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Global Upscaling

Harald H. Soleng and Arne Skorstad

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Plan

- Ten commandments of upscaling

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- Local upscaling

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- Global upscaling results

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- Conclusion

Ten commandments of upscaling

1. Thou shalt not hold on to irrelevant details

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Ten commandments of upscaling

1. Thou shalt not hold on to irrelevant details
2. Thou shalt not throw away essential information

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10. Thou shalt not neglect off-diagonal components

Local permeability upscaling

Find the upscaled permeability K that gives the same flux through a coarse cell as its corresponding fine cells

$$\nabla \cdot (K \nabla p) = 0.$$

Many different boundary conditions possible.

Fine scale scalar permeability K gives tensor permeability on coarse scale $\mathbf{K}$.

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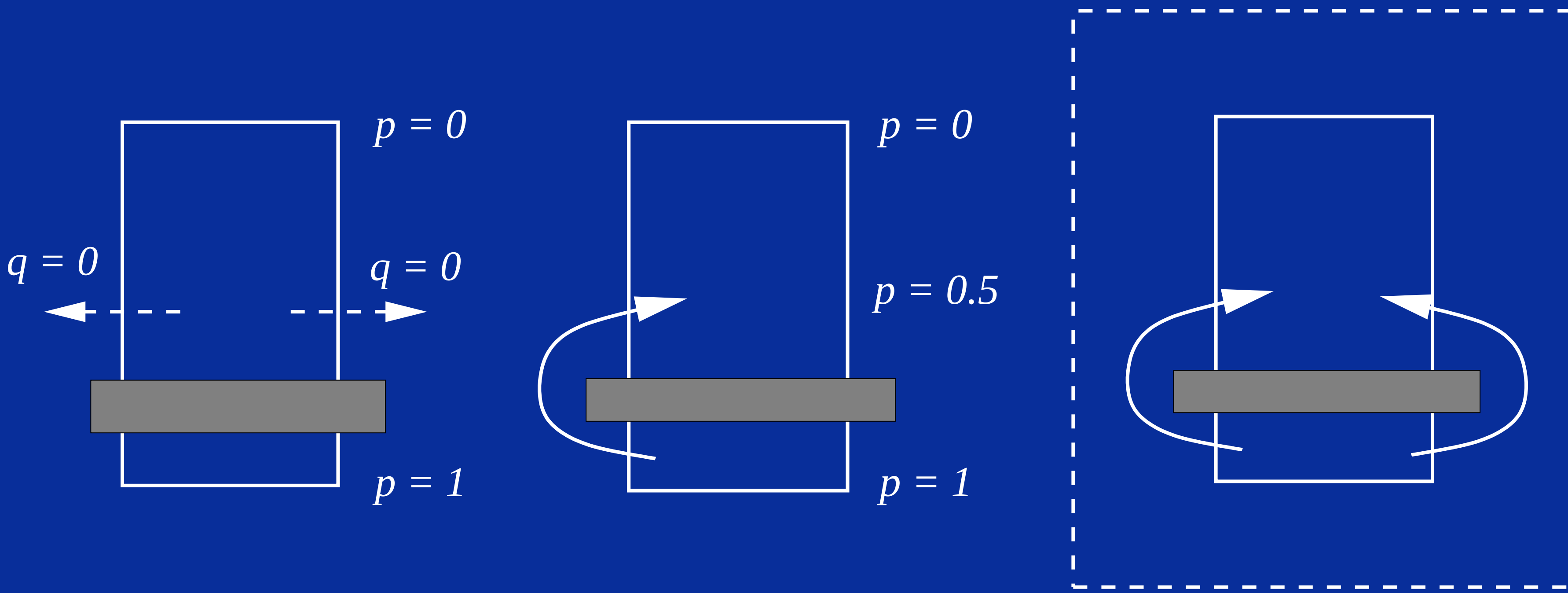
Local permeability upscaling (cont'd)

Noflow edge | Linear pressure | Skin



Mod. het. | Larger eff. perm. | Bridge to global

Correct boundary conditions depend on situation.

Thou shalt not hold on to irrelevant details

- Dynamics on a larger scale may be a totally different ballgame than on the smaller scales

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- Dynamics on a larger scale may be a totally different ballgame than on the smaller scales
- Upscaling in other fields:

  Atomic physics: from quarks and gluons to nuclear particles

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- Upscaling in other fields:

  Atomic physics: from quarks and gluons to nuclear particles

  Chemistry: from nucleons and electrons to atoms and molecules

  F**luid dynamics:** from molecules to fluid elements
- Rationale: To obtain a comprehensible size of equations

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Thou shalt not throw away essential information

What is meant by essential?

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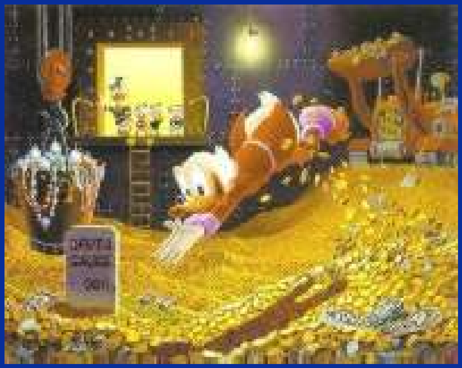

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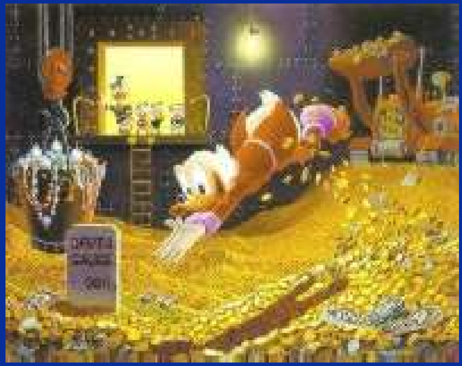

Flow

- Connectivity

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What is meant by essential?

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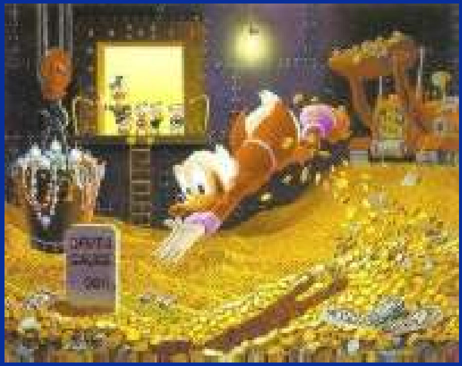
- Connectivity
- Flow barriers

Thou shalt not throw away essential information



What is meant by essential?

Flow

- Connectivity
- Flow barriers
- Flow paths

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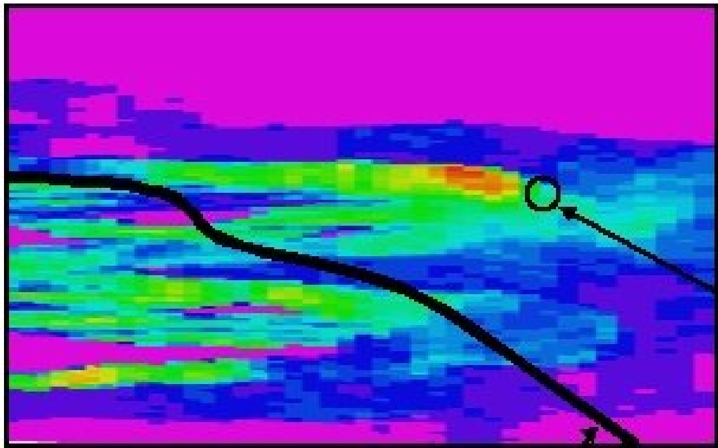
Honour thy welldata and thy well tests



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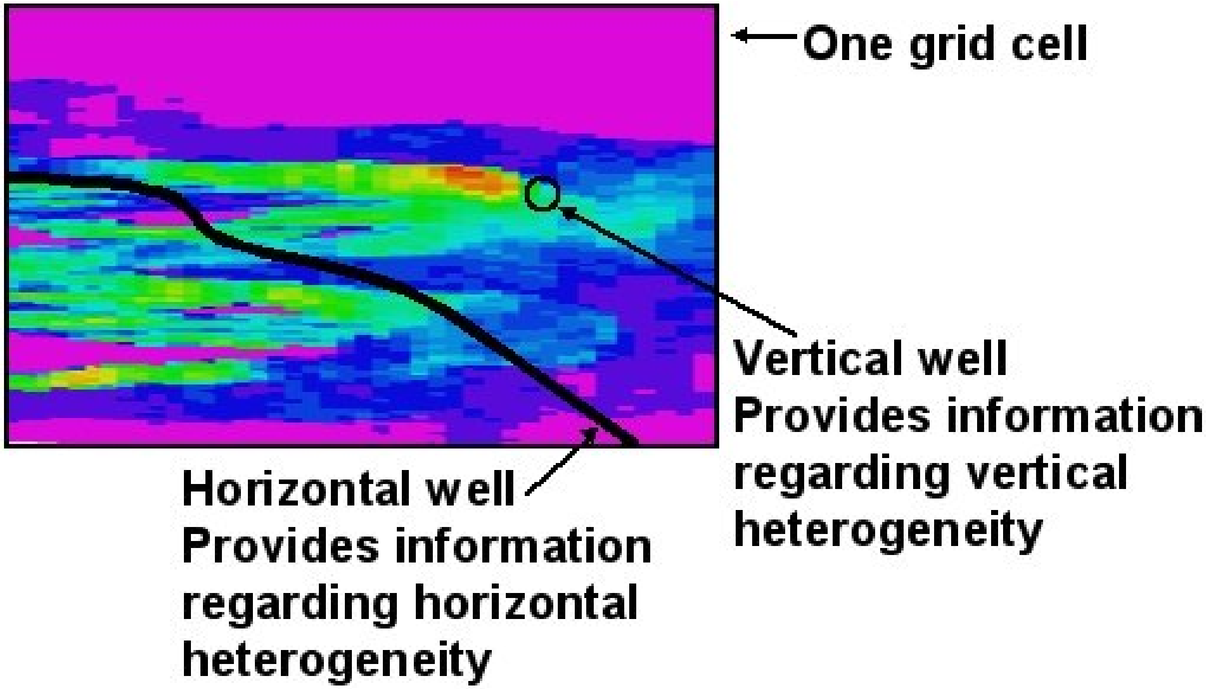

Hard data: vanishing support volume

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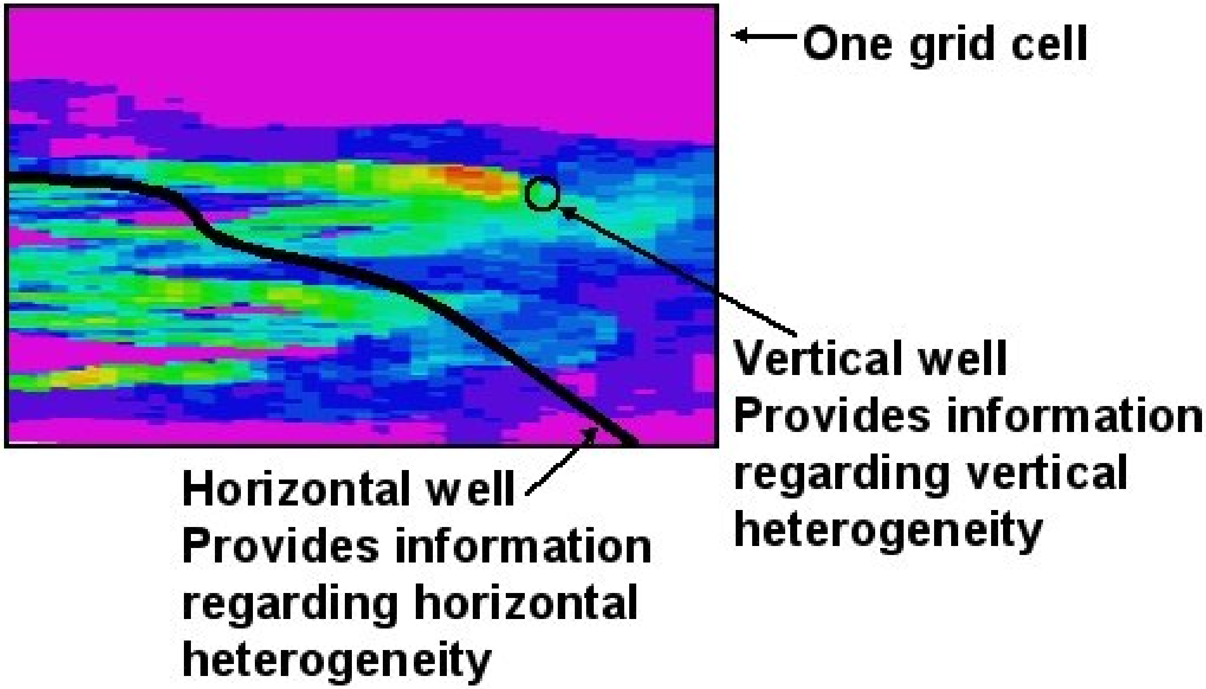

Hard data: vanishing support volume

Well test: information about flow (proper scale)

What is a proper upscaling?

Essential properties carried over to the coarse scale

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Essential properties carried over to the coarse scale

fine scale petrophysics	$\xrightarrow{\text{upscale}}$	coarse scale petrophysics
$\downarrow$		$\downarrow$
fine scale flow	$\xrightarrow[\text{projection}]{\text{upscale by}}$	coarse scale flow

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How to make sure?

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Essential properties carried over to the coarse scale

fine scale petrophysics —upscale→ coarse scale petrophysics

↓ ↓

fine scale flow —upscale by projection→ coarse scale flow

results should be similar

How to make sure?

Let the fine scale flow influence the permeability upscaling

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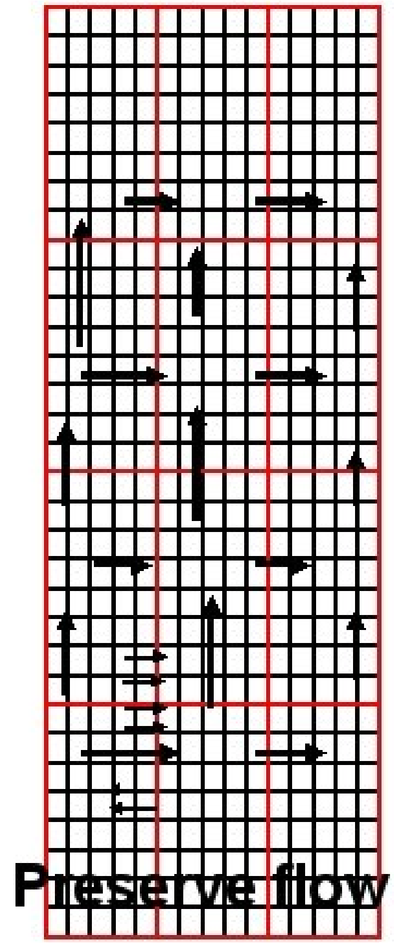
Global upscaling: the idea

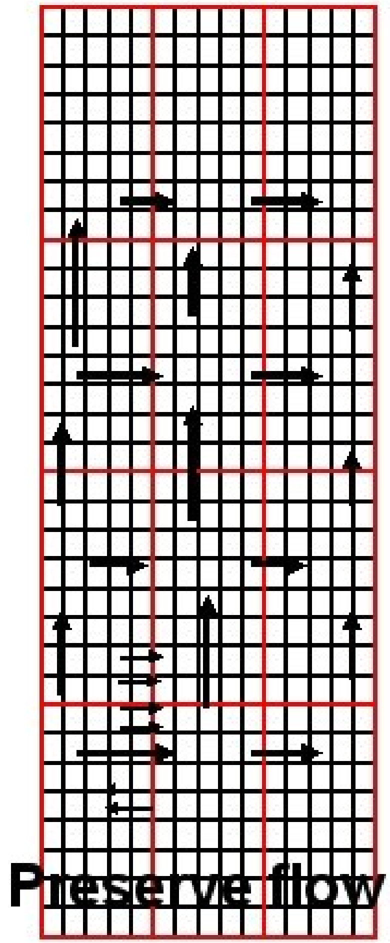
- Minimize errors of flow between the fine and coarse scales



Global upscaling: the idea

- Minimize errors of flow between the fine and coarse scales

- p and q on fine scale give correct boundary conditions on the coarse scale



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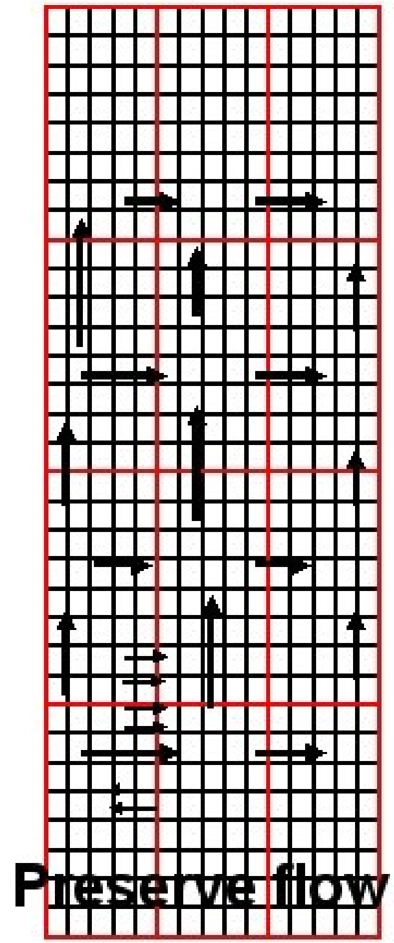
Global upscaling: the idea

- Minimize errors of flow between the fine and coarse scales
- p and q on fine scale give correct boundary conditions on the coarse scale
- The coarse scale K is the value that preserves the transmissibility over the block



Global upscaling: the algorithm

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$$\overline{T}^{ij} = {q^{ij}}_c / ({p^i}_c - {p^j}_c)$$

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4. Find

$${T^{ij}}_c \in [{T^{ij}}_L, {T^{ij}}_U], \quad \text{minimizing} \quad \left| {T^{ij}}_c - \overline{T}^{ij} \right|$$

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4. Find

$${T^{ij}}_c \in [{T^{ij}}_L, {T^{ij}}_U], \quad \text{minimizing} \quad \left| {T^{ij}}_c - \overline{T}^{ij} \right|$$

or if

$${\overline{T}^{ij}}_c \notin [{T^{ij}}_L, {T^{ij}}_U]$$ adjust p_c and reiterate from 3

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Changing boundary conditions

Global upscaling optimizes the transmissibilities with respect to a flow pattern.

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The flow pattern contains essential information.

According to the second commandment, we shall not throw away essential information, and hence, the *upscaling must be redone when boundary conditions change.*

Fluvial reservoir examples

Fluvial reservoirs are highly heterogenous and spaghetti-like.

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Traditional upscaling: badly overcooked pasta. ☹

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	2 channels, 4% sand gross 1 injector, 1 producer			18 channels, 30% sand gross 1 injector, 2 producers		
Data	Optimal	Global	Local	Optimal	Global	Local
p error	0.013	0.013	0.099	0.027	0.027	0.047
v error	0.71	0.71	0.87	0.65	0.66	23.5
I1 rate	86.2	84.9	32	2.30	2.37	42.9
P1 rate	86.2	84.9	32	1.0	1.1	42.1
P2 rate	n/a	n/a	n/a	1.3	1.3	0.8

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We got the desired *al dente* spaghetti!

Boundary condition sensitivity

11 km $\times$ 3 km fluvial reservoir

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50 m thick with seven injectors and 13 producers

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Fine scale: $75 \times 75 \times 50$ cells
Coarse scale: $25 \times 25 \times 25$ cells

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Boundary condition sensitivity

11 km $\times$ 3 km fluvial reservoir
50 m thick with seven injectors and 13 producers

Fine scale: $75 \times 75 \times 50$ cells
Coarse scale: $25 \times 25 \times 25$ cells

Data	Optimal	Global	Local
p error	0.015	0.016	0.022
v error	0.68	0.70	0.80
Mean well rate error		3%	39.3%

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Again, *Global Upscaling* excels, but is it stable?

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Boundary condition sensitivity (cont'd)

Perturb well pressures to find "perturbed" transmissibilities applied to non-perturbed data

	Optimal proj.	Perturbed global upscaling					Local
		0%	10%	25%	50%	100%	
p error	0.015	0.016	0.016	0.016	0.017	0.019	0.022
v error	0.68	0.70	0.70	0.71	0.77	0.83	0.80
Mean rate error		3.0%	7.7%	12.2%	39.7%	30.5%	39.3%

Boundary condition sensitivity (cont'd)

Perturb well pressures to find "perturbed" transmissibilities applied to non-perturbed data

	Optimal proj.	Perturbed global upscaling					Local
		0%	10%	25%	50%	100%	
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v error	0.68	0.70	0.70	0.71	0.77	0.83	0.80
Mean rate error		3.0%	7.7%	12.2%	39.7%	30.5%	39.3%

Bias in local upscaling: always lower rates than the fine scale solution.

Updating global upscaling

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Updating global upscaling

Global upscaling is not stable under large boundary value changes.

Reason: A global upscaling probes regions of the reservoir with flow. Some regions are badly or not determined at all.

Changing boundary conditions gives a new flow pattern and flow into unprobed regions. There are two options:

1. redo from scratch
2. update only the badly determined regions

Conclusions

- Breaking the commandments is a sin against the truth

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- Upscaling affects the flow simulation significantly
- Global upscaling preserves flow by construction
- Upscaling must be updated when changing boundary conditions

Bibliography

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Pressure adjustment formulae

$$p^i{}_c(n+1) = \frac{1}{2}\left(p^i{}_c(n) + p^j{}_c(n) + \frac{q^{ij}}{T^{ij}{}_c(n)}\right)$$

$$p^j{}_c(n+1) = \frac{1}{2}\left(p^i{}_c(n) + p^j{}_c(n) - \frac{q^{ij}}{T^{ij}{}_c(n)}\right)$$

If all fails, use

$$T^{ij}{}_c = \left(T^{ij}{}_L T^{ij}{}_U\right)^{1/2}.$$

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