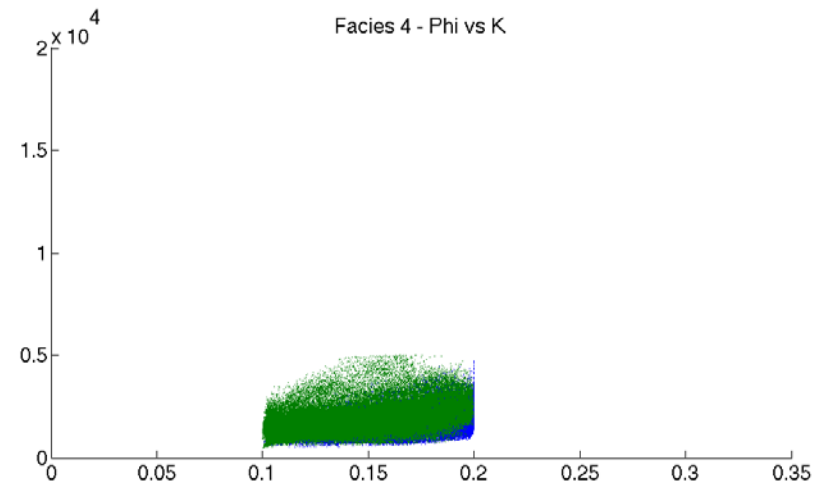
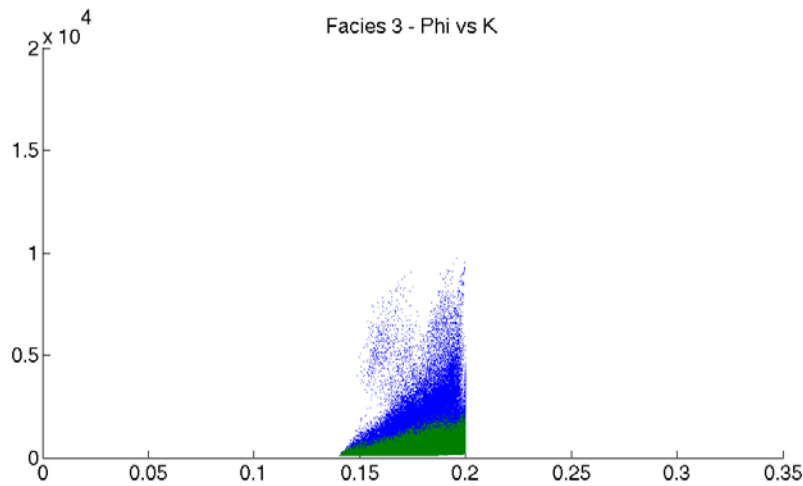


Some failed simulations – Lower statistical validity

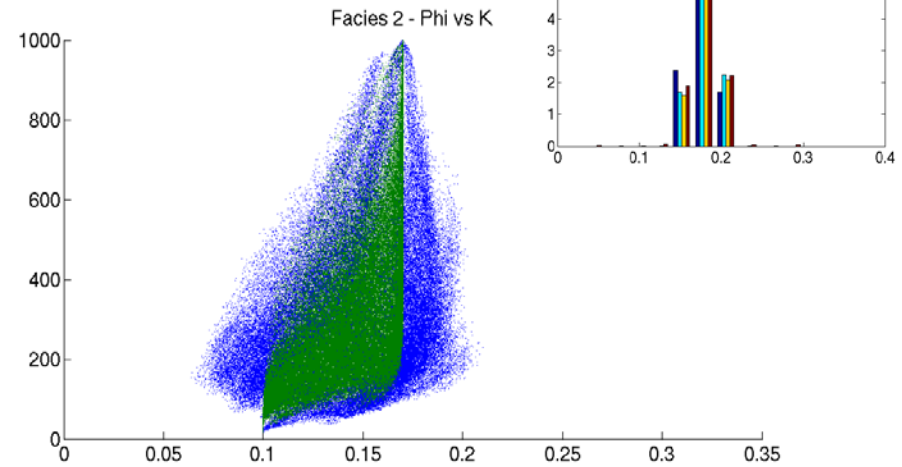
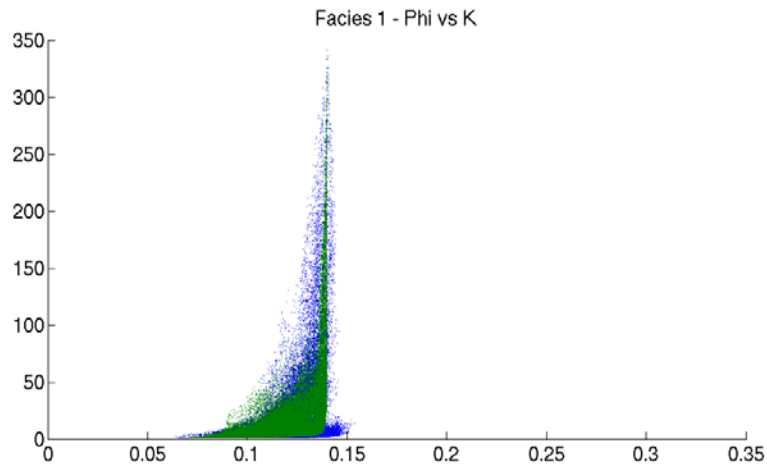
GEOLOGICAL REALISM



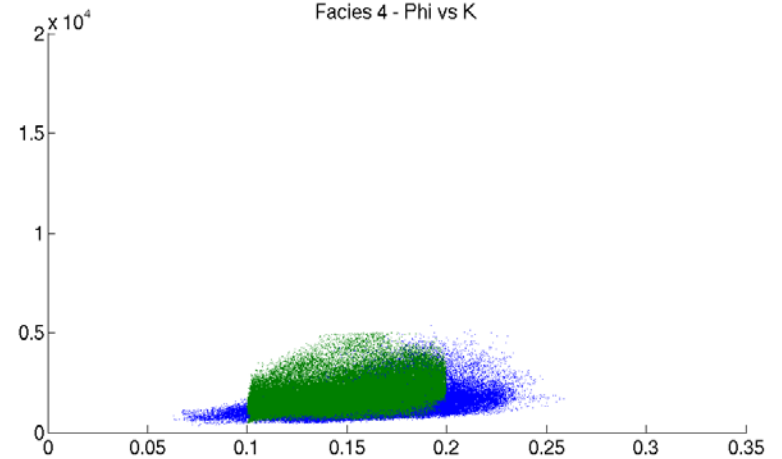
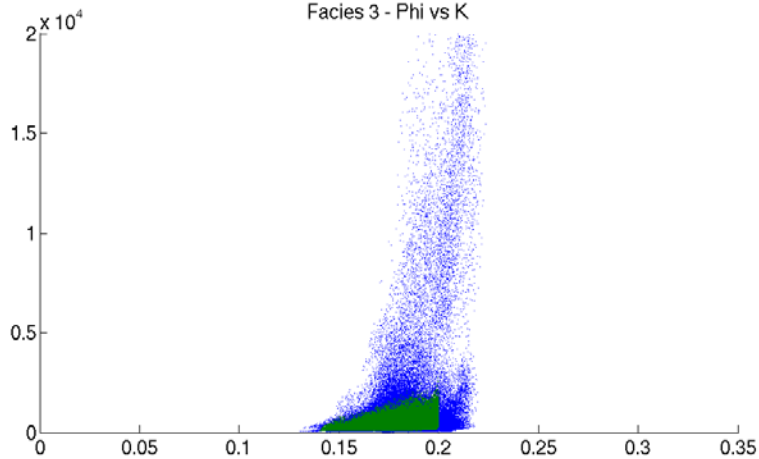
INITIAL(BLUE) vs. TRUTH (GREEN)



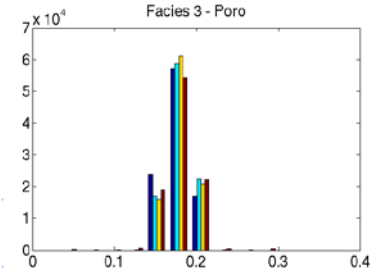
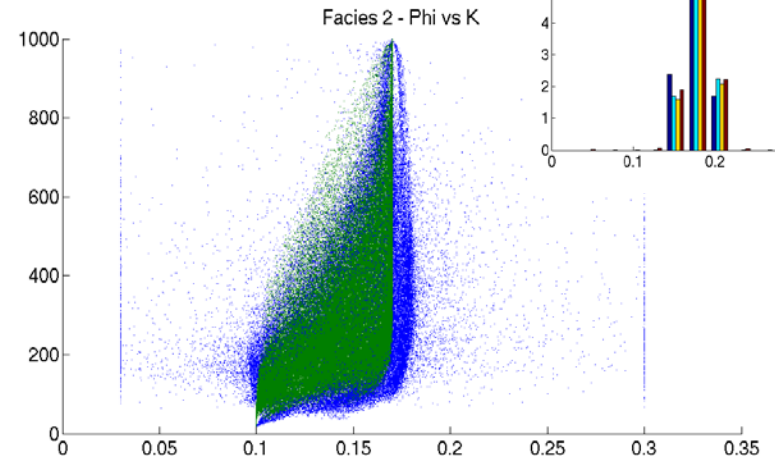
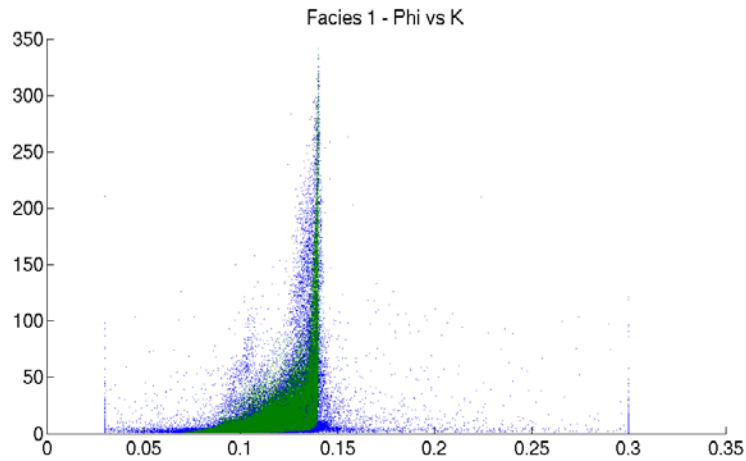
GEOLOGICAL REALISM



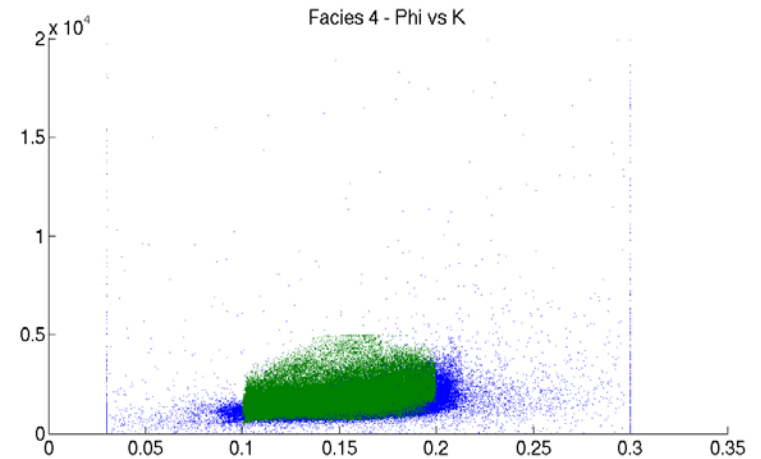
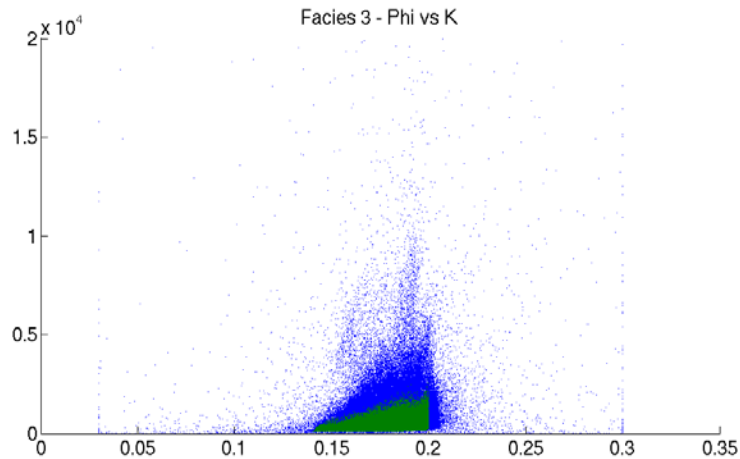
UPDATED (No Vario - BLUE) vs. TRUTH (GREEN)



GEOLOGICAL REALISM



UPDATED (Vario. Norm - BLUE) vs. TRUTH (GREEN)



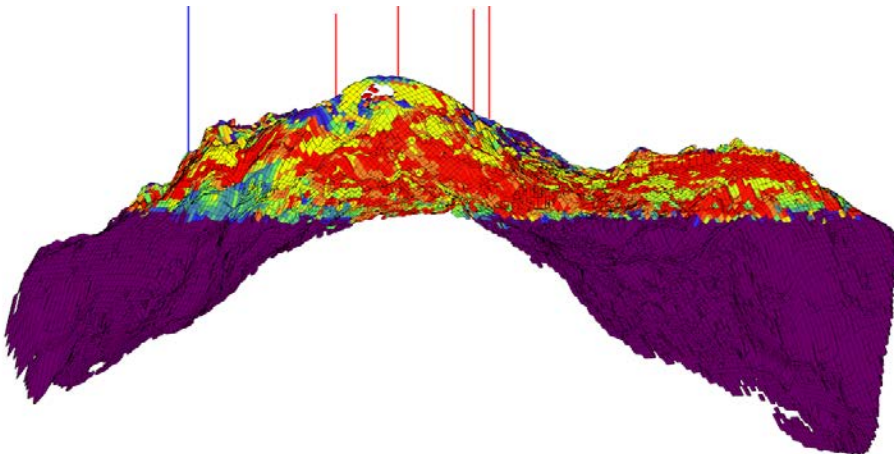
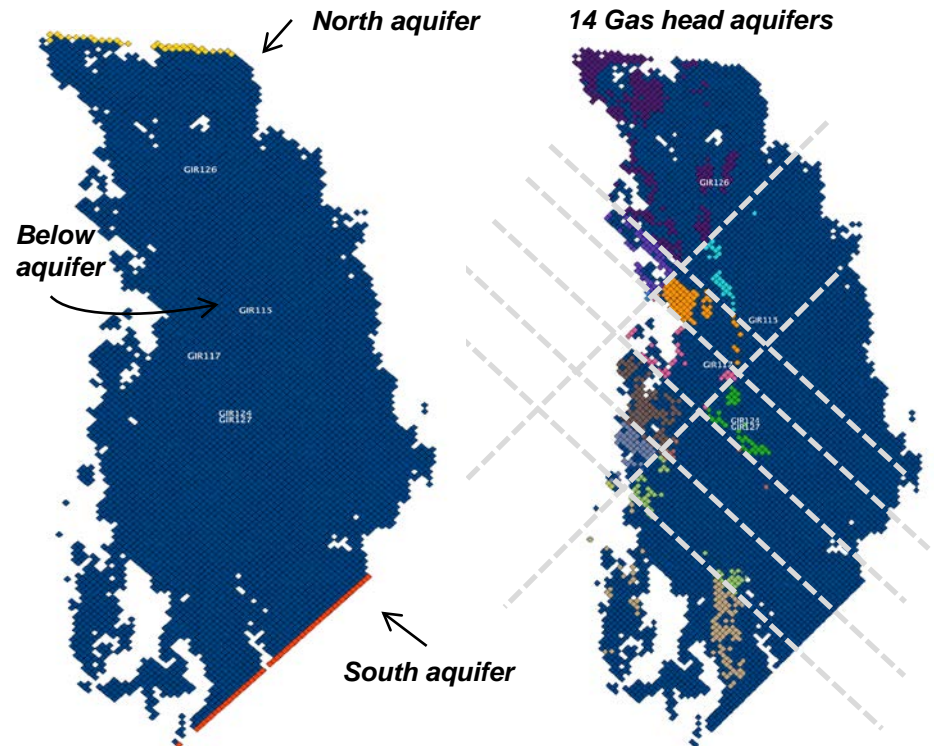
TEST ON A REAL RESERVOIR MODEL

Uncertain parameters:

- Porosity
- Permeability X
- Permeability Z via the ratio Kv/Kh
- Net to Gross
- Facies (4 facies type)
- Well Skin
- Table of influence for Carter-Tracy aquifers
- IP of the head gas aquifers
- Pressure of head gas aquifers

- Dimensions: 171 * 151 * 40 (100m * 100m * 0-6m)
- 4 producers, and 2 water injectors.
- 8 years of production (May 2003 to July 2011)

Uncertain, unrealistic boundary condition



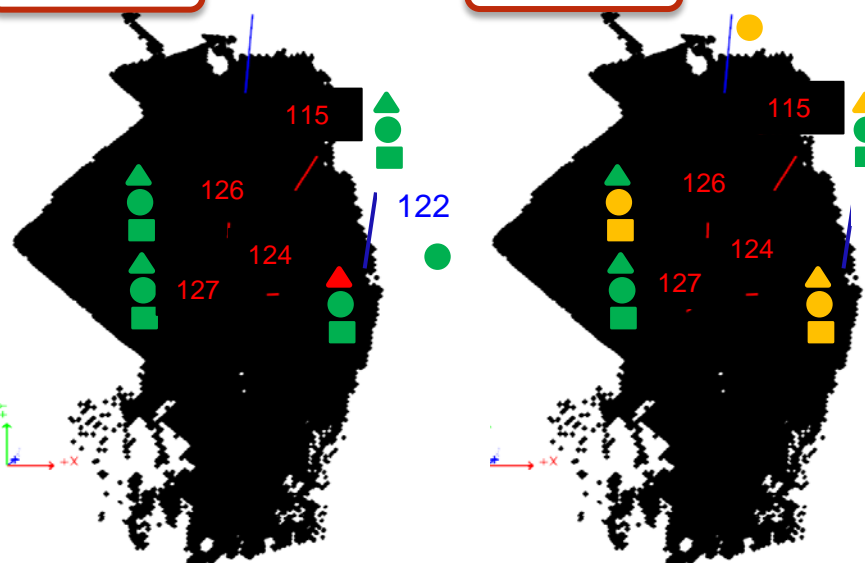
FACIES VS PETROPHYSICS

Just Facies

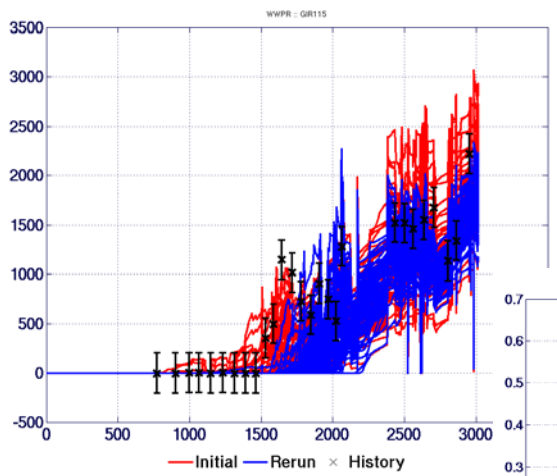
126

Just Petro

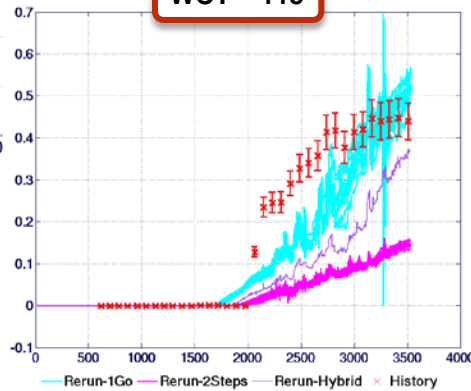
126



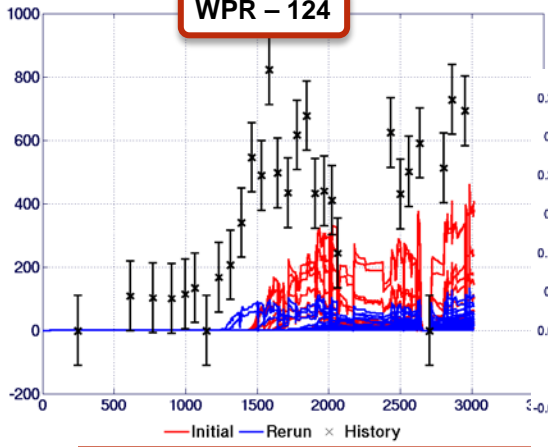
Not Matched ▲ WCT
 Acceptable ● BHP
 Matched ■ GOR



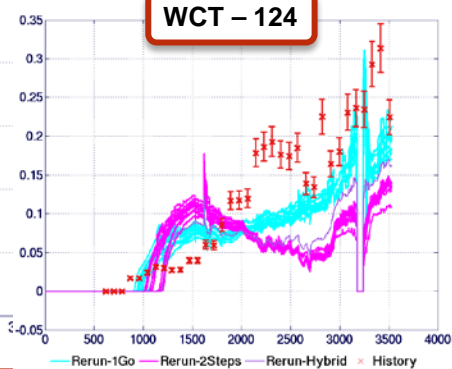
WCT - 115



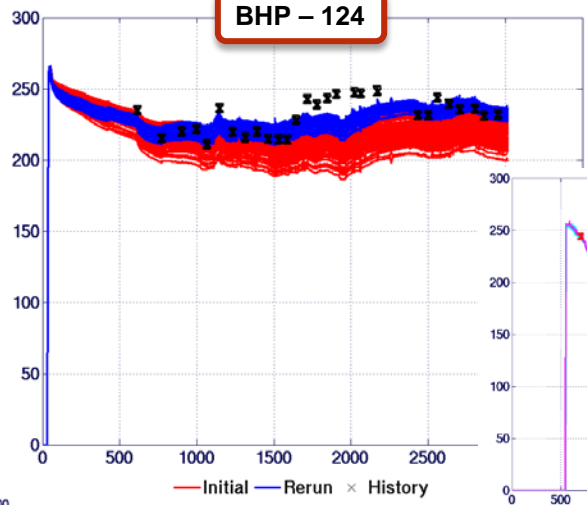
WPR - 124



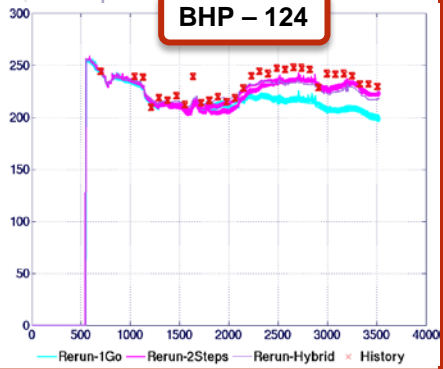
WCT - 124



BHP - 124



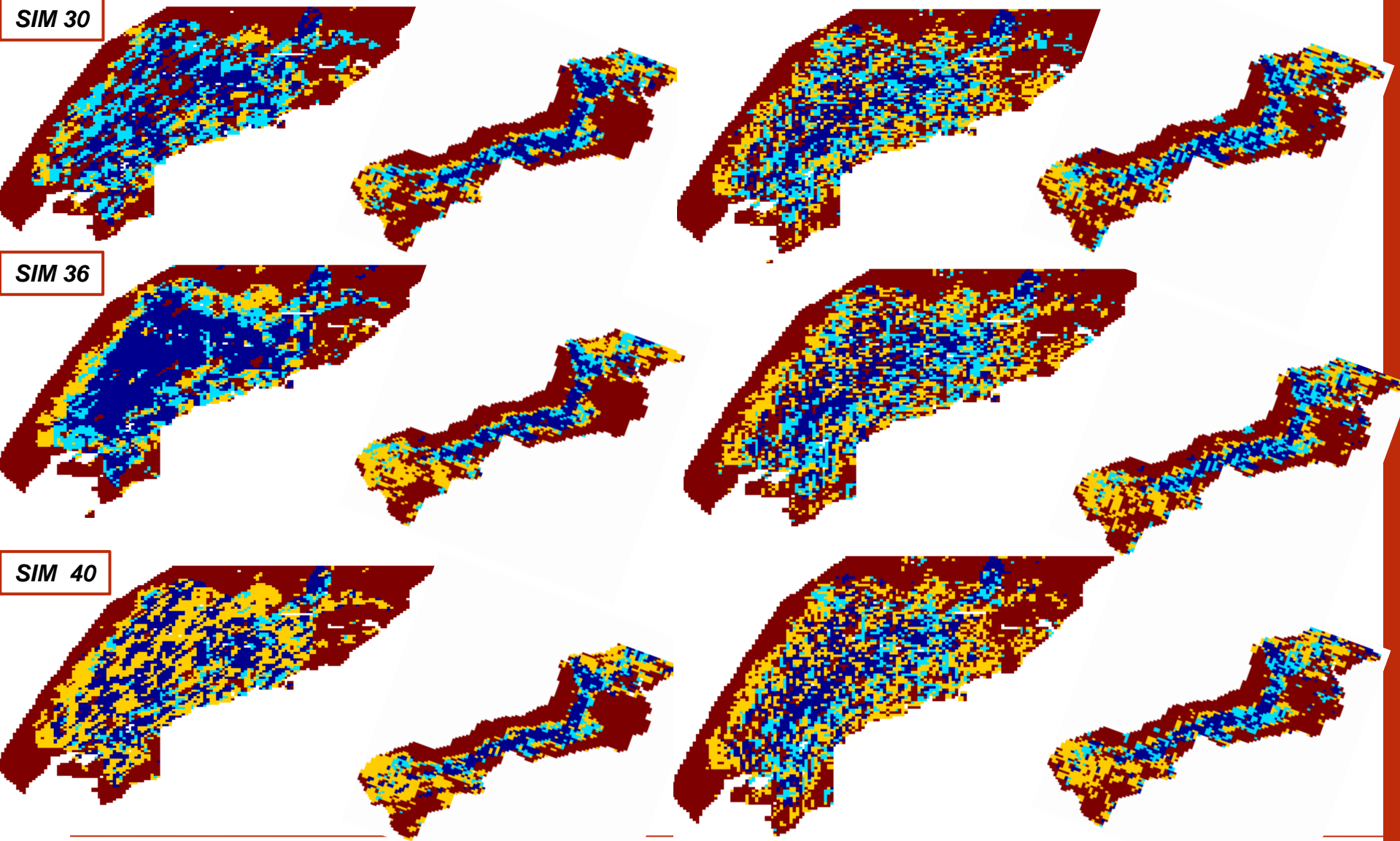
BHP - 124



FACIES UPDATE

Initial Models

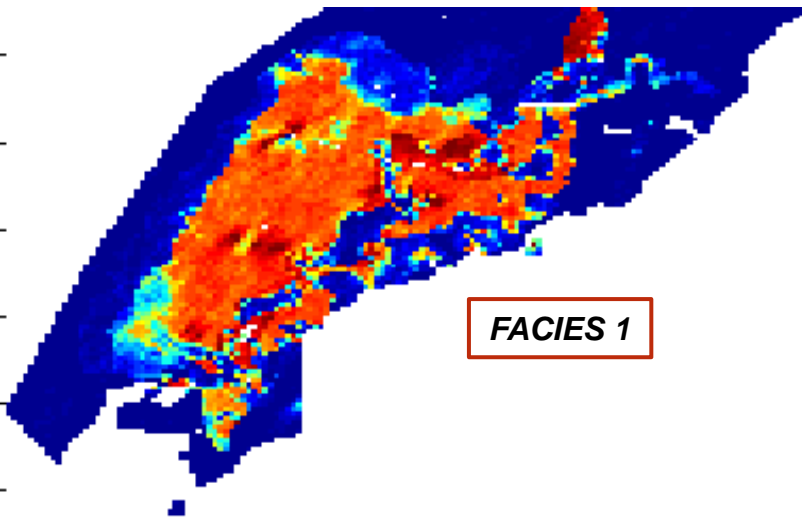
Final Models



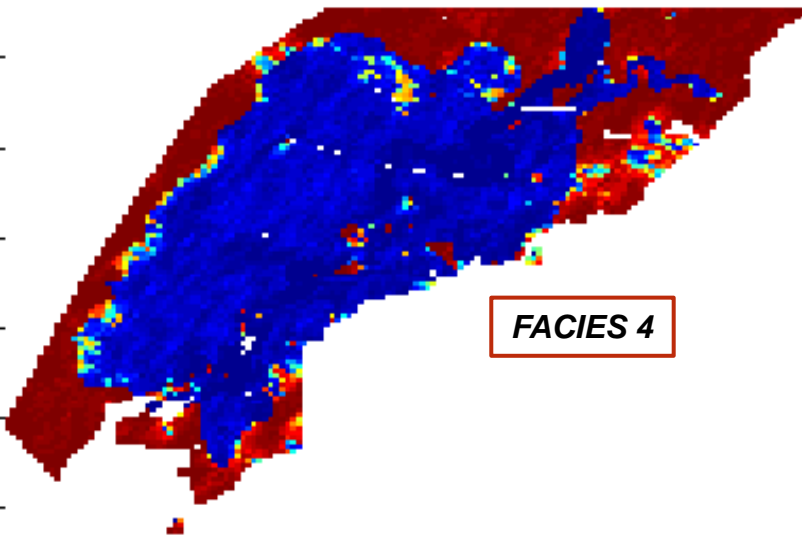
FACIES PROPORTION

Initial Models

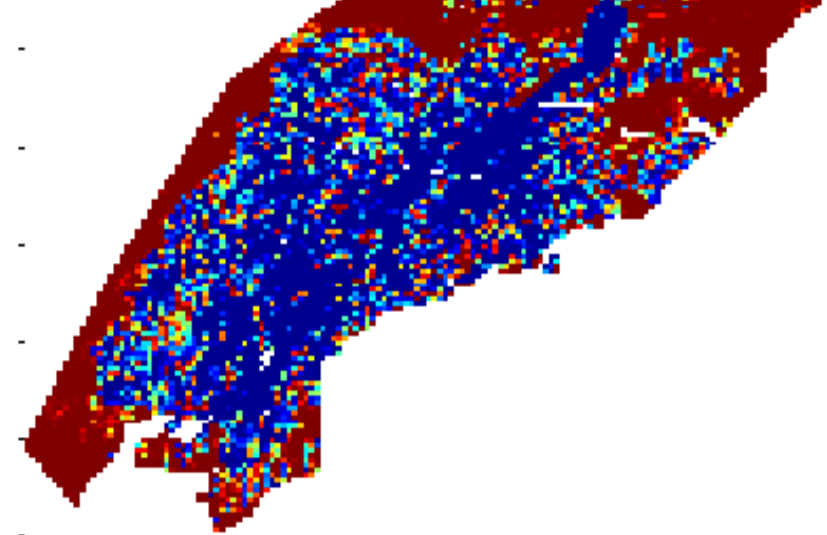
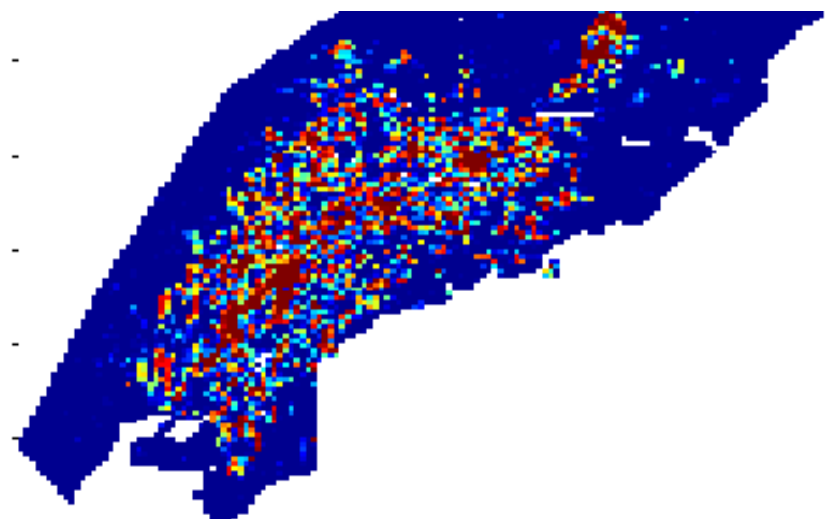
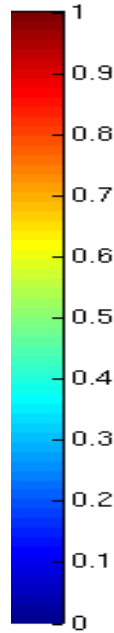
Final Models



FACIES 1

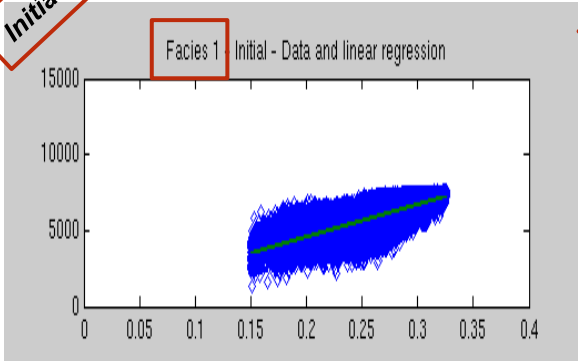


FACIES 4

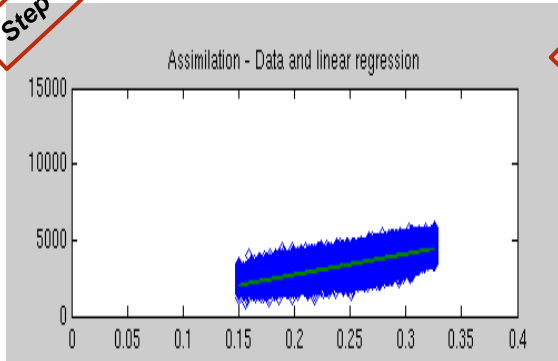


DATA ASSIMILATION ON MAP PROPERTIES – PHI/K EVOLUTION

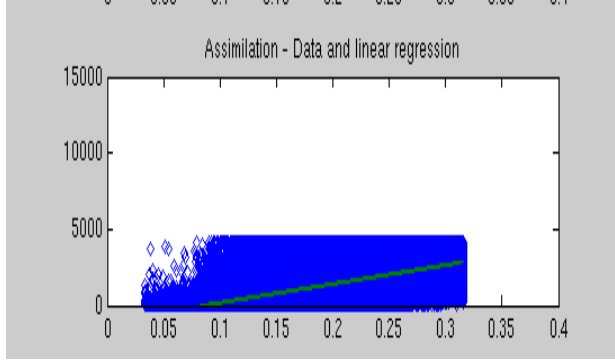
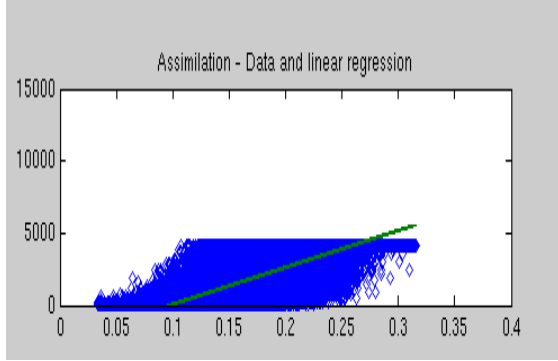
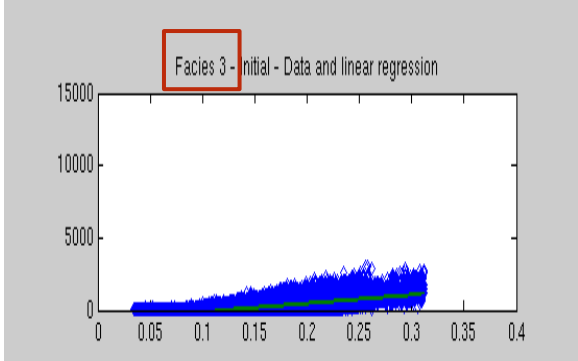
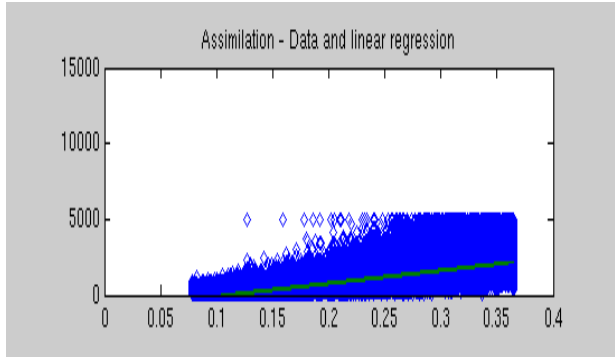
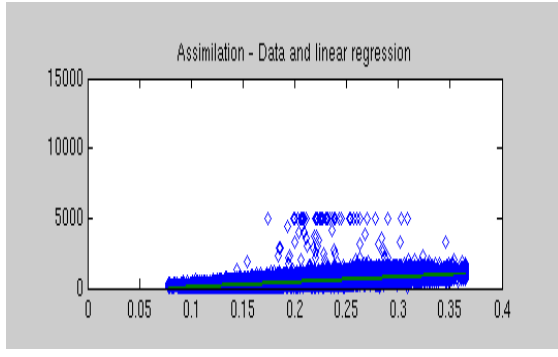
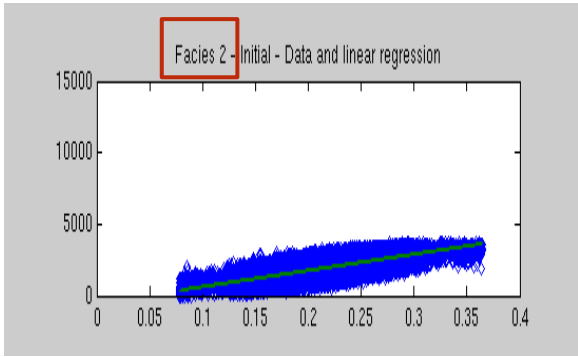
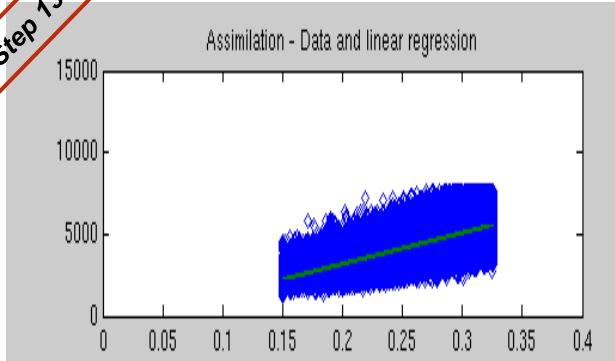
Initial



Step 4

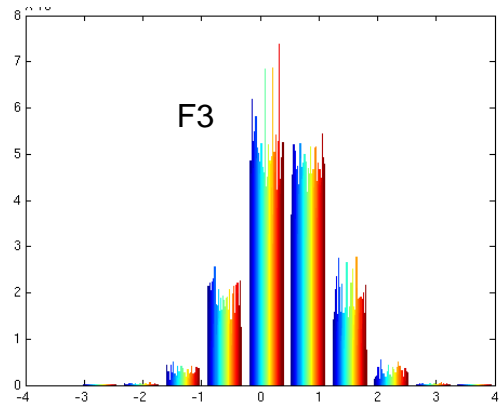
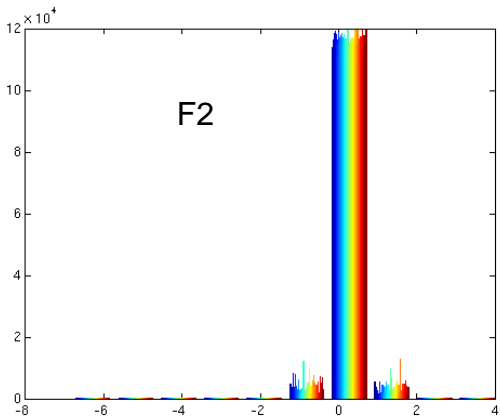
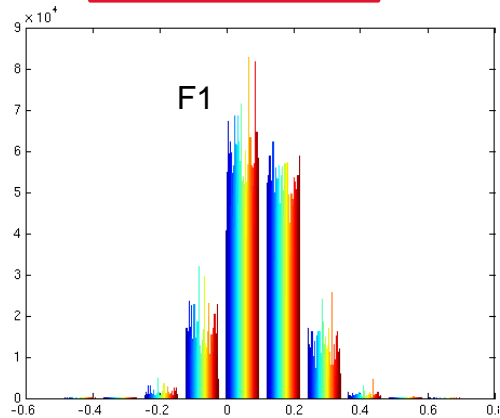


Step 13



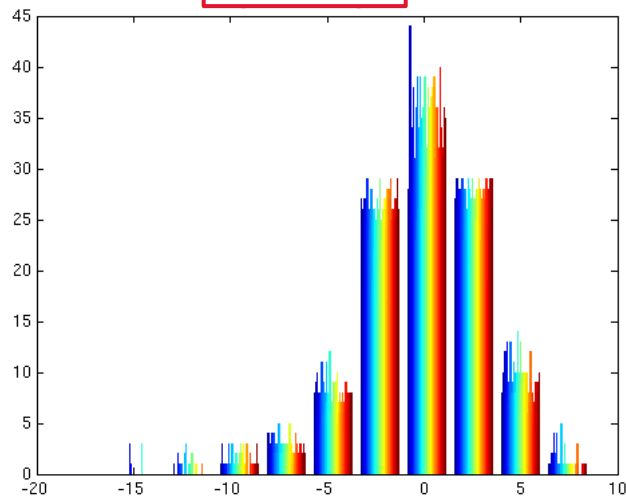
FACIES 1-2-3 – PERMX UPDATES

Correction term



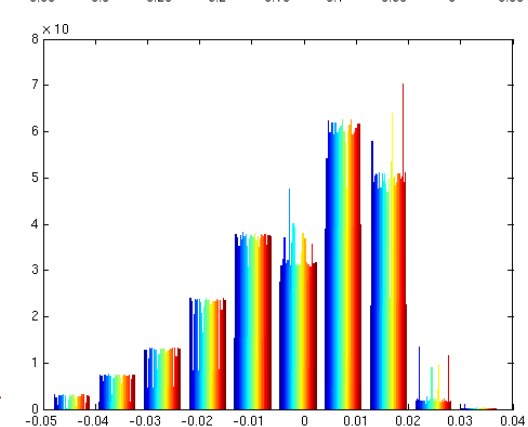
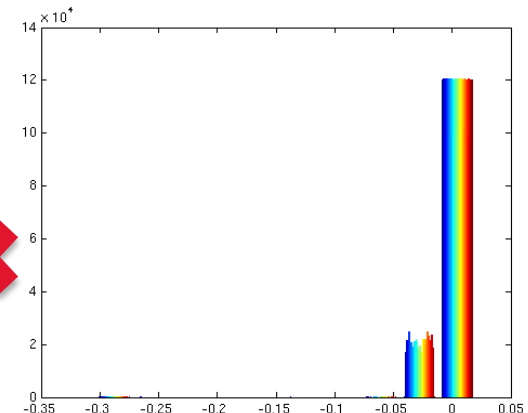
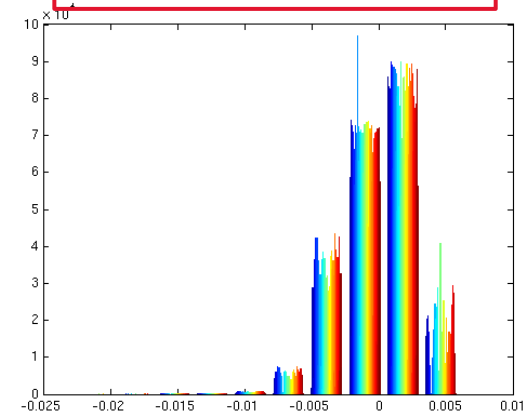
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Misfit term

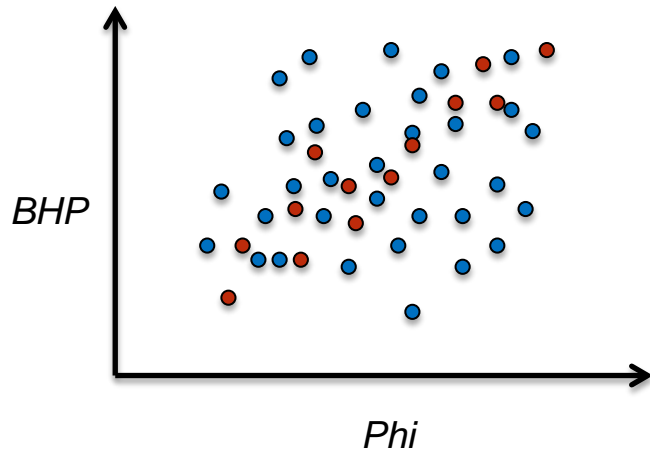


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Deviation in the Ensemble

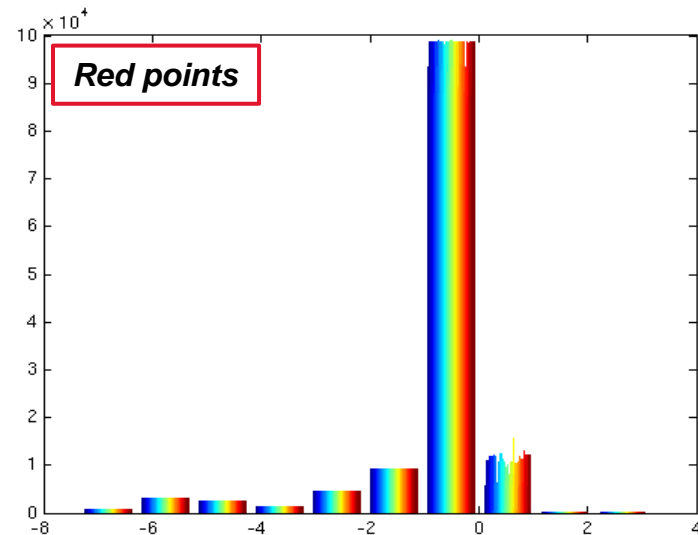
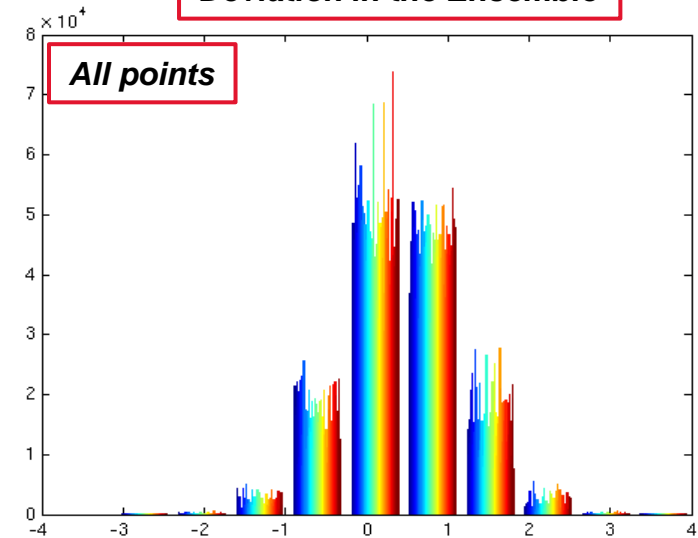


UNUSED DATA & SPURIOUS CORRELATION



- Spurious correlation with unused values might be the reason for high deviation.
- Taking just into account the used ones doesn't solve the problem because of under sampling .
- Bootstrapping inside the used ones might be the solution in general case.

Deviation in the Ensemble



CONCLUSION & WAY FORWARD

Distance to the boundary parameterization proved to be a powerful tool to deal with facies uncertainty as well as 4D seismic observation.

Results obtained seems a big step forward in respecting the complex geology.

To better respect the initial proportion of the facies distribution this information should be also included in the parameterization scheme.

A synthetic test case model with clearer 4D seismic image as well as less uncertainty in the position of the channel might be a better representative of the capability of the proposed workflow.

Proposed parameterization to deal with the facies showed interesting results on a real data set.

Handling both facies and petrophysical parameters remains still challenging for a highly uncertain problem far from the solution.