Adaptive Multiscale Streamline Simulation and Inversion for High-Resolution Geomodels (SPE 106228)

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Summary

Objective: direct integration of production data in geomodels

Multiscale-streamline method:

- Very fast evaluation of production responses
- Generalized travel-time inversion with analytical sensitivities
- Selective work reduction based on sensitivities

☞ History matching of million-cell models within the hour!

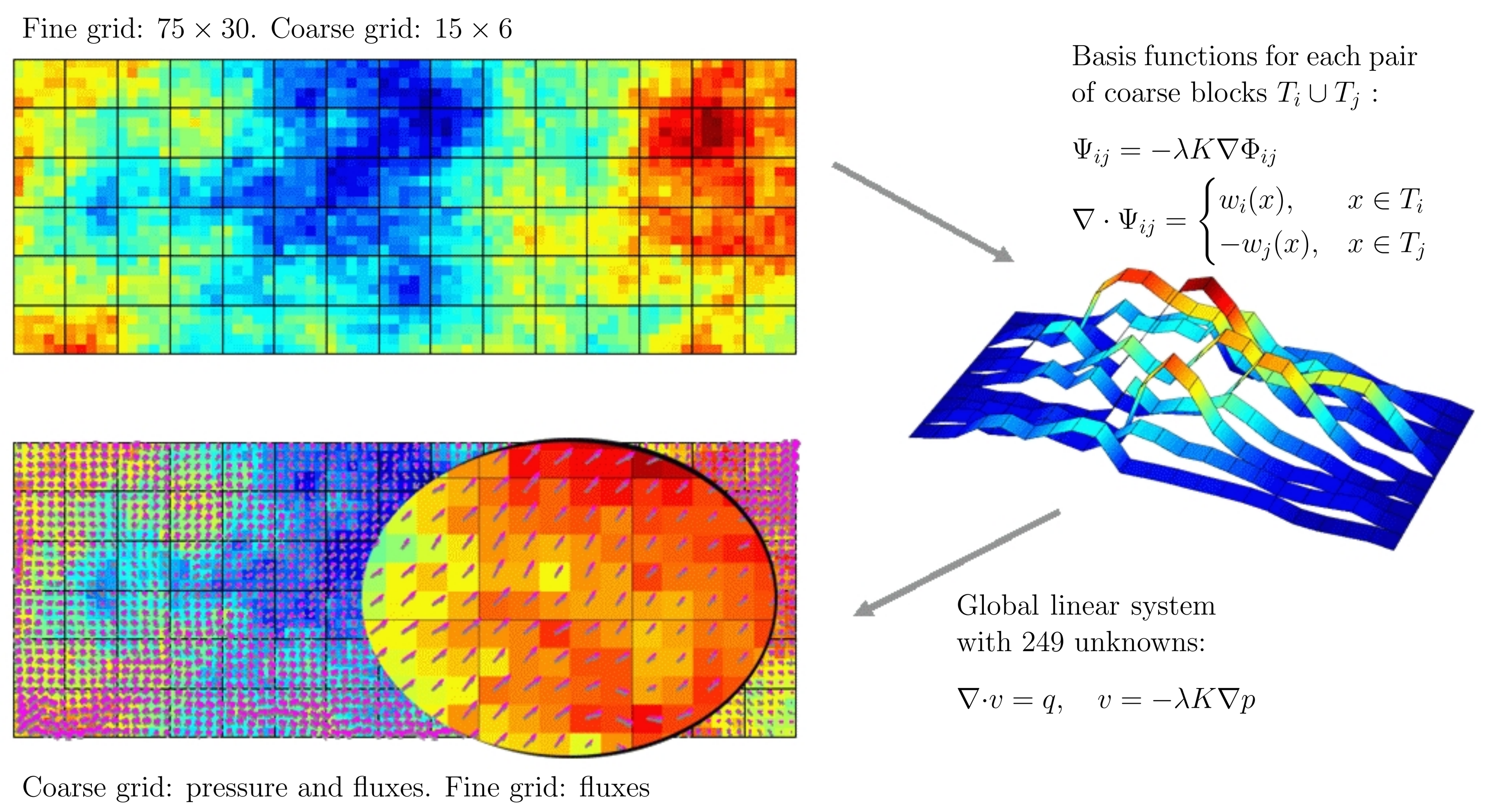
Flow Simulator

Streamline method:

- Mass-conservative streamline formulation [1]
- Analytical computation of production sensitivities

Multiscale pressure solver (MsMFEM) [2,3]:

- Basis functions: representative *fine-scale* flow patterns inside pairs of coarse blocks. Obtained by solving local flow problems as in flow-based upscaling
- Pressure and velocity updated by solving a global problem on the *coarse grid*
- Work reduction: basis functions not recomputed in regions that have negligible influence on production responses



Properties of MsMFEM:

- ✓ Incorporates small-scale effects into the coarse-scale solution
- ✓ Mass conservative on coarse grid and subgrid
- ✓ Scalable since basis function are processed independently
- ✓ Flexible: given a fine-grid solver, coarse cell = a collection of connected fine-grid cells
- ✓ Robust: method can always be defined and will always produce a result (in contrast to upscaling)
- ✓ Accuracy: good, provided that coarse grids follow simple guidelines
- ✓ The method is fast when basis functions are update infrequently

Inversion Method

Generalized travel-time inversion [4,5] minimizes functional:

$$\|\Delta \mathbf{T} - \mathbf{G}\delta\mathbf{k}\| + \overbrace{\underbrace{\beta_1\|\delta\mathbf{k}\|}_{\text{norm}} + \underbrace{\beta_2\|\mathbf{L}\delta\mathbf{k}\|}_{\text{smoothing}}}^{\text{Regularization}}$$

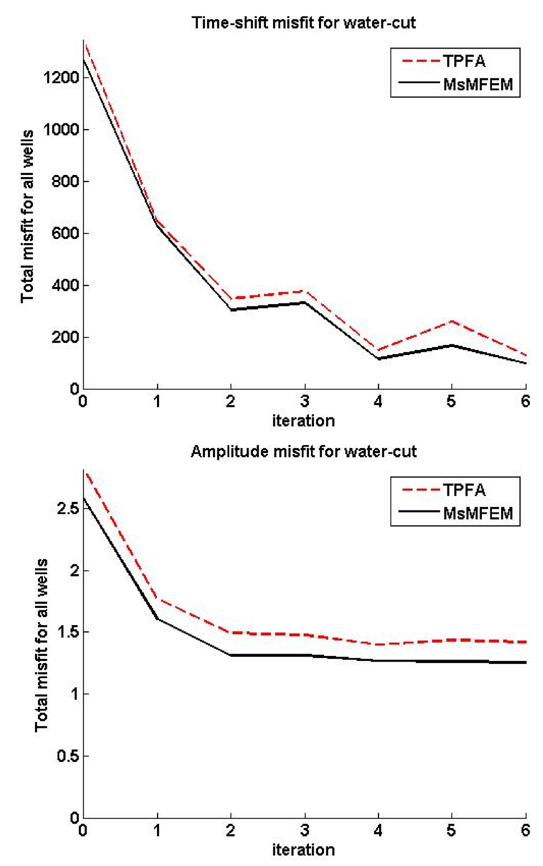
Here: $\Delta\mathbf{T}$ = travel-time shifts, $\mathbf{G}$ = sensitivity matrix, $\mathbf{k}$ = permeability

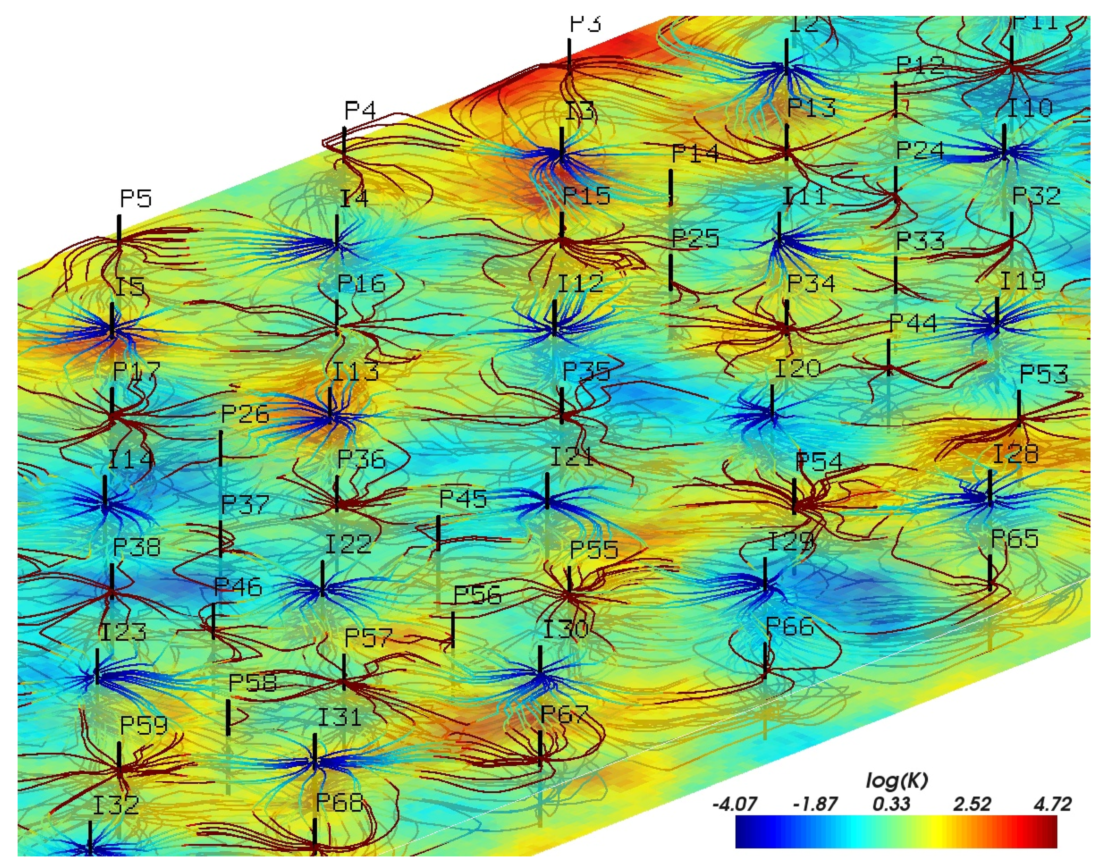
- ✓ Solution by a least-squares algorithm
- ✓ $\mathbf{G}$ computed analytically based on a single forward simulation

Results

History match of a high-resolution 3D geomodel:

- Fine-grid: $256 \times 128 \times 32$ (1,048,576 active cells)
- Coarse-grid: $32 \times 16 \times 8$ (each coarse cell 8×4 fine cells)
- 32 injectors and 69 producers (vertical wells)
- Incorporating 2475 days of water-cut data (almost 7 years) to adjust permeability
- Each forward simulation: 15 pressure steps of 165 days





Pressure solver	Reduction in % for misfit: Time-shift	Amplitude	$\overline{\Delta \log k}$	CPU time 2.4 GHz
Initially	100.0	100.0	0.821	–
7-point FV (TPFA)	9.6	50.4	0.806	39min
MsMFEM	7.6	48.7	0.808	17min

Conclusions

The new multiscale-streamline method:

- ✓ allows rapid history matching of large reservoir models
- ✓ matched 7 years of production history in 17 minutes for a million-cell reservoir model with 69 producers
- ✓ gave significant reductions in computational time using selective updating of basis functions
- ✓ gives updated models that are geologically realistic
- ✓ applies in principle to more complicated grids (corner-point, unstructured)

References

[1] V. Kippe, H. Hægland, and K.-A. Lie. A method to improve the mass balance in streamline methods. SPE 106250, SPE 07 RSS, Houston, 26–28 February, 2007.
[2] Z. Chen and T.Y. Hou. A mixed multiscale finite element method for elliptic problems with oscillating coefficients. *Math. Comp.*, 72:541–576, 2003.
[3] J.E. Aarnes, V. Kippe, and K.-A. Lie. Mixed multiscale finite elements and streamline methods for reservoir simulation of large geomodels. *Adv. Water Resour.*, 28(3):257–271, 2005.
[4] D.W. Vasco, S. Yoon, and A. Datta–Gupta. Integrating dynamic data into high-resolution reservoir models using streamline-based analytic sensitivity coefficients. *SPE J.*, pp. 389–399, December 1999.
[5] Z. He, S. Yoon, and A. Datta–Gupta. Streamline-based production data integration with gravity and changing field conditions. *SPE J.*, pp. 423–436, December 2002.

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