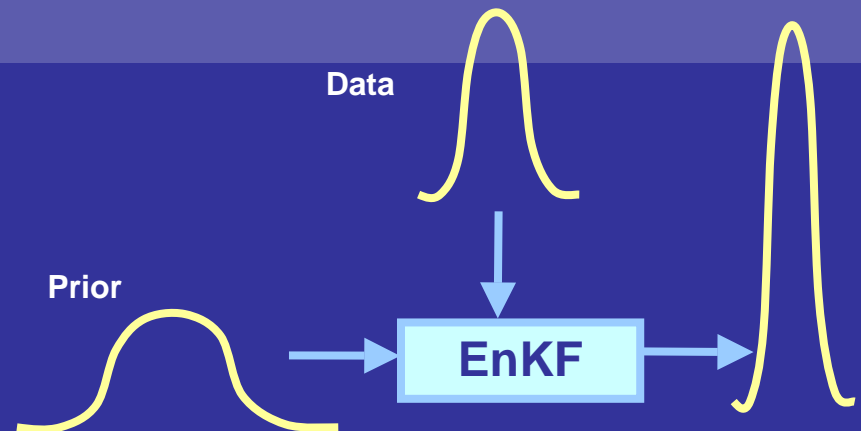




EnKF application

Geir Evensen



Problem definition: history matching

Find posterior pdf of state and parameters given measurements and model with available prior error statistics

Combined parameter and state estimation problem

Bayesian formulation

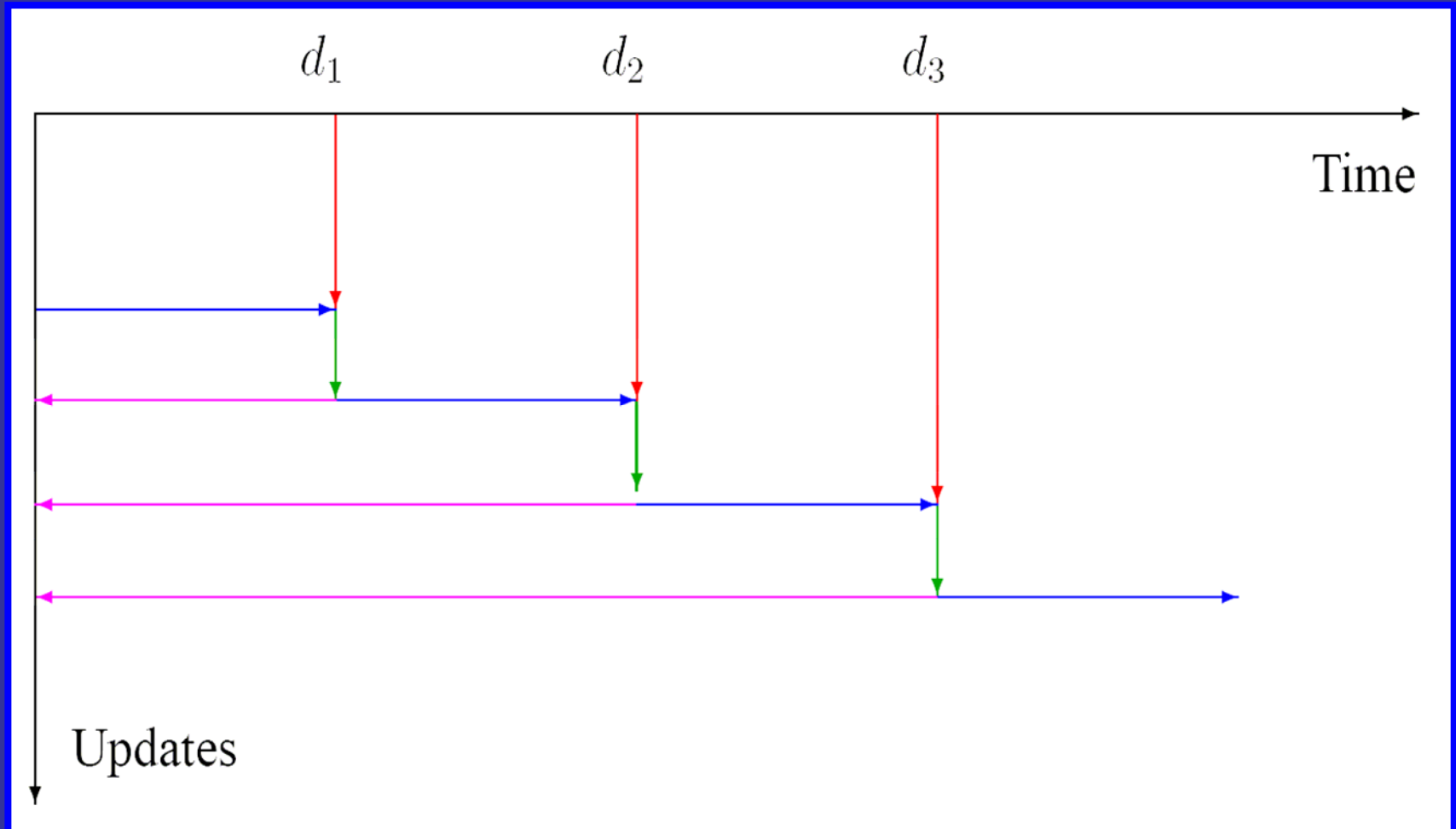


Bayes' Theorem:

EnKF – Ensemble Kalman Filter

- **Sequential Monte Carlo estimation method.**
 - Sequential updating of model state and parameters
 - Model state and parameters converge towards true values
 - Information accumulates and uncertainty is reduced at each update
- **Keeps model on-track and reduces possibility of finding local minima**
- **Starts with ensemble of unconditioned sampled realizations**
- **Result is an ensemble of realizations conditioned on production data**

Sequential processing of measurements

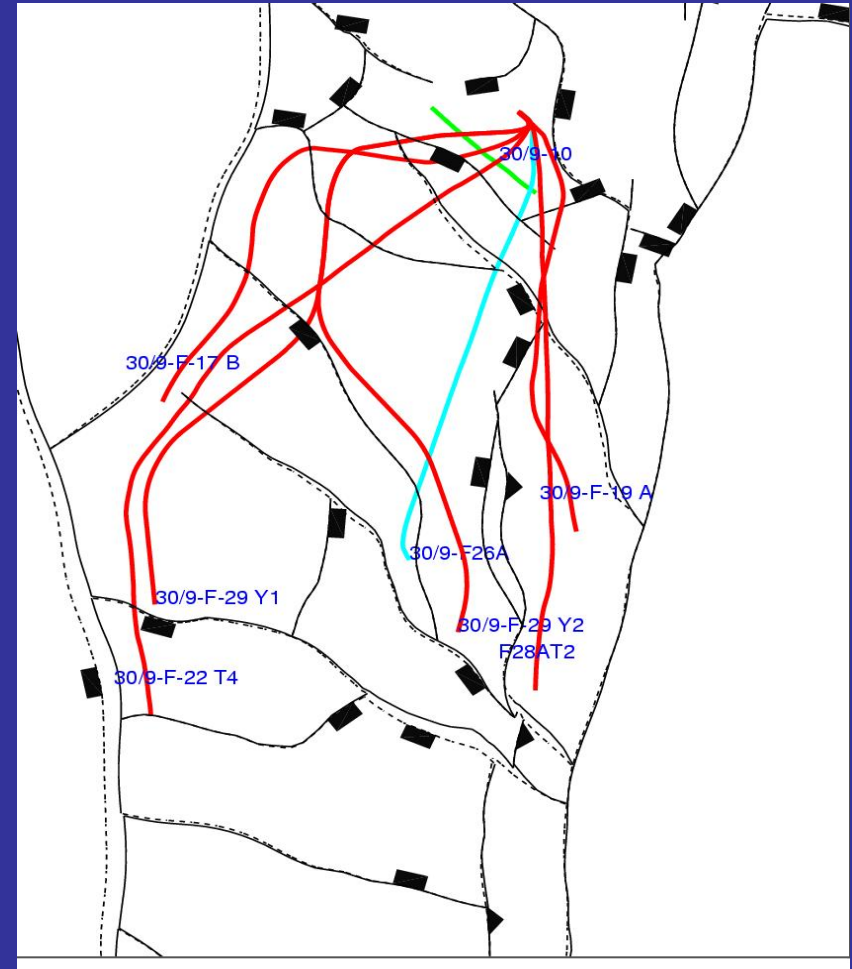


EnKF methodology

- **Representation of error statistics by an ensemble of model states**
- **Evolution of error statistics by ensemble integrations**
- **Assimilation of measurements using variance minimizing update scheme:**
 - Updates both state and static parameters
 - Consistent with the Kalman filter for linear dynamics

Field model

- **Complex reservoir**
 - Heterogeneous/low permeability
 - Unclear vertical communication
 - Many faults
 - Isolated regions
 - Poorly known fault properties
 - Poorly known initial contacts
- **Parameters to estimate**
 - PORO and PERM
 - MULTZ
 - MULTFLT
 - WOC
 - GOC
- **Conditioning on production data**
 - OPR
 - WCT
 - GOR
- **Conditioning on RFT data**

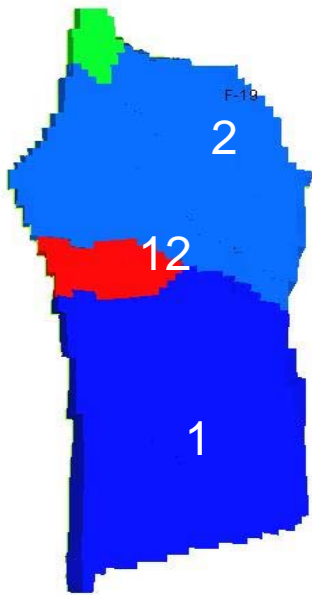


Experiment

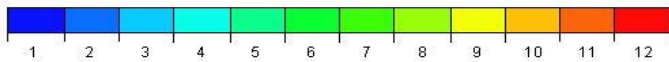
- **Initial ensemble:**
 - All priors extracted from geomodel.
 - Initial contacts have std dev of 20 m.
- 1. **Pure ensemble run with no updating**
 - Examine the uncertainty span of the initial model
- 2. **Assimilation run**
 - Conditioning on production data
- 3. **Verification experiment**
 - Rerun realizations using estimated parameters

EQUIL regions

EQUIL Regions (lay 01)



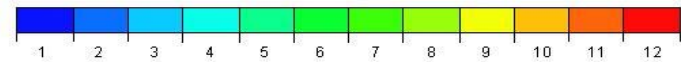
EQLNum



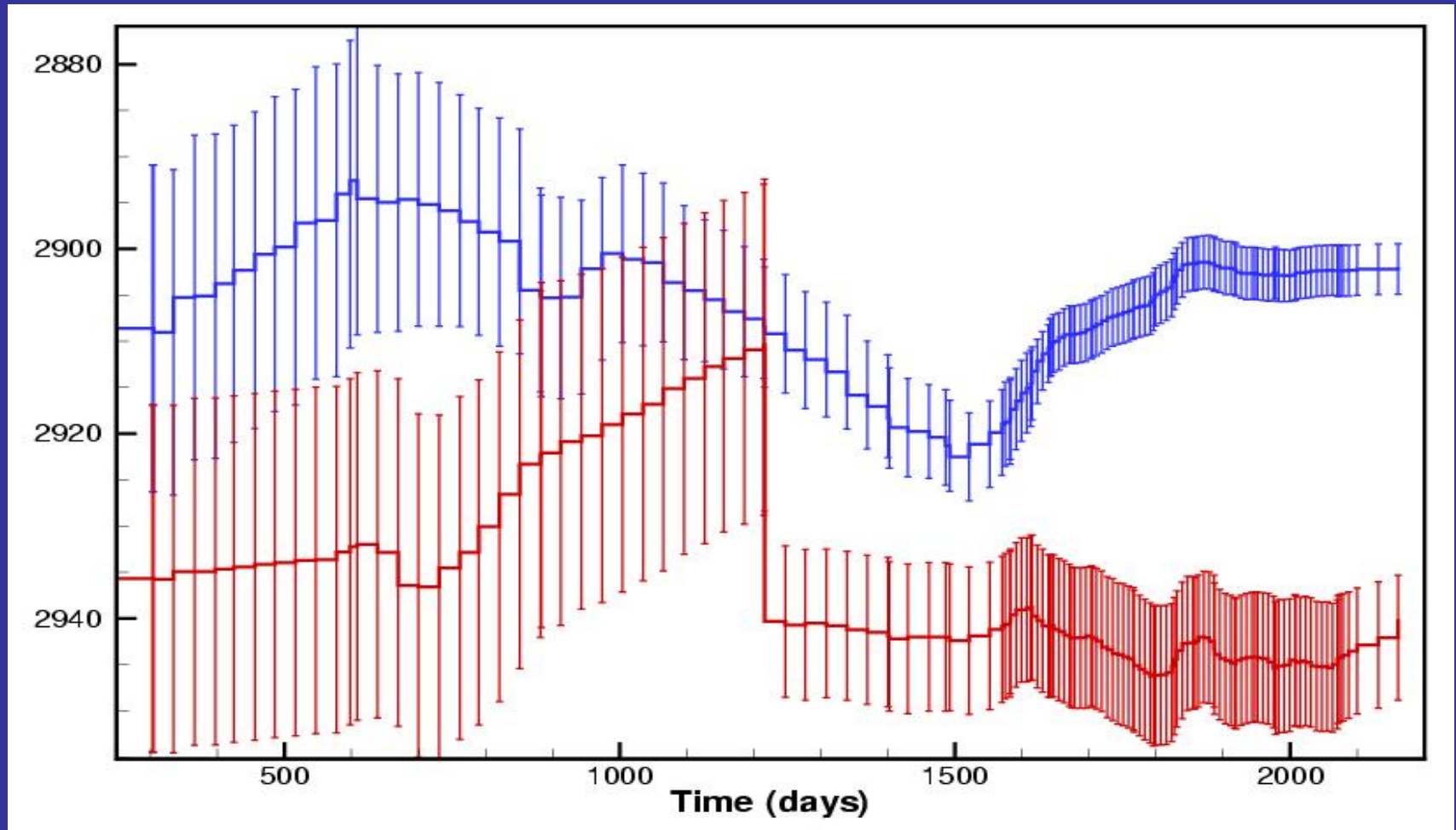
EQUIL Regions (lay 38)



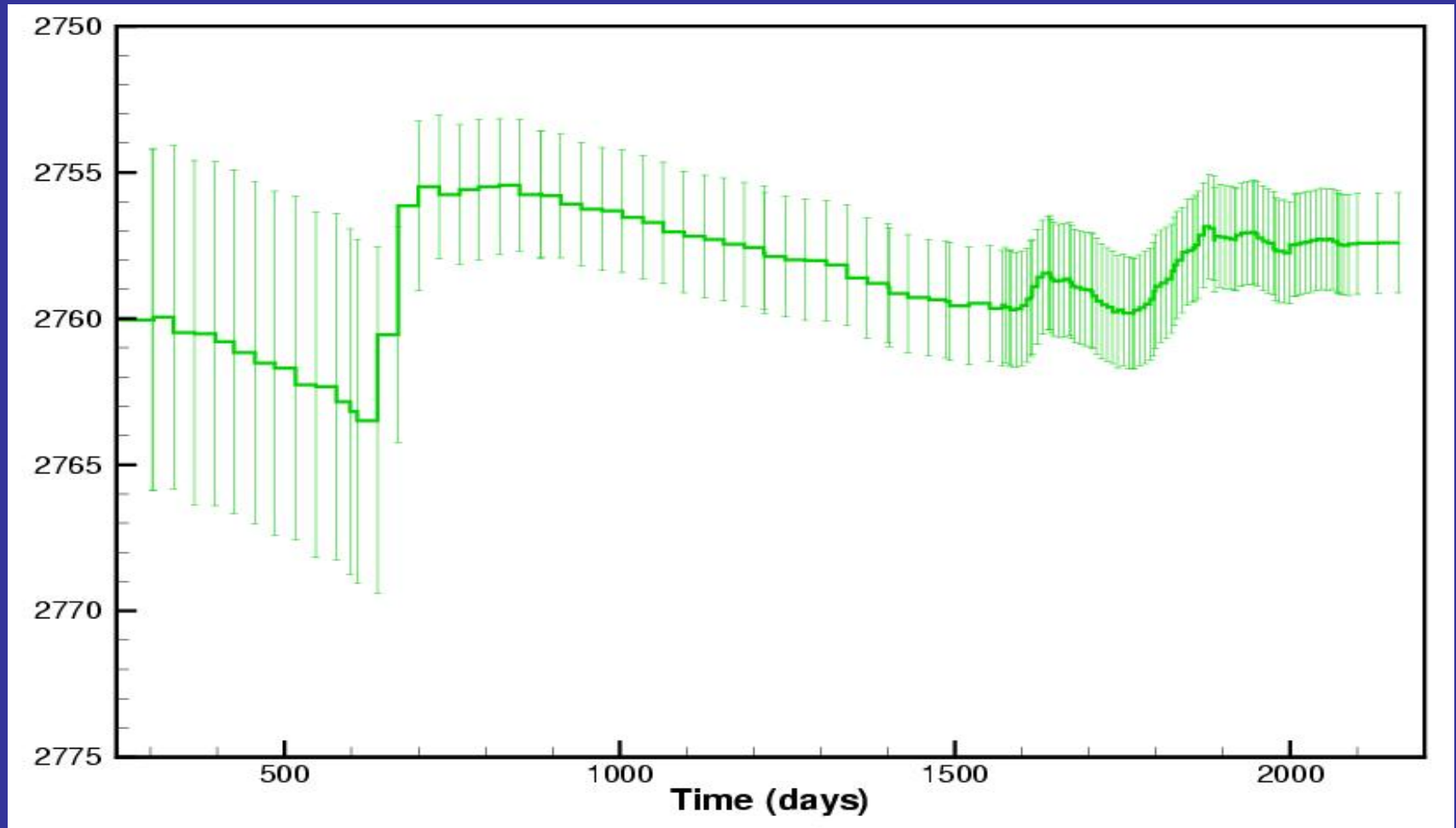
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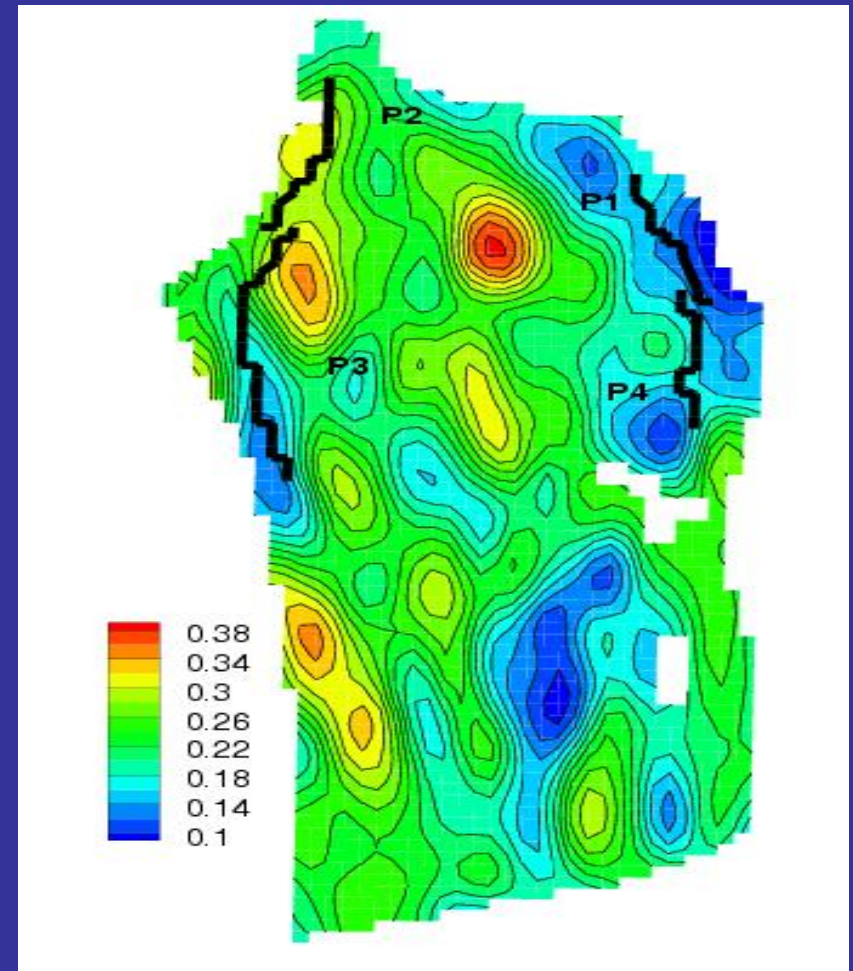
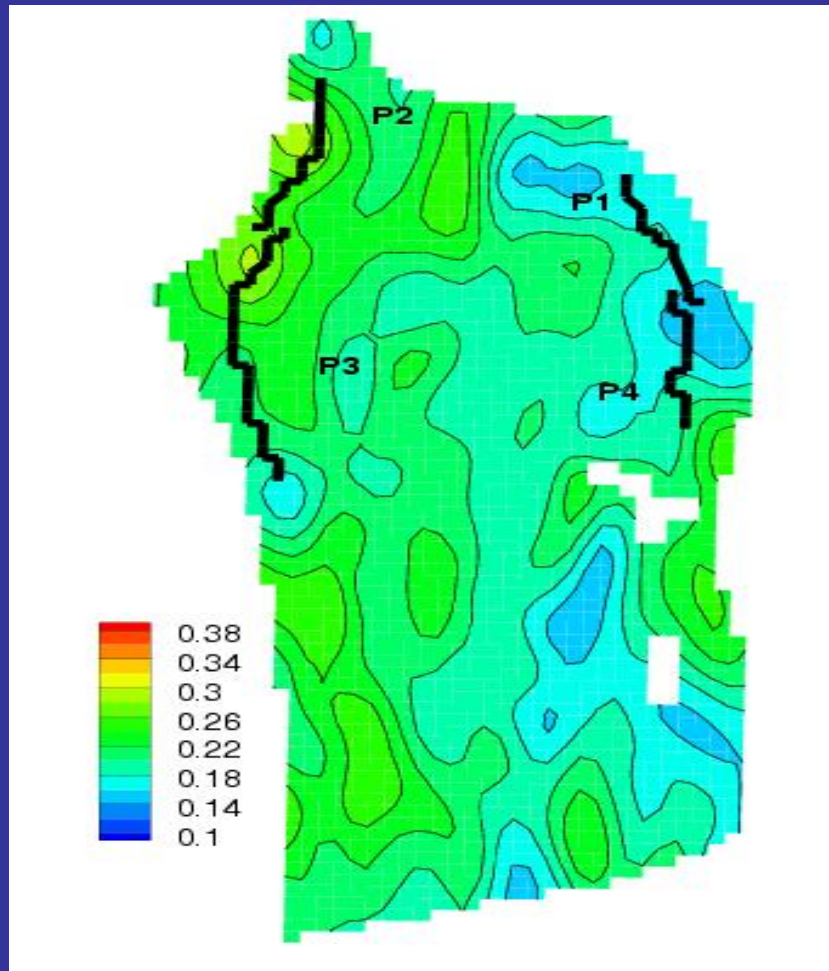
Updates of WOC (2 blue, 12 red)



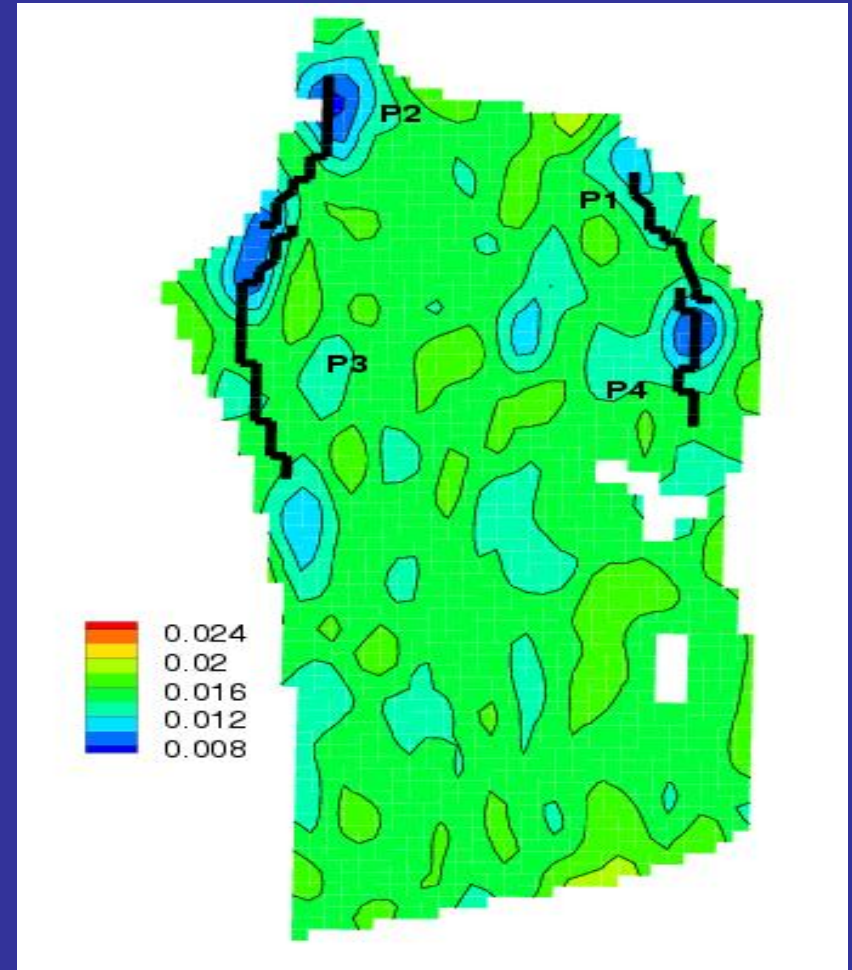
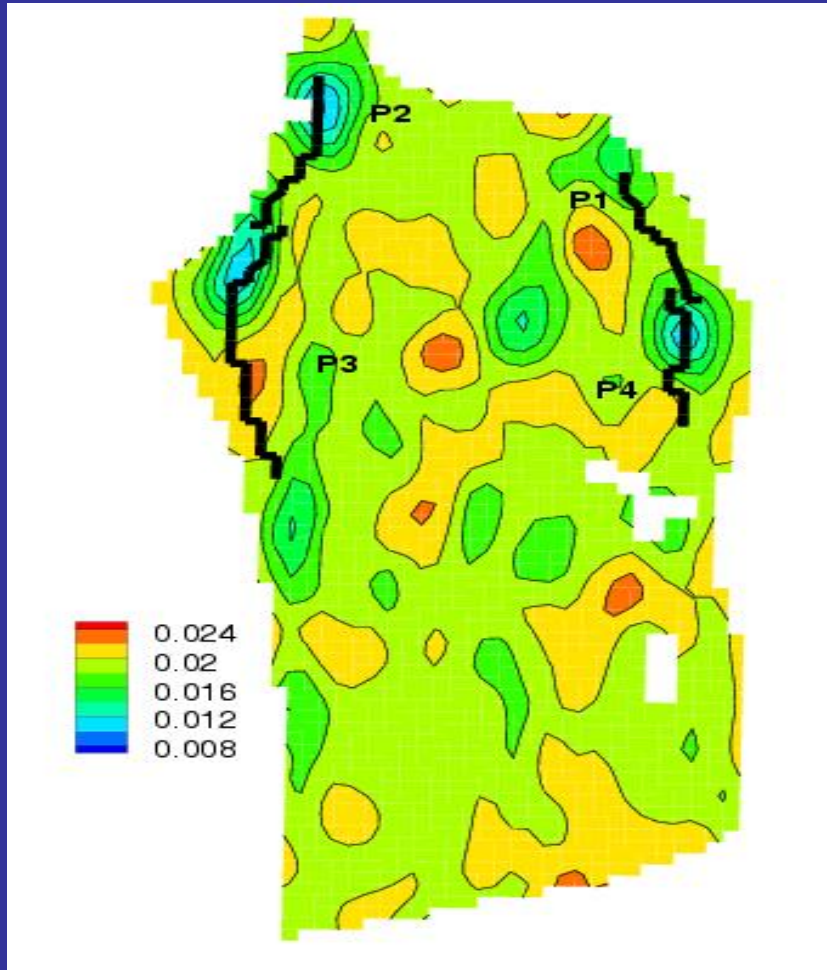
Updates of GOC



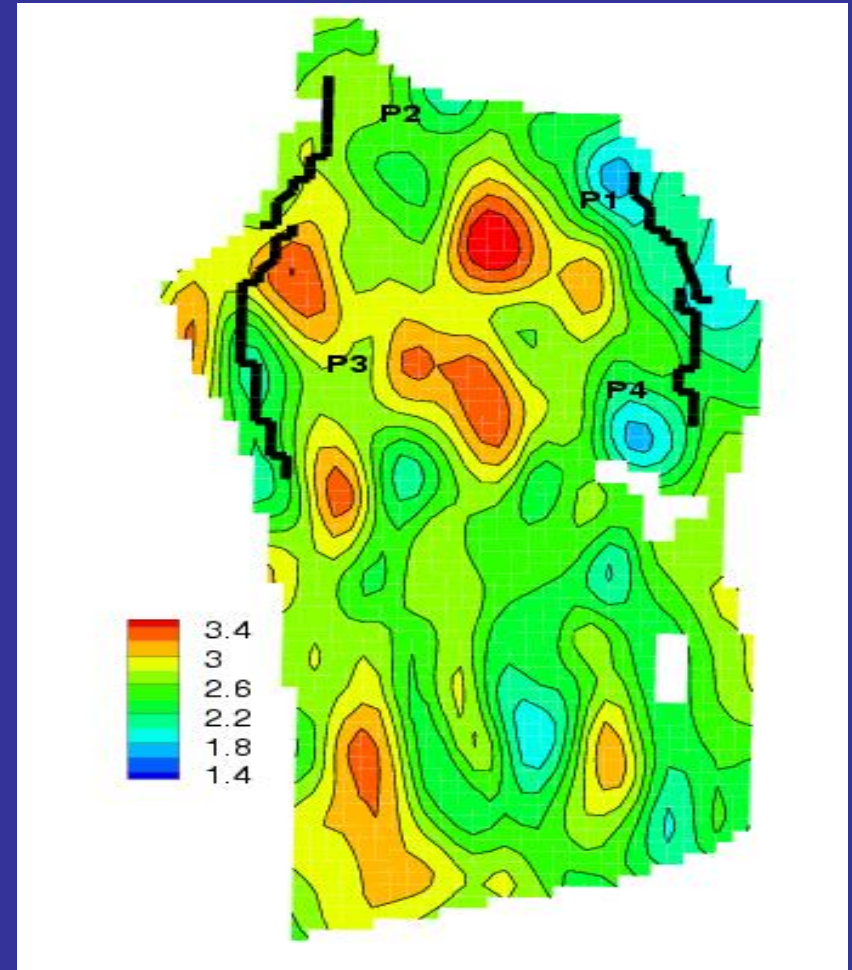
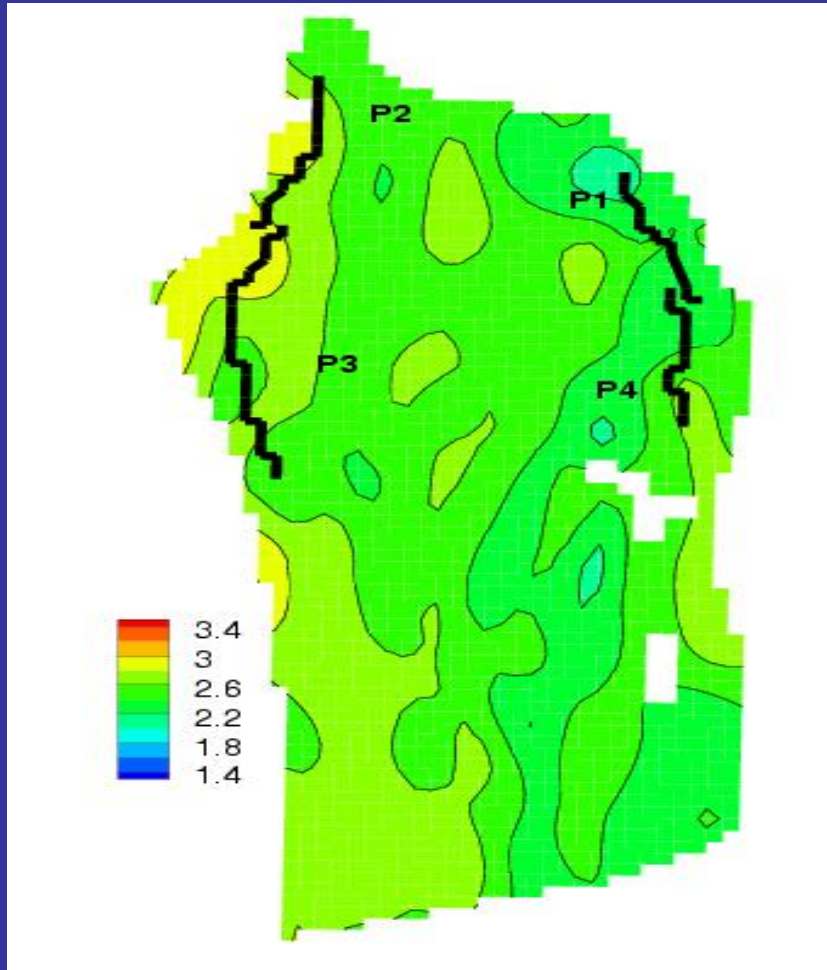
Porosity layer 35, prior and posterior



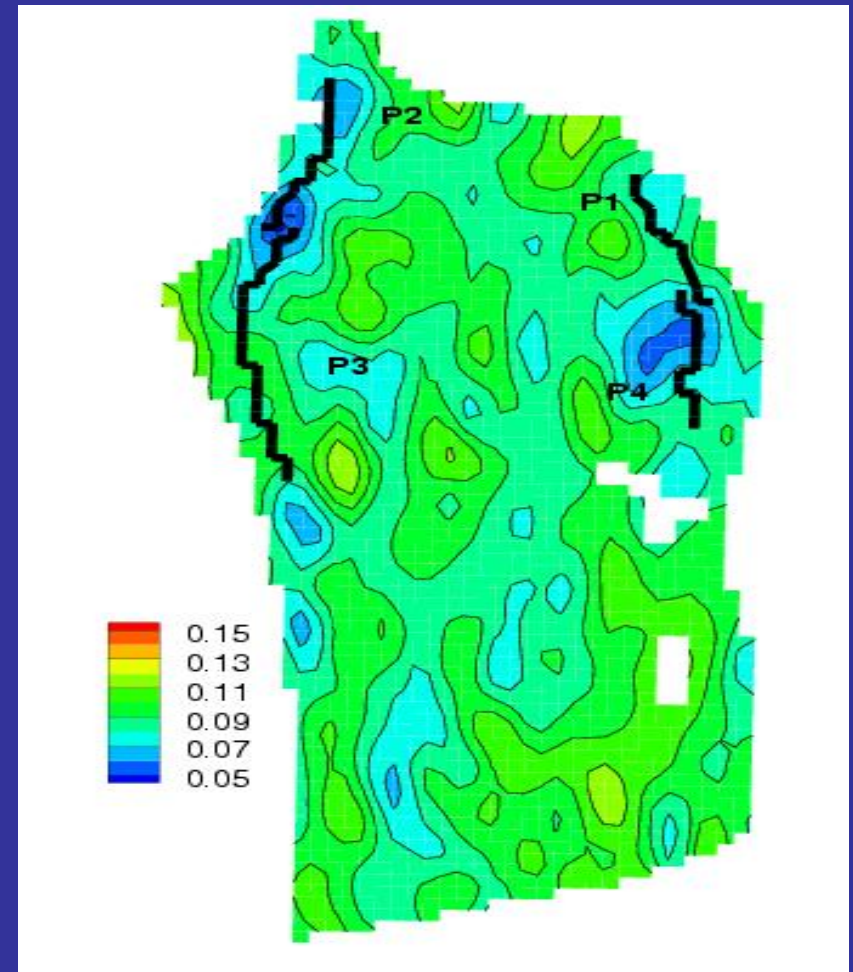
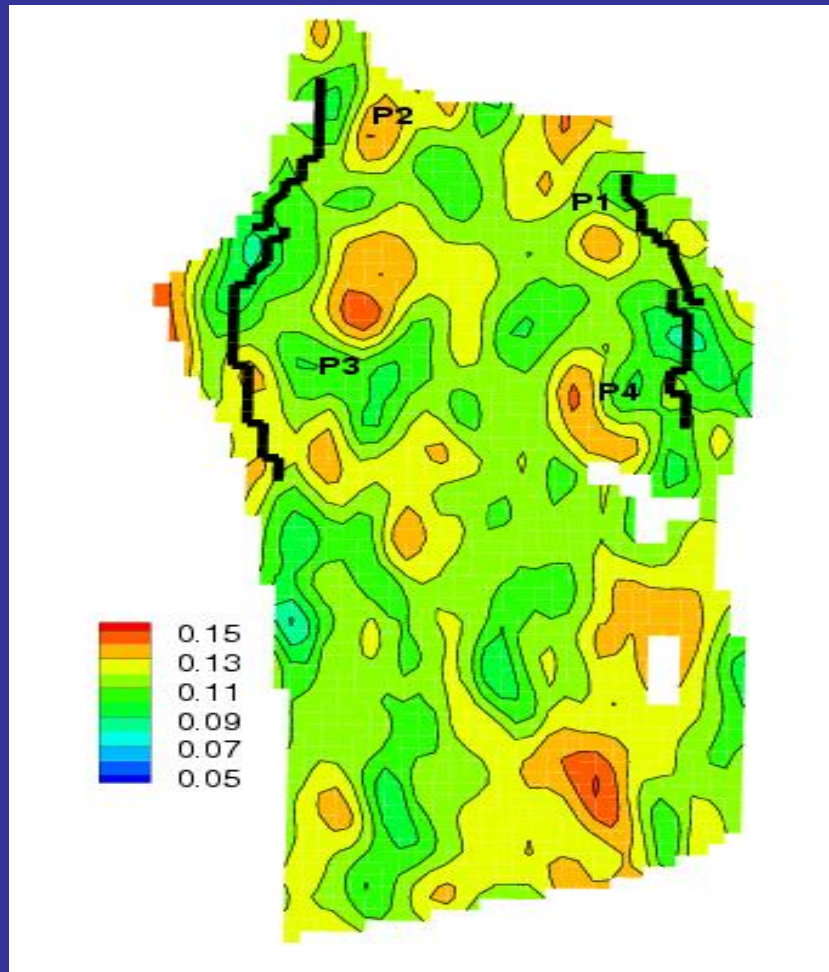
Porosity std dev layer 35, prior and posterior



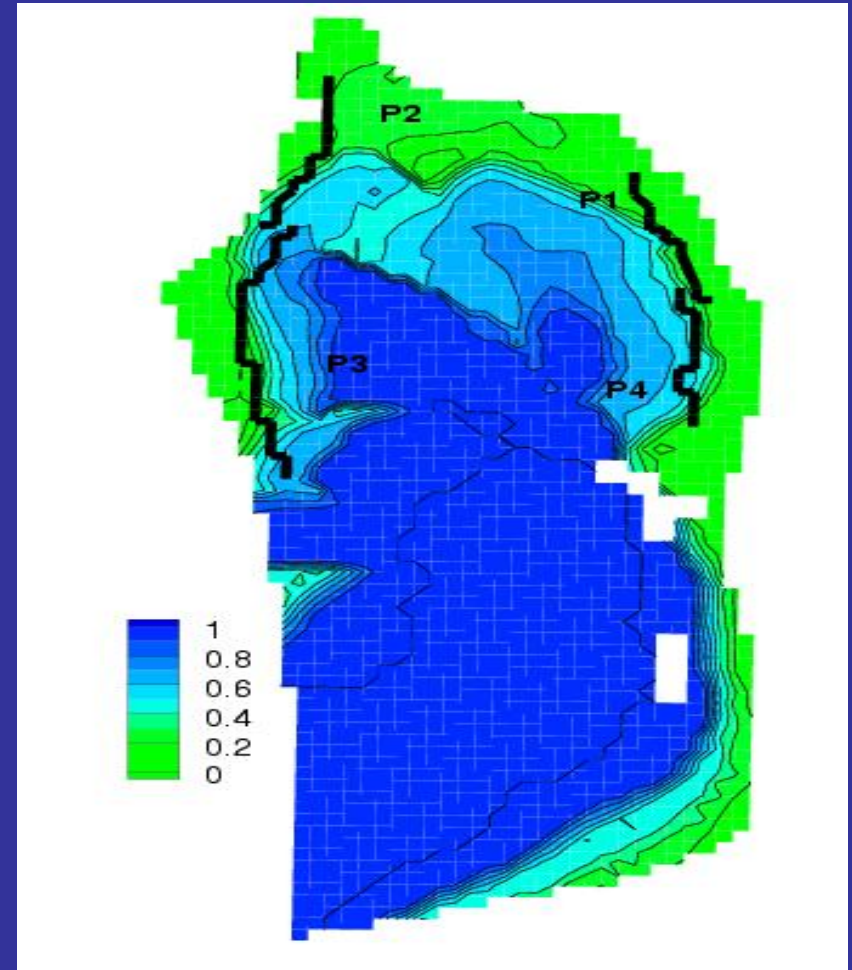
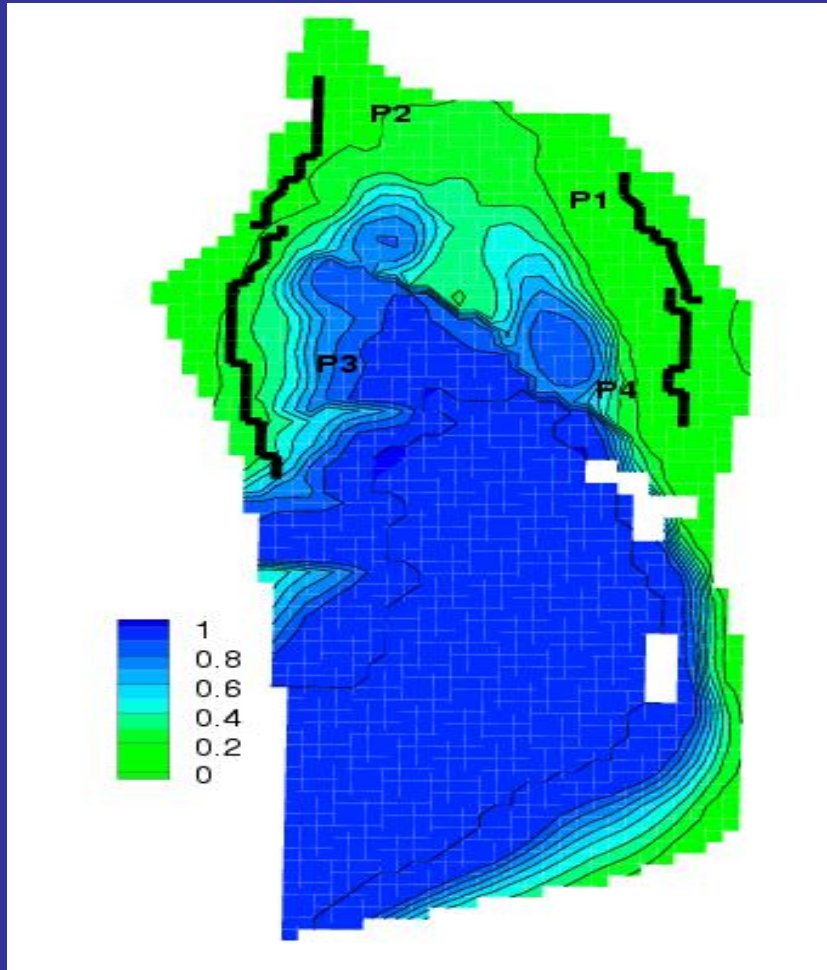
Permeability layer 35, prior and posterior



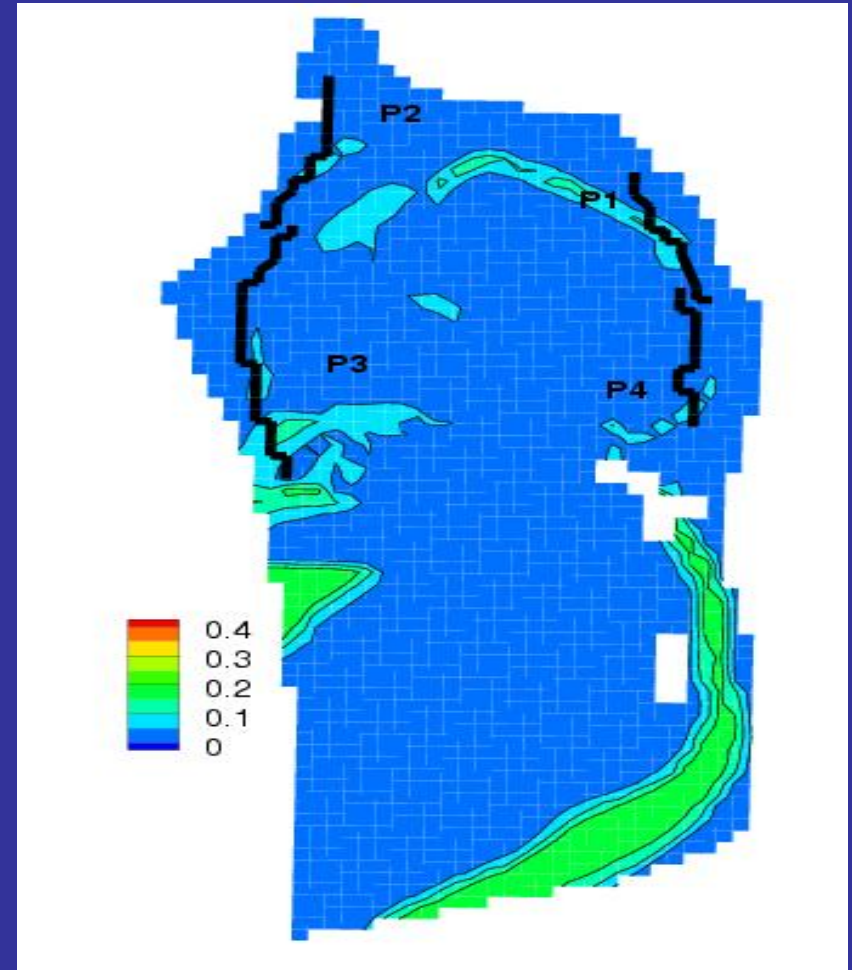
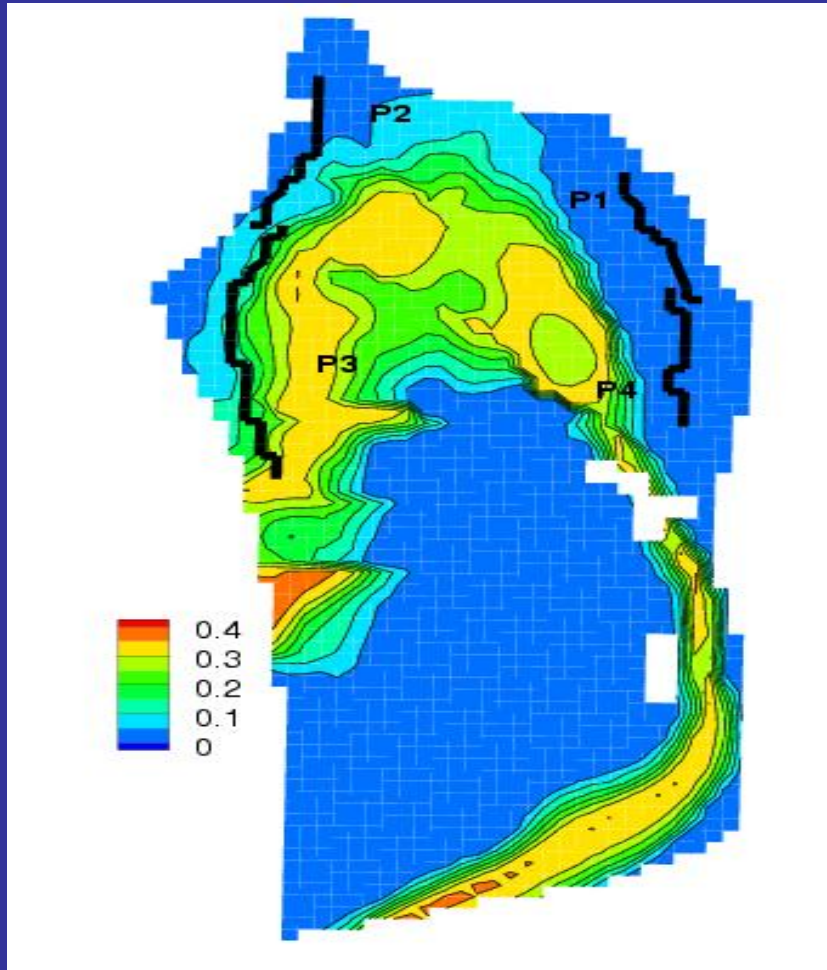
Permeability std dev layer 35, prior and posterior



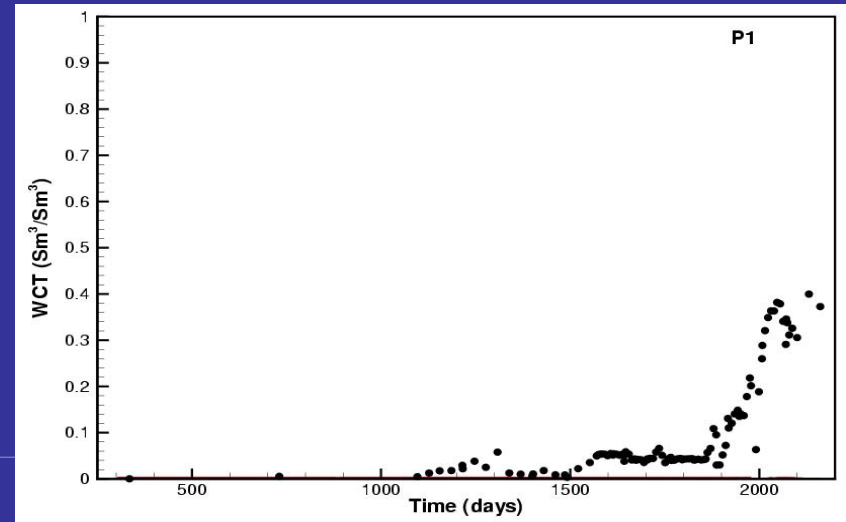
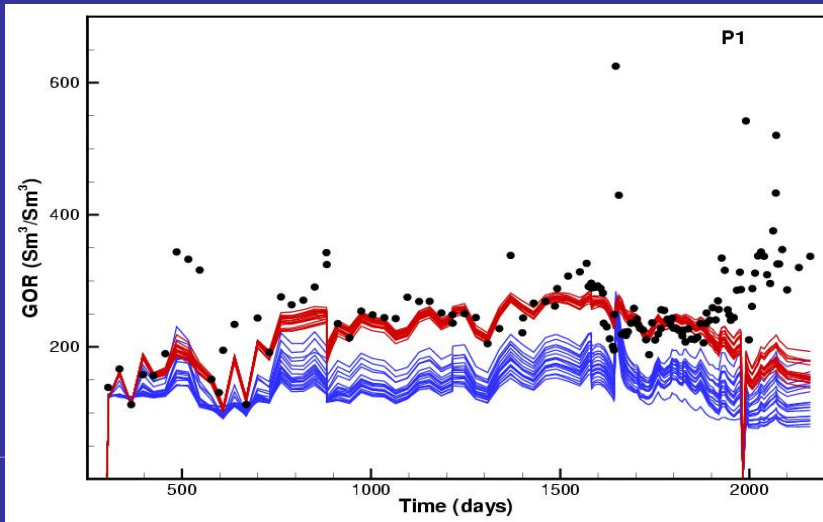
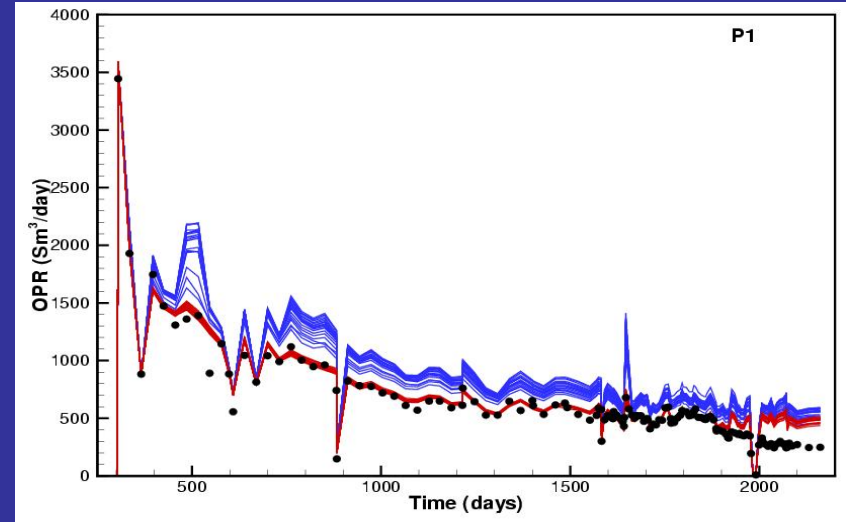
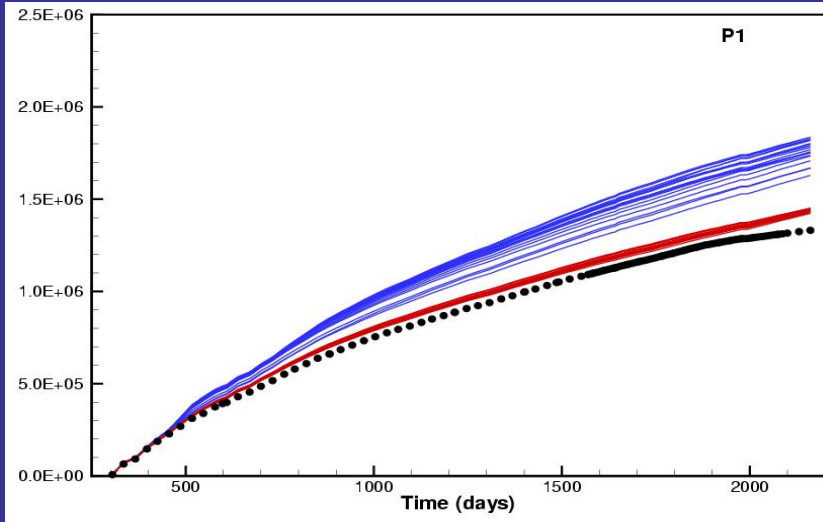
SWAT layer 35, prior and posterior



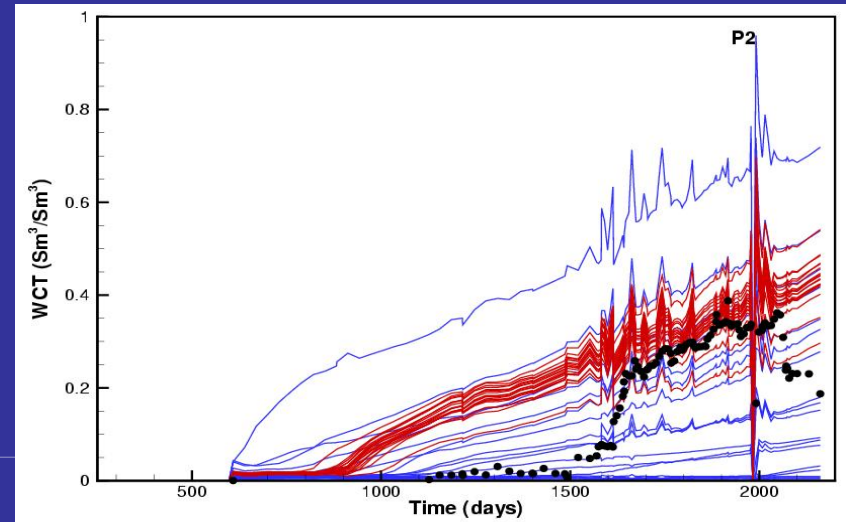
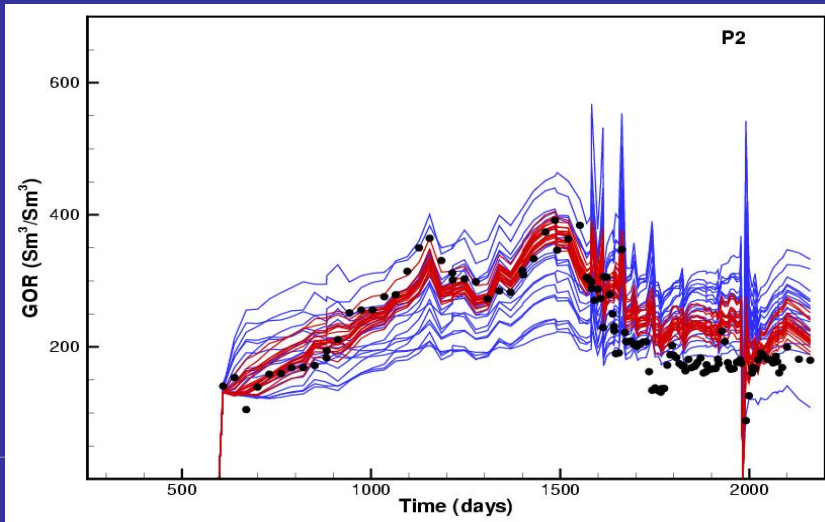
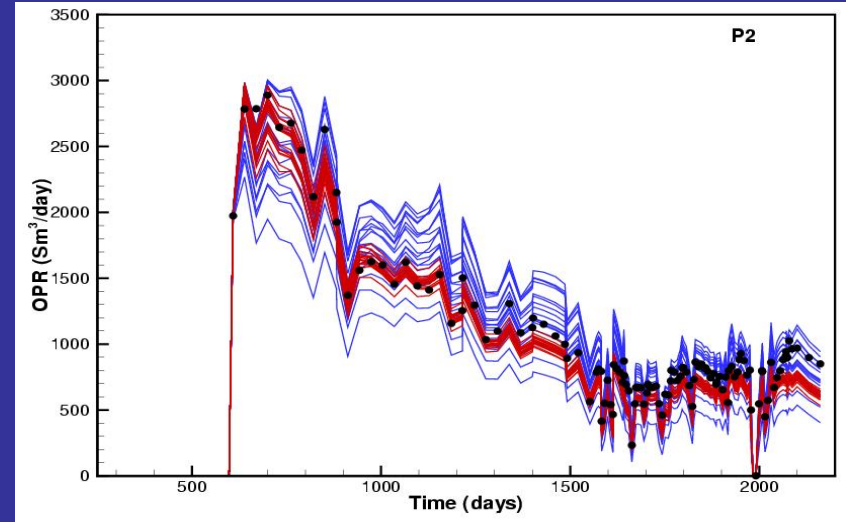
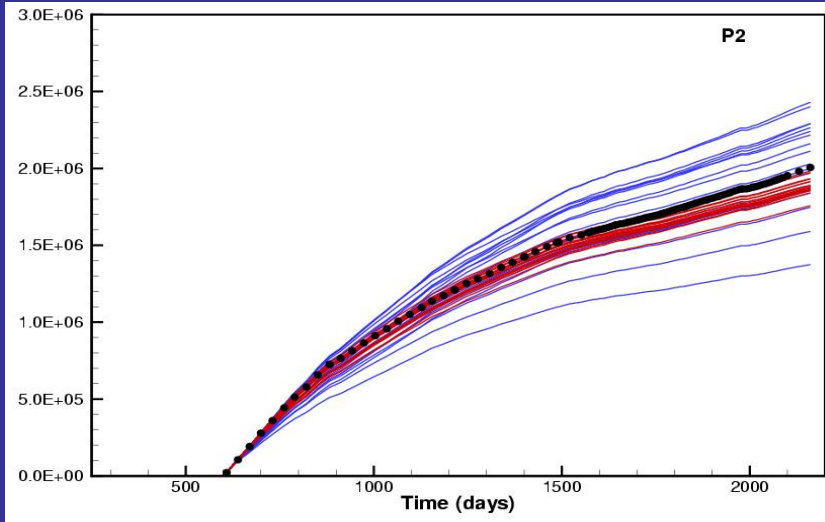
SWAT std dev layer 35, prior and posterior



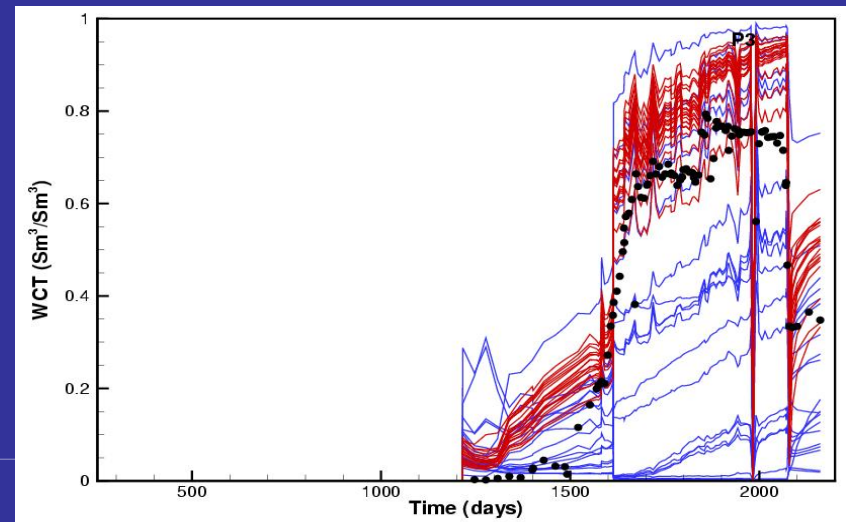
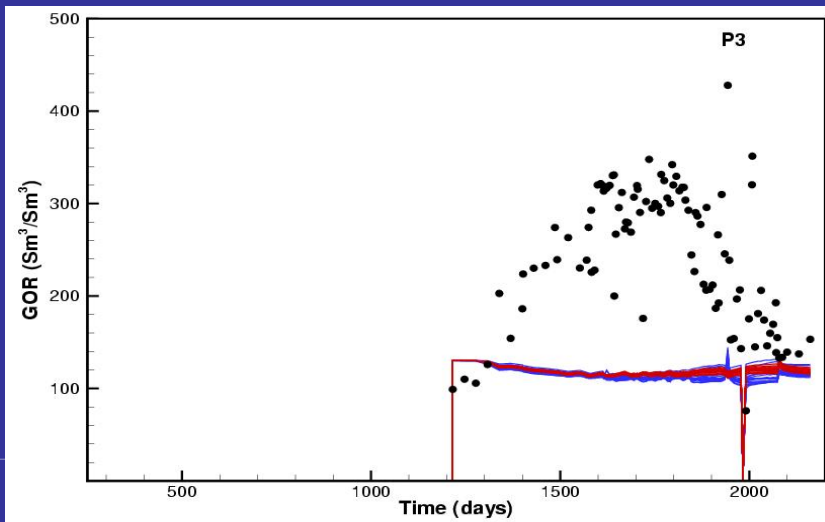
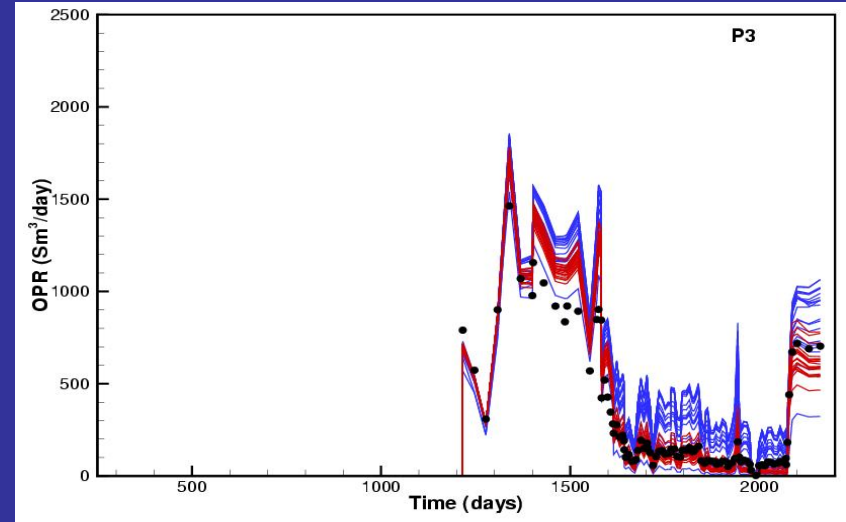
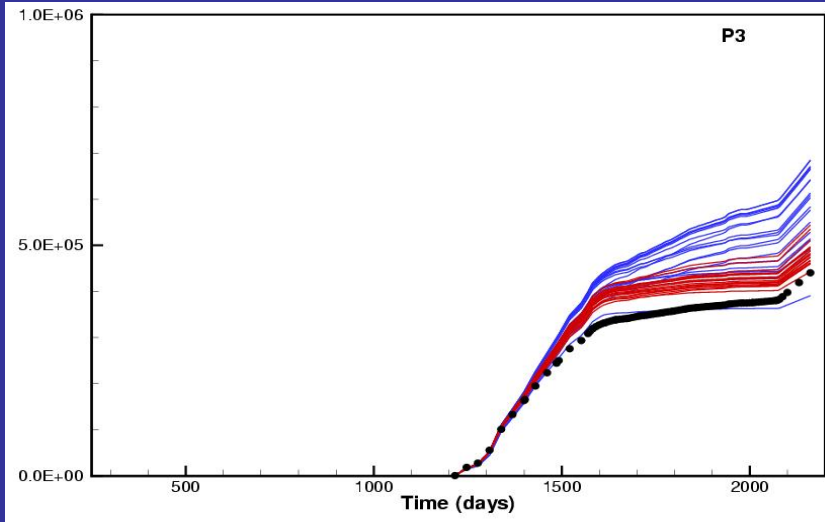
P1



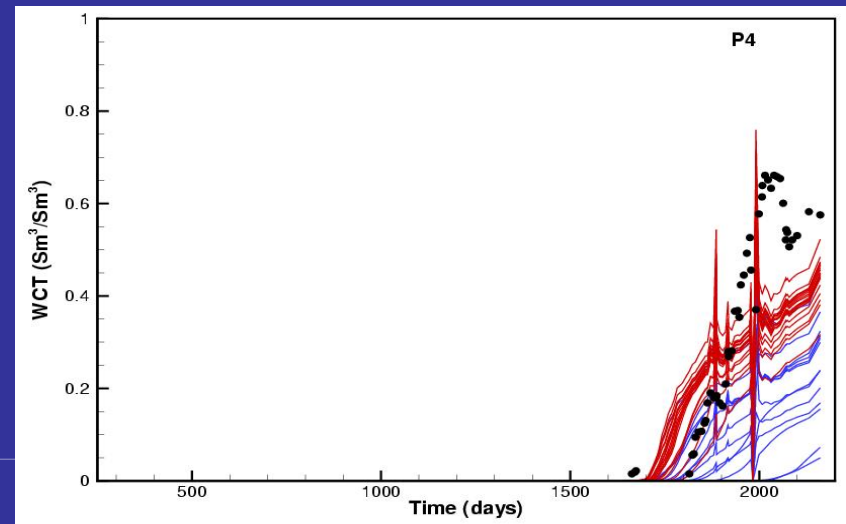
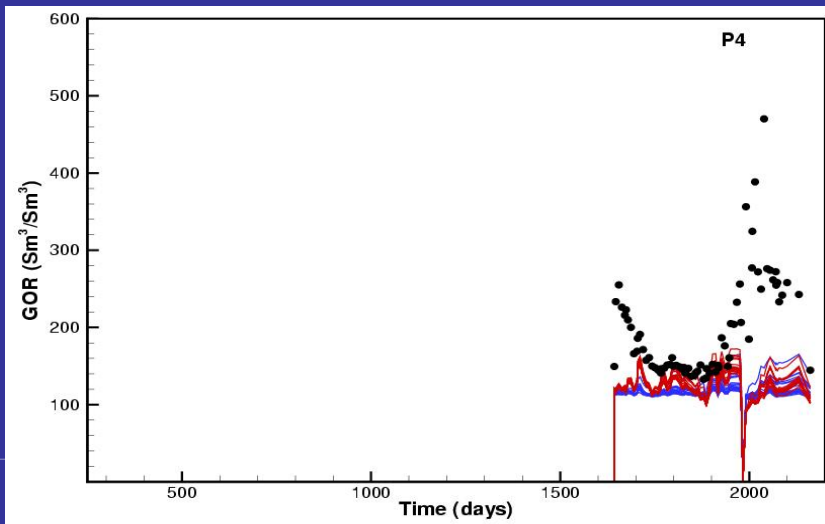
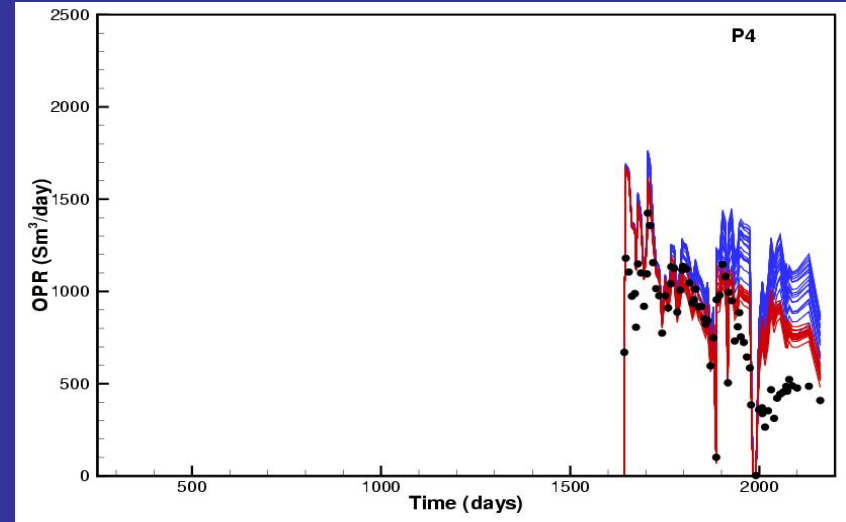
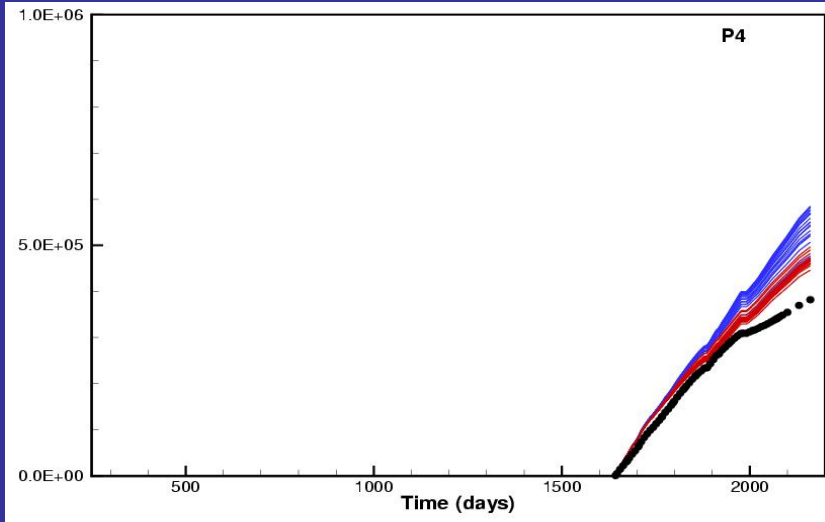
P2



P3



P4



Summary

- **Successful EnKF application**
- **Improved estimates of some parameters.**
- **Remaining issues:**
 - Parameterization.
 - Prior uncertainties.
 - Use of RFT data.
- **EnKF**
 - Starts with ensemble of realizations representing prior uncertainties.
 - Results in conditioned realizations with reduced uncertainties.
- **Allows for predictions with uncertainty estimate.**