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Tenth SPE Comparative Solution Project: A Comparison of Upscaling Techniques

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Abstract

This paper presents the results of the Tenth SPE Comparative Solution Project on Upscaling. Two problems were chosen. The first problem was a small 2D gas injection problem, chosen so that the fine grid could be computed easily, and both upscaling and pseudoisation methods could be used. The second problem was a waterflood of a large geostatistical model chosen so that it was hard (though not impossible) to compute the true fine grid solution. Nine participants provided results for one or both problems.

Introduction

The SPE Comparative Solution Projects provide a vehicle for independent comparison of methods and a recognized suite of test datasets for specific problems. The previous nine comparative solution projects[1 – 9] have focussed on black-oil, compositional, dual porosity, thermal or miscible simulations, as well as horizontal wells and gridding techniques.

The aim of the tenth comparative solution project was to compare upgridding and upscaling approaches for two problems. Full details of the project, and data files available for downloading can be found on the project web site[10].

The first problem was a simple 2000 cell 2D vertical cross section. The tasks specified were to apply upscaling or pseudoization methods and obtain solutions for a specified coarse grid, and a coarse grid selected by the participant.

The second problem was a 3D waterflood of a 1.1 million cell geostatistical model. This model was chosen to be sufficiently detailed that it would be hard, though not impossible, to run the fine grid solution and use classical pseudoisation methods.

We will not review the large number of upscaling approaches here. For a detailed description of these methods see any of the reviews of upscaling and pseudoisation techniques, for example[11 – 14].

Description of Problems

Model 1

The model is a 2-phase (oil and gas) model that has a simple 2D vertical cross-sectional geometry with no dipping or faults. The dimensions of the model are 762 meters long by 7.62 meters wide by 15.24 meters thick. The fine scale grid is 100 x 1 x 20 with uniform size for each of the grid blocks. The top of the model is at 0.0 metres with initial pressure at this point of 100 psia. Initially the model is fully saturated with oil (no connate water).

The permeability distribution is a correlated geostatistically generated field, shown in **Fig 1**. The fluids are assumed to be incompressible and immiscible. The fine grid relative permeabilities are shown in **Fig 2**. Capillary pressure was assumed to be negligible in this case. Gas was injected from an injector located at the left of the model and dead oil was produced from a well on the right of the model. Both wells have a well internal diameter of 1.0 ft and are completed vertically throughout the model. The injection rate was set to give a frontal velocity of 0.3 m/d (about 1 foot/day or 6.97 m^3 per day), and the producer is set to produce at a constant bottom pressure limit of 95 psia. The reference depth for the bottom hole pressure is at 0.0 meters (top of the model).

The tasks specified were to apply upscaling or pseudoization method in the following scenarios:

1. 2D – 2D uniform 5 x 1 x 5 coarse grid model
2. 2D – 2D nonuniform coarsening. Max 100 cells.

Directional pseudo relative permeabilities were allowed if necessary.

Model 2

This model has a sufficiently fine grid to make use of any method that relies on having the full fine grid solution almost impossible. The model has a simple geometry, with no top structure or faults. The reason for this choice is to provide maximum flexibility in selection of upscaled grids.

At the fine geological model scale, the model is described on a regular cartesian grid. The model dimensions are 1200 x 2200 x 170 (ft). The top 70 ft (35 layers) represents the Tarbert formation, and the bottom 100 ft (50 layers) represents Upper Ness. The fine scale cell size is 20 ft x 10 ft x 2 ft. The fine scale model has 60 x 220 x 85 cells (1.122×10^6 cells). The porosity distribution is shown in **Fig 3**.

The model consists of part of a Brent sequence. The model was originally generated for use in the PUNQ project[15]. The vertical permeability of the model was altered from the original: originally the model had a uniform k_v/k_h across the whole domain. The model used here has a k_v/k_h of 0.3 in the channels, and a k_v/k_h of 10^{-3} in the background. The top part of the model is a Tarbert formation, and is a representation of a prograding near shore environment. The lower part (Upper Ness) is fluvial.

Participants and Methods

Chevron

Results were submitted for model 2 using CHEARS, Chevron's in house reservoir simulator. They used the parallel version and the serial version for the fine grid model, and the serial version for the scaled-up model.

Coats Engineering Inc

Runs were submitted for both model 1 and model 2. The simulation results were generated using SENSOR. The simulator runs used the conventional 5- or 7-point finite difference formulation, zero capillary pressure, and no directional relative permeability.

GeoQuest

A solution was submitted for model 2 only, with coarse grid runs performed using ECLIPSE 100. The full fine grid model was run using FRONTSIM, a streamline simulator[16], to check the accuracy of the upscaling. The coarse grid models were constructed using FloGrid, GeoQuest's gridding and upscaling application.

Landmark

Landmark submitted entries for both model 1 and model 2 using the VIP simulator. The fine grid for model 2 was run using parallel VIP.

Phillips Petroleum

Solutions were submitted for both model 1 and model 2. The simulator used was SENSOR.

Roxar

Entries were submitted for both model 1 and model 2. The simulation results presented were generated using Roxar's Black Oil, Implicit Simulator, *Nextwell*. The upscaled grid properties were generated using Roxar's Geological Modelling software, *RMS*, in particular the *RMSsimgrid* option.

Streamsim

Streamsim submitted an entry for model 2 only. Simulations were run using 3DSL, a streamline based simulator[17].

TotalFinaElf

TotalFinaElf submitted a solution for model 2 only. The simulator used for the results presented was ECLIPSE; results were checked using the streamline code 3DSL.

University of New South Wales

The University of New South Wales submitted results for model 1 only using CMG's IMEX simulator.

Results

Model 1

Fine Grid Solution

All participants were able to compute the fine grid solution, and the solutions from the different simulators used were very close, as shown in **Fig 4**. The University of New South Wales fine grid solution departs slightly from the other fine grid solutions; it was not possible to track down the source of this discrepancy in the short time between receiving this solution and the paper submission deadline.

Upscaled Solutions

Participants were asked to generate solutions on a 5 x 5 grid, and on a grid of their choice with a maximum of 100 cells. The reason for the choice of the 5 x 5 grid was that, with that grid size, the coarse grid boundaries fall on high permeability streaks which is generally a problem for upscaling methods which don't compute the fine grid solution.

The solutions submitted for the 5 x 5 grid used single phase upscaling only (Roxar), or single phase upscaling plus regression based pseudoisation of relative permeabilities (Coats, Phillips, Landmark). The solutions with pseudo relative permeabilities are very close to the fine grid solution, and Roxar's solution using only single phase upscaling shows a significant discrepancy (**Fig 5**).

A second set of solutions was presented by some participants (shown in **Fig 6**). Here Roxar used single phase upscaling in conjunction with a streamline approach to generate local grid refinements (with a total of 96 cells) which captured the details of the flow in the early, mid, and late-time regions. Coats showed that good results could also be obtained with homogeneous absolute permeability and no alteration of relative permeability, and Phillips showed that good results could be obtained from a 6 x 2 grid. The University of New South Wales solution was based on a global upscaling and upgridding approach which attempts to minimize the variance of permeability within a cell[18]. Their solution is close to their fine grid solution, although the difference between their fine grid solution and the other fine grid solutions tends to make their method appear to perform less well.

Model 2

Fine Grid Solution

Five participants provided fine grid results as well as an upscaled solution. Landmark and Chevron ran the full fine grid on a parallel reservoir simulator. GeoQuest and

Streamsim provided results using streamline codes (TotalFinaElf also provided streamline results using 3DSL. We have not shown their production curves as they are the same as Streamsim's). A comparison of the fine grid results is shown in **Fig 7, 8, 9, 10.** All the figures shows very good agreement between all four fine grid submissions. Although only producer 1 well plots are shown here for reasons of space, plots of the remaining well rates and watercuts show equally high levels of agreement between the four fine grid solutions. The differences that occur likely to be due to either different time steps early on, where the production rate is very sensitive to the transient pressure response, or to different treatment of the injection well, which was at the corner of four cells in the fine model, leading to different injectivity indices.

Upscaled Solutions

There were two methodologies used to generate the upscaled solutions. Some participants used finer scale information in some way, and then history matched a coarser grid to the finer grid results. Others made no use of fine scale flow information, and used standard, well documented upscaling procedures to compute upscaled grids and upscaled effective permeabilities.

Landmark, Phillips Petroleum, and Coats Engineering used some level of fine scale flow information to determine upscaled relative permeabilities for a coarse grid model. All other participants used some form of single phase upscaling, some in conjunction with flow-based upgridding. There were significant variations in final grid sizes and upscaling approaches chosen.

Landmark ran the full fine grid model, and then used flow based upscaling[19] to generate upscaled absolute permeabilities on a 5 x 11 x 17 grid. Regression on the fine grid results[20] was used to generate a single set of effective relative permeabilities which ensured a good match to the fine grid.

Coats upscaled the 60x220x85 geostatistical grid to a 30x55x85 grid of 40 ft x 40 ft x 2 ft coarse grid blocks. The results of a model run for that grid were considered "correct" for the purpose of further flow-based upscaling. The 60x220x85 grid was upscaled to 10x20x10 and 3x5x5 coarse grids. The coarse blocks of the 10x20x10 grid were 120 ft x 110 ft x (14 ft in the Tarbert, 20 ft in the Upper Ness). Those of the 3x5x5 grid were 400 ft x 440 ft x 34 ft. Coats reported three sets of results: the 30x55x85 grid, the 10x20x10 grid with a pseudo $k_{rw}=S_{wn}^{1.28}$, and the 3x5x5 grid with a pseudo $k_{rw}=S_{wn}^{1.2}$.

Phillips first upscaled the 60x220x85 grid, 1.122 million cell geological model using a flow-based method[19] to a 31x55x85 grid containing 40ft x 40ft square areal grids except for rows 27, 28, and 29 where delta Y was equal to 50ft, 60ft, and 50ft, respectively. This approach results in a fairly uniform grid across the field including well cells, which are located in the center of their corresponding grid blocks. Peaceman's equation[19] was used to calculate the productivity index for each layer in the well. Simulation results from this "fine grid" model were used as the basis for developing the coarse grid upscaled model for use in the full field model. The million cell geological model was used directly to upscale to a 11x19x11 coarse grid model for use in field scale simulations. Pseudoization of the coarse grid results to match the fine grid calculations was performed by varying the Corey type relative permeability exponents. Values of 1.6 for n_w and 2.4 for n_o were obtained.

Chevron used single phase flow-based upscaling in conjunction with a 3d nonuniform grid coarsening code[21]. Although they had fine scale model results available, these were not used in determining the grid or the upscaled properties. Instead, a single-phase tracer solution on both the fine and proposed coarse grids was compared, and the grid coarsening strategy was varied to ensure reasonable agreement on quantities of interest such as breakthrough time. This resulted in a coarse grid size of 22 x 76 x 42.

TotalFinaElf adopted a similar strategy, using internal software to compute a coarsened grid. This software performs tracer flow simulations on the fine grid and on a series of coarse grids. A pressure gradient is imposed across the reservoir, with injection on one side and production on the other. Incompressible, single-phase flow is assumed. Four criteria are used to assess the results of the simulations on a particular coarse grid: total flux across the reservoir, tracer breakthrough time, a measure of the spread of the produced tracer concentration curve and a curve fit coefficient (a measure of the difference from the fine grid produced tracer concentration curve). As the grids become coarser areally, there is a gradual degradation of their quality as measured by these criteria, but with no obvious break-point where the quality of the grid becomes suddenly worse. On the other hand, as the number of layers is reduced, the quality appears to decline rapidly when less than 13 layers are used (only nearly uniform grids were considered). As a result of these tests, it was decided to use a 10 x 37 x 13 grid, with 5 layers in the Tarbert and 8 in the Ness. The quality criteria also suggested that using no flow lateral boundary conditions in the upscaling of permeabilities would be better than using linear boundary conditions.

GeoQuest submitted solutions using the following methods on a 15x55x17 coarse grid, where each coarse block contains a subgrid of dimensions 4x4x5. Porosity was upscaled with the usual volume weighted arithmetic average. Permeability was upscaled using the following upscaling methods:

- Arithmetic-harmonic
- Harmonic-arithmetic
- Power averaging
  (with power = 10^6 to extract maximum permeability)
- No-side-flow boundary conditions

- Linear boundary conditions
- Half-block permeability.

The fine grid relative permeability curves were used in the coarse grid simulations.

Streamsim used a combination of arithmetic and geometric upscaling only. They first used arithmetic upscaling on Kx and Ky and geometric upscaling on Kz to go from 60x220x85 to 60x220x17. All upscaling starting from 60x220x17 was then done using geometric upscaling only.

Roxar used layered sampling to map the 35 layers of the Tarbert onto 9 layers on the upscaled model. The 50 layers of the Upper Ness were mapped onto 13 layers in the coarse grid giving 22 layers in the Z-direction: almost a factor of 4. The x- and y-directions were upscaled by a factor of 4 to 15 and 55 cells, respectively, giving a total of 18150 global cells. A single discrete parameter was constructed on the fine grid being the Time of Flight from the Injector between 0 and 700 days. This parameter was upscaled to the coarse grid where it was used to pick the cells to which a 2x2x2 LGRs were applied. 3120 LGRs were generated giving a total of 39990 active global and LGR cells. *RMSsimgrid*'s single-phase *Diagonal Tensor* method was used to upscale the permeabilities and the *Arithmetic* average method was used to upscale the porosity onto this non-uniform grid.

Figures 11, 12 show fine and coarse grid water saturations computed using 3DSL by TotalFinaElf. Although much of the fine detail is missing from the coarse grid solution, the overall shape of the saturation map is similar.

Figure 13 shows field oil production rate results from all 8 participants. The overall level of agreement is good, despite the fact that the methods use different grid sizes and simulators.

For a more detailed analysis, the results have been split into those that use pseudo relative permeabilities in some form, and those that use only single phase upscaling and upgridding, and keep the relative permeabilities the same as the original rock curves.

The grid sizes used varied enormously. **Table 1** includes information on grid sizes for each entry. For the pseudo based approaches, grid sizes ranged from 125 cells (Coats) to 2299 cells (Phillips). For the non-pseudo approaches, grid sizes varied from 4810 cells (TotalFinaElf) to 70224 cells (Chevron)

Generally, producers 1 and 2 show the greatest variation between participants, with producers 3, 4 showing a higher level of agreement. We have chosen to show the producer 1 results as well as field totals to give an indication of the level of variability in the results.

We have chosen to plot the Landmark fine grid solution as a reference fine grid solution. Both Landmark and Chevron fine grid solutions are almost identical after the first 100 days of production, and differences before that time are almost certainly due to different time step strategies. The two streamline solutions are also very close after 150 days, and therefore we selected a single solution as a reference.

Figure 14 shows the pseudo based solutions for oil rate for producer 1, along with the reference fine grid solution. All solutions show some discrepancies at early times, and then generally agree very well. The Landmark solution is the closest to the fine grid after 200 days, although it has the largest discrepancy in initial oil rate. **Figure 15** investigates the impact that pseudoisation to an intermediate grid is likely to have had on the Coats and Phillips results. Figure 15 shows the Landmark fine grid solution, along with the three solutions submitted by Coats: the 30 x 55 x 85 intermediate grid, the 10 x 20 x 10 and 3 x 5 x 5 coarse grids. The intermediate grid solution is close to the true fine grid solution, and provides a good starting point for a pseudo based approach. Both Coats upscaled solutions using pseudo relative permeabilities provide good predictions of the fine grid results.

Figure 16 shows an equivalent plot for the upscaling-based methods, where the relative permeabilities are left unchanged. Here, there is a significantly larger degree of scatter, reflecting the fact that knowledge of the fine grid solution allows the relative permeabilities to be adjusted to give good agreement with the fine grid solution. We plotted the no-flow boundary condition entry from GeoQuest in this plot, and in all other comparative plots of upscaling entries. **Figure 17** shows the results presented by GeoQuest to examine the variation in rate that can be predicted on a fixed grid (15 x 55 x 17) by changing the upscaling method. The worst method here is the use of linear pressure gradient boundary conditions, which significantly overestimates the flow rate. This is in contrast to previously reported studies[22]. Both no-flow boundary conditions and arithmetic-harmonic averaging give good predictions.

Figures 18, 19, 20 show predictions of the watercut from producer 1 for the same three groups of solutions. There is a slightly larger difference between the three pseudo based approaches shown in Fig 18. In Fig 19, there is now a significant spread in predictions, with water breakthrough varying between 200 and just over 400 days. The variation in results due to choice of method is again significant (Fig 20), although now the power law upscaling provides the worst prediction of watercut. Both no-flow boundary conditions and arithmetic-harmonic methods still provide good predictions.

Figures 21, 22, 23 look at the prediction of cumulative oil produced for producer 1. In Fig 21, the pseudo-based methods all do a good job of predicting cumulative oil production. In Fig 22, which shows the upscaling based submissions, the

Chevron solution is by far the closest, although it is also the most finely gridded solution. The others show the cumulative impact of errors in prediction at early times. Fig 23 shows that the impact of upscaling technique is as large as the spread between participants.

Since no participant submitted a very coarse grid solution using non-pseudo based methods, we ran a set of cases at Heriot-Watt on grid sizes from 30x55x17 down to 5x11x6 using single phase upscaling only. The coarsest grids used were of a size that might have been used if this were a pattern element in a full field model. The upscaling method used was a pressure solution technique with no-flow boundary conditions, and so was consistent with the method of choice of many of the participants. The predictions were run using FRONTSIM, GeoQuest's streamline based simulator. **Figure 24** shows the predictions of cumulative oil production from producer 1 with varying grid size. We can see that going to a coarse grid (of the size that might be used if the model here represented a pattern element of a full field model) induces large errors. Interestingly, there is little difference between the 20 x 44 x 17 and the 30 x 55 x 17 predictions, but both are some way away from the fine grid solution.

Figures 25, 26, 27, 28 show the variation in predictions for both oil rate and watercut for producer 3, which is the largest producer. The results are much closer here than for producer 1, although there are still reasonable errors in prediction of water breakthrough time.

The final set of results, **Figures 29, 30, 31, 32** show the predictions of field average pressure. The differences between the pseudo-based methods and the upscaling methods are less apparent here, with around the same level of variation between the two groups (Figs 29, 31). However, part of this variation is due to the difference in field average pressure computed on the intermediate grid used by Coats and Phillips (Fig 30). In Fig 32, we can see that the closest pressure prediction is provided by the harmonic-arithmetic average, with no-flow boundary conditions close behind. The power law method (which here selected only the maximum permeability) clearly overestimates the effective permeability of the system, and predicts too low a field average pressure.

Because this problem has low compressibility, the quality of the water and oil rate predictions is almost independent of the quality of the field average pressure prediction. So long as the upscaling method correctly estimates the ratios of the four producer productivity indices, the production split between the wells will be correct. However, field average pressure is determined by both the absolute values of the well PIs and the pressure drop between the wells, and so is sensitive to estimating the correct absolute value of the well PI. This sensitivity to the well PI also has implications for the fine grid field average pressure. If the wells had been moved a small distance, the well PI's might have changed significantly, and hence the computed fine grid field average pressure is potentially sensitive to small changes in the well locations.

Conclusions

The fine grid results were all in good agreement. This was true for both model 1, where computing the fine grid was easy, and for model 2 which was significantly more time consuming.

Model 1 was a relatively easy problem, and all participants were able to obtain coarse grid solutions that agreed well with their own fine grid results. Mostly these results were obtained by a history matching process to compute coarse grid relative permeabilities. Roxar showed that it was also possible to obtain good results using only single phase upscaling and local grid refinement, and Coats showed that it was possible to obtain a good match with a homogeneous permeability and the original rock curves on a coarse grid.

For model 2, the fine grid streamline simulations submitted by GeoQuest and Streamsim were in very good agreement with the fine grid finite difference solutions submitted by Landmark and Chevron. In addition, the intermediate grid solutions submitted by Phillips and Coats were very close to the full fine grid solutions, except for the field average pressure.

Where the fine grid can be run, a regression approach to pseudoisation can give good agreement with the fine grid results. Upscaling approaches where only the absolute permeability was averaged gave more scatter, though overall agreement on rate is generally good.

There was more scatter on prediction of individual well rates. This was true for both pseudoisation approaches and upscaling approaches.

At the grid sizes submitted, there was as much variation in results due to the choice of upscaling method as there was variation between individual solutions.

The coarse grid solutions from Heriot-Watt University showed that there was potential for significant errors due to excessive grid coarsening if only single phase upscaling is used.

Use of linear pressure gradient boundary conditions was not a good choice for the model considered here. This is in contrast to other geological models where linear pressure boundary conditions have resulted in a significant improvement in upscaling.

The best overall single phase method in this case was flow-based upscaling using no-flow boundary conditions.

Accurate calculation of field average pressure is not a good measure of accuracy of prediction of oil or water rates in this problem. The accuracy with which field average pressure is calculated is significantly influenced by the calculation of the upscaled well PIs.

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Appendix 1 – Details of model 1

The model is a 2-phase (oil and gas) model that has a simple 2D vertical cross-sectional geometry with no dipping or faults. The dimensions of the model are 762 meters long by 7.62 meters wide by 15.24 meters thick. The fine scale grid is 100 x 1 x 20 with uniform size for each of the grid blocks. The top of the model is at 0.0 metres with initial pressure at this point of 100 psia. Initially the model is fully saturated with oil (no connate water).

The initial properties of the fine grid model is as follows: porosity, $\phi = 0.2$; grid block sizes, DX = 7.62 m, DY = 7.62 m and DZ = 0.762 m; viscosities, $\mu_o = 1$ cp, $\mu_g = 0.01$ cp (constant throughout the run), densities, $\rho_o = 43.68$ 1b/ft^3 or 700 kg m^{-3}, $\rho_g = 0.0624$ 1b/ft3 or 1.0 kg m^{-3}.

The permeability distribution is a correlated geostatistically generated field (log *k* is shown in Fig 1). The permeability field and the relative permeabilities were downloaded from the project website.

The fluids are assumed to be incompressible and immiscible. The fine grid relative permeabilities are shown in Fig 2. Capillary pressure was assumed to be negligible in this case. Gas was injected from an injector located at the left of the model and dead oil was produced from a well on the right of the model.

Both wells have a well internal diameter of 1.0 ft and are completed vertically throughout the model. The injection rate was set to give a frontal velocity of 0.3 m/d (about 1 foot/day or 6.97 m^3 per day), and the producer is set to produce at a constant bottom pressure limit of 95 psia. The reference depth for the bottom hole pressure is at 0.0 meters (top of the model).

Appendix 2 – Details of model 2

This model has a sufficiently fine grid to make use of classical pseudoisation methods almost impossible. The model has a simple geometry, with no top structure or faults. The reason for this choice is to provide maximum flexibility in choice of upscaled grids.

At the fine geological model scale, the model is described on a regular cartesian grid. The model dimensions are 1200 x 2200 x 170 (ft). The top 70 ft (35 layers) represents the Tarbert formation, and the bottom 100 ft (50 layers) represents Upper Ness. The fine scale cell size is 20 ft x 10 ft x 2 ft. The model consists of part of a Brent sequence. The model was originally generated for use in the PUNQ project. The top part of the model is a Tarbert formation, and is a representation of a prograding near shore environment. The lower part (Upper Ness) is fluvial.

Fig.3 shows the porosity for the whole model. The fine scale model size is 60 x 220 x 85 cells (1.122x106 cells). The porosity and permeability maps were downloaded from the project web site.

Water properties are: B_w= 1.01, c_w = 3.10-6 psi^{-1}, μ_w = 0.3 cp
The dead oil pvt table was:

P(psi)	B_o	μ_o
300	1.05	2.85
800	1.02	2.99
8000	1.01	3.0

Relative permeabilities are:

$$k_{rw} = \left(\frac{S - S_{wc}}{1 - S_{wc} - S_{or}} \right)^2$$

$$k_{ro} = \left(\frac{1 - S - S_{or}}{1 - S_{wc} - S_{or}} \right)^2$$

$$S_{wc} = S_{wi} = S_{or} = 0.2$$

All wells were vertical, and completed throughout formation. The central injector has an injection rate of 5000bbl/day (reservoir conditions) and a maximum injection bottom hole pressure of 10000 psi. There are 4 producers in the four corners of the model, each produces at 4000psi bottom hole pressure.

Company	Upscaling Method	Final Grid Size
GeoQuest	1. Arithmetic-harmonic 2. Harmonic-arithmetic 3. Power Law 4. Flow Based – no side flow 5. Flow Based – linear pressure 6. Flow Based – half cell	15 x 55 x 17
Landmark	Flow Based, Regression based for rel perms	5 x 11 x 17
Roxar	Diagonal Tensor	15 x 55 x 22 (plus lgrs)
Streamsim	Geometric Averaging	12 x 44 x 17 30 x 110 x 17 30 x 110 x 85 60 x 220 x 17 60 x 220 x 85
Phillips	Single phase to intermediate grid, regression on rel perms to final grid.	11 x 19 x 11
TotalFinaElf	Upgridding & flow based upscaling with no-side flow bcs	10 x 37 x 13
Coats	Flow-based, regression based pseudo rel perms	30 x 55 x 85 10 x 20 x 10 3 x 5 x 5
Chevron	Upgridding, flow based upscaling	22 x 76 x 42

Table 1: Summary of Entries for Case 2

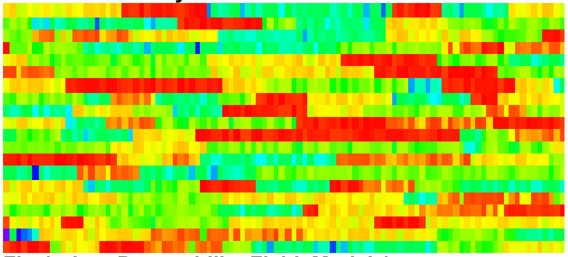

Fig 1: Log Permeability Field, Model 1

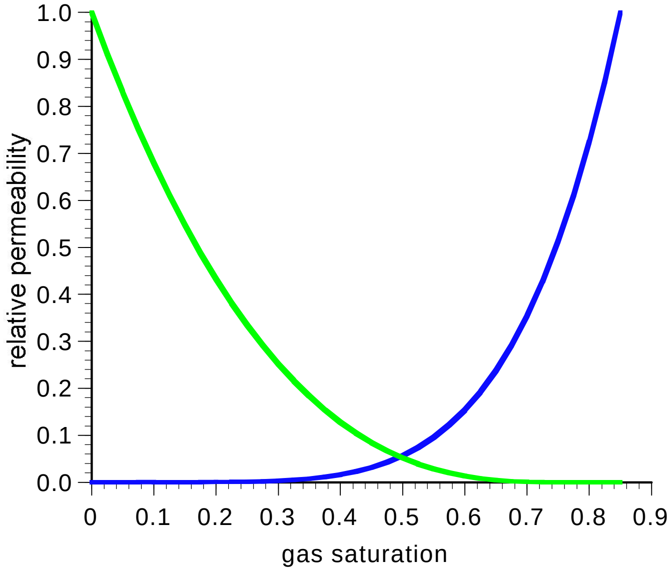

Fig 2: Relative Permeabilies for Model 1

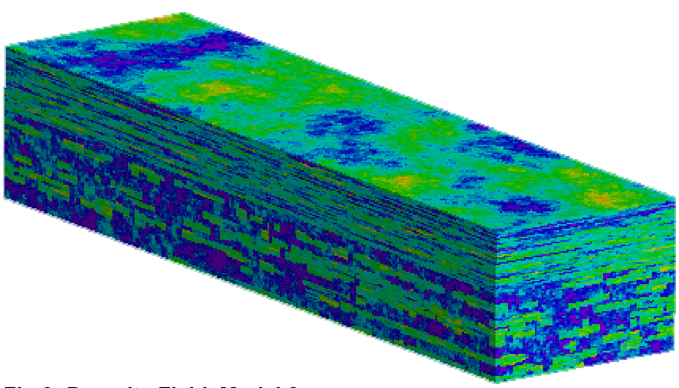

Fig 3: Porosity Field, Model 2

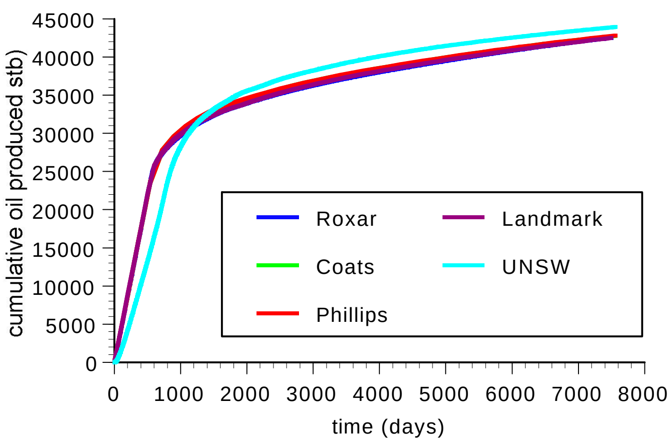

Fig 4: Comparison of Fine Grid Results, Model 1

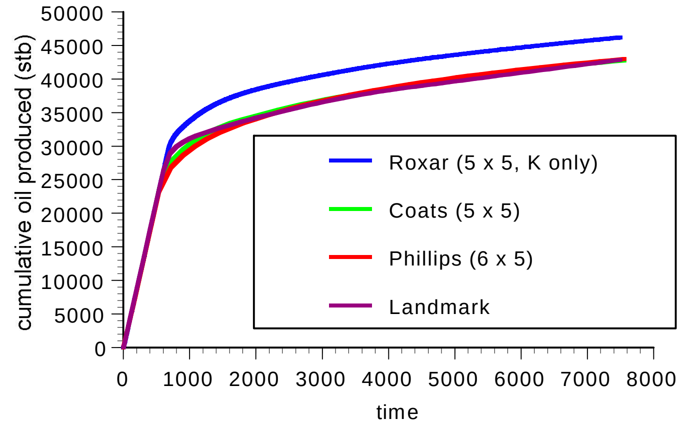

Fig 5: Comparison of 5 x 5 Results, Model 1

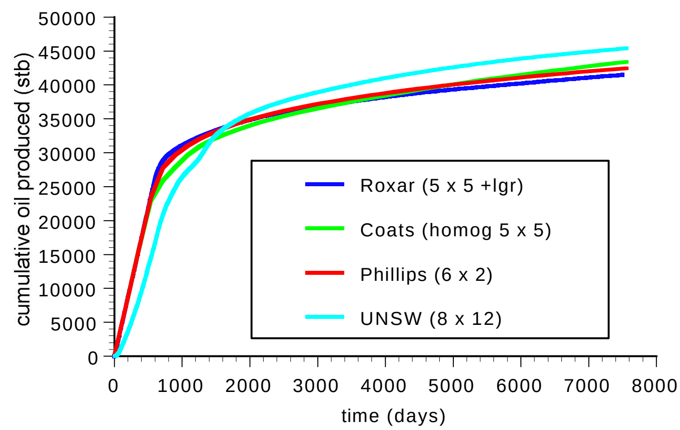

Fig 6: Comparison of Alternative Models for Model 1

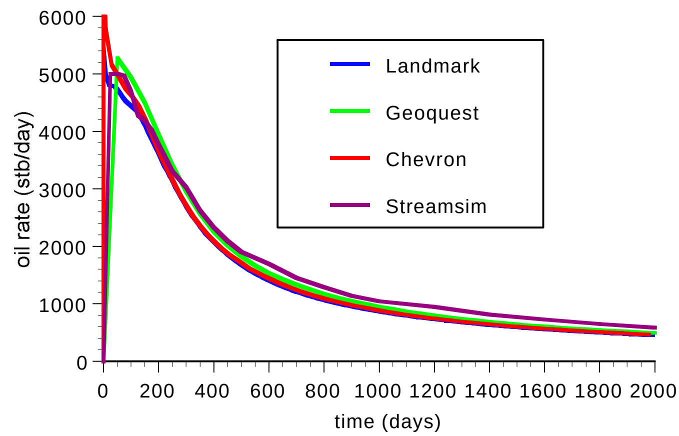

Fig 7: Comparison of Fine Grid Field Oil Rate, Model 2

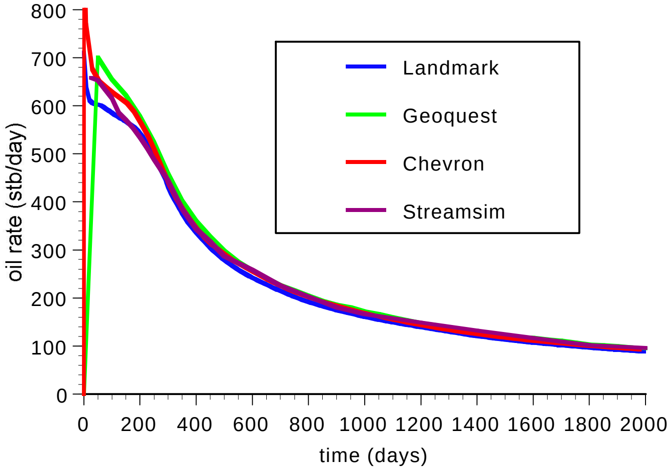

Fig 8: Comparison of Fine Grid Producer 1 Oil Rate, Model 2

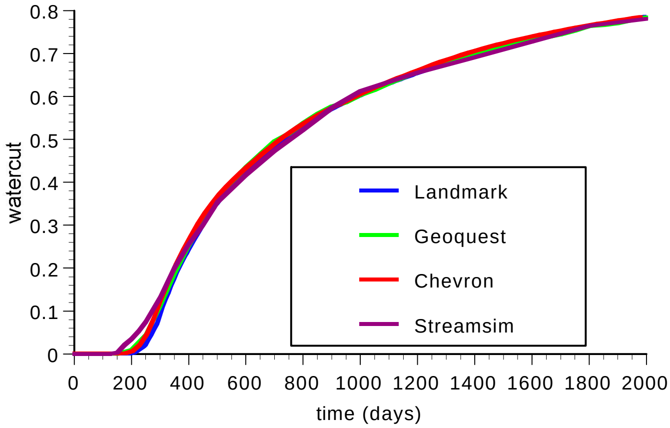

Fig 9: Comparison of Fine Grid Producer 1 Watercut, Model 2

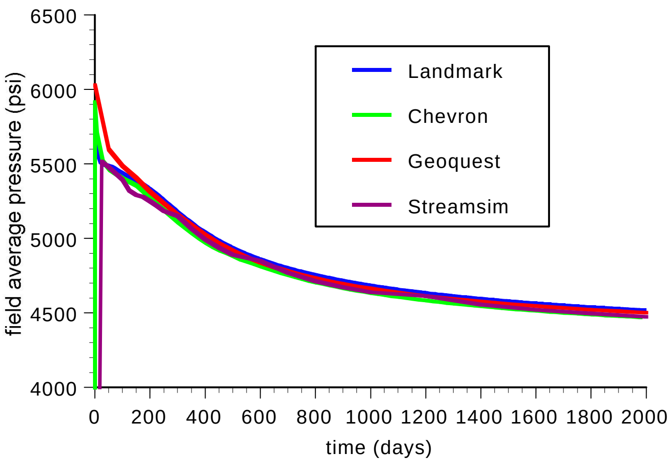

Fig 10: Comparison of Fine Grid Field Average Pressure, Model 2

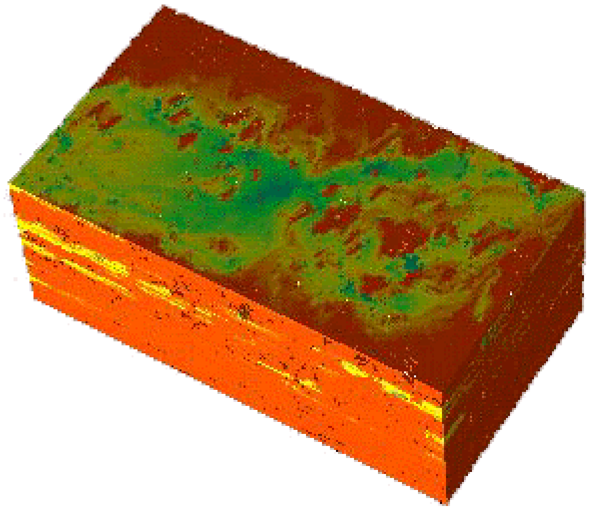

Fig 11: TotalFinaElf Fine Grid Water Saturation for Model 2 at 800 days using 3DSL

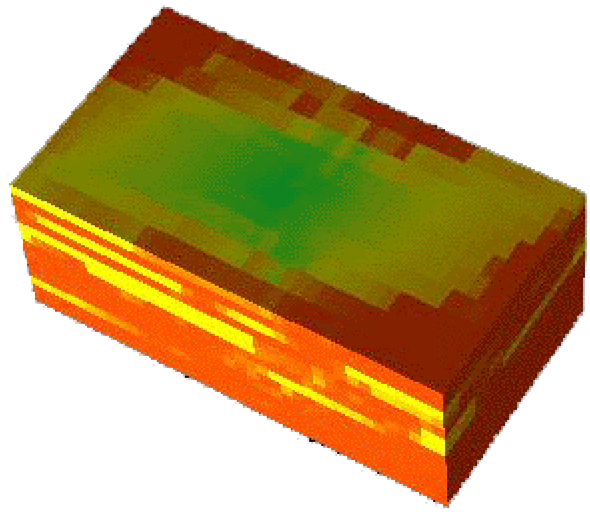

Fig 12: TotalFinaElf Coarse Grid Water Saturation for Model 2 at 800 days using 3DSL

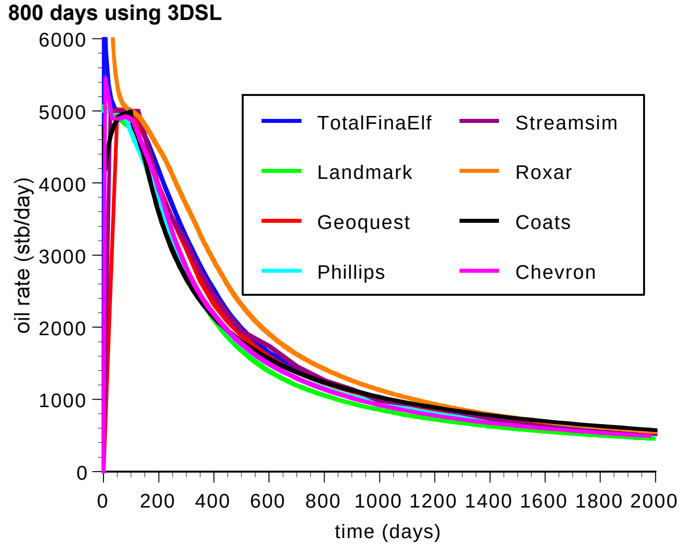

Fig 13: Comparison of All Field Oil Rate Curves for Model 2

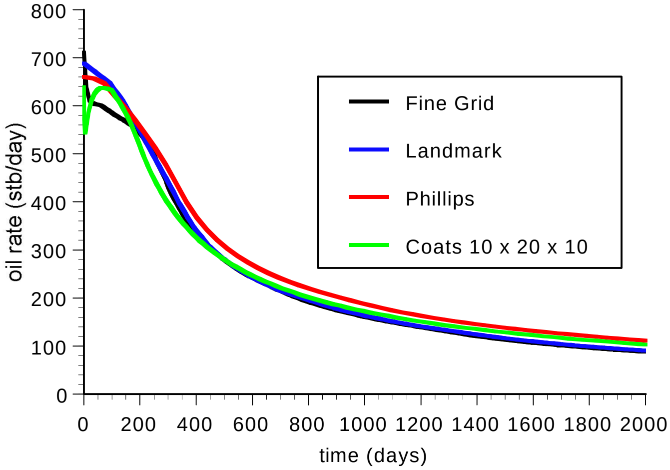

Fig 14: Comparison of Pseudo-Based Upscaled Producer 1 Oil Rate Curves with Landmark Fine Grid Oil Rate for Model 2

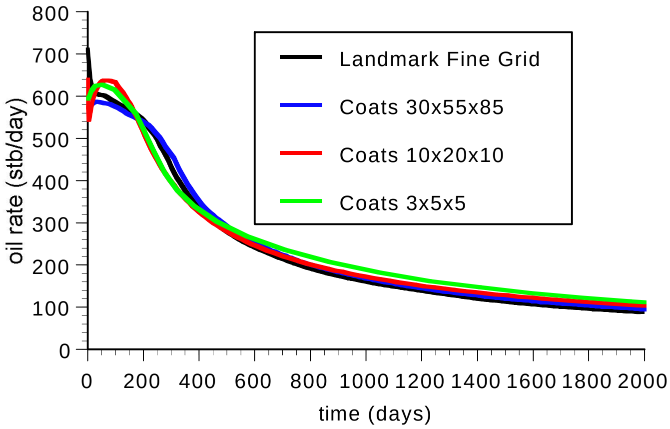

Fig 15: Comparison of Coats Intermediate Grid Solution with Fine Grid and Two Coarse Grid Solutions for Oil Rate for Producer 1

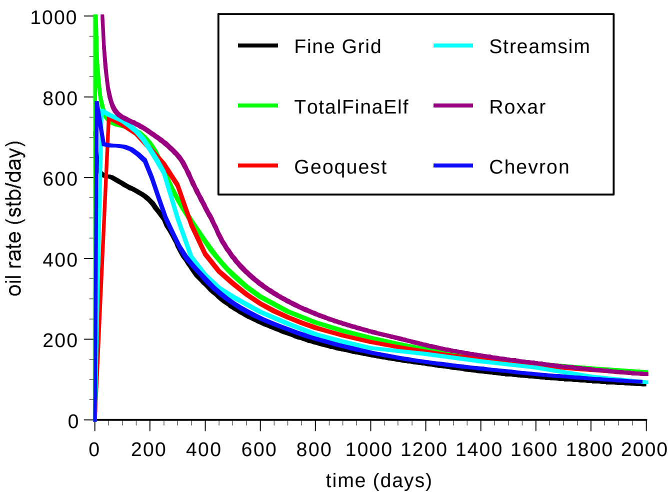

Fig 16: Comparison of Non-Pseudo Upscaled Producer 1 Oil Rate Curves with Landmark Fine Grid Oil Rate for Model 2

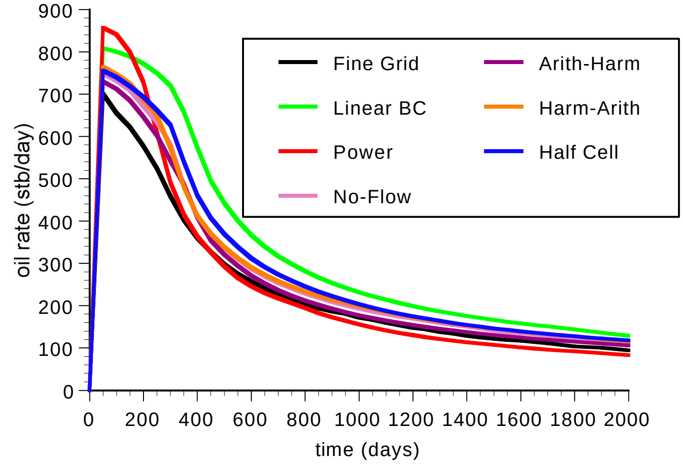

Fig 17: Variation of Producer 1 Oil Rate With Upscaling Method For Fixed Coarse Grid for Model 2

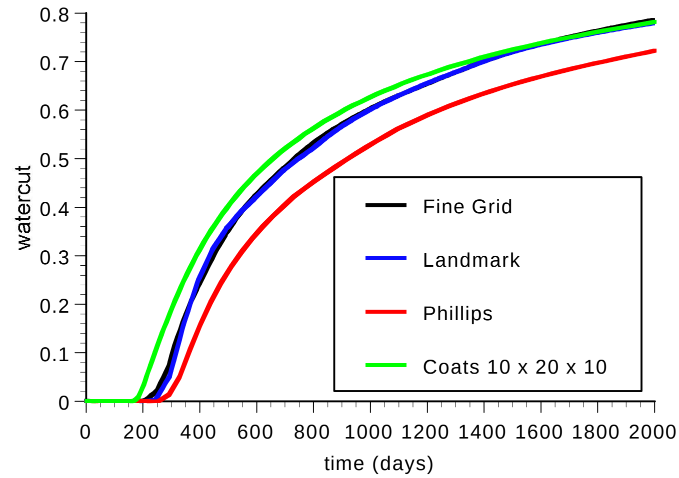

Fig 18: Comparison of Pseudo-Based Upscaled Producer 1 Watercut Curves with Landmark Fine Grid Watercut for Model 2

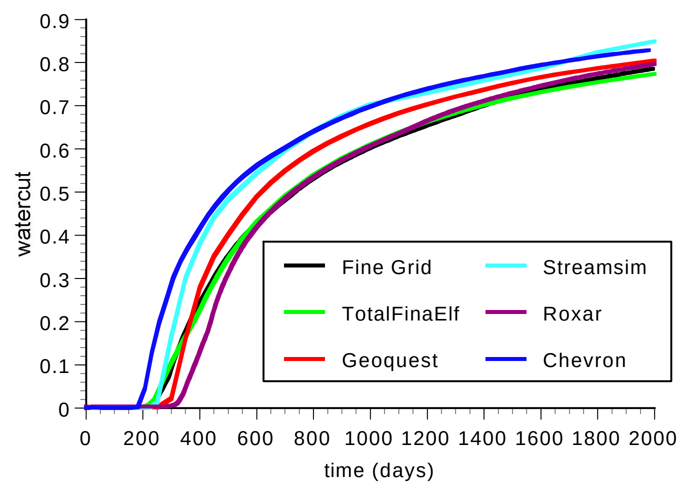

Fig 19: Comparison of Non-Pseudo Upscaled Producer 1 Watercut Curves with Fine Grid Result for Model 2

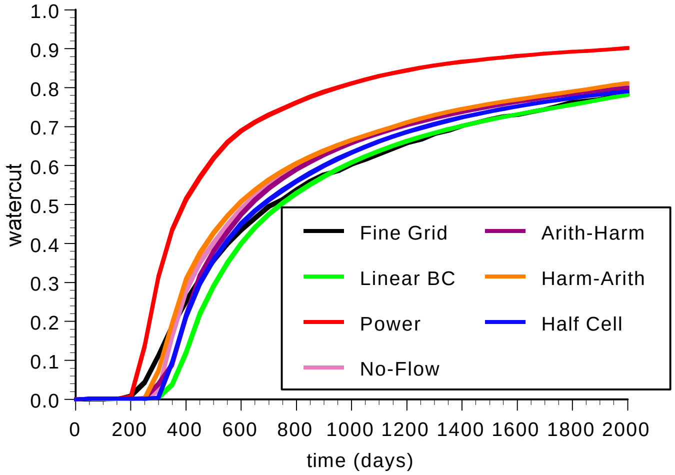

Fig 20: Variation of Producer 1 Watercut With Upscaling Method For Fixed Coarse Grid for Model 2

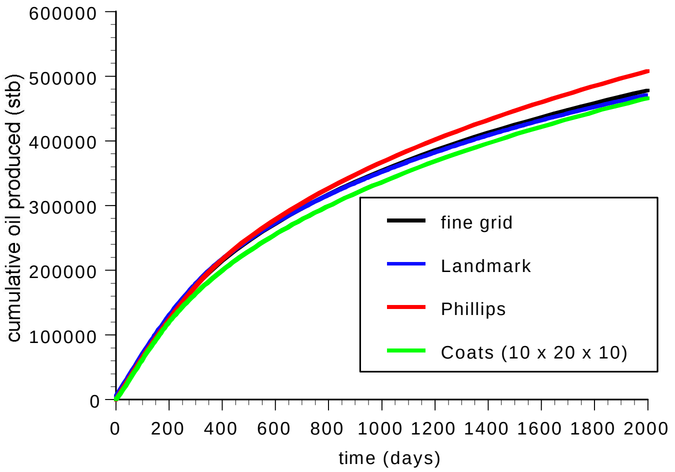

Fig 21: Variation in Cumulative Oil Production for Producer 1 for Pseudo Approaches

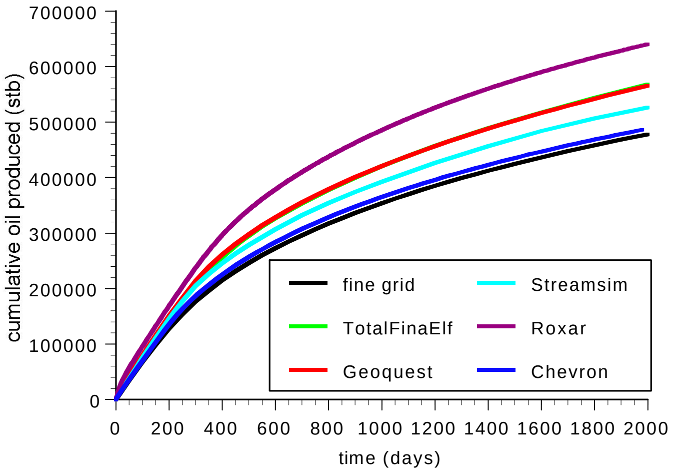

Fig 22: Variation in Cumulative Oil Production for Producer 1 for Non-Pseudo Approaches

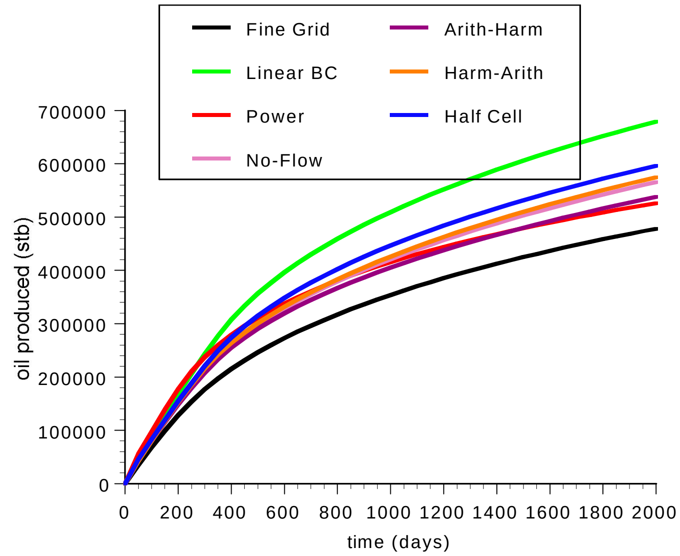

Fig 23: Variation of Cumulative Oil Produced for Producer 1 With Upscaling Method For Fixed Coarse Grid for Model 2

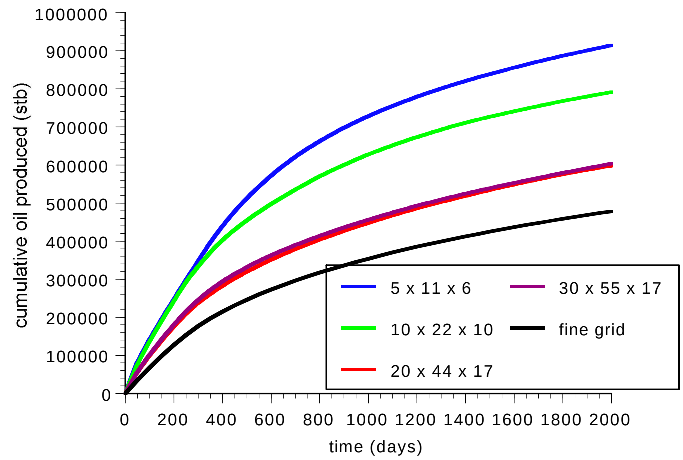

Fig 24: Variation in Cumulative Oil Production for Producer 1 with Upscaled Grid Size.

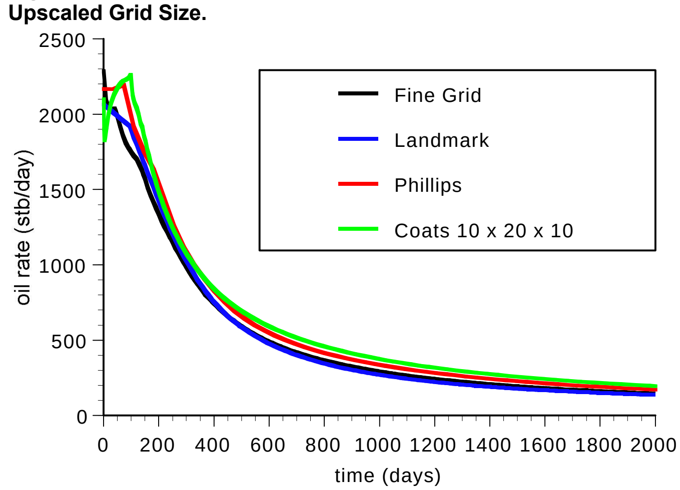

Fig 25: Comparison of Pseudo-Based Upscaled Producer 3 Oil Rate Curves with Landmark Fine Grid Oil Rate for Model 2

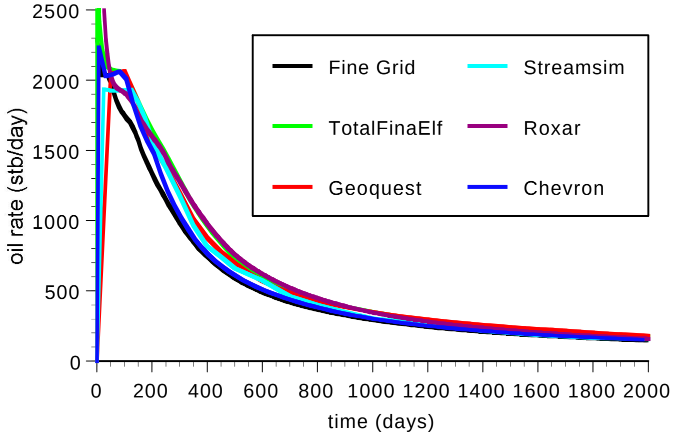

Fig 26: Comparison of Non-Pseudo Upscaled Producer 3 Oil Rate Curves with Landmark Fine Grid Oil Rate for Model 2

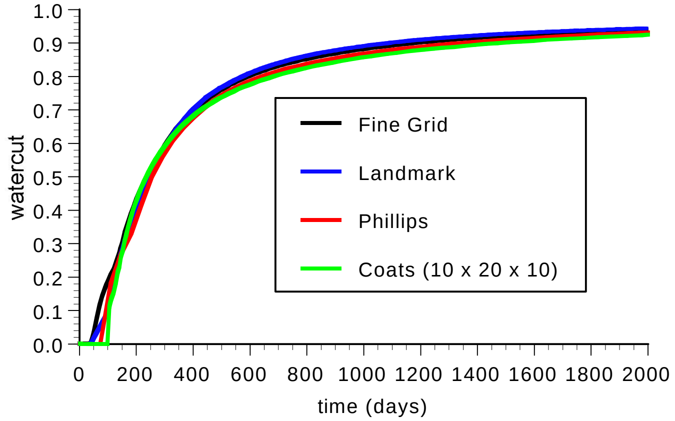

Fig 27: Comparison of Pseudo-Based Upscaled Producer 3 Watercut Curves with Landmark Fine Grid Oil Rate for Model 2

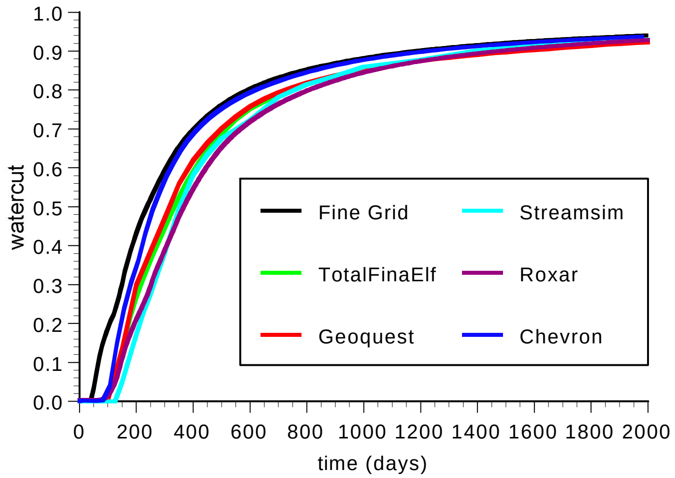

Fig 28: Comparison of Non-Pseudo Upscaled Producer 3 Watercut Curves with Landmark Fine Grid Oil Rate for Model 2

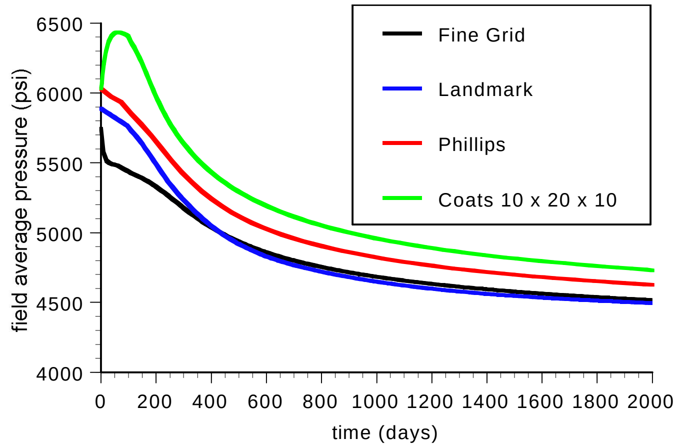

Fig 29: Comparison of Pseudo-Based Upscaled Field Average Pressure Curves with Fine Grid Field Average Pressure for Model 2

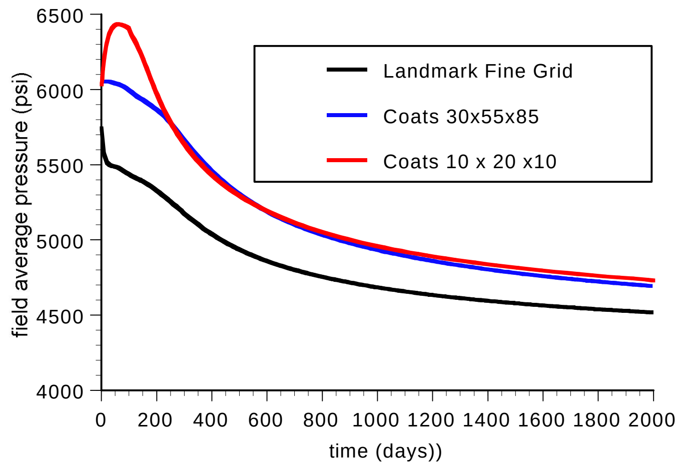

Fig 30: Comparison of Coats Field Average Pressure Curves for Intermediate and Coarse Grids with Fine Grid for Model 2

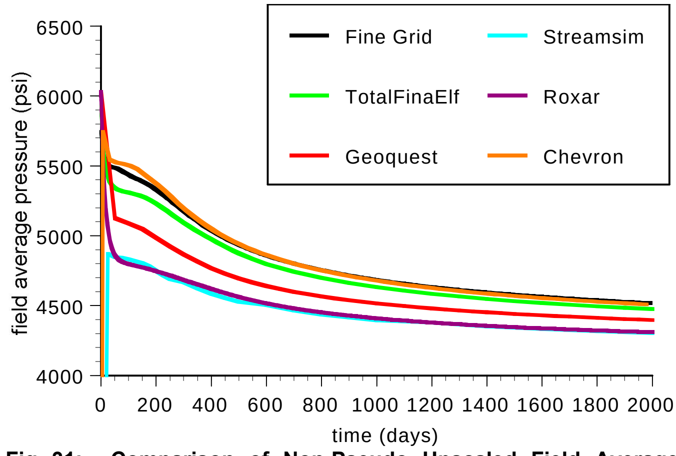

Fig 31: Comparison of Non-Pseudo Upscaled Field Average Pressure Curves with Fine Grid Result for Model 2

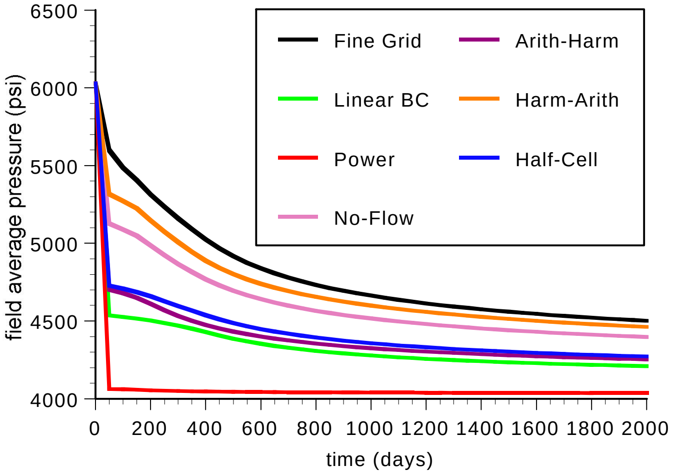

Fig 32: Variation of Field Average Pressure With Upscaling Method For Fixed Coarse Grid for Model 2