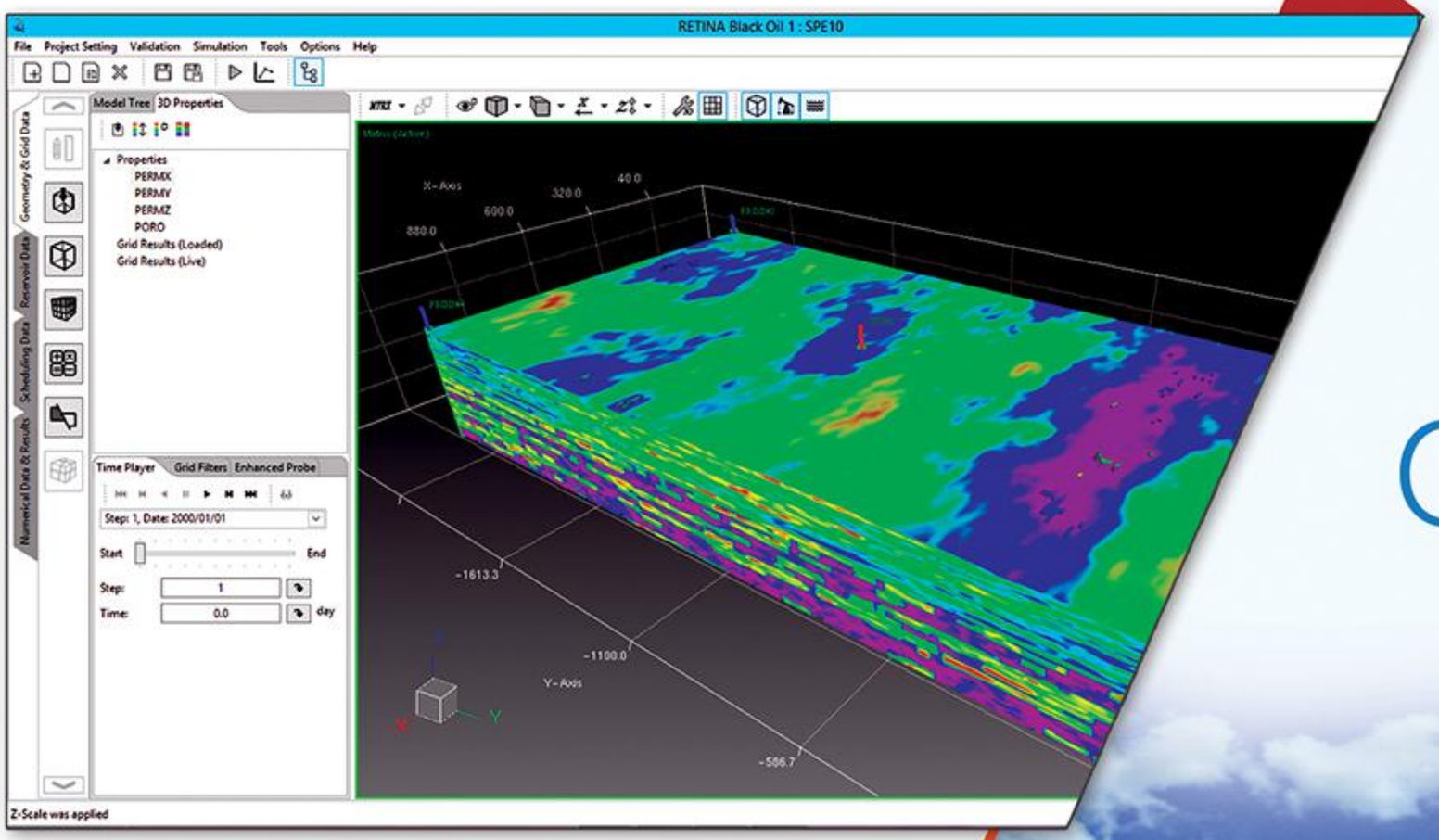
An Efficient and Robust Solution for



Unconventional Reservoirs

RETINA
SIMULATION

Case studies

ESTD

Engineering Support & Technology Development

Company Brief

Founded in 2012, Engineering Support & Technology Development (ESTD) is an engineering consultation and software development company focused on upstream oil and gas section.It has developed several engineering software products including :

RETINA™ SIMULATION RETINA™ STATION and RETINA™ STIMULATION.

The main specialty of ESTD, is engineering software development which requires advanced mathematical modeling expertise and numerical analysis capabilities.

In addition to software development, and due to having access to special tools and highly educated engineers, ESTD offers several distinct and professional services. These services range from well stimulation design to non-conventional full field studies.

RETINA SIMULATION

RETINA STATION

RETINA STIMULATION

RETINA SIMULATION

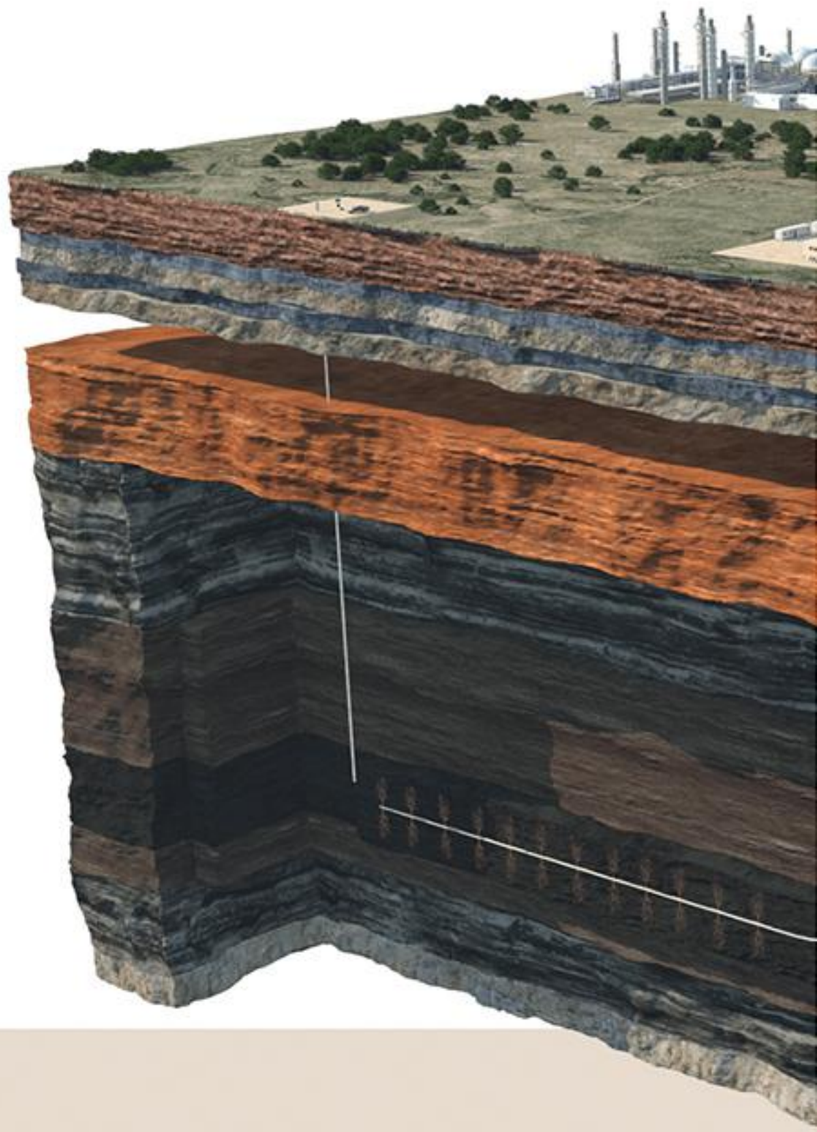
RETINA Simulation™ is a Black-Oil and Compositional reservoir simulation software fully developed in ESTD during the past 4 years. RETINA has been tested and certified by 4 of National Iranian Oil Company subsidiaries in cases of accuracy and stability compared to ECLIPSE 100™:
KARANJ-Asmari from National Iranian South Oil Company (NISOC), DOROUD-Asmari from Iranian Offshore Oil Company (IOOC), East PAYDAR-Asmari from Iranian Central Oil Fields Company (ICOFC) and North AZADEGAN-Sarvak from Petroleum Engineering and Development Company (PEDEC). RETINA results have less than 5% difference compared to ECLIPSE 100 in all cases. Main features of RETINA Simulation™ are:

- Powerful and stable linear solver and preconditioner: CPR AMG based ILU0
- All of the non-EOR physical models of ECLIPSE 100
- Fully integrated pre and post processor capable of loading ECLIPSE 100 and 300 DATA files completely and automatically
- Equipped with real time result visualization (plot and 3D) and live update of the model

RETINA STATION

RETINA Station™ is the main platform for data management and workflow integration of the RETINA software suite. It is used to manage all the petroleum engineering data as well as to create RETINA Simulation™ cases. RETINA Station™ is developed specially for E&P companies to meet their needs in management and analysis of their data. The main features of RETINA Station™ are:

- Importing and visualizing all Well data such as path, completion, logs, core data, observed data and well test
- Filtering, correcting and creating well logs
- Importing, organizing, modifying, visualizing and exporting all the common formats of Grid data
- Importing and visualizing all dynamic reservoir data such as PVT, SCAL and VFP tables
- Property calculation, static volumetric calculation, well log filtering and calculation and generating different cross-plots
- Comprehensive and integrated platform for all seismic to simulation tools

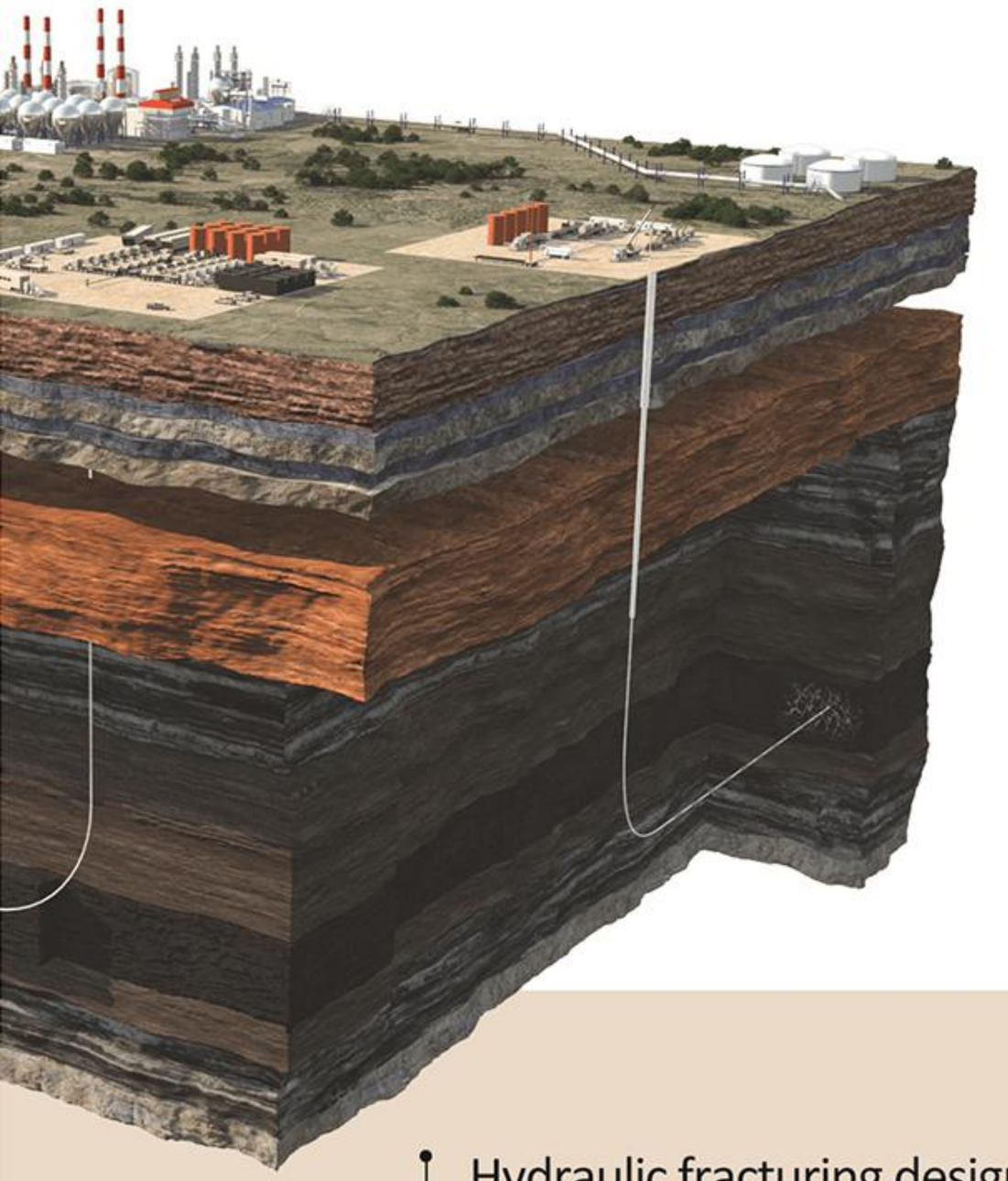


Main Services

Being composed of highly educated and talented engineers and access to their deep knowledge of physical models and numerical analysis, makes ESTD's team one of the best, most flexible and fastest consultation teams in the market. ESTD provides several specialized engineering services some of which are unique in terms of tools and workflows.

RETINA STIMULATION

RETINA Stimulation™ is a modeling tool used for designing stimulation methods and predicting perforation efficiency. It is used in real field cases to design the dynamic underbalanced perforation and propellant gas fracturing operations in the Persian Gulf region. Hydraulic Fracture design and modeling is also added to the software recently. The main features of RETINA Stimulation™ are:



- Conventional perforation prediction module
- Dynamic underbalance perforation module
- Propellant gas fracturing module
- Hydraulic fracturing module

Hydraulic fracturing design and optimization using RETINA Stimulation™

Perforation design and optimization using RETINA Stimulation™

Carbonate fractured reservoir full field study using RETINA Simulation™

Non-conventional reservoir full field study using RETINA Simulation™

Tight Carbonate

Model description

The case is an onshore oil field located in the Middle East area. Production from this field started in 2004. The history matching model of this field was run by RETINA Simulation™ to be compared with ECLIPSE 100™ results.

The model is dual porosity with very tight matrix (average of 0.09 md permeability) and extremely conductive natural fractures (average of 66444 md permeability). It is initially a near bubble point reservoir with a moderate aquifer as its boundary condition. The model has only 1 active oil producing well.

More details about the model are described in Table 1.

Table 1

Model type	Black oil dual porosity
No. of active cells	186432
No. of active wells	1
Model run duration	10 years
Special model	Hysteresis, GRAVDR, AQUCT

Detailed information about the case study

The model is simulated with RETINA Simulation™ and results from ECLIPSE 100™ are used for comparison and verification.

The two simulators are allowed to select their own time step sizes and no special tuning is done. The main restriction on time step size is the frequency of input history rates which is almost every one month. The results from these two simulators for this case are compared from two aspects: accuracy and speed.

Accuracy

Figures 1 and 2 show the comparison between RETINA Simulation™ and ECLIPSE 100™ results for the only well of the model. All the results match almost perfectly. Maximum relative difference between these two simulator results are shown in table 2.

Table 2

Simulation result	Max. of relative difference (percent)
Field Average Pressure	0.096%
Field Oil Production Rate	0.0000046%
Field Gas Oil Ratio	0.10%
Field Water Cut	0.20%
Wells Gas Oil Ratio	0.10%
Wells Water Cut	0.20%
Wells Bottom Hole Pressure	0.16%
Wells Static Pressure	0.16%

Summary of simulation results comparison between RETINA and ECLIPSE

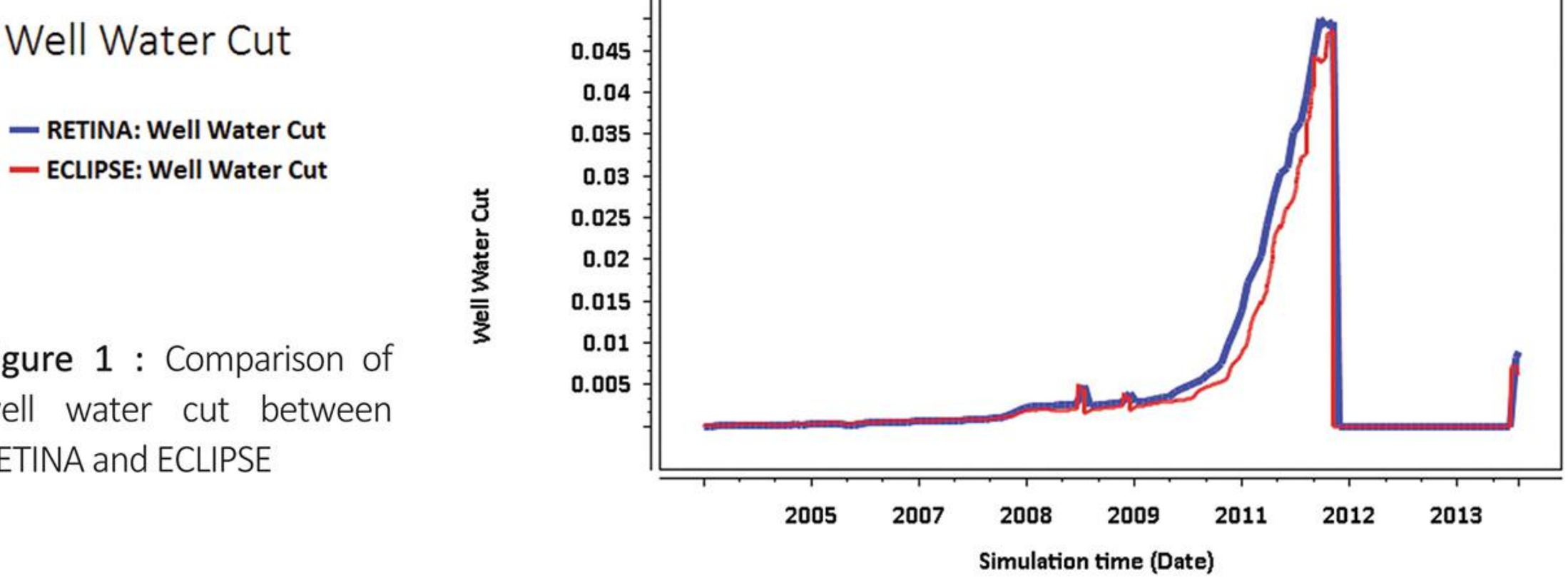


Figure 1 : Comparison of well water cut between RETINA and ECLIPSE

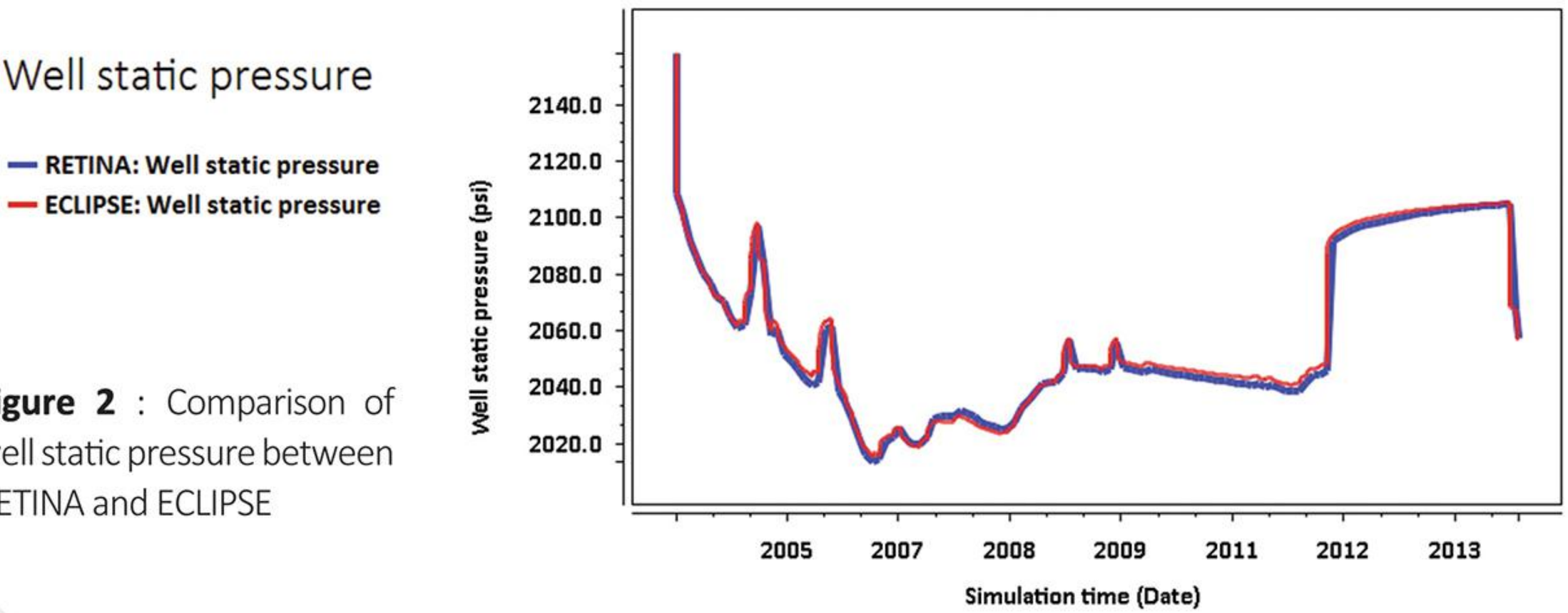


Figure 2 : Comparison of well static pressure between RETINA and ECLIPSE

Engineering Support & Technology Development (ESTD)

Speed

As seen in figures 3 and 4, RETINA Simulation™ can take larger time steps in this model, and it has less elapsed time. RETINA Simulation™ is usually more stable and can get larger time steps in the case of dual porosity models with tight matrices and high conductive fractures. This is due to superior linear solver and pre-conditioner used in RETINA Simulation™. Tight matrix and conductive fractures are typical in tight oil and shale gas fields. More details about speed comparison are explained in the following sections.

1 Simulation elapsed time in seconds.

This parameter represents the time taken to perform the simulation from time 0 to a specified simulation time (10 years in this case). Figure 3 shows that RETINA Simulation™ can simulate the model a lot faster than ECLIPSE 100™ can. RETINA Simulation™ takes only 8838 seconds where ECLIPSE 100™ needs 32770 seconds to run the entire model; which means, RETINA Simulation™ can run the model almost four times faster.

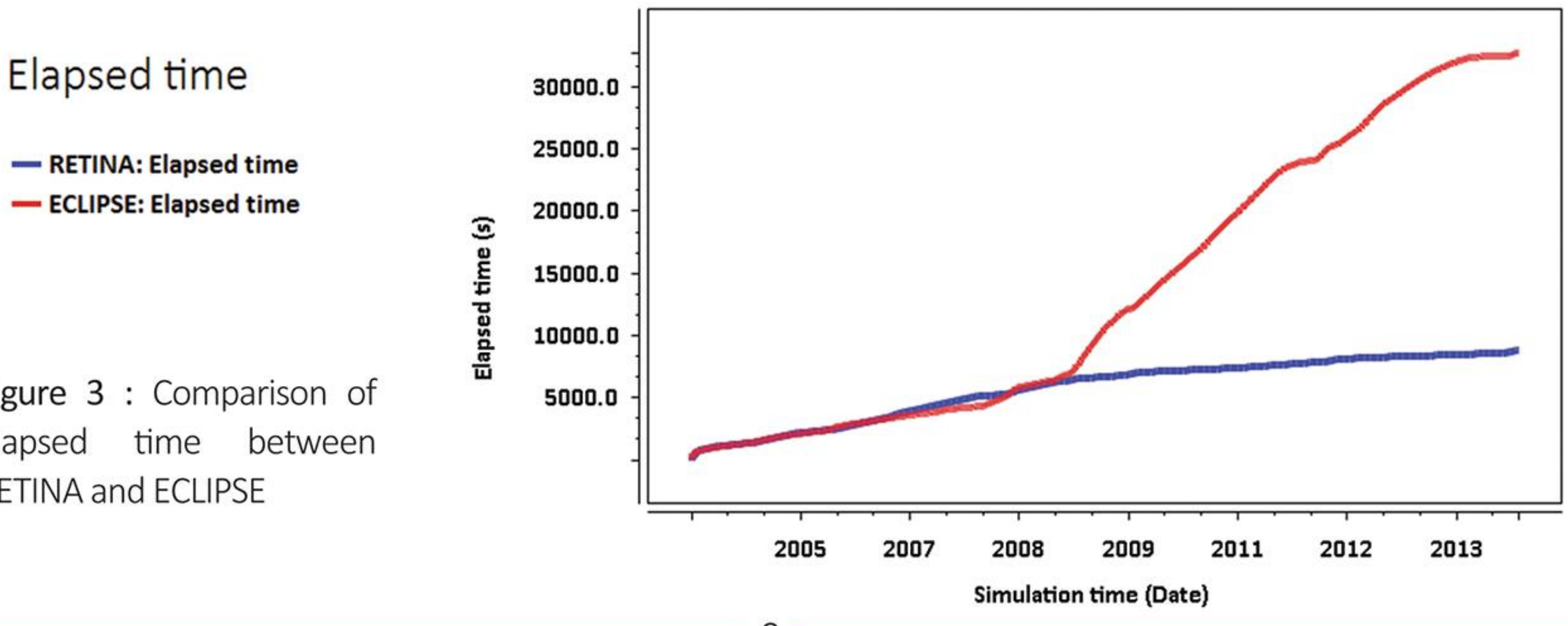


Figure 3 : Comparison of elapsed time between RETINA and ECLIPSE

2 Time step size

Figure 4 is the comparison of time-step size between RETINA Simulation™ and ECLIPSE 100™. RETINA Simulation™ has generally larger time-steps compared to ECLIPSE 100™. Average size of time-steps in RETINA Simulation™ is 6.61 days where ECLIPSE 100™ has the average of 0.68 days. From the accuracy comparison it is evident that, large time step sizes does not lead to higher time truncation error in RETINA Simulation™. RETINA has more stable solution in the case of tight carbonate dual porosity models. Larger time-steps showcase the superiority and robustness of non-linear and linear solvers in RETINA Simulation™.

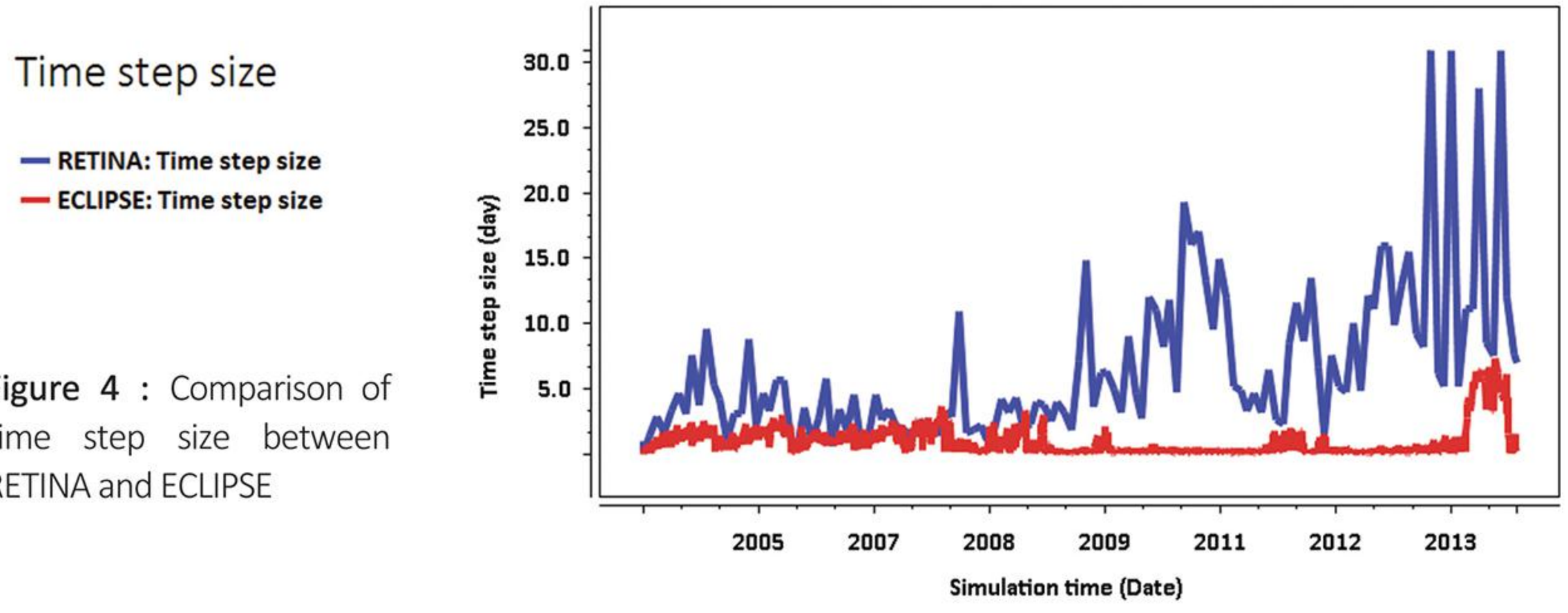
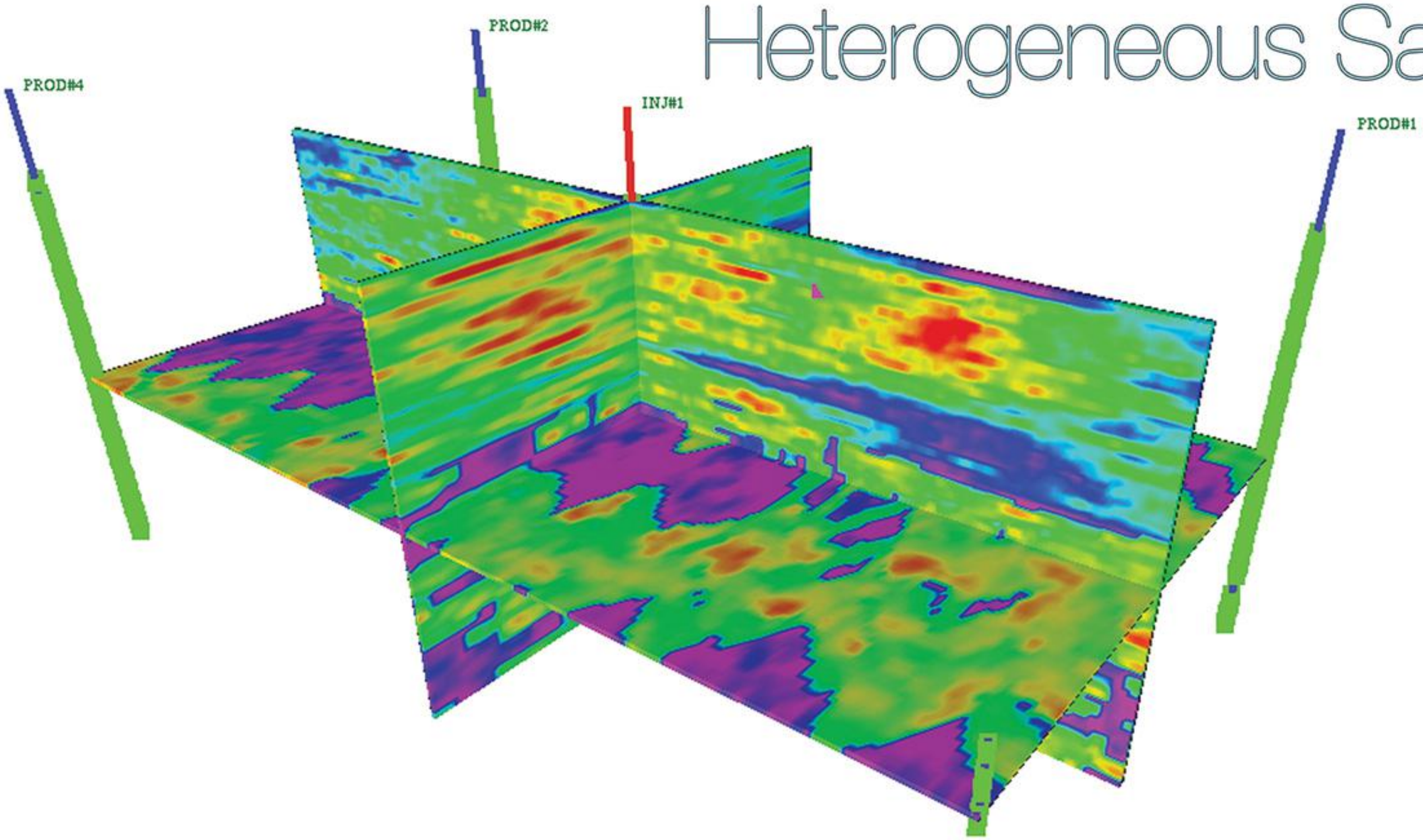


Figure 4 : Comparison of time step size between RETINA and ECLIPSE

Engineering Support & Technology Development (ESTD)

Heterogeneous Sandstone



Model description

This case is the tenth SPE comparative project fine model: A large structured fine grid with a reverse five-spot pattern water injection. This model is run by RETINA Simulation™ to be compared with ECLIPSE 100™.

The model is single porosity with highly heterogeneous channel and floodplain sands. The model is initially under-saturated and remains two-phase throughout the simulation. A water injection well is drilled at the center of the model and four oil production wells are producing at the corners. Model is run for 2000 days with a maximum report step-size of 20 days.

More details about the model are described in Table 1.

Table 1

Model type	Black oil single porosity
No. of active cells	1094421
No. of active wells	5
Model run duration	2000 days
Special model	Pattern water injection

Detailed information about the case study

The model is simulated with RETINA Simulation™ and results from ECLIPSE 100™ are used for comparison and verification.

The two simulators are allowed to select their own time-step sizes and no special tuning is defined. The main restriction on time-step size is the frequency of report requests which is every 20 days. The results from these two simulators are compared from two aspects: accuracy and speed.

Accuracy

Figures 1 and 2 show comparison between RETINA Simulation™ and ECLIPSE 100™ results for one of the producing wells. All the results match almost perfectly. Since ECLIPSE 100™ was unable to run the model to the end after 48 hours, results of the first 300 days of simulation are shown for this simulator.

Table 2

Simulation result	Max. of relative difference (percent)
Field Average Pressure	0.77%
Field Oil Production Rate	0.018%
Field Gas Oil Ratio	0.00%
Field Water Cut	0.018%
Wells Gas Oil Ratio	0.00%
Wells Water Cut	9.74%
Wells Bottom Hole Pressure	0.00%
Wells Static Pressure	0.94%

Summary of simulation results comparison between RETINA and ECLIPSE

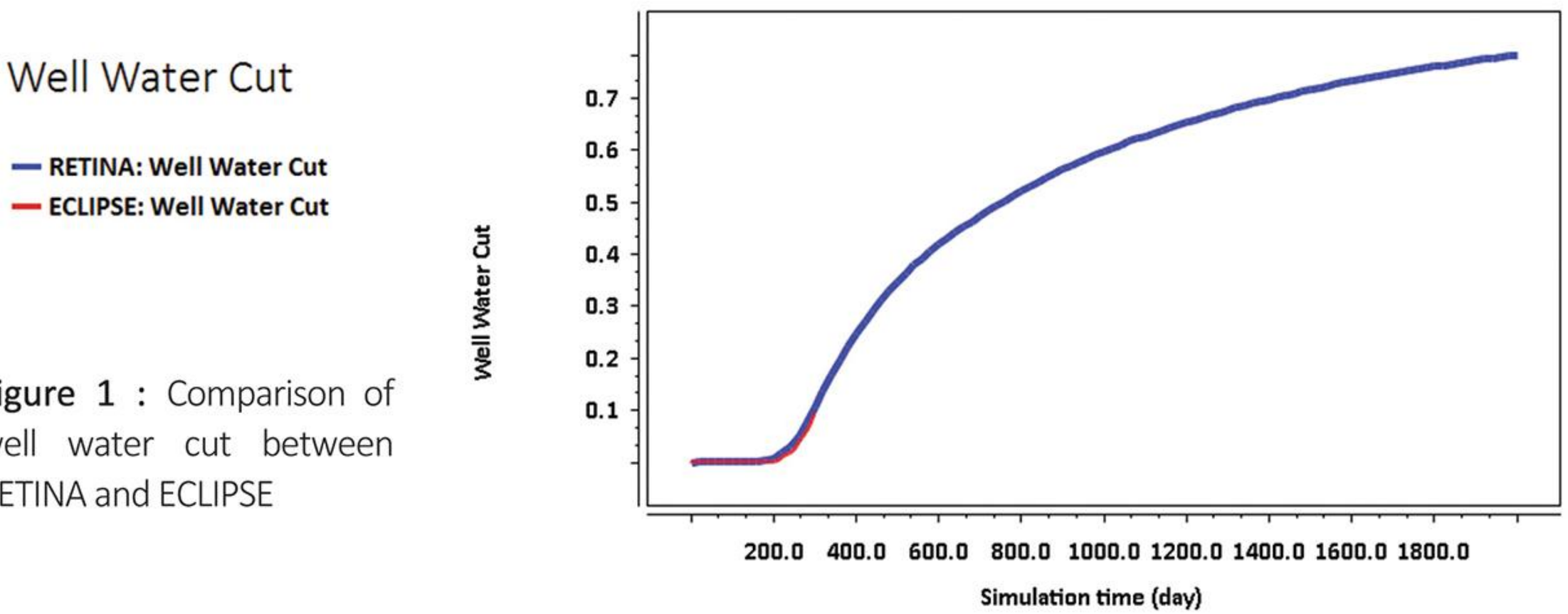


Figure 1 : Comparison of well water cut between RETINA and ECLIPSE

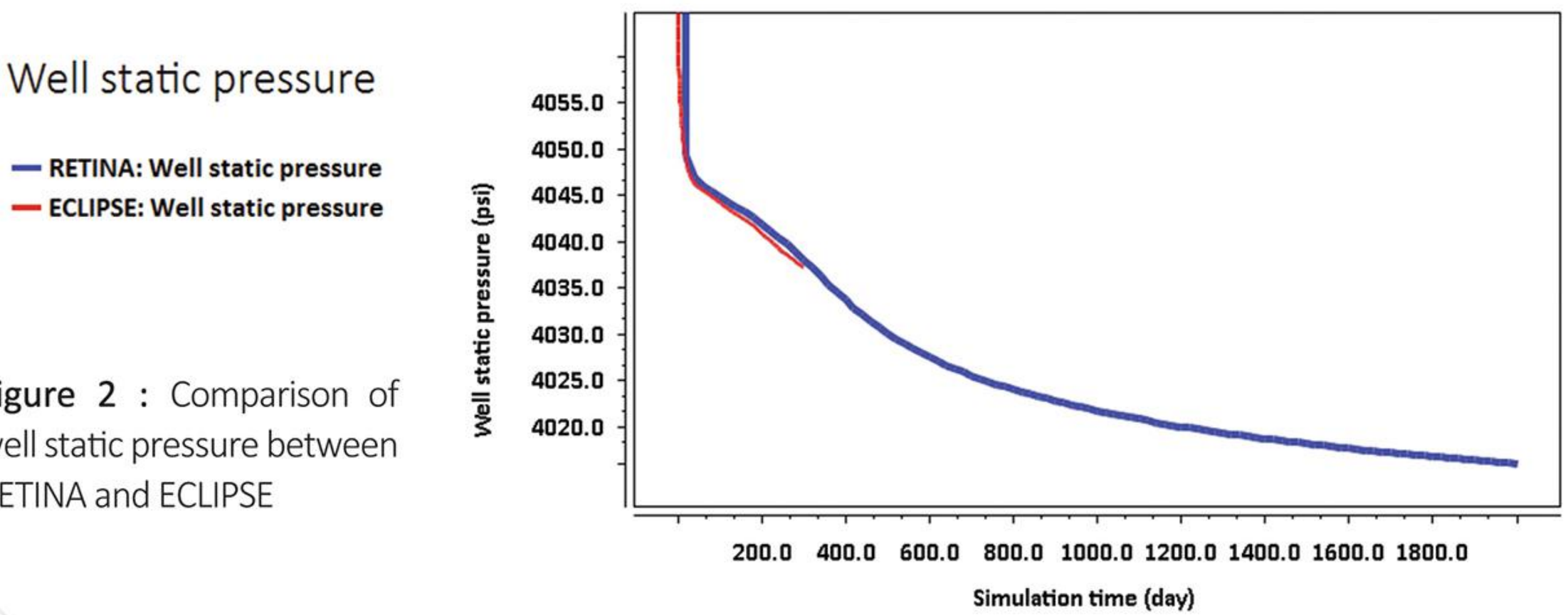


Figure 2 : Comparison of well static pressure between RETINA and ECLIPSE

Speed

As seen in figures 3 and 4, RETINA Simulation™ can take very larger time-steps for this model, and therefore it has a better elapsed time. This is an extremely heterogeneous reservoir. ECLIPSE 100™ solver could not handle this level of heterogeneity while RETINA Simulation™, can perform the simulation as easy as any simple model. RETINA Simulation™ needs about one hour to run the entire 2000 days of this complex model while ECLIPSE 100™ takes 48 hours to run the first 300 days.

1 Simulation elapsed time in seconds.

This parameter represents the time which is needed to perform the simulation from time 0 to a specified simulation time (2000 days in this case). Figure 3 shows that RETINA Simulation™ has shorter elapsed time and can run the model a lot faster than ECLIPSE 100™. RETINA Simulation™ takes 3916 seconds for entire model where ECLIPSE 100™ needs 171268 seconds to run the first 300 days.

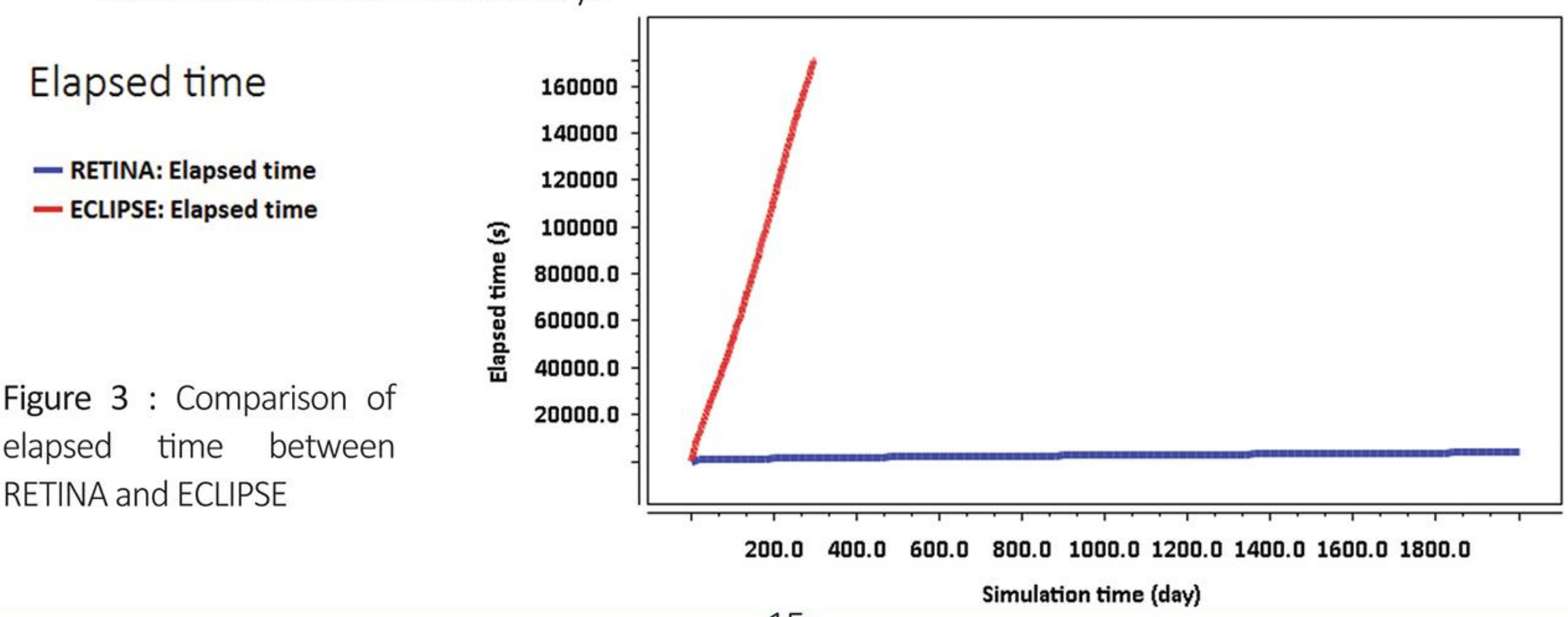


Figure 3 : Comparison of elapsed time between RETINA and ECLIPSE

2 Time step size

Figure 4 is the comparison of time-step size between RETINA Simulation™ and ECLIPSE 100™. RETINA Simulation™ has extremely larger time steps compared to ECLIPSE 100™. The main restriction for RETINA Simulation ™ time step is the 20 days report step imposed by the user. Average size of time-steps in RETINA Simulation™ is 19.40 days while ECLIPSE 100™ has an average of 0.45 days. Again, looking at the accuracy comparison, it is evident that large time-step sizes do not lead to higher time truncation error in RETINA Simulation™. The main conclusion would be that RETINA Simulation™ has an exceptional and stable performance for simulating highly heterogeneous models.

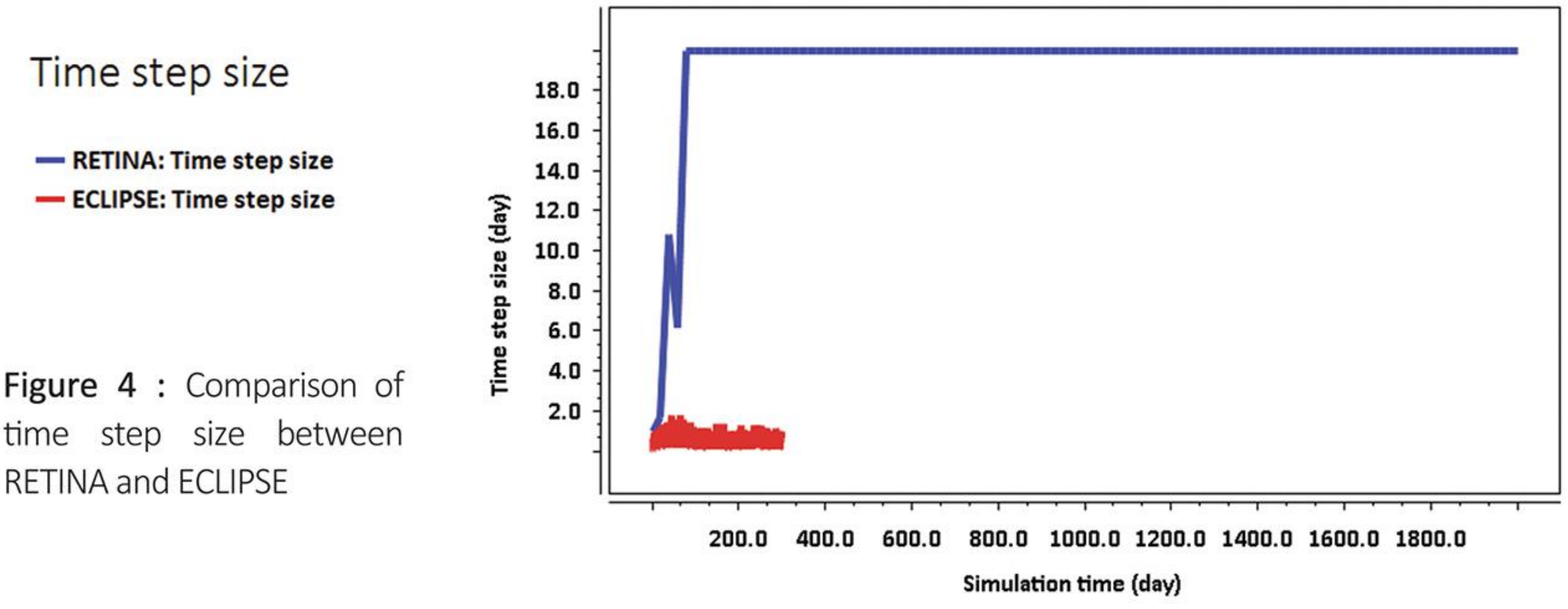


Figure 4 : Comparison of time step size between RETINA and ECLIPSE

Conventional Field

Model description

The case is a large onshore oil field located in Iran. Production from this field started in 2008. The model is a 7 year history matching model continued with 23 years of prediction scenario which is run by RETINA Simulation™ to be compared with ECLIPSE 100™.

The model is single porosity with moderate heterogeneity in all directions. It is initially an under-saturated reservoir with no aquifer. In its prediction scenario, 57 horizontal wells are drilled in the model and minimum bottom-hole pressure and maximum water-cut is set as their production limits. All the wells are controlled using their hierarchical group structure.

More details about the model are described in Table 1.

Table 1

Model type	Black oil single porosity
No. of active cells	923514
No. of active wells	57
Model run duration	30 years
Special Feature(s)	Group control, Auto workover

Detailed information about the case study

The model is simulated using RETINA Simulation™ and results from ECLIPSE 100™ are used for comparison and verification.

The two simulators are allowed to select their own time-step sizes and no special tuning is defined. The main restriction on time-step size is the frequency of report request which is every year. The results from these two simulators for this case are compared from two aspects: accuracy and speed.

Accuracy

Figures 1 and 2 show the comparison between RETINA Simulation™ and ECLIPSE 100™ results for only one of the wells, due to confidentiality of data. All of the results match almost perfectly but there are some differences in some specific wells. The main reason for difference in this model is the natural sensitivity of prediction models to time-step size, especially when automatic work-over option is used. Automatic work-over option is done fully explicitly in both simulators and therefore, to get the exact match between them, time-steps should be small and exactly the same in both.

Table 2

Simulation result	Max. of relative difference (percent)
Field Average Pressure	0.21%
Field Oil Production Rate	0.13%
Field Gas Oil Ratio	0.0092%
Field Water Cut	0.032%
Wells Gas Oil Ratio	0.003%
Wells Water Cut	21.56%
Wells Bottom Hole Pressure	2.52%

Summary of simulation results comparison between RETINA and ECLIPSE

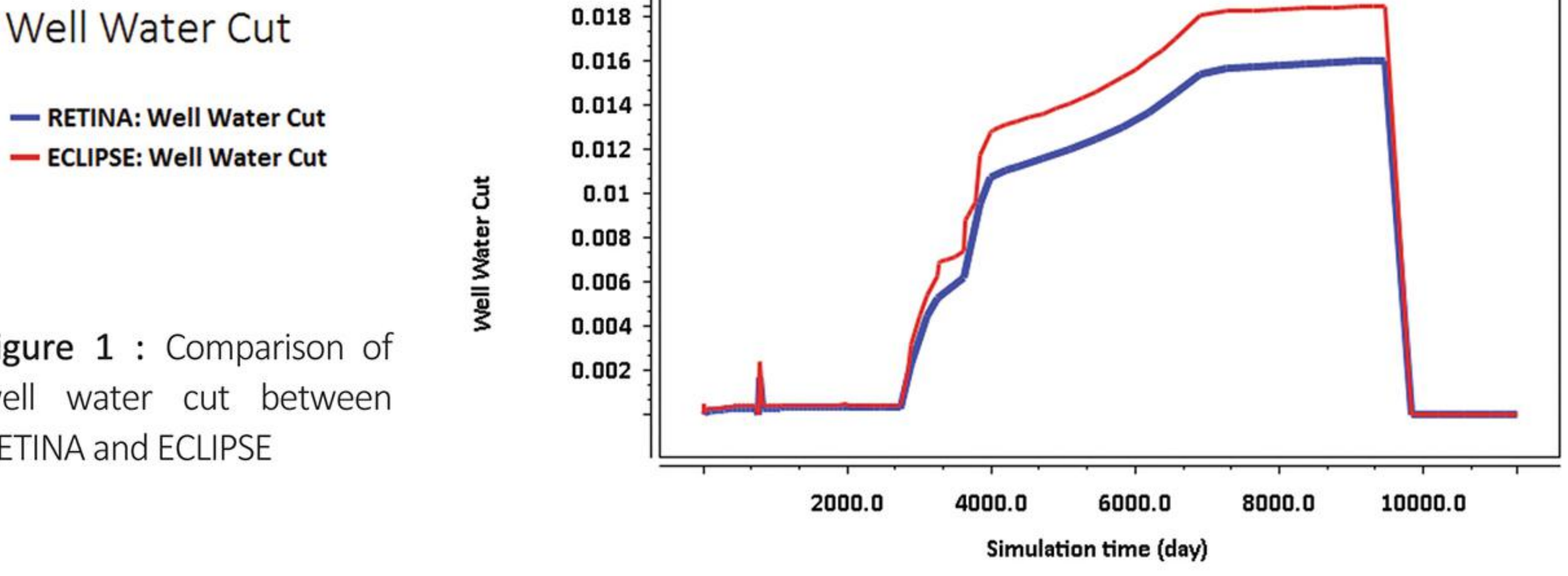


Figure 1 : Comparison of well water cut between RETINA and ECLIPSE

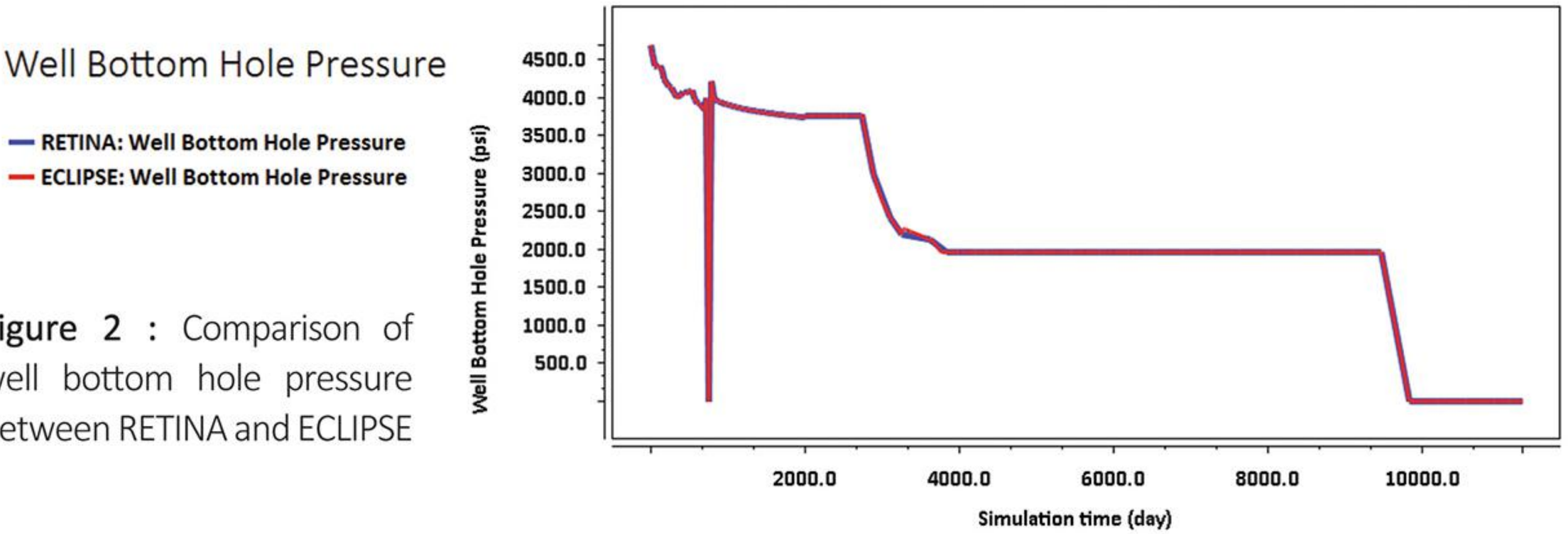


Figure 2 : Comparison of well bottom hole pressure between RETINA and ECLIPSE

Speed

As seen in figures 3 and 4, although RETINA Simulation™ takes time-steps with the same size as ECLIPSE 100™, it has greater elapsed time. RETINA Simulation™ uses a solver that is more general than the one used by ECLIPSE 100™, and in some special cases that ECLIPSE 100™ performs great, RETINA Simulation™ cannot perform as fast. But in the case of complex, especially dual porosity models RETINA Simulation™ delivers a better performance.

1 Simulation Elapsed Time in Seconds

This parameter represents the time needed to perform the simulation from time 0 to the specified simulation time (30 years in this case). Figure 3 shows that RETINA Simulation™ has longer elapsed time, and simulates the model slower than ECLIPSE 100™. RETINA Simulation™ needs 3228 seconds while ECLIPSE 100™ needs 2109 seconds to run the entire model.

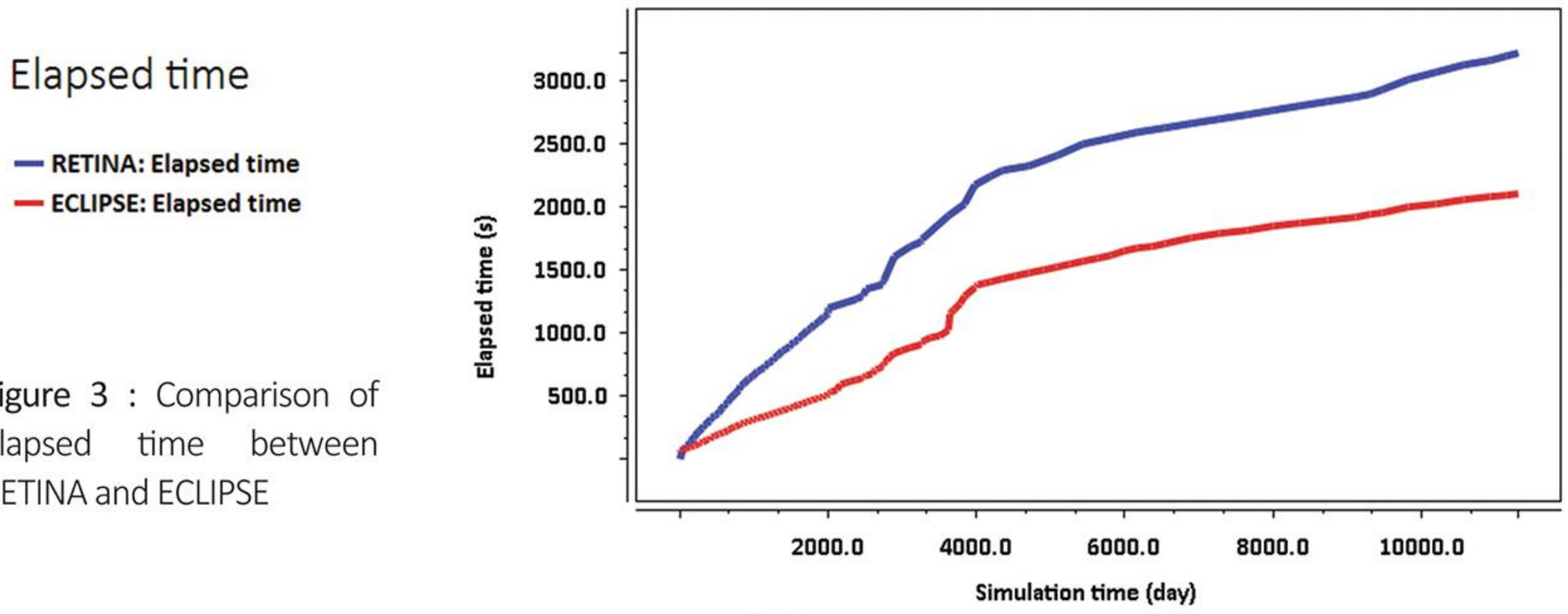


Figure 3 : Comparison of elapsed time between RETINA and ECLIPSE

2 Time step size

Figure 4 is the comparison of time-step size between RETINA Simulation™ and ECLIPSE 100™. RETINA Simulation™ has almost the same time step size compared to ECLIPSE 100™. Average size of time steps in RETINA Simulation™ is 76.29 days while ECLIPSE 100™ has an average of 71.02 days. These types of models (single porosity models with moderate heterogeneity and few non-neighbor connections) are ideal models for ECLIPSE 100™ to run. To be fair, ECLIPSE 100™ is the best reservoir simulator for this specific type of models. By the way, RETINA Simulation™ shows that in this typical model, it just is as robust and reliable as ECLIPSE 100™.

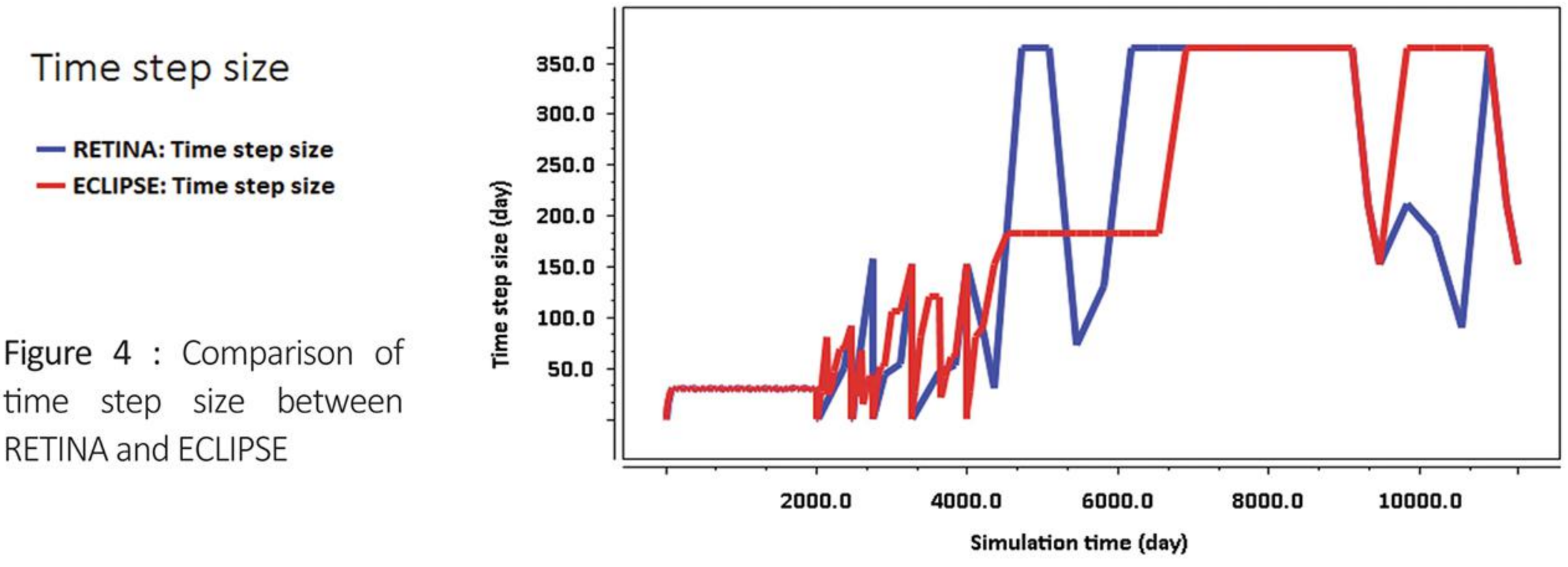


Figure 4 : Comparison of time step size between RETINA and ECLIPSE

Naturally Fractured

Model description

The case is a giant onshore fractured carbonate oil field. Production from this field started in 1937.

The history match model is run by RETINA Simulation™ to be compared with ECLIPSE 100™.

The model is dual porosity with moderate to tight matrix properties (average permeability of 0.1260 md) and highly conductive fractures (average of 1099.51 md permeability). The field is initially saturated with a small gas cap. Wells are connected to large number of cells because they are mostly completed as open-hole wells. They have extremely high production rates for a long period of time during history period. The model is a very complex case for numerical simulation and takes a couple of days to run for both simulators.

More details about the model are described in Table 1.

Table 1

Model type	Black oil dual porosity
No. of active cells	702264
No. of active wells	463
Model run duration	76 years
Special model	Hysteresis, GRAVDR, STOG, AQUCT

Detailed information about the case study

The model is simulated with RETINA Simulation™ and results from ECLIPSE 100™ are used for comparison and verification.

The two simulators are allowed to select their own time step sizes and no special tuning is defined. The main restriction on time step size is the frequency of entering historical rates for wells, which is every month. The results from these two simulators are compared from two aspects: accuracy and speed.

Accuracy

Figures 1 and 2 show the comparison between RETINA Simulation™ and ECLIPSE 100™ results for only one of the wells, due to confidentiality of data. All the results match almost perfectly but there are some differences in some specific wells. The main source for difference between these two models in some wells is due to high time-sensitivity of tight dual porosity model results. Explicit calculation of well segmented density calculation which is used in both simulators by default, could also be another source of difference.

Table 2

Simulation result	Max. of relative difference (percent)
Field Average Pressure	0.40%
Field Oil Production Rate	3.25%
Field Gas Oil Ratio	32.02%
Field Water Cut	0.025%
Simulation result	**Average relative difference (percent)**
Field Average Pressure	0.40%
Field Oil Production Rate	0.015%
Field Gas Oil Ratio	0.5%
Field Water Cut	0.000084%

Summary of simulation results comparison between RETINA and ECLIPSE

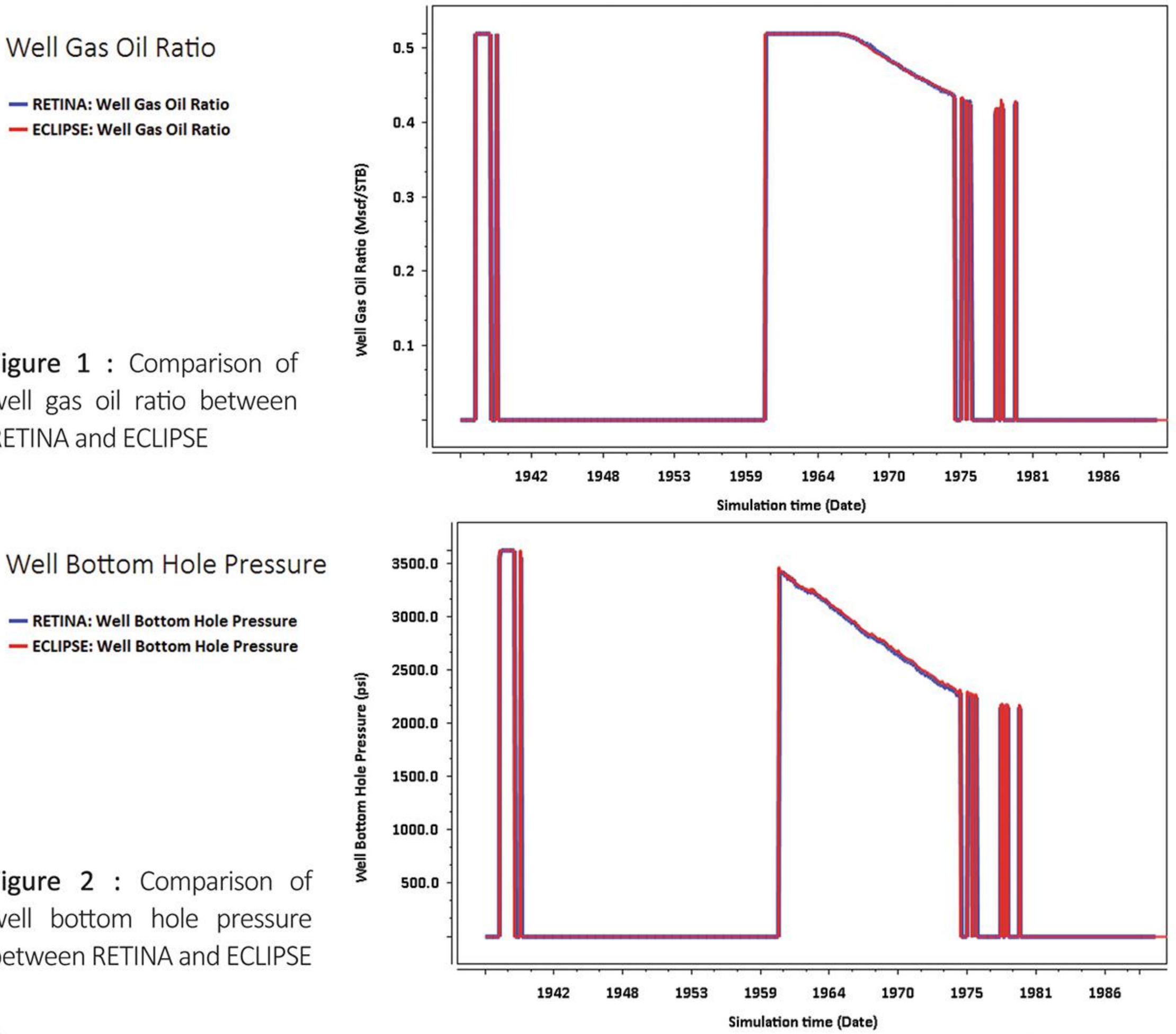


Figure 1 : Comparison of well gas oil ratio between RETINA and ECLIPSE

Figure 2 : Comparison of well bottom hole pressure between RETINA and ECLIPSE

Speed

As seen in figures 3 and 4, RETINA Simulation™ can take larger time-steps and therefore run the model in shorter time. RETINA Simulation™ is usually more stable and can take larger time-steps in case of dual porosity models because of its superior linear solver. More details about speed comparison are explained in the following sections.

1 Simulation Elapsed Time in Seconds

This parameter represents the time taken to perform the simulation from time 0 to a specified simulation time (76 years in this case). Figure 3 shows that RETINA Simulation™ has shorter elapsed time and runs the model faster than ECLIPSE 100™. For the first 50 years of simulation, RETINA Simulation™ takes 73640 seconds where ECLIPSE 100™ needs 122310 seconds.

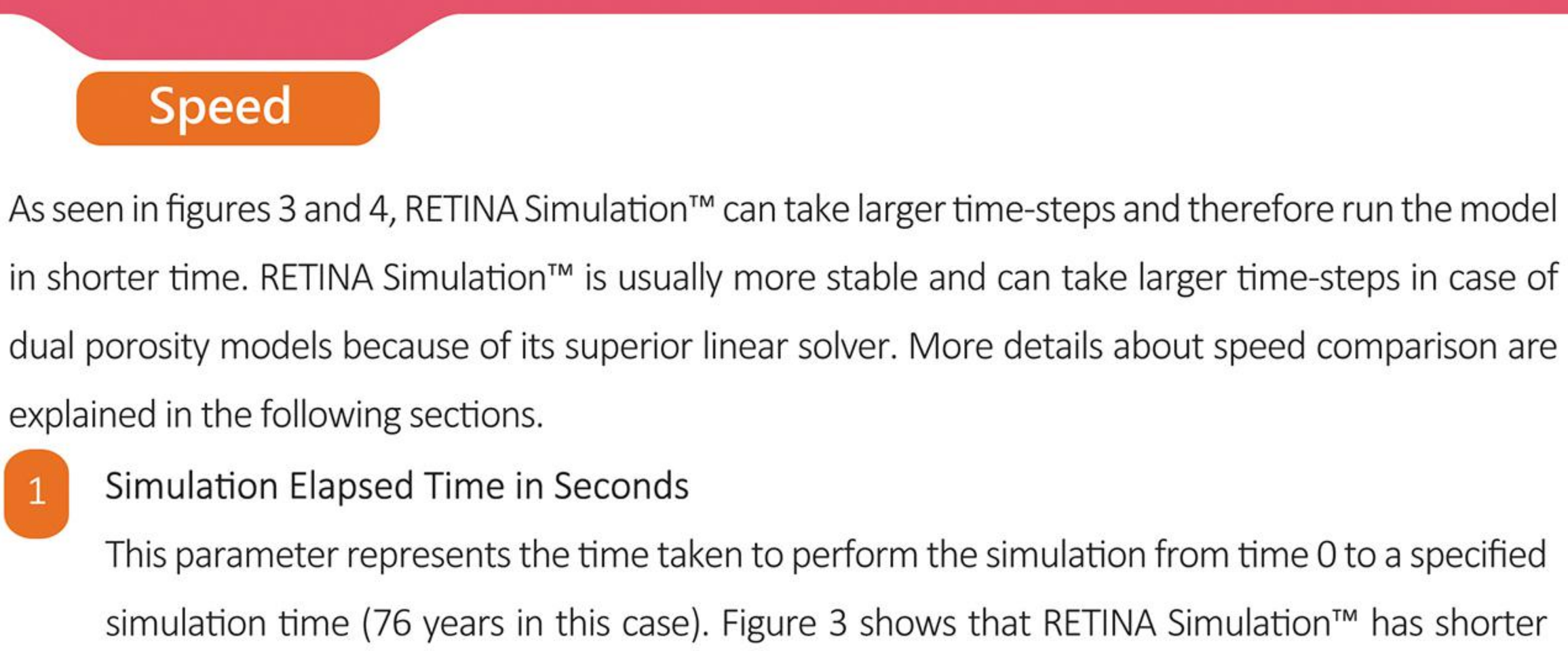


Figure 3 : Comparison of elapsed time between RETINA and ECLIPSE

2 Time step size

Figure 4 is the comparison of time-step size between RETINA Simulation™ and ECLIPSE 100™. RETINA Simulation™ has generally larger time-steps compared to ECLIPSE 100™. Average size of time-steps in RETINA Simulation™ is 14.87 days while ECLIPSE 100™ has an average of 2.01 days. From the accuracy comparison, it is evident that large time-step sizes does not lead to higher time truncation error in RETINA Simulation™. The advantage of RETINA Simulation™ over current reservoir simulators is that it needs almost no numerical tuning to run complex giant reservoir models. It is powerful and robust in face of any new simulation cases.

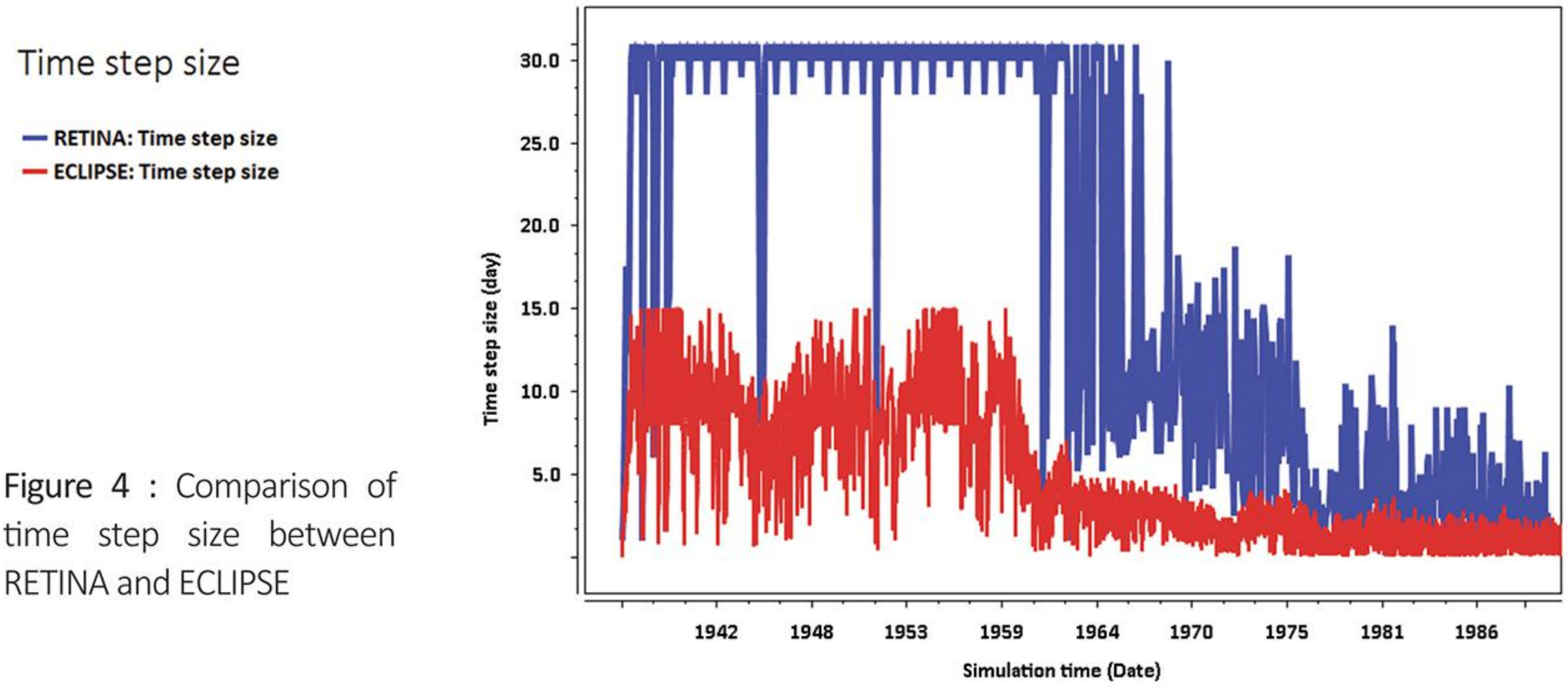


Figure 4 : Comparison of time step size between RETINA and ECLIPSE

Engineering Support & Technology Development (ESTD)

Layered Structure

Model description

The case is an Iranian offshore oil field located in Persian Gulf. Production from this field started in 1972. The history matching model of this field was delivered to ESTD in an agreement between IOOC and ESTD aimed at validating and certifying RETINA Simulation™. The model is dual porosity with some single porosity layers (indicated by DPNUM). It is an under-saturated reservoir with a moderate aquifer as its boundary condition. During its history-matching period, this model has 8 active oil produciton wells.

More details about the model are described in Table 1.

Table 1

Model type	Black oil dual porosity with DPNUM
No. of active cells	211410
No. of active wells	8
Model run duration	24 years
Special model	Hysteresis, GRAVDR, STOG, AQUCT

Detailed information about the case study

The model is simulated with RETINA Simulation™ and results from ECLIPSE 100™ are used for comparison and verification.

The two simulators are allowed to select their own time step sizes and no special tuning is defined. The main restriction on time step size is the frequency of input history rates which is almost every one month. The results from these two simulators for this case are compared from two aspects: accuracy and speed.

Accuracy

Figures 1 and 2 show the comparison between RETINA Simulation™ and ECLIPSE 100™ results for only one of the wells, due to confidentiality of data. All the results match almost perfectly and this is the case for all the other wells and vectors. The selected well is the first producing well and hence has more results throughout simulation.

Table 2

Simulation result	Max. of relative difference (percent)
Field Average Pressure	0.051%
Field Oil Production Rate	0.000025%
Field Gas Oil Ratio	0.5%
Field Water Cut	4.7%
Wells Gas Oil Ratio	0.83%
Wells Water Cut	5.1%
Wells Bottom Hole Pressure	0.98%
Wells Static Pressure	0.78%
Aquifer Rate	2.7%

Summary of simulation results comparison between RETINA and ECLIPSE

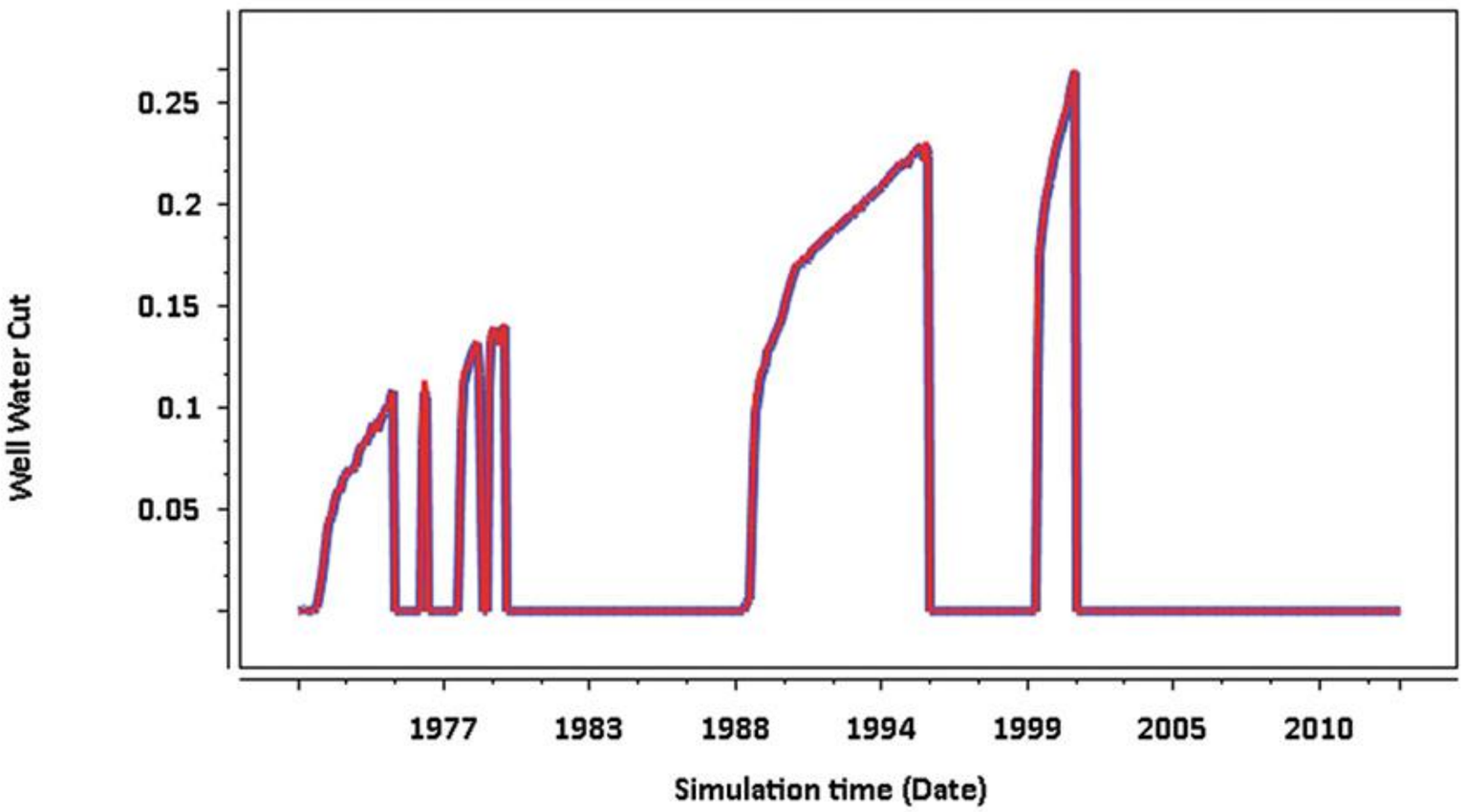


Figure 1 : Comparison of well water cut between RETINA and ECLIPSE

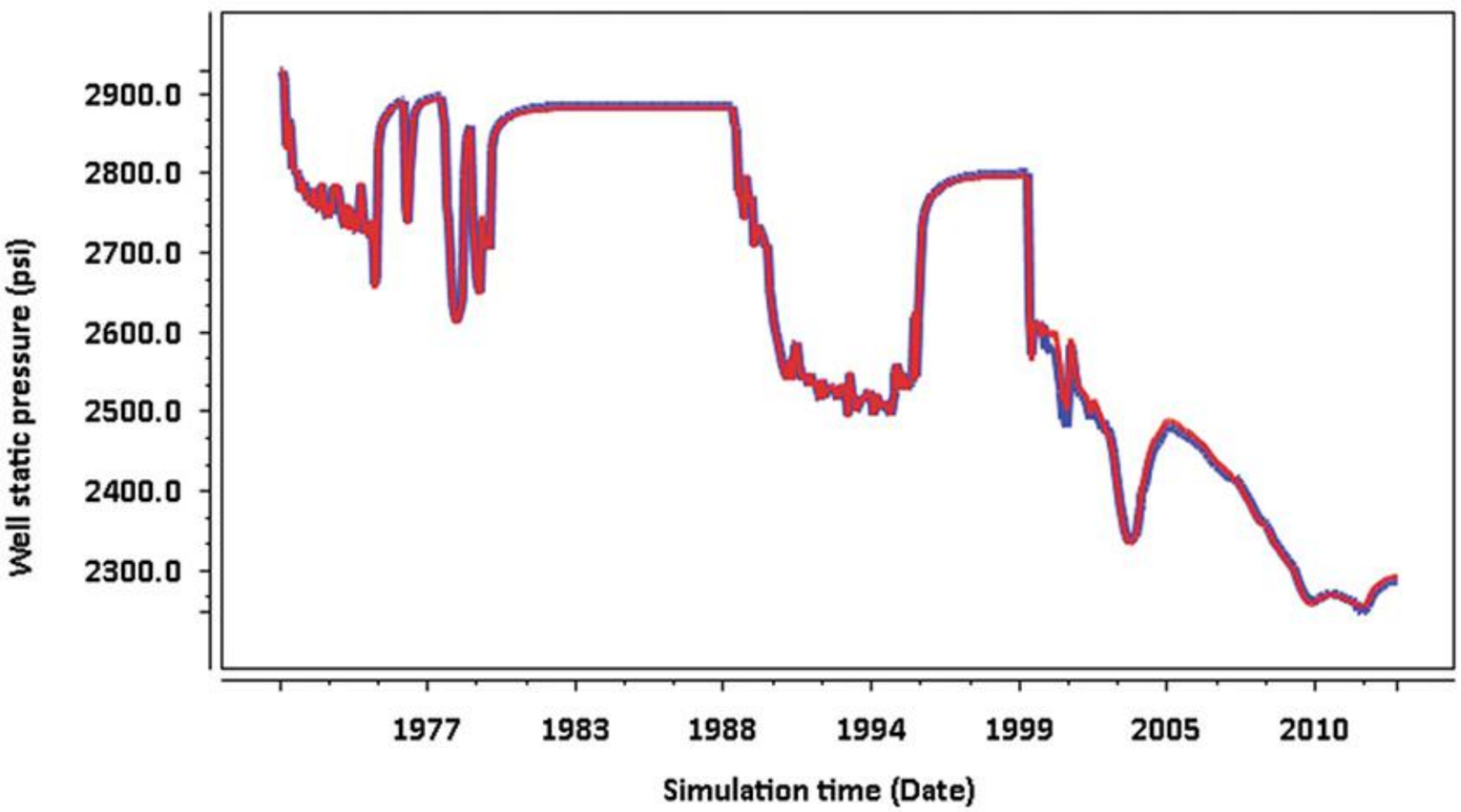


Figure 2 : Comparison of well static pressure between RETINA and ECLIPSE

Speed

As seen in figures 3 and 4, RETINA Simulation™ can take larger time steps in this model and therefore it has shorter simulation run time. This case is is a complex structre layered, single and dual porosity reservoir. Due to its superior linear solver, RETINA Simulation™ can run the model super fast compared to ECLIPSE 100™ and it has very larger time steps. More details about speed comparison are explained in the following sections.

1 Simulation elapsed time in seconds.

This parameter represents the time taken to perform the simulation from time 0 to a specified simulation time (24 years in this case). Figure 3 shows that RETINA Simulation™ has shorter elapsed time and can run the model almost nine times faster than ECLIPSE 100™. RETINA Simulation™ takes only 4997 seconds where ECLIPSE 100™ needs a whopping 45633 seconds to run the entire model.

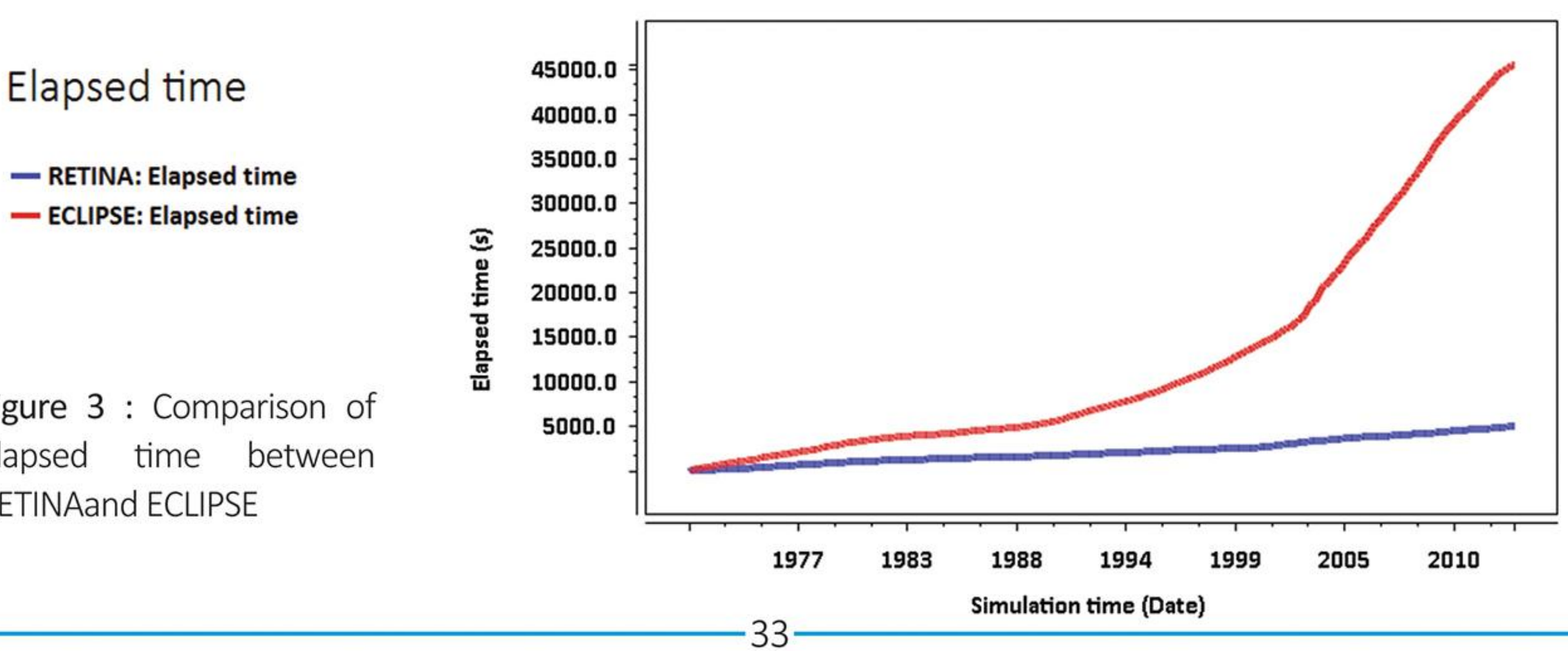


Figure 3 : Comparison of elapsed time between RETINAand ECLIPSE

2 Time step size

Figure 4 is the comparison of time-step size between RETINA Simulation™ and ECLIPSE 100™. It is clear that the report step size is the limiting factor for time-steps in RETINA Simulation™ most of the time; whereas ECLIPSE 100™ faces trouble taking large time steps matching the size of report step size. Average size of time-steps in RETINA Simulation™ is 25.20 days where ECLIPSE 100™ has the average of 4.44 days. And from the accuracy comparison it is evident that, large time step sizes do not lead to higher time truncation error in RETINA Simulation™.

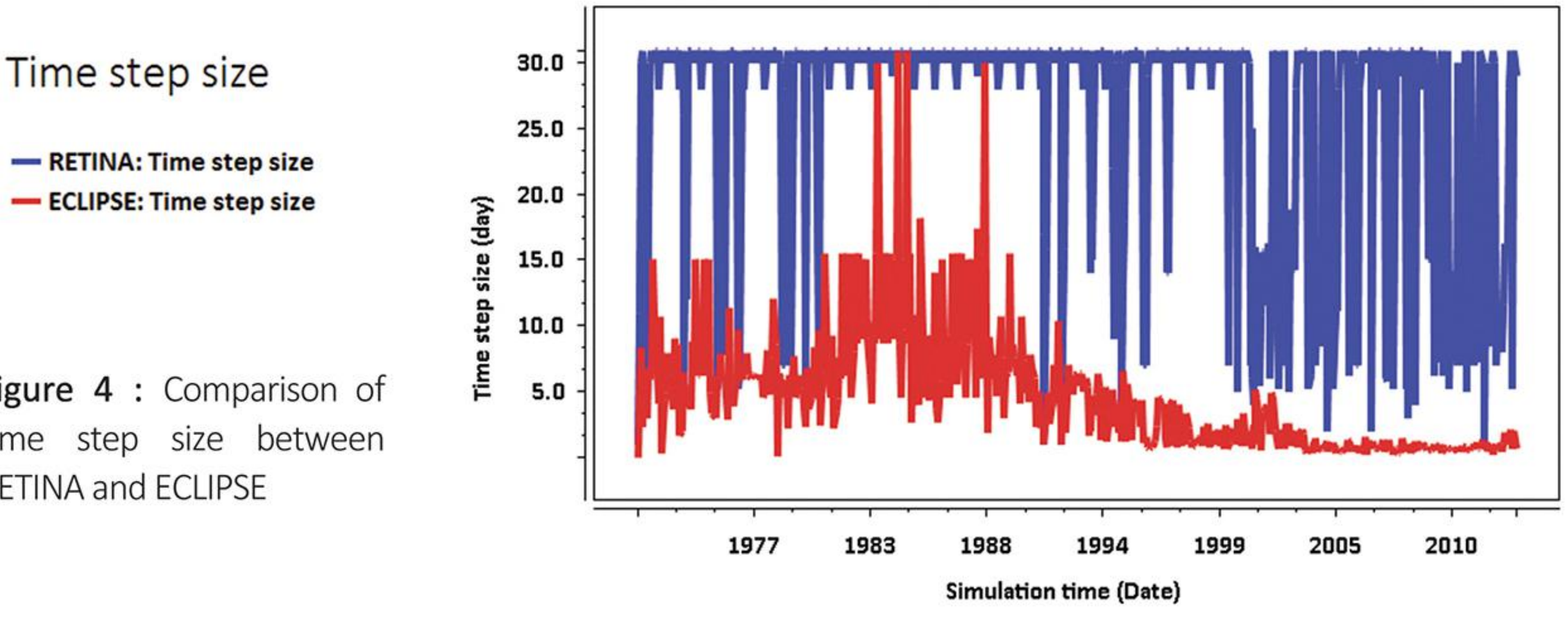
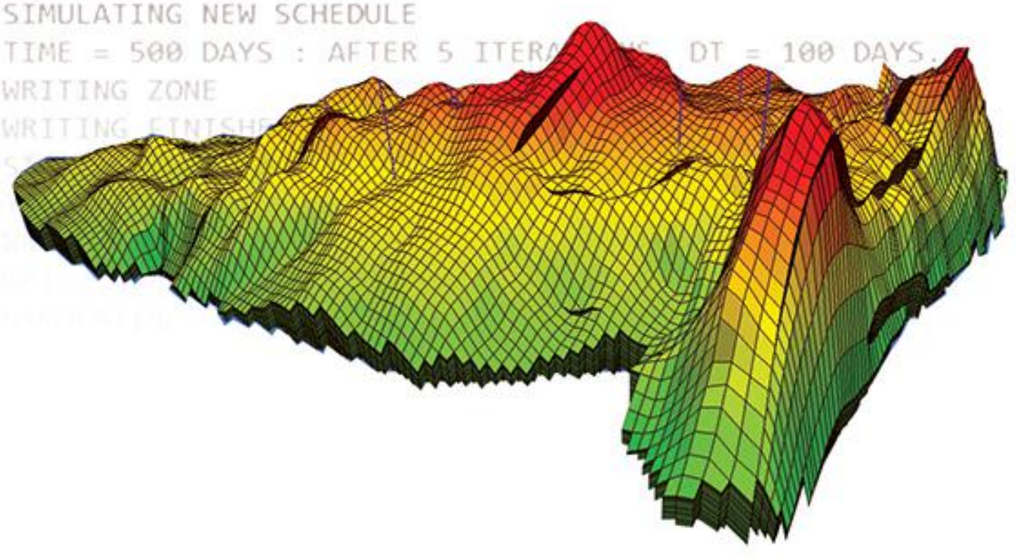


Figure 4 : Comparison of time step size between RETINA and ECLIPSE

```
WRITING ZONE
WRITING FINISHED
SIMULATING NEW SCHEDULE
TIME = 184.375 DAYS : AFTER 6 ITERATIONS. DT = 84.375 DAYS.
TIME = 200 DAYS : AFTER 4 ITERATIONS. DT = 15.625 DAYS.
WRITING ZONE
WRITING FINISHED
SIMULATING NEW SCHEDULE
TIME = 284.375 DAYS : AFTER 5 ITERATIONS. DT = 84.375 DAYS.
TIME = 300 DAYS : AFTER 4 ITERATIONS. DT = 15.625 DAYS.
WRITING ZONE
WRITING FINISHED
SIMULATING NEW SCHEDULE
TIME = 400 DAYS : AFTER 5 ITERATIONS. DT = 100 DAYS.
WRITING ZONE
WRITING FINISHED
SIMULATING NEW SCHEDULE
TIME = 500 DAYS : AFTER 5 ITERA
                          DT = 100 DAYS.
WRITING ZONE
WRITING FINISH
```



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