# Horizontal Simulation Grids as Alternative to Structure-Based Grids for Thin Oil-Zone Problems: A Comparison Study on a Troll Segment

by

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# Troll 101

- ***Large gas field w. thin (0-26m) oil zone***
- ***Alternating high-perm (C) & low-perm (M) sands***
- ***Successfull oil production by optimal positioning of horizontal wells***
- ***Simulation models:***
  - ***Large area ⇒ large grid cells***
  - ***Thin oil zone ⇒ small grid cells***
  - ***Overall compromise challenging***
  - ***Norsk Hydro: Purpose-made LGRs***
  - ***Henriquez, Cheshire ++: LGR + VE***

# Outline

- ***Description & Discussion of Grid Types***
- ***Test Models***
- ***Results & Conclusions***

# Geo-grid & Hor-grid

- ***Geo-grid: Grid layers along geo-structures***
- ***Hor-grid: All layers horizontal – no geometric connection to geology***
- ***Hybrid grid: Combination of the two***

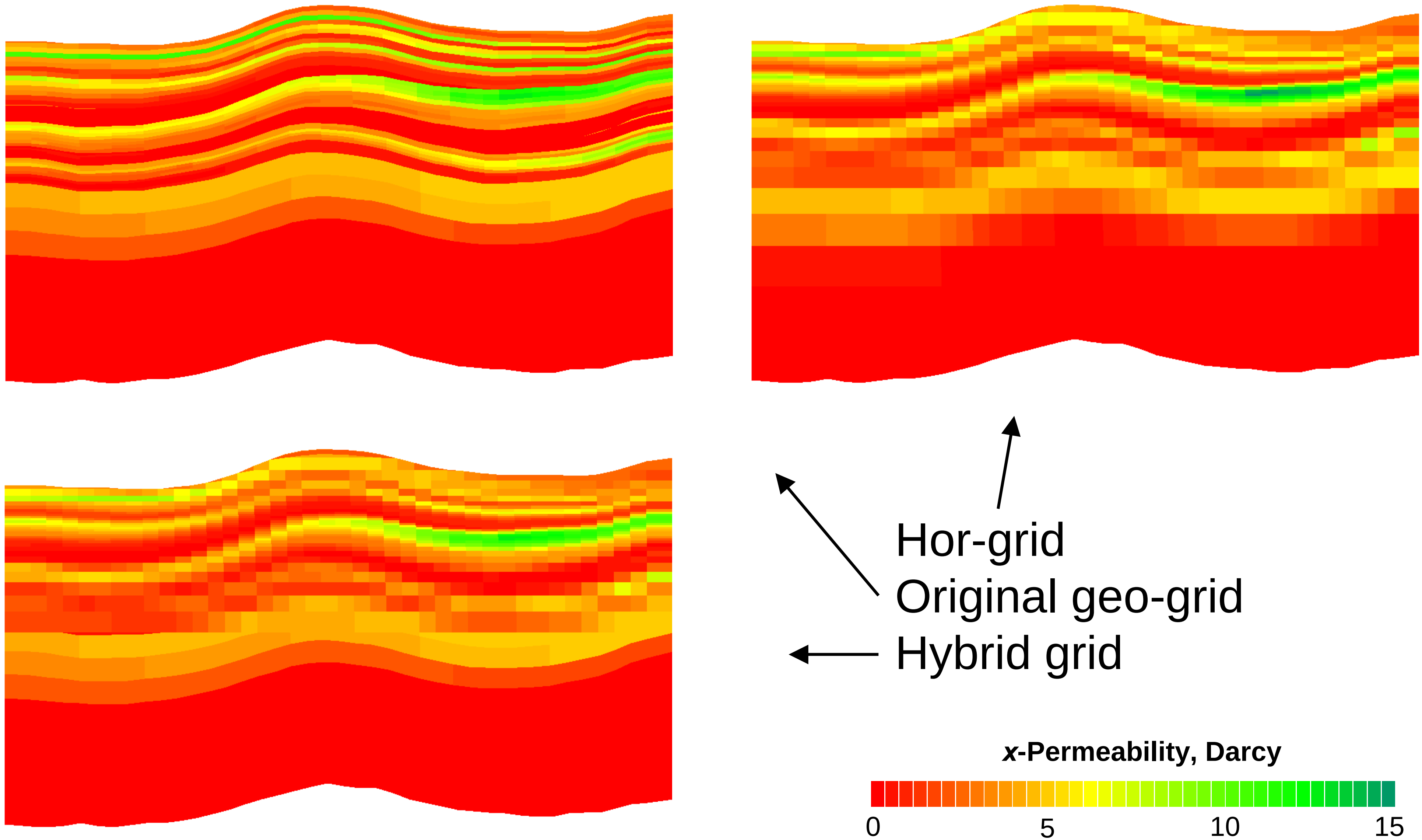
# Benefits and Drawbacks of Geo-grid vs. Hor-grid

(A priori intuitive feeling)

| | **Geo-grid** | **Hor-grid** |
|---|---|---|
| **Geol. layering** | Accurate | No |
| **Petrophysics** | Honours data | Approx. honours data |
| **Fluid Contacts** | Approximate | Exact |
| **Contact movement** | Approximate | Better (?) |
| **Well completions** | Approximate | Can be exact |
| **General fluid flow** | Simulator quality | ??? (Topic of talk) |

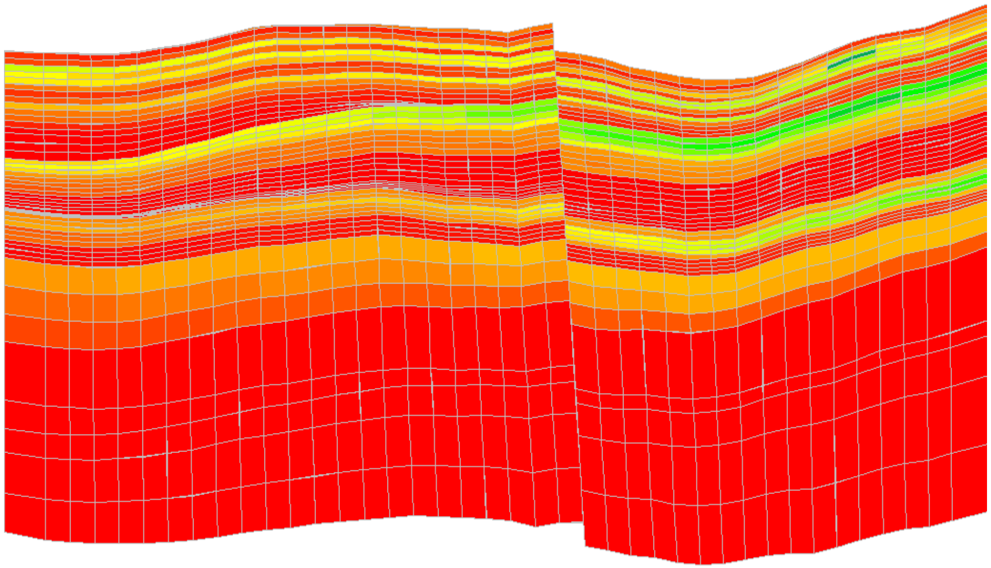
Historically: Grid layers aligned to geology model highly desired / required. Real or conceived concern?

# Examples

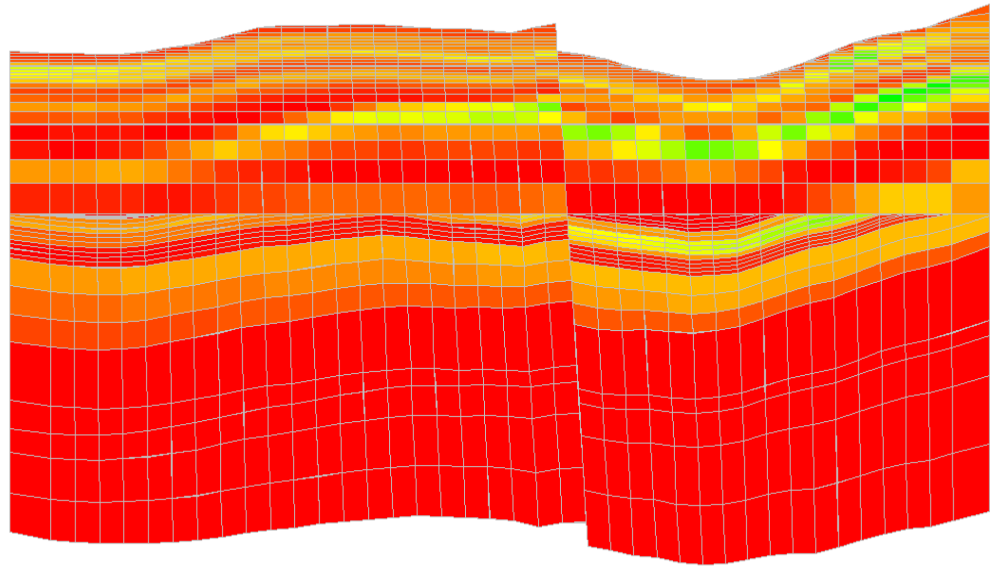


Hor-grid
Original geo-grid
Hybrid grid
x-Permeability, Darcy
0
5
10
15

# Examples (2) – Cross-section w. Fault

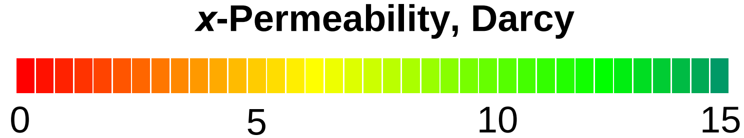


Original geo-grid



Hybrid grid

Note:
No non-neighbour connections across fault in horizontal grid



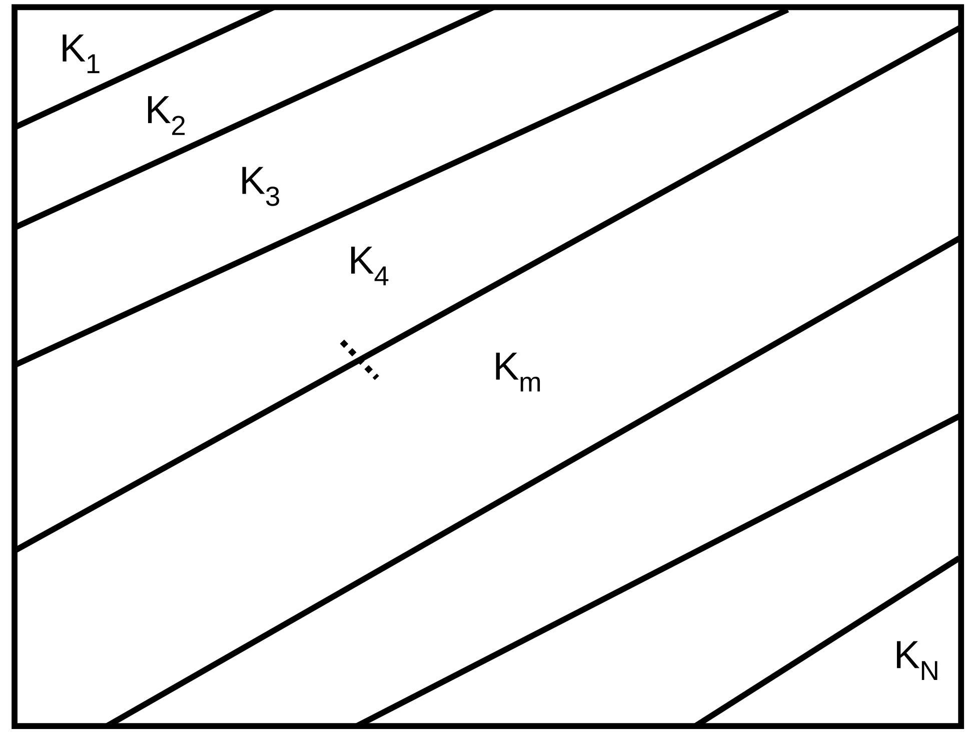
# Rescaling Geo-grid → Hor-grid

N geo-layers pass through one horizontal cell, with volumes
$V_1, V_2, \ldots, V_N$

Integer data (typical region numbers):
Value associated w. largest $V_i$.

Std. averages (porosity, NTG,...):
Volume-weighted arithmetic average

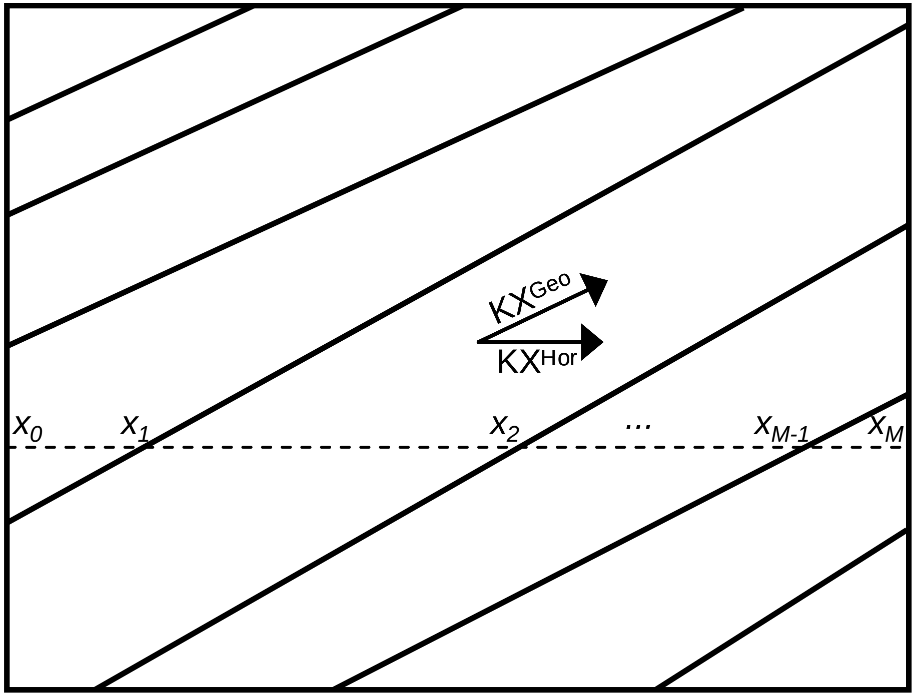
Barriers (shale layers, faults,...) are handled by transforming input MULTX/MULTY/MULTZ to new multipliers, defining the closest approximation to input surface



# Rescaling Permeability Geo-grid → Hor-grid

* Computational scheme favours flow between direct neighbours.
  This is different for sloping and horizontal cells

Scheme attempts to conserve flow directionality from geo-grid when permeability is rescaled to the horizontal cells




(example for *x*-permeability):

First compute $KX^{Hor}$, the sum of the projections of all $KX^{Geo}$ on *x*-axis
Then compute *harmonic average* of $KX^{Hor}$ along dashed line:

$$\frac{x_M - x_0}{KX^{Hor}_{inline}} = \sum_{m=1}^{M} \frac{x_m - x_{m-1}}{KX^{Hor}_m}$$

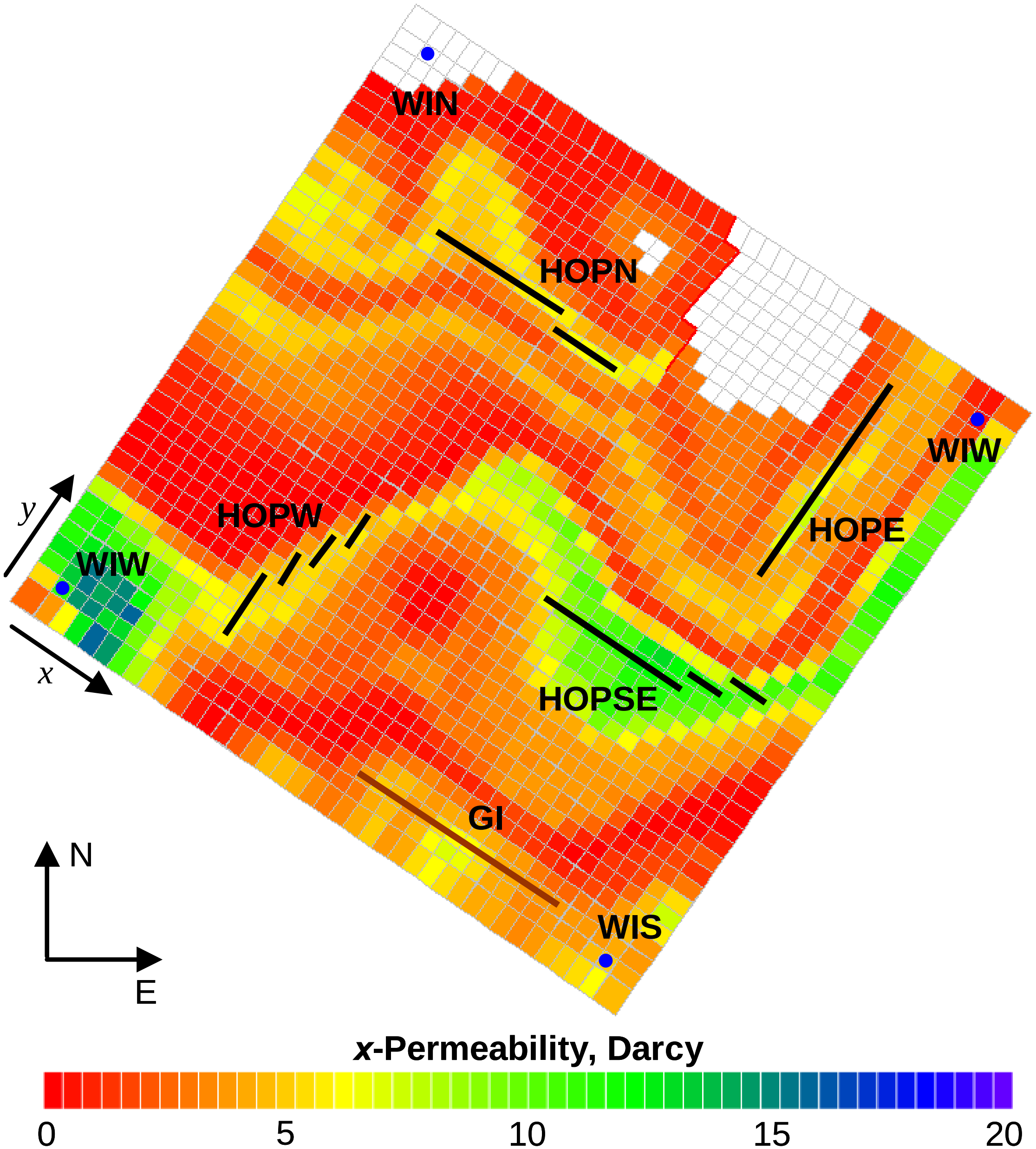
Lastly compute volume weighted arithmetic average of these

→ “Redirects” flow from pure horizontal to more “diagonal”

# Base Test-models (Troll Segment)

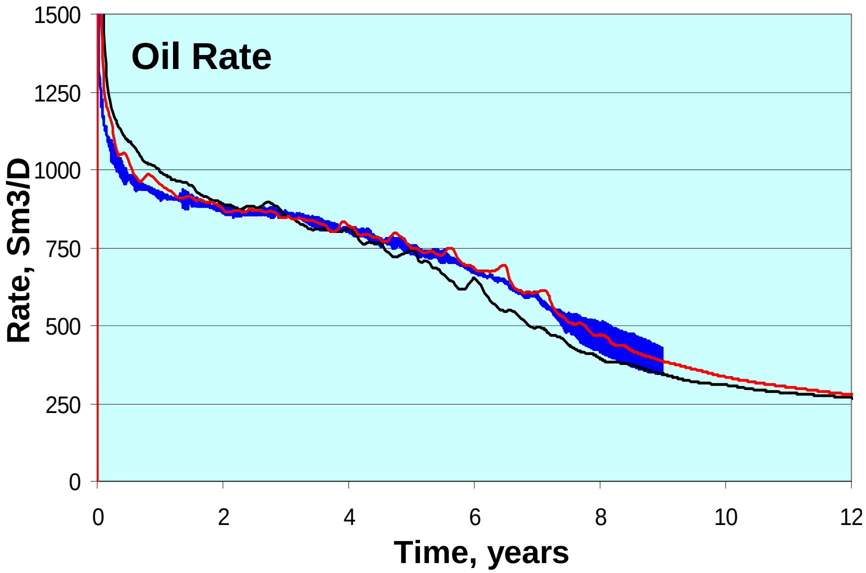
- ***Cell diameters ($\Delta$x, $\Delta$y): 40-50 m***
- ***Gas cap 40 m, Oil zone 13 m, Water zone ~160 m***
- ***Four deep water injectors in corners***
- ***Four horizontal oil producers 0.5 m above OWC***
- ***One horizontal gas injector near top***
- ***BASEGEO: 56 layers ( ≡ geomodel)***
- ***GEOLGR: BASEGEO w. LGR on/around producers***
- ***BASEHOR: Hybrid grid with***
  - ***13 equi-thick horizontal layers in oil zone***
  - ***horizontal layers of increasing $\Delta$z from GOC upwards and OWC downwards***
  - ***geo-layers at top and bottom***

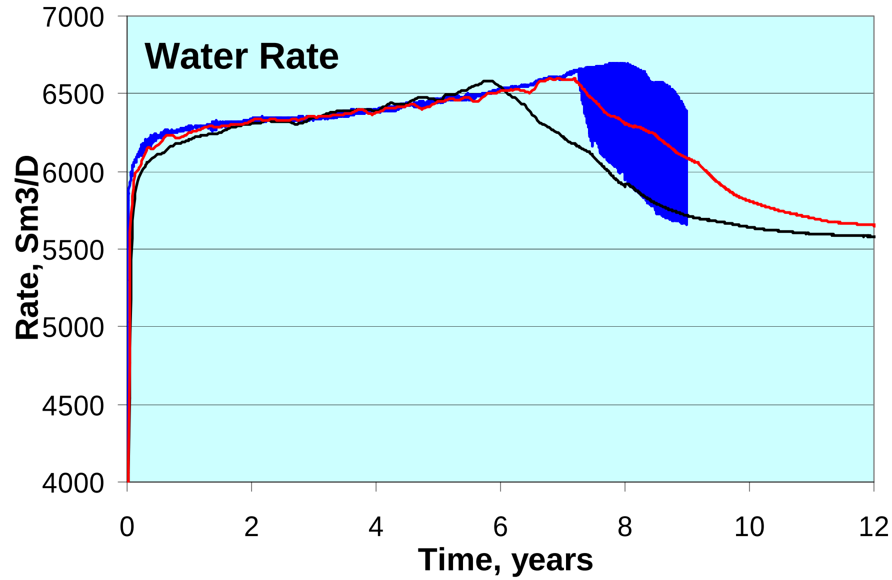
# Horizontal Slice at Producer Depth

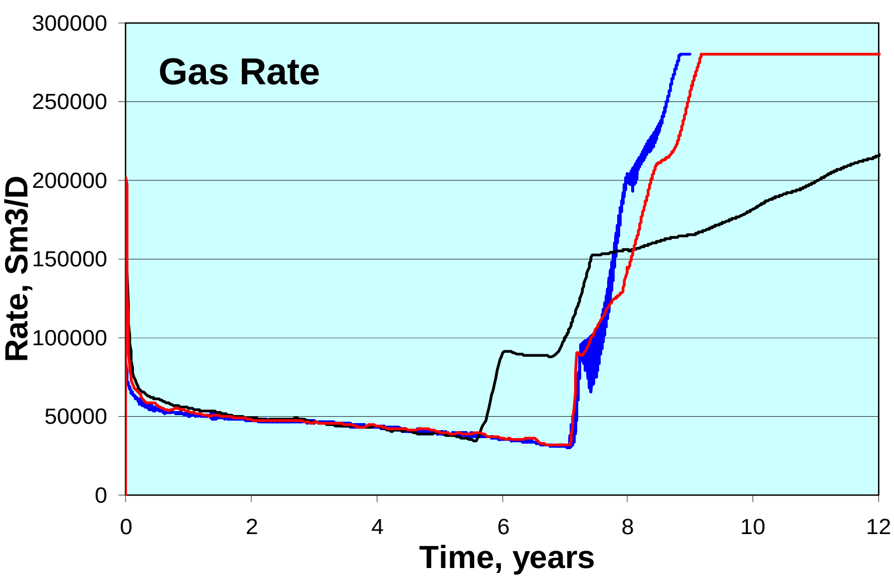


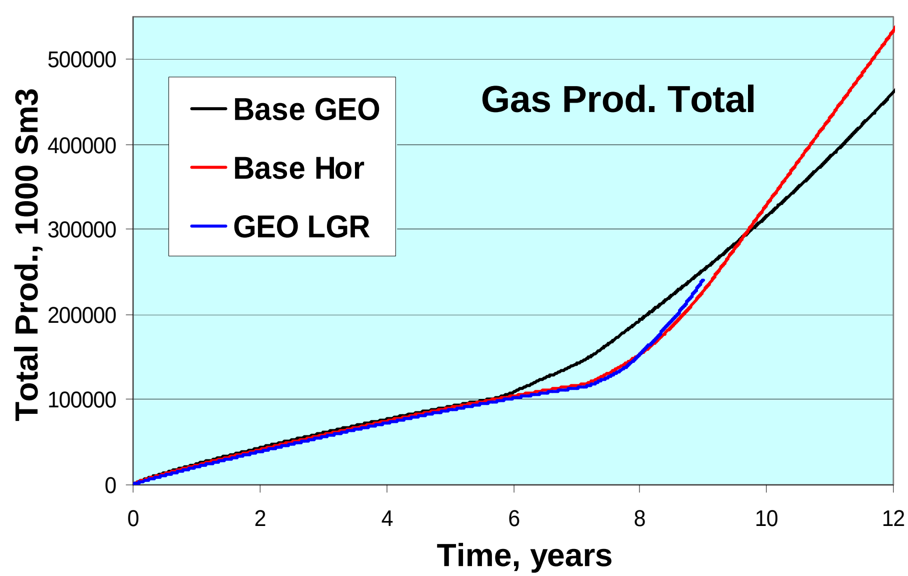

Producers are placed in high-permeability areas (C-sands) with communication to gas cap through C-sands.
→Intuitive physical expectation of gas production

# Field Production Rates

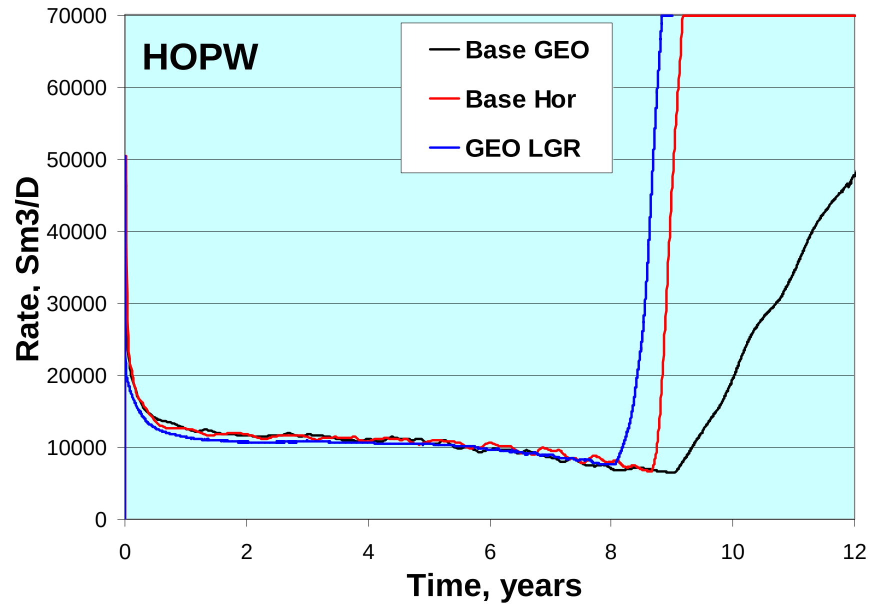


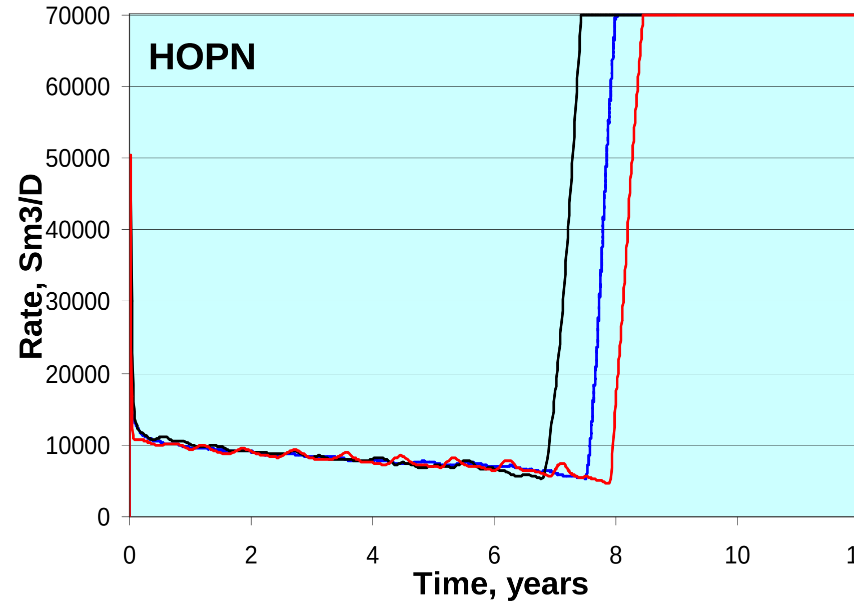



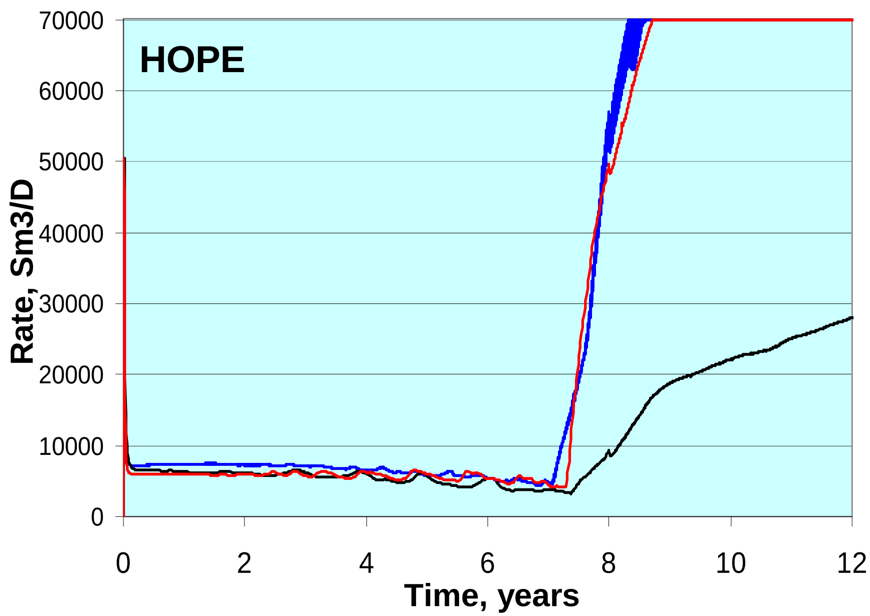



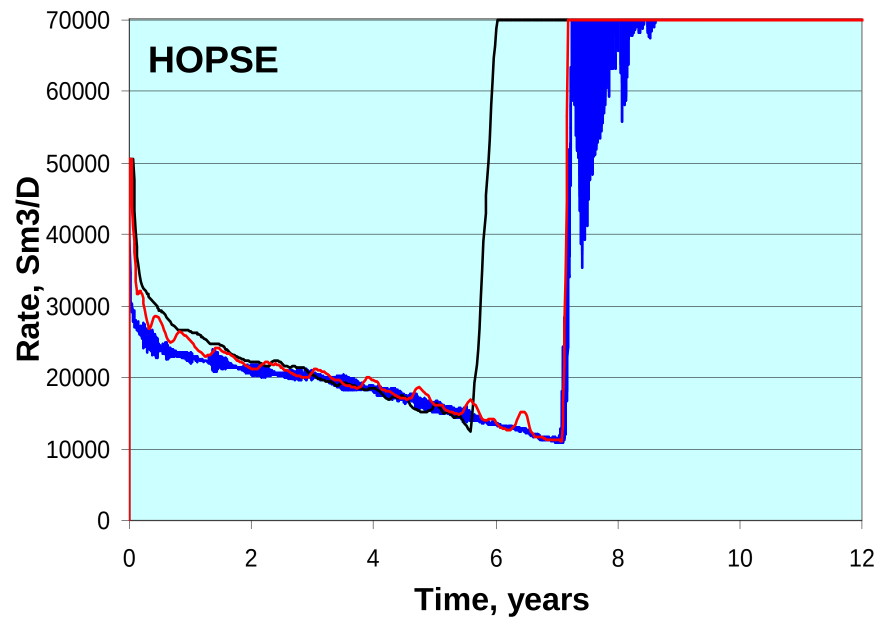



# Gas Rate from wells



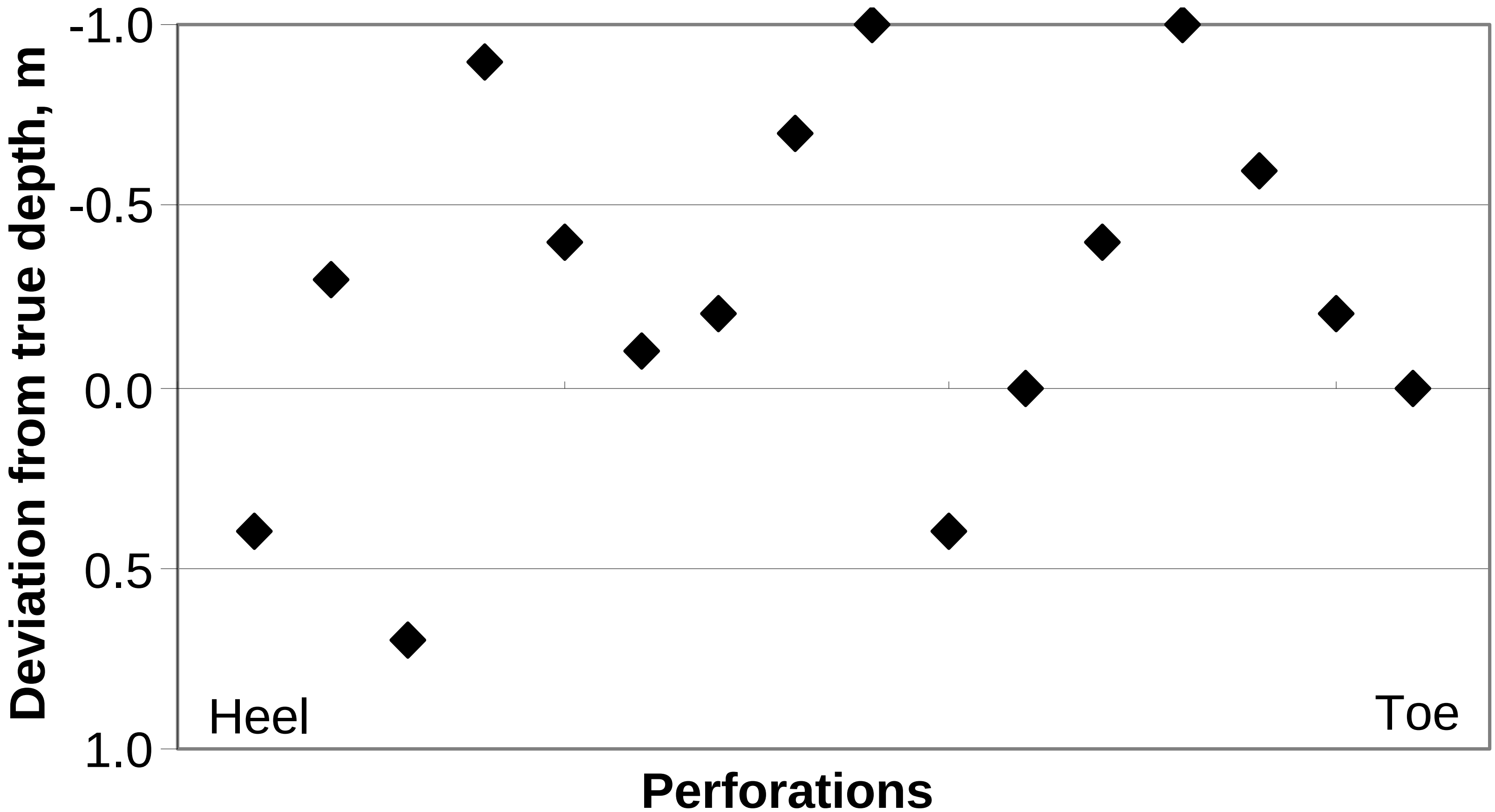



# Comments

- *In general, BASEHOR ~ GEOLGR, while BASEGEO deviates*
- *BASEHOR & GEOLGR: Reflect a priori physical expectations*
  - *BASEGEO does not*
- *Fluid contact movement ~equal in all models*
- *Sensitivities:*
  - *BASEGEO with LGR in gas cap and top of oil zone*
  - *BASEGEO with various LGRs to capture contact movement*
  - *Results ~equal to BASEGEO*
  - *→ Differences are not due to inaccurate modelling of frontal movement*

# Completion Modelling

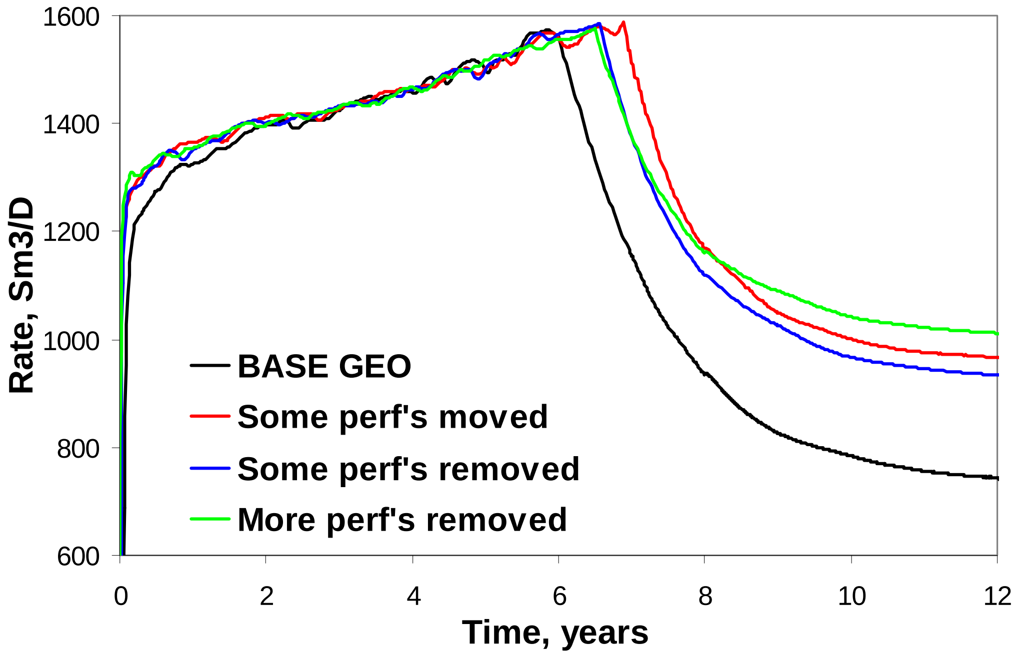



Difference between actual perforation depth and modelled depth (cell-centre depth) in BASEGEO model

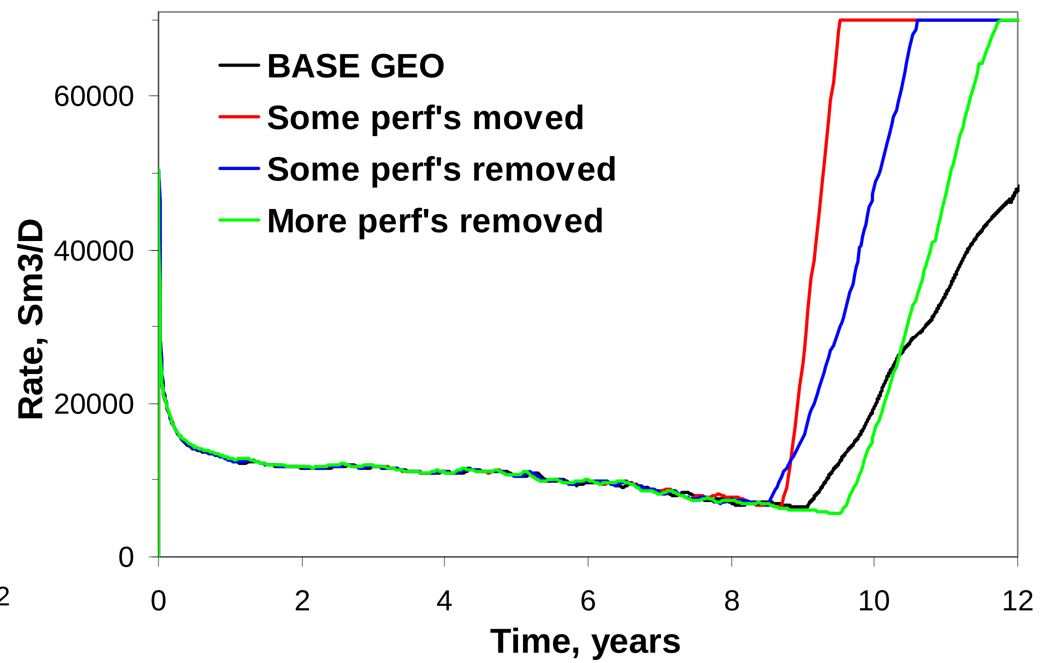
# Sensitivities on Completion Modelling

*All sensitivities done on BASEGEO model*

1. *All model perforations above true perforation depth moved to cell below*
2. *All model perforations more than 0.7 m above true depth removed*
3. *All model perforations more than 0.25 m above true depth removed*




Water rates, well HOPSE



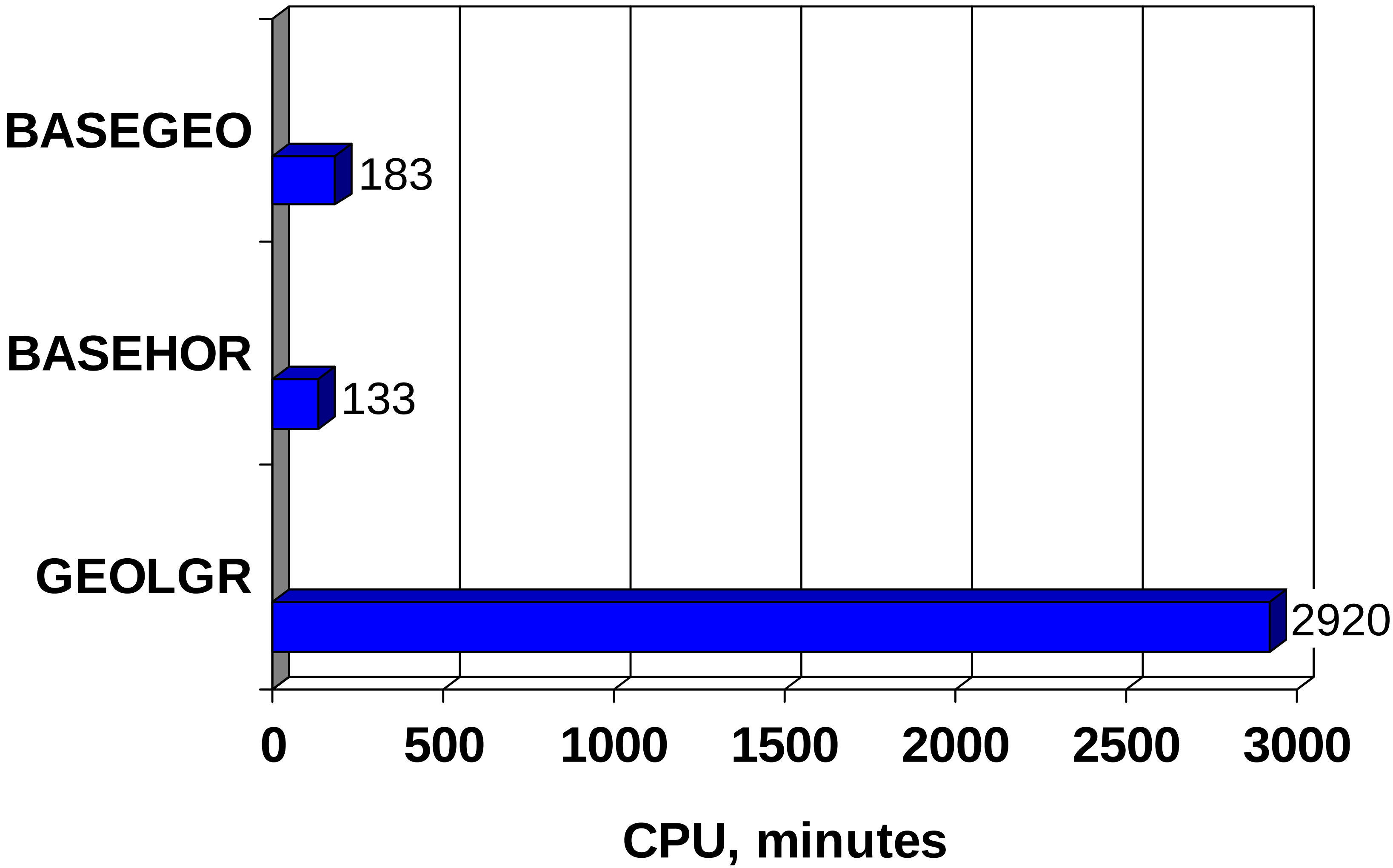

Gas rates, well HOPW

# Summary First Batch of Runs

1. ***Fluid front movement is adequately described in all three models***
2. ***BASEGEO fails to capture essentials of gas flow near producers***
   - ***To a lesser degree also applies to water flow***
3. ***BASEHOR & GEOLGR mostly had comparable results***
   - ***Also more in accordance with physical intuition than BASEGEO***
4. ***GEOLGR suffers from partly severe rate oscillations***

- ***BASEHOR: High resolution cells concentrated to areas where they are most needed.***

# Computing Times



# Cell Sizes

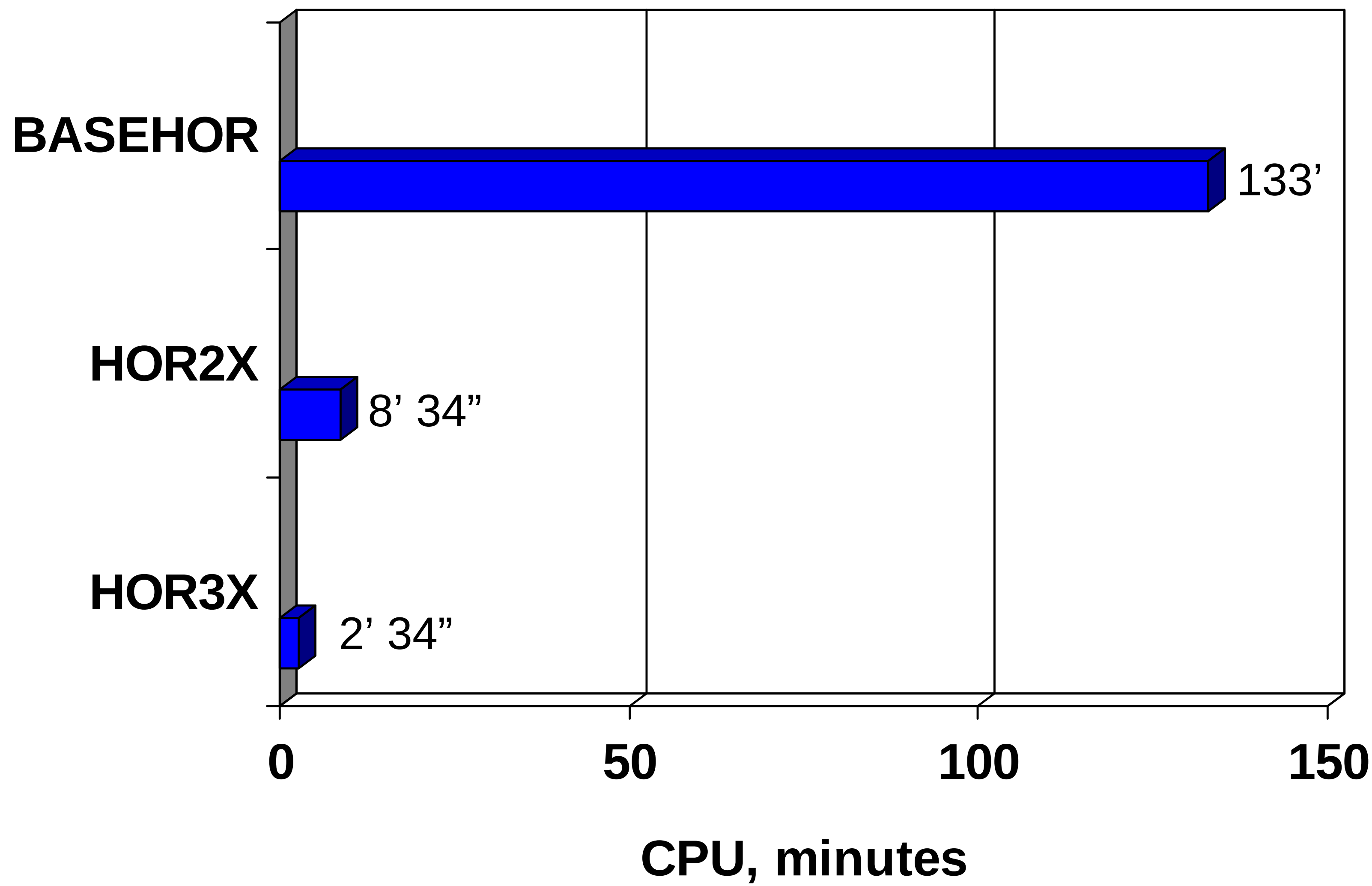
- ***Cell diameter ($\Delta x$, $\Delta y$) was ~45 m in BASEGEO & BASEHOR***
- ***Sensitivity runs***

  ***(only on hor-grid – geo-grid won't be any better if coarsened):***
  - ***HOR2X: Cell Diameter ~90m***
  - ***HOR3X: Cell Diameter ~135m***

- ***BASEHOR and HOR2X almost identical results***
- ***HOR3X deviated, but not significantly***

- ***Hence, grid diameters < ~150 m appear acceptable.***

# Computing Times



# Second Batch of Runs: Optimizing the Hor-Grid

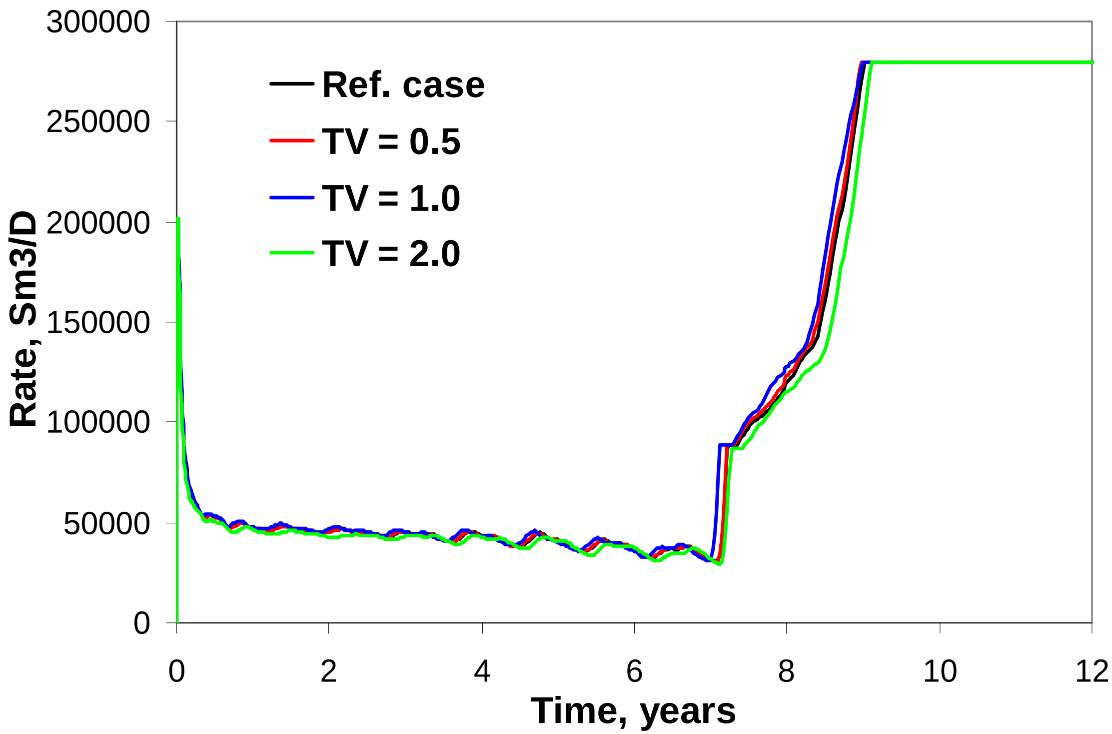
- ***Determine optimal layer thicknesses in***
  - ***gas zone***
  - ***oil zone***
  - ***water zone***
- ***Based on HOR2X grid cases***
- ***~80 cases were run***
- ***Quality determined by Total Variation***
  - ***using a case resembling BASEHOR as reference R***

$$TV = \frac{1}{N} \sum_{V \in RV} \sum_{t=1}^{N} \{ r_V(t) - R_V(t) \}^2$$

$R$: reference solution, $r$: current solution, (normalized)
summed over oil, water & gas rates from all
four wells, and all times (15-day intervals)

# Second Batch of Runs (2):

- ***Guideline:***
  - ***TV < 1 ↔ As good as equal***
  - ***Differences begin to be significant at TV ~2***




**Example interpretation of TV, Field Gas Rate**

# Oil Zone

- ***Current case: Oil Zone = 13 m***
- ***13 equithick layers of 1 m worked fine***
  - ***Thinner layers: No improvement, increased computing time***
  - ***2 m layers: Not significantly different, minimal speed-up***
- ***Note:***

  ***Perforation depths should always be at cell centers***

# Gas Zone

- ***Highest resolution: 8 geo-layers + 10 hor. layers***
  - ***TV = 0.43, CPU = 602 sec***

- ***Coarsest resolution: No geo-layers, 2 hor. layers (8 & 38.5 m)***
  - ***TV = 0.52, CPU = 513 sec***

- ***All tested cases had***
  - ***TV between 0.4 and 0.52***
  - ***CPU between 513 and 602 sec***

- ***Strategy doesn't matter for gas zone!***

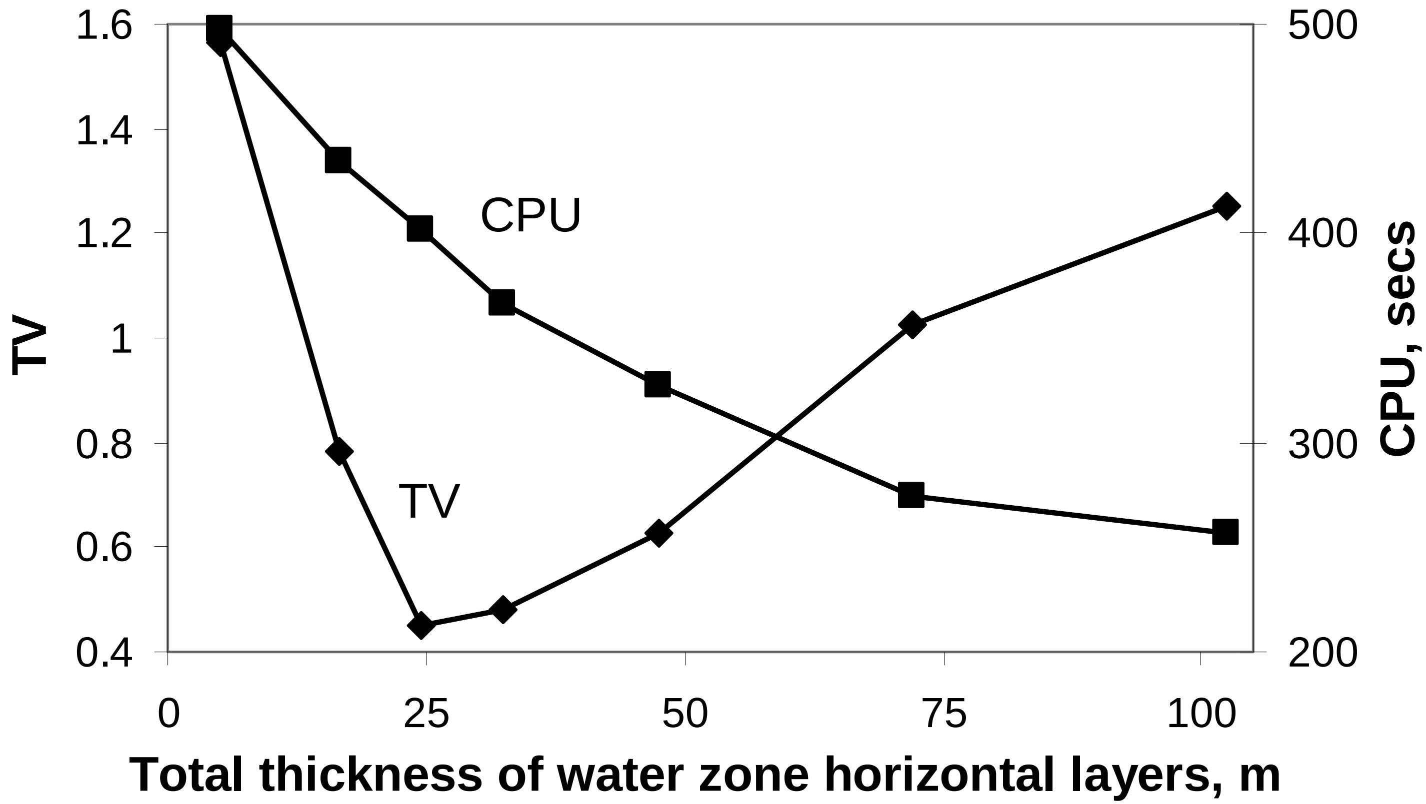
- ***But: This case is an expanding gas cap –***
  ***conclusion is probably not general.***

# Water Zone

- ***Typical strategy: Horizontal layers with geometrically increasing thickness from OWC down to transition depth, geo-layers below***
- ***Some cases with constant layer thicknesses in water zone***

- ***In general, hybrid grids worked better than pure horizontal grids in the water zone.***

# Hybrid Grid in the Water Zone




**Distribution of horizontal vs. geo-layers in the hybrid grid**

**→Apparently, there's an optimal distribution.**

**→Geo-description in deepest parts needed for simulation of water influx**

# Some Other Strategy Tests

- ***Hor. grid in oil zone only (TV = 2.0)***
- ***Hor. grid in lower part of oil zone only (TV 2.1 – 2.4)***
- ***Hor. grid for well layer only (TV = 2.3)***
- ***6 equi-thick hor. layers in oil zone ($\Rightarrow$ perf. depth 0.6 m off) (TV = 9.5)***

- ***Not recommended practice***
  - ***(Slightly worse performance, little if any gain CPU-wise)***

# Conclusions

- ***The hor-grid has better performance than the traditional geo-grid with the same areal resolution***
- ***Comparable results were obtained from a hor-grid and a geo-grid with LGR, but the latter had more than an order of magnitude larger computing time***
- ***Hor-grids can be constructed such that high resolution domains are defined where most needed***
- ***Accurate representation of well completion depths most critical factor***
- ***Hor-grid performance acceptable / good for cell diameters up to 150 m***
  - ***Coarse Hor-grid + LGR probably optimal (not tested)***
- ***Layering strategy can be optimized w.r.t. accuracy and effciency by exploiting the behaviour of gas cap and water zone (case dependent)***

## Final Observation

**The horizontal grids performed astonishingly well**

**Can the strategy have a more general potential?**

**(non-thin-oil-zone reservoirs)**

# Acknowledgements

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Petoro AS,
A/S Norske Shell,
Statoil Petroleum AS,
Total E&P Norge AS)
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