Improved Reservoir Description using Seismic History Matching

Outline

• Aims
• What is Seismic History Matching?
  – Improving reservoir description
• Improving convergence
• Application to
  – Schiehallion
  – Nelson
• Conclusions
Seismic history matching aims

• We want to develop
  – Appropriate geo-modelling and updating strategies
  – Quantified quality of seismic prediction and observation
  – Good rate of convergence during history matching

• This leads to
  – Spatio-dynamic reservoir characterisations
  – Improved predictive capability of models

• And thus: better decisions
  – Well planning
  – Workovers
  – Gas/water handling
Technical introduction: Seismic History Matching

Generate multiple models

Evaluate misfit

Update parameters

Compare observed & predicted data

Details in: SPE94173-PA, SPEJ, December 2006.
Technical introduction:
Seismic History Matching

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Depth

Time

Reservoir model
Model parameterisation

- Static (Pre-SHM)
  - Porosity, NTG
- Flow properties
  - Facies based
  - Permeability/NTG
  - Fault/barrier transmissibility
  - Geobody properties
- PE transform
Technical introduction: Seismic History Matching

Generate multiple models

Evaluate misfit

Update parameters

Compare observed & predicted data

reservoir model

depth time

$M = \Sigma \Delta x |C| \Delta x$
Impedances/attributes

Modelled seismic data

TIME

DEPTH

RESEVOIR

FEEDBACK OF COMPARISONS FOR UPDATE

PETROPHYSICAL MODEL

Pressures and saturations

Borehole seismic and well logs

cross-equalized seismic datasets

calibrate

inversion

reconciled 4D signature

Modelled seismic data

PETROPHYSICAL MODEL

Pressures and saturations

PETROPHYSICAL MODEL
Time to depth

ΔEI cross section

Maximum amplitude for each layer

Maps of ΔEI
  Top
  Middle

Maps of ΔI

RMS over time window

Nelson

Schiehallion
Technical introduction: Seismic History Matching

Generate multiple models

Update parameters

Evaluate misfit

$M = \Sigma \langle \Delta x | C | \Delta x \rangle$

Compare observed & predicted data

Depth

Reservoir model

Time
Misfit Definition

- Misfit per variable (e.g. water rate, $\Delta AI$, etc.)

\[
M_j = \langle o_j - m_j \mid C_j^{-1} \mid o_j - m_j \rangle
\]

- Total Misfit for all variables

\[
M = \sum_{j=1}^{n} M_j
\]
Technical introduction: Seismic History Matching

- Generate multiple models
- Evaluate misfit
- Update parameters
- Compare observed & predicted data
- Reservoir model
- Depth time

\[ M = \sum \Delta x |C| \Delta x \]
Neighbourhood Algorithm

- Quasi-Global
- Multiple model
  - Random initial sample
  - Identify neighbourhoods
  - Pick best nr
  - Add ns:nr per best nr
  - Generate new models
  - Repeat

Parameter 1

Parameter 2

Misfit surface
NA with Proxy derived Gradients (NAPG)

- Local sensitivities
  - Calculate gradient of misfit,

\[
\nabla M = \sum_{i=1}^{N} \frac{\partial M}{\partial p_i} n_i
\]

- Use gradient to bias sampling in voronoi cells
- Proxy models

\[
M(x) = C_o + \sum_{i=1}^{nd} C_i X_i + \sum_{i=1}^{nd} C_{i+nd} X_i^2 + \sum_{i=1}^{nd-1} \sum_{j=i+1}^{nd} C_{ij} X_i X_j
\]

Arwini and Stephen, 2010 (SPE 131545S)
Schiehallion – NA v. NAPG

- 6 surveys (4 monitors)
  - Pressure dominated
- Improving
  - Fault transmissibility
  - NTG
  - Permeability
- Barriers
  - Location may be obvious
  - What is the transmissibility?
History matching

- 10 dimensional problem
  - Barrier transmissibility
- Updating of regression equation
- NA convergence rate improved 2-3 times
- Same outcome for final models

Arwini and Stephen, 2010 (SPE 131545S)
"Divide and Conquer" - faster convergence

Exploration and exploitation of entire parameter space

Non-Orthogonal

\( \phi_v(g)(x_1, x_2) = g_v(x_1, x_2) \)

Search orthogonal parameter space

Orthogonal

\( \phi_v(g)(x_1, x_2) = g_v(x_1) + g_v(x_2) \)

\[
F(x) = \sum_{i=1,3,5,7} (x_i^2 + x_{i+1}^2 + x_i x_{i+1})
\]

Number of Models for Specified Misfit Threshold

- \( n_i = 128 \)
- \( n_s = 64 \)
- \( n_r = 32 \)

Cases

- 14D
- 12D+2D
- 10D+4D
- 8D+6D
- 6D+2*4D
- 3*4D+2D
- 7*2D

Increasing decomposition

- \( n_s = 64 \)
- \( n_r = 32 \)

Number of models
Divide parameter space: decomposition

- Initialisation
- Decomposition
- Final result

Ensemble of data

Interaction terms

Polynomial Response Surface

Interacting parameters threshold

Decompose to Sub-misfits

\[ f(\theta) = a_0 + \sum_{i=1}^{nd} a_i \theta_i + \sum_{i=1}^{nd} b_i \theta_i^2 + \sum_{i=1}^{nd} \sum_{j > i}^{nd} b_{ij} \theta_i \theta_j \]

\[ J(\theta) = j_1(\theta_1...\theta_p) + j_2(\theta_{p+1}...\theta_q) + ... + j_k(\theta_{m...n}) \]
18-dimensional history matching

- History match to 2004
- Updating pilot points and faults/barriers simultaneously
- 12 faults and barriers
- Pilot points (6 groups)
  - NTG, PermH, PermZ

Diagram:
- Injector 1
- Master Pilot Points location roughly
- Producer 4
- Producer 5
Schiehallion

- Initialization: Central Composite Experimental Design of 549 models
- Good convergence
- Good match

Sedighi and Stephen, 2009 (SPE121210) and Sedighi and Stephen, EAGE 2010
Nelson

- Turbidite reservoir
  - Three intervals
- Baseline and three monitors
  - EI and Amplitudes
  - Saturation dominated
- Uncertainties dominated by shale content

Channel shales affect NTG, Kh and Kz

Gill et al, 2007
Nelson – Appropriate updating

- Streamline guide
- Locations from streamlines  
  - good history match
- Ad hoc well vicinity  
  - good history match
- Forecasting  
  - Streamlines give best

Kazemi and Stephen, 2010 (SPE 131540)
4D normalization

Before normalization

Normalising observed 4D

\[ Y = a \times x + b \]

After normalization

Synthetic 4D

Observed 4D

Synthetic 4D

SPE 131538
Nelson results – using well data

- PSHM better match
- PSHM better forecast
- PHM makes seismic much worse

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<tr>
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<th>PHM</th>
<th>PSHM</th>
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<td>Production, 1994-2000</td>
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<td>Production, 2000-2003</td>
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Kazemi et al., 2010 (SPE 131538)
Summary

- 4D seismic helps to condition simulation models
- Proxy models help with convergence
  - Sensitivities via gradients
  - Divide and Conquer
- Streamlines guide where to update
- 4D seismic must be normalised
  - Use well data
- Production data gives match but forecast is poor
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