Use of Grid Computing in Ensemble Kalman Filter Based Data Assimilation for Hydrocarbon Reservoirs

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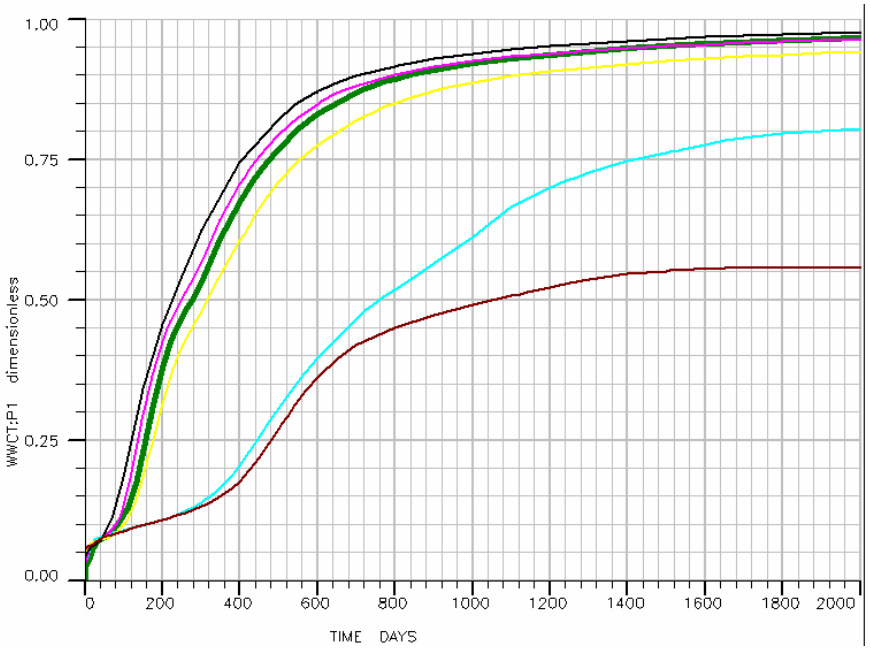
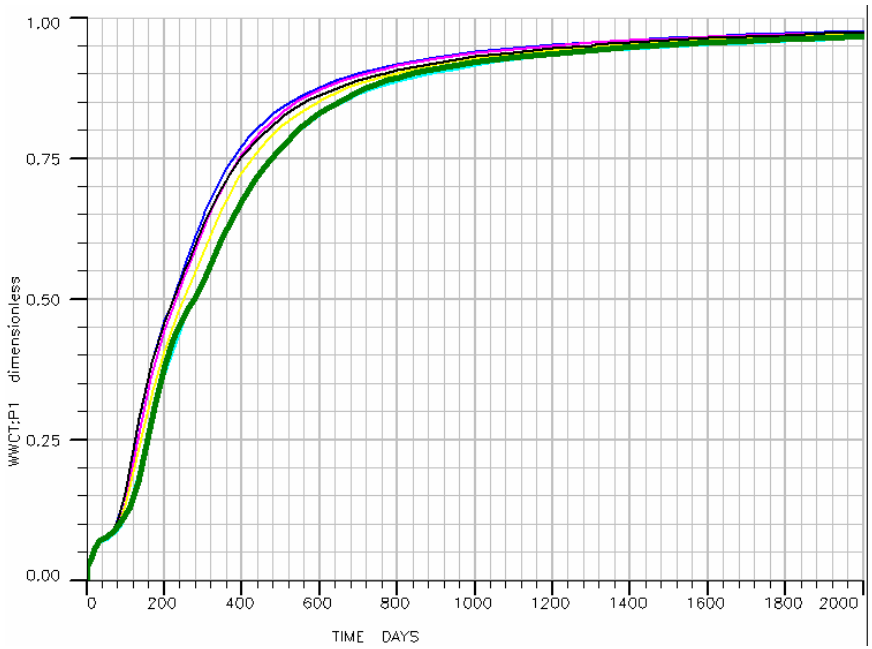
Outline

- Objective
- Approach
- Implementation
- Results
- Conclusions

History Matching



Original



Matched

What is the Ensemble Kalman Filter (EnKF)?

- It is a sequential updating technique.
- Developed for weather forecasting.
- Now put to use in
  - Reservoir Characterization.
  - Ocean Current Modeling.

Intro to Bayes Theorem: Objective Function

We need to minimize this function with respect to 'm' to find a solution to the history matching problem.

$$F\langle m|d\rangle \propto \underbrace{[d-g(m)]^T C_d^{-1}[d-g(m)]}_{\text{Data Misfit}} + \underbrace{[m-m_p]^T C_M^{-1}[m-m_p]}_{\text{Prior Term}}$$

EnKF: The Equations Behind It

KALMAN GAIN

DATA MISFIT

$$m_a = m_p + C_M G^T \left[G C_M G^T + C_D \right]^{-1} (d_{obs} - G m_p)$$

OPTIMAL ESTIMATE OF THE MODEL PARAMETERS

m^a Updated Model

m^p Apriori Model

$C_M G^T$ Cross Covariance Data and Permeability

C_M Model Parameter Covariance

d_{obs} Observations

C_D Data Noise Covariance

$d=Gm$ Relation, data and model

EnKF
The Equations Behind It

$$C_M \approx C^{p}_{M,\,ensemble} = \frac{1}{N_e - 1}\sum_{j=1}^{N_e}(m_j^p - \overline{m}^p)(m_j^p - \overline{m}^p)^T$$

OPTIMAL IF N_e IS LARGE OR APPROACHES INFINITY

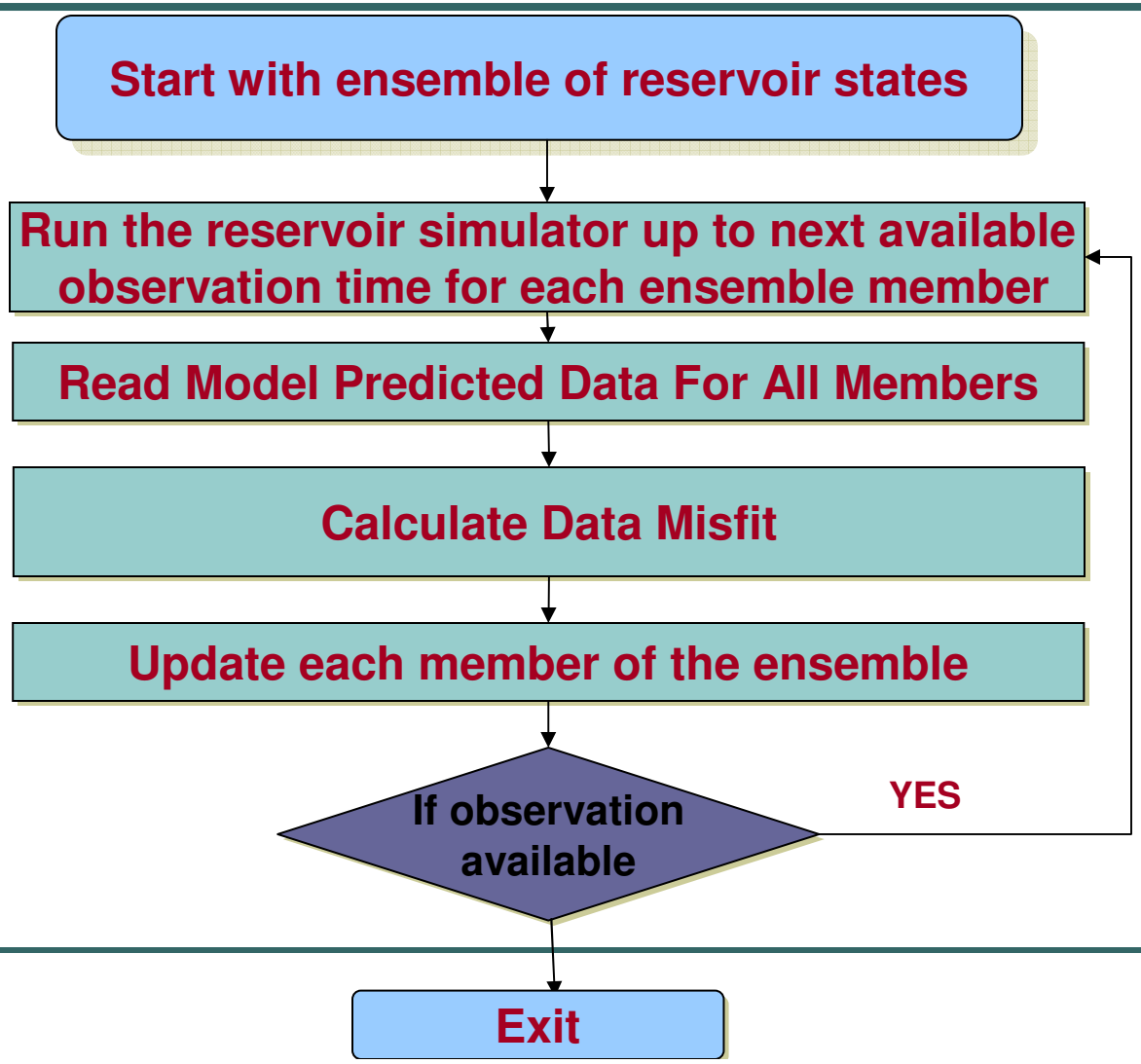
EnKF: Setup

$$m_k = \begin{bmatrix} \text{Pressure}(1...n_{\text{gridblock}}) \\ \text{Water Saturation}(1...n_{\text{gridblock}}) \\ \text{Permeability}(1...n_{\text{grdiblock}}) \end{bmatrix}$$

State vector or Model

Vector of observations $d_k = \begin{bmatrix} \text{Gas Oil Ratio}(1...n_{\text{wells}}) \\ \text{Water Cut}(1...n_{\text{nwells}}) \\ \text{BHP}(1...n_{\text{nwells}}) \end{bmatrix}$

EnKF: Workflow

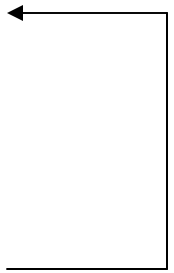


Implementation

- Running forward model for all members is calculation intensive step
- Different kind of data needs to be assimilated simultaneously
  - Means running different numerical simulators for each model

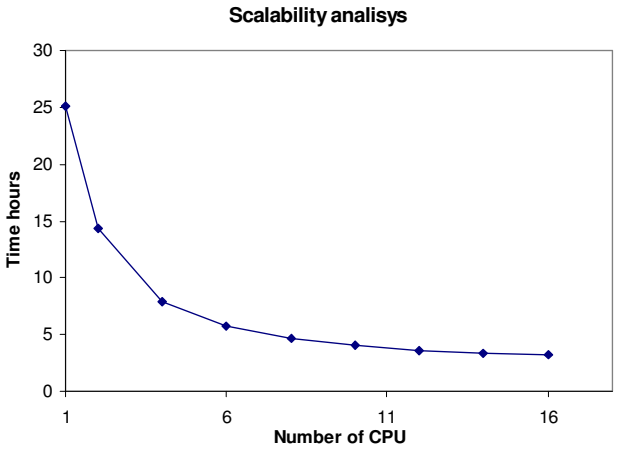
Implementation Issues

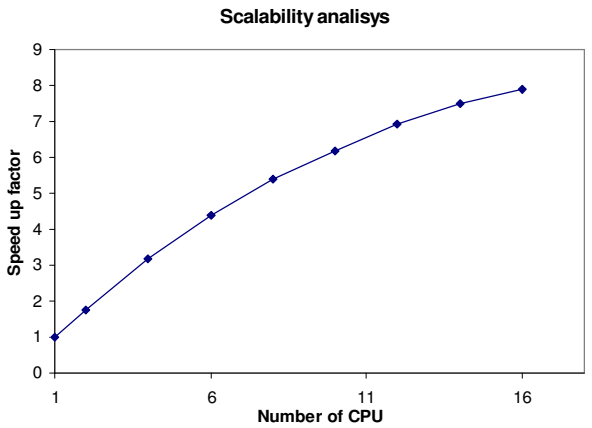
- Start at master node
- Run different models in parallel
- Collect results at the master node
- Update models



Parallelization

- Our computer code
  - Object oriented
  - Fairly general
  - Works with Eclipse and Frontsim
  - Unix Parallel version at Texas A&M (128 CPU) super computer





Implementation Issues

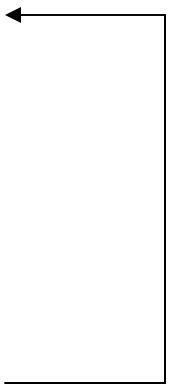
- What if
  - Very large model
  - Very large number of models
  - Different kind of data handled together

Grid Computing

- Using computing resources across various institution
- Running forward model for different models using WS-GRAM

Calculation Sequence

- Start at master node
- Run different models in parallel across different campuses
- Collect results at the master node
- Update models



Participating Institutions

- Texas A&M University : COSMOS
- Texas Tech University : MINIGAR
- University of Houston

WS-GRAM Implementation

```
#!/bin/bash
set -x

# GRID COMPUTING
globusrun-ws -S -submit -f run1.xml
globusrun-ws -S -submit -f run2.xml
globusrun-ws -S -submit -f run3.xml
globusrun-ws -S -submit -f run4.xml
globusrun-ws -S -submit -f run5.xml
```

WS-GRAM Implementation

```
<?xml version="1.0" encoding="UTF-8"?>
<multiJob
    xmlns:gram="http://www.globus.org/namespaces/2004/10/gram/job"
    xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
   <factoryEndpoint>
      <wsa:Address>
         https://localhost:8443/wsrf/services/ManagedJobFactoryService
      </wsa:Address>
      <wsa:ReferenceProperties>
         <gram:ResourceID>Multi</gram:ResourceID>
      </wsa:ReferenceProperties>
   </factoryEndpoint>
   <directory>${GLOBUS_LOCATION}</directory>
   <count>1</count>
```

WS-GRAM Implementation

```
<job>
      <factoryEndpoint>
<wsa:Address>https://minigar.hpcc.ttu.edu:8443/wsrf/services/ManagedJobFactoryService</wsa:Address>
         <wsa:ReferenceProperties>
            <gram:ResourceID>Fork</gram:ResourceID>
         </wsa:ReferenceProperties>
      </factoryEndpoint>
      <executable>./runForward</executable>
<directory>/home/a0k6313/enkf/run/bimodal2/out9/member001</directory>
      <stdout>/home/a0k6313/enkf/run/bimodal2/out9/member001/stdout.p1</stdout>
      <stderr>/home/a0k6313/enkf/run/bimodal2/out9/member001/stderr.p1</stderr>
      <count>1</count>
   </job>
```

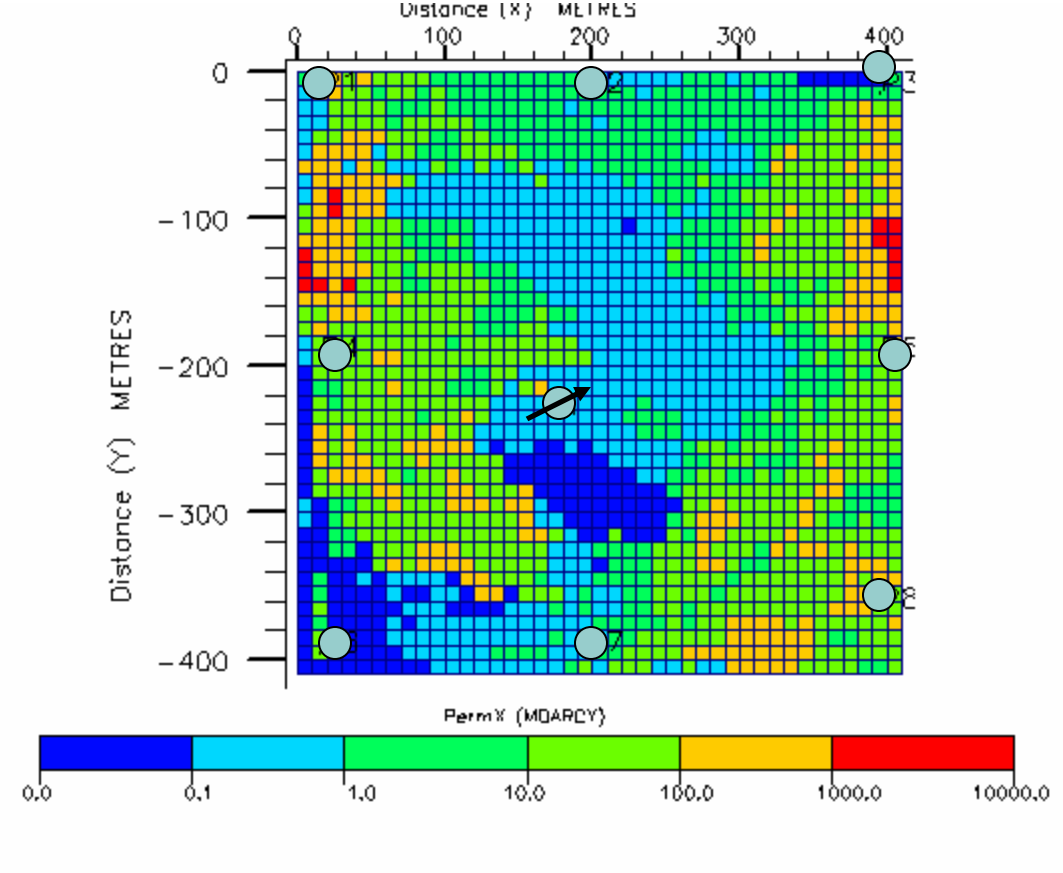
WS-GRAM Implementation

```
<job>
    <factoryEndpoint>
  <wsa:Address>https://cosmos.tamu.edu:8443/wsrf/services/ManagedJ
  obFactoryService</wsa:Address>
      <wsa:ReferenceProperties>
        <gram:ResourceID>Fork</gram:ResourceID>
      </wsa:ReferenceProperties>
    </factoryEndpoint>
    <executable>./runForward</executable>
  <directory>/scratch/a0k6313/enkf/run/bimodal2/out9/member007</direc
  tory>
  <stdout>/scratch/a0k6313/enkf/run/bimodal2/out9/member007/stdout</
  stdout>
  <stderr>/scratch/a0k6313/enkf/run/bimodal2/out9/member007/stderr</st
  derr>
  <count>1</count>
```

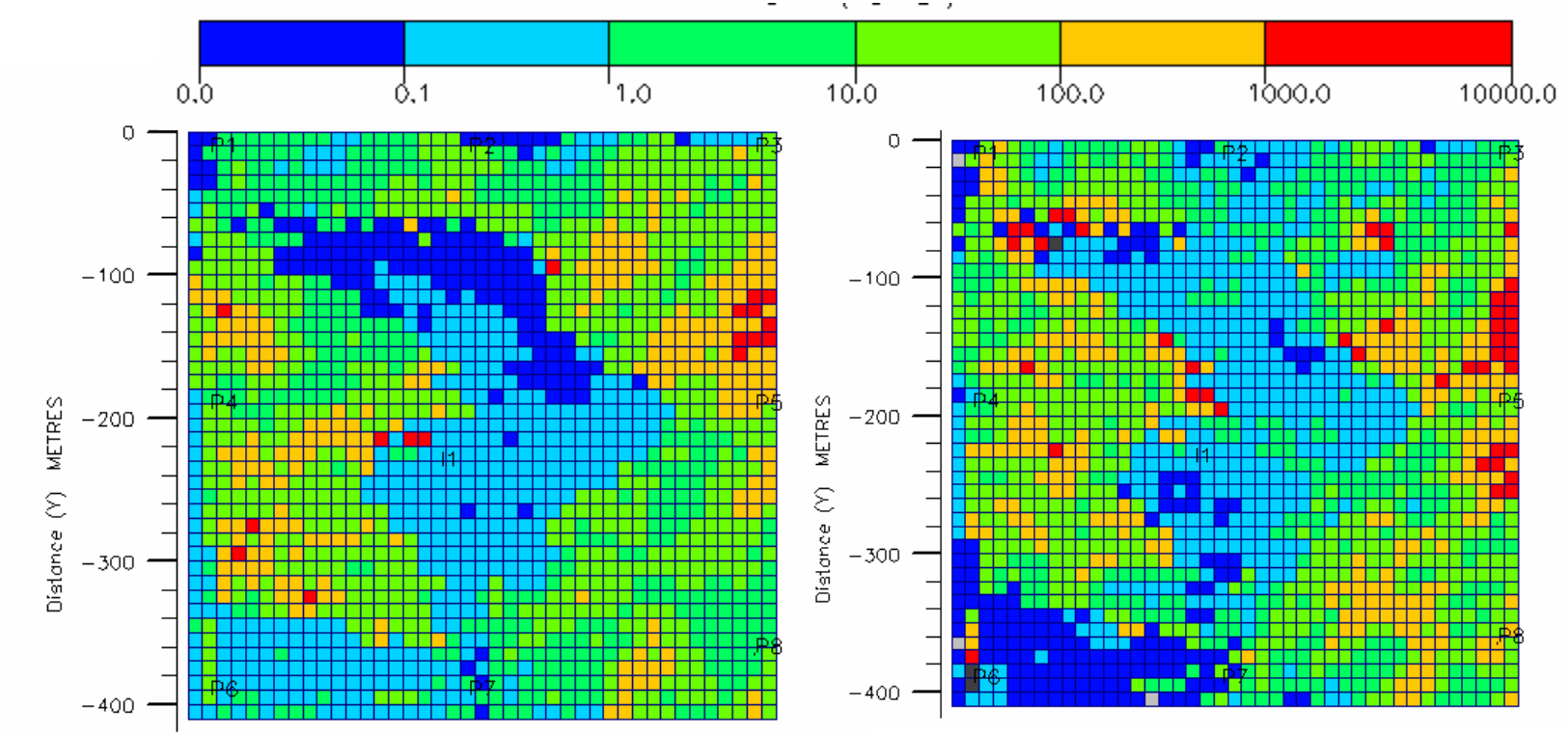
WS-GRAM Implementation

```
<fileStageIn>
    <transfer>
  <sourceUrl>gsiftp://minigar.hpcc.ttu.edu:2811/home/a0k6313/enkf/run/bimodal2/out9/member007/PERMX.DAT</sourceUrl>
  <destinationUrl>file:///scratch/a0k6313/enkf/run/bimodal2/out9/member007/PERMX.DAT</destinationUrl>
    </transfer>
</fileStageIn>
<fileStageOut>
    <transfer>
  <sourceUrl>file:///scratch/a0k6313/enkf/run/bimodal2/out9/member007/SIMWWCT.temp</sourceUrl>
  <destinationUrl>gsiftp://minigar.hpcc.ttu.edu:2811/home/a0k6313/enkf/run/bimodal2/out9/member007/SIMWWCT.temp</destinationUrl>
    </transfer>
</fileStageOut>
```

True Permeability Field and Well Placement



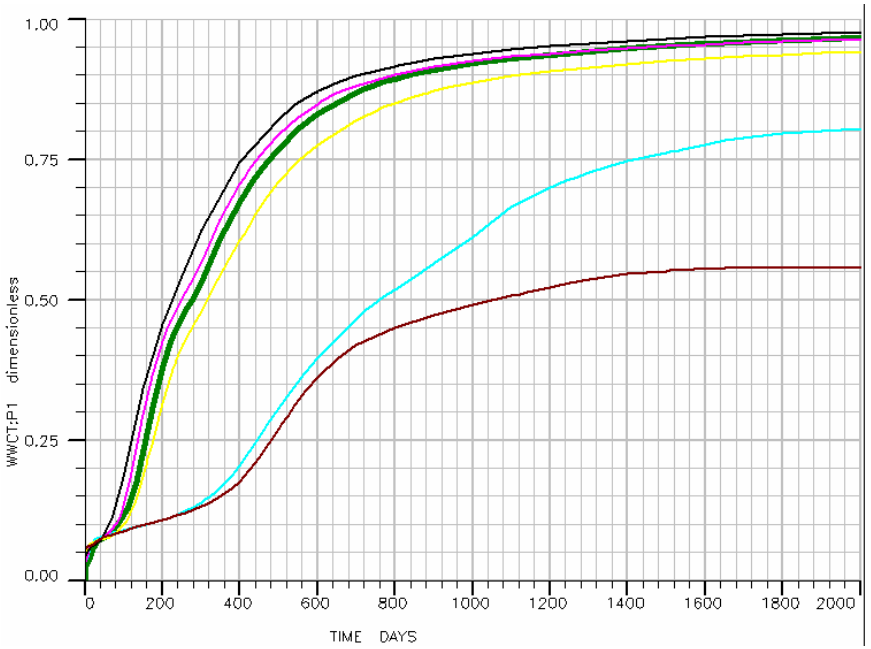
Initial and Final Permeability: Model 1



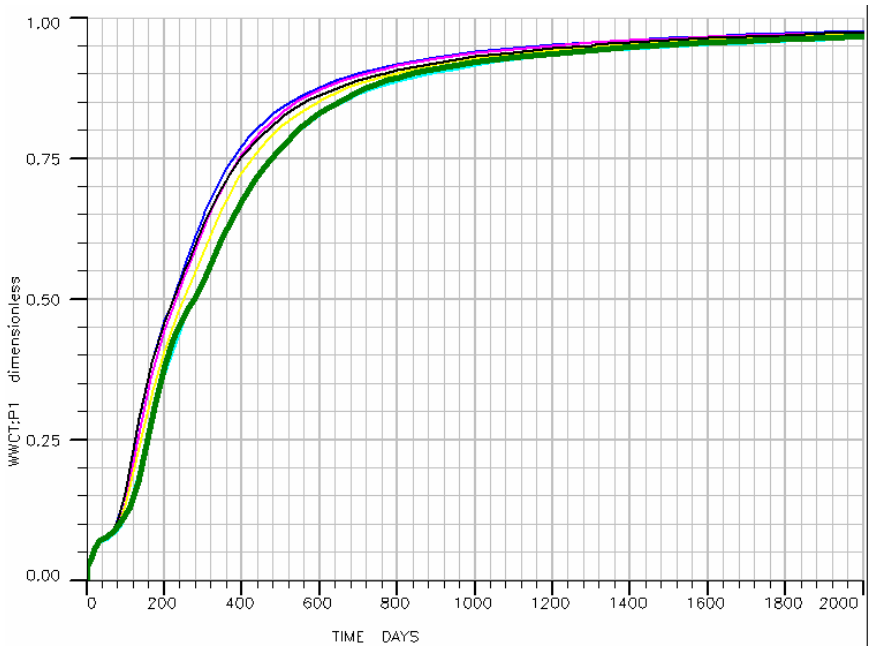
Original

Matched

Water Cut – Well P1



Original



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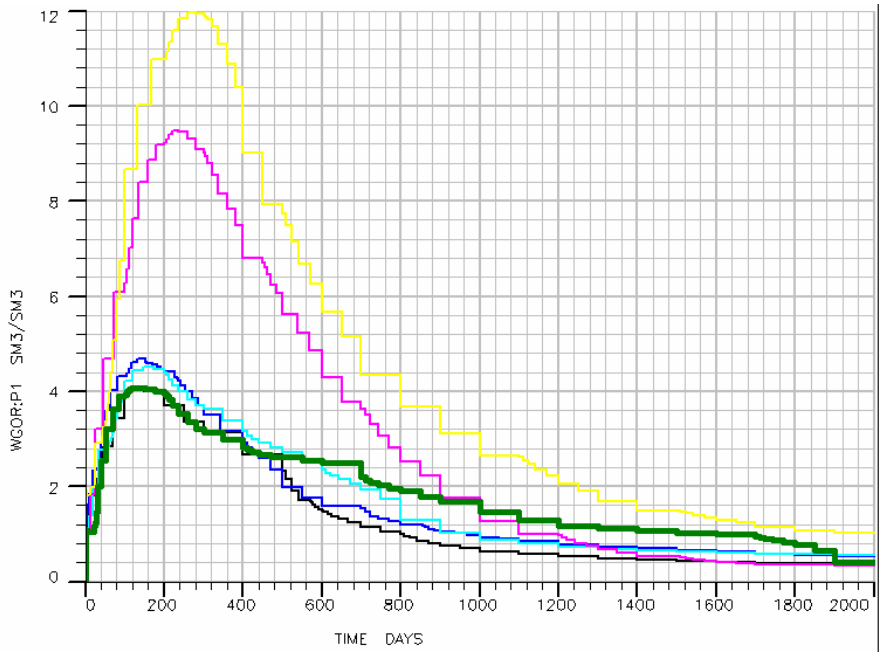
Gas Oil Ratio: Well P1



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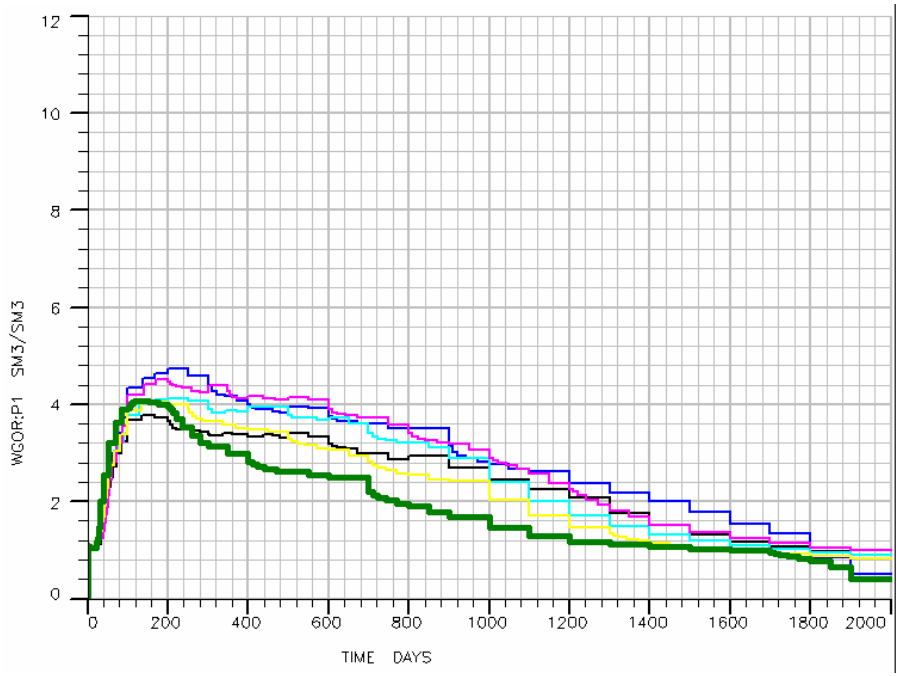

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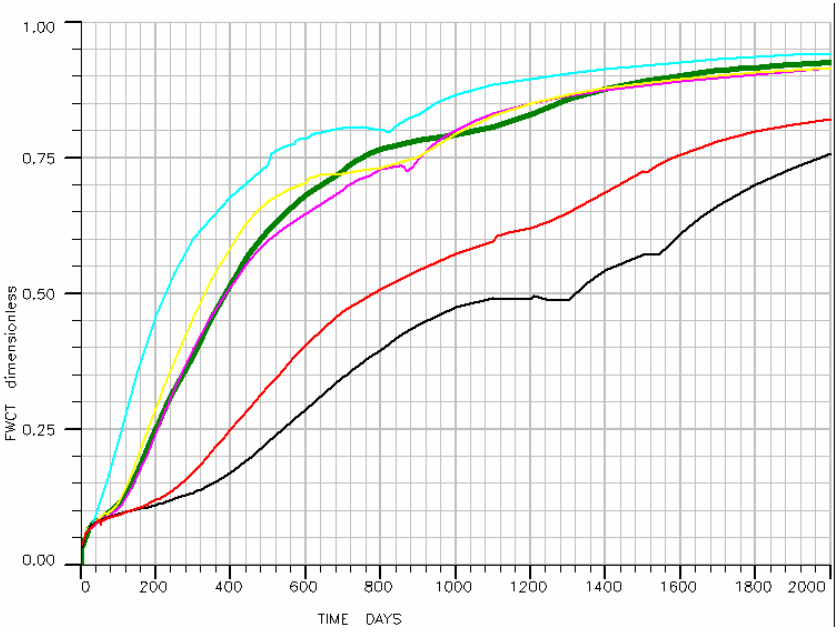
Field Water Cut



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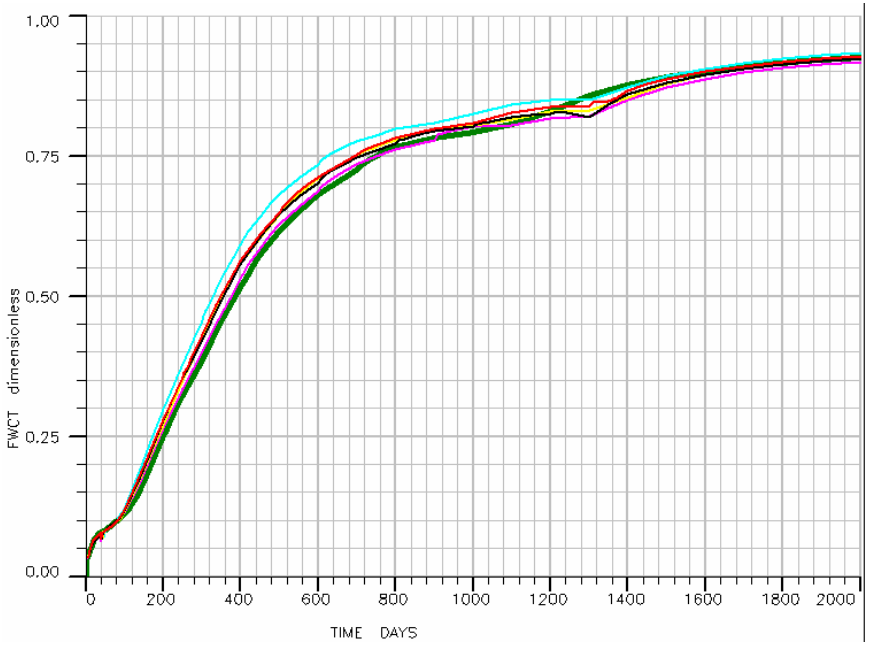

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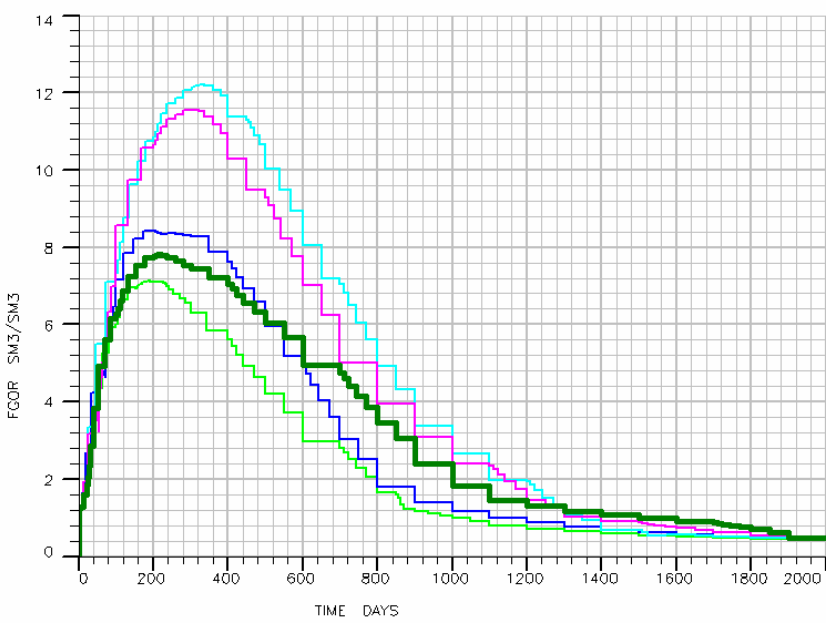
Field GOR (Gas Oil Ratio)



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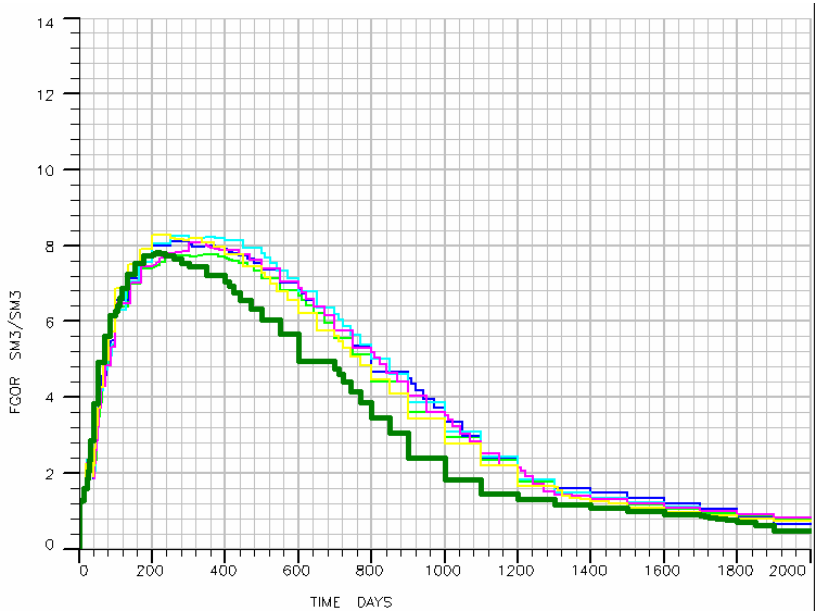

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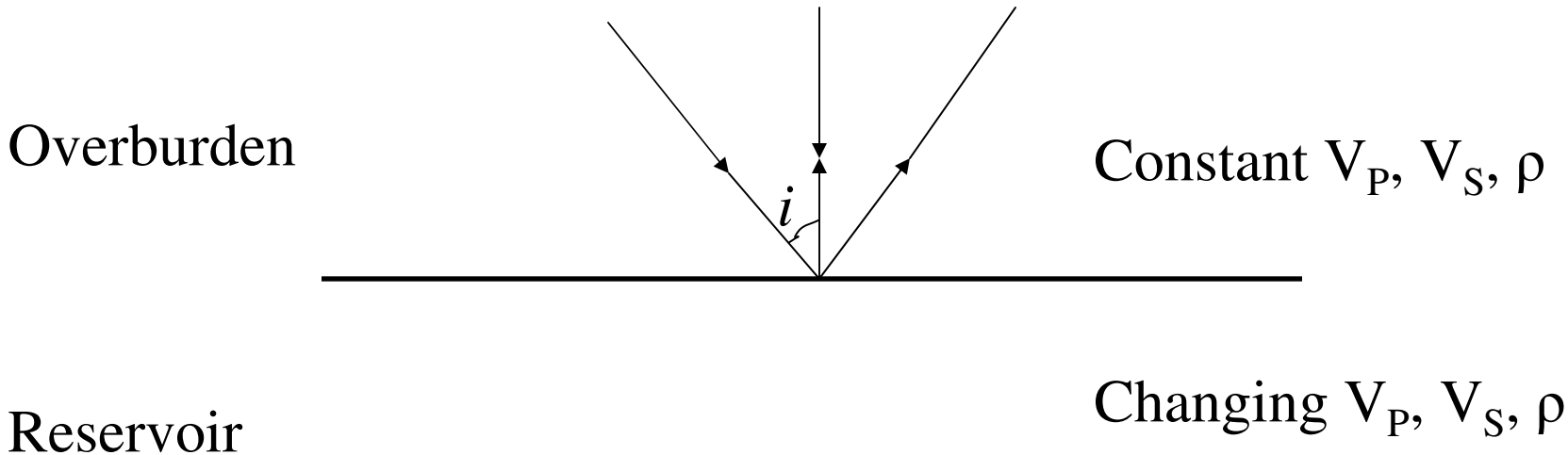
Next

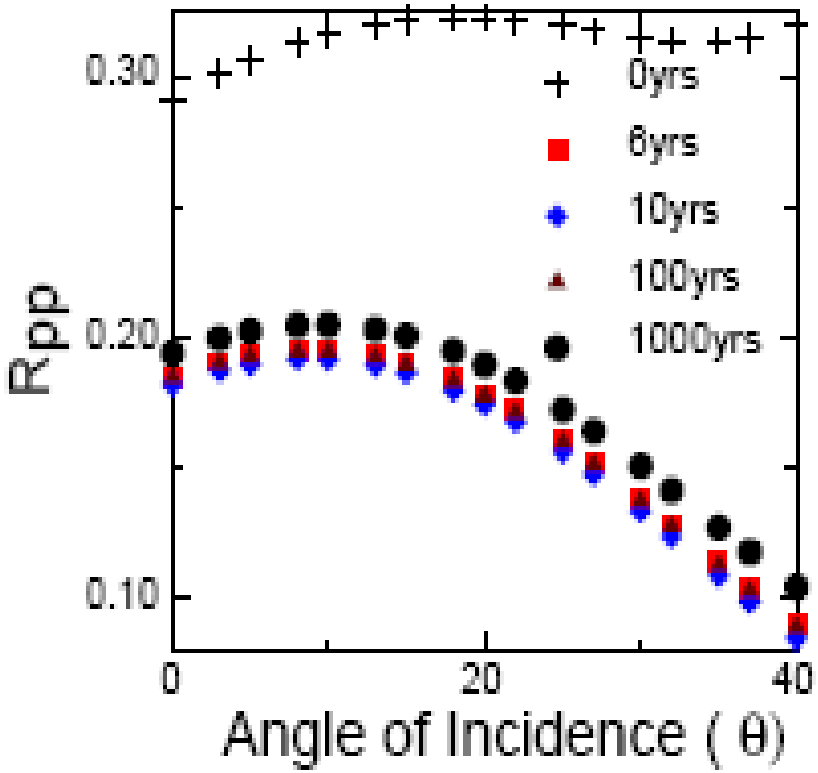
- Integrating seismic data
  - Rock-physics modeling
  - Seismic amplitude calculation

Schematic of the System



$$R(i) \approx R(0) + G \sin^2 i$$

Reflection Coefficient



Conclusion

- Successful implementation of EnKF code with grid computation technology.
- Studies with large ensemble size possible
- More integrated studies may be planned