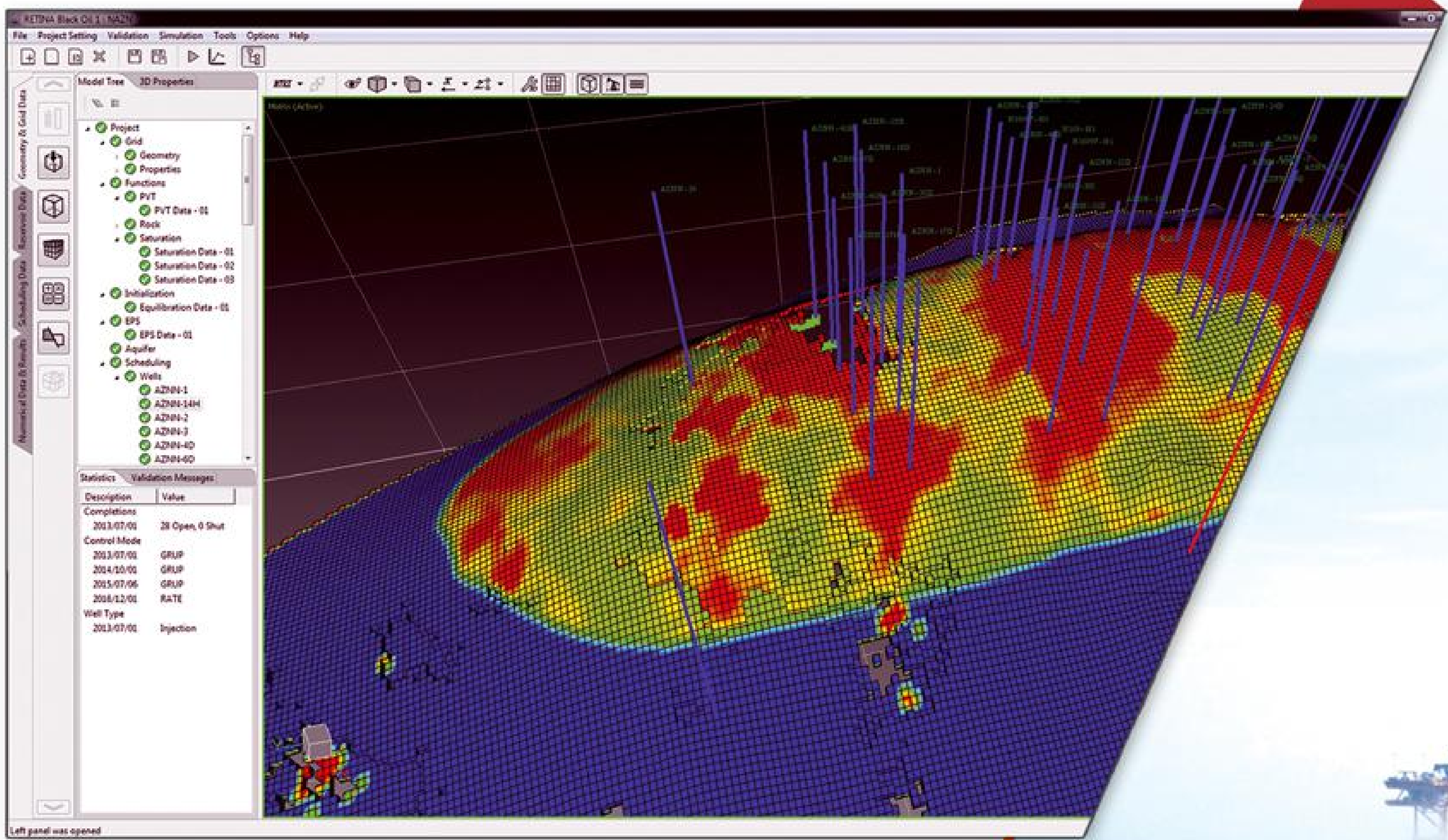
An Efficient and Robust Solution for



Unconventional Reservoirs

RETINA
SIMULATION

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

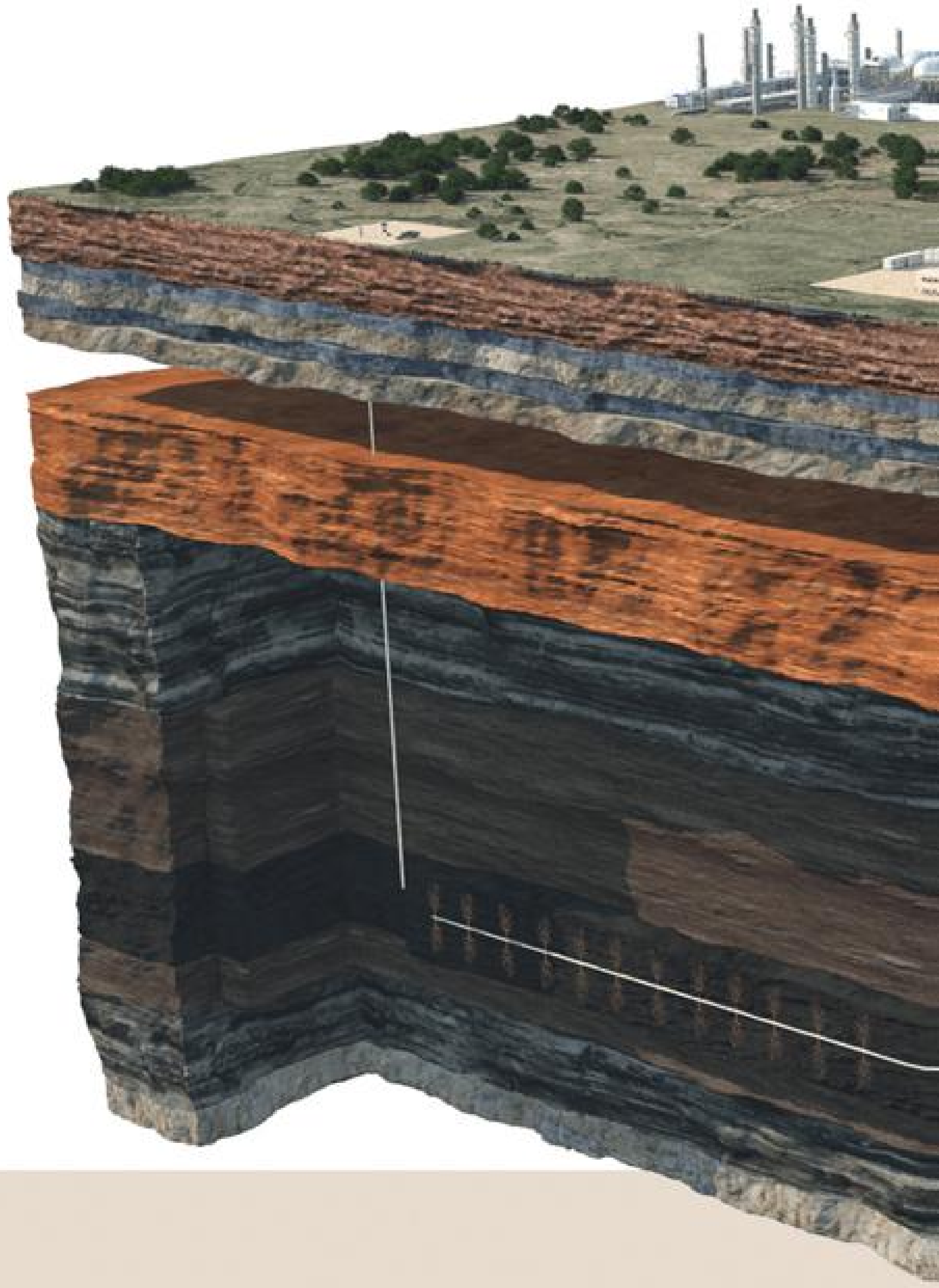
RETINA Simulation™ is a Black-Oil and Compositional reservoir simulation software fully developed in ESTD during the past 4 years. RETINA has been tested and certified by 4 of National Iranian Oil Company subsidiaries in cases of accuracy and stability compared to ECLIPSE 100™: KARANJ-Asmari from National 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

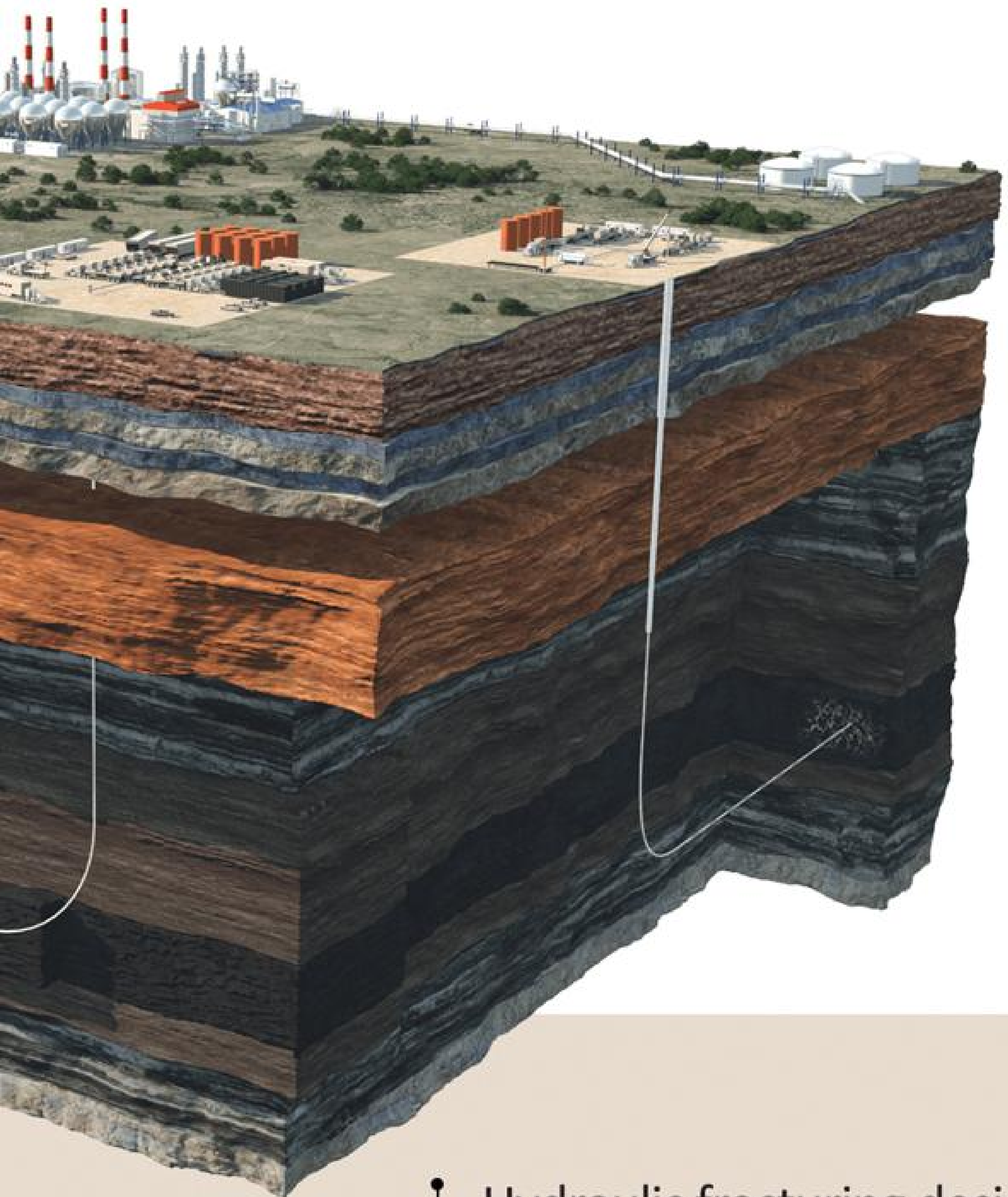


Main Services

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™

ESTD

Engineering Support & Technology Development

RETINA Simulation™ is the main and the most technological product of ESTD. It is developed in past 4 years using the valuable numerical analysis and software development knowledge of developer team. RETINA Simulation™ is a black-oil and compositional, finite volume, unstructured based and parallel reservoir simulator which is built and optimized to be fast and stable specially for big, complex and fractured heterogeneous reservoirs.

RETINA Simulation™ has been tested by several carbonate fractured and non-fractured oil fields in middle east area. It's accuracy and stability is officially certified by 4 of National Iranian Oil Company subsidiaries on their real field models. The certifications are issued by NISOC on Karanj-Asmari reservoir, IOOC on Doroud-Asmari reservoir, ICOF on East Paydar-Asmari reservoir and by PEDEC on North Azadegan-Sarvak reservoir.

In this document, key features of RETINA Simulation™ are described in three parts including pre-processing, simulation and post-processing. Also the main advantages and capabilities of this software are presented. Finally, its accuracy and speed is discussed in a real case study.

RETINA
SIMULATION

Key features

Engineering Support & Technology Development (ESTD)

Key features

Pre-processing

1. ECLIPSE DATA file is read and transferred directly to RETINA Simulation™ model automatically.
2. All the imported data can be edited and removed and new data can be added to the model easily.
3. Pre-processor is completely user friendly and easy to use.
4. 3D visualizer can display all the imported and created properties, wells and well completions.
5. PVT and SCAL tables and graphs are displayed and can be edited.
6. RETINA Simulation™ model can be built in an interactive and user-friendly environment from scratch.
7. Data model is bounded to simulator core. There is no such thing as DATA file.
8. All the data are entered and built in the software. No need to modify the DATA file.
9. Simulation models can be easily created. Different data (PVT, SCAL, CFP, PPGrid Properties, Aquifer and Wells) can be imported seamlessly.
10. Grid properties could be modified using property calculator.
11. Simulation models can be run and restarted easily

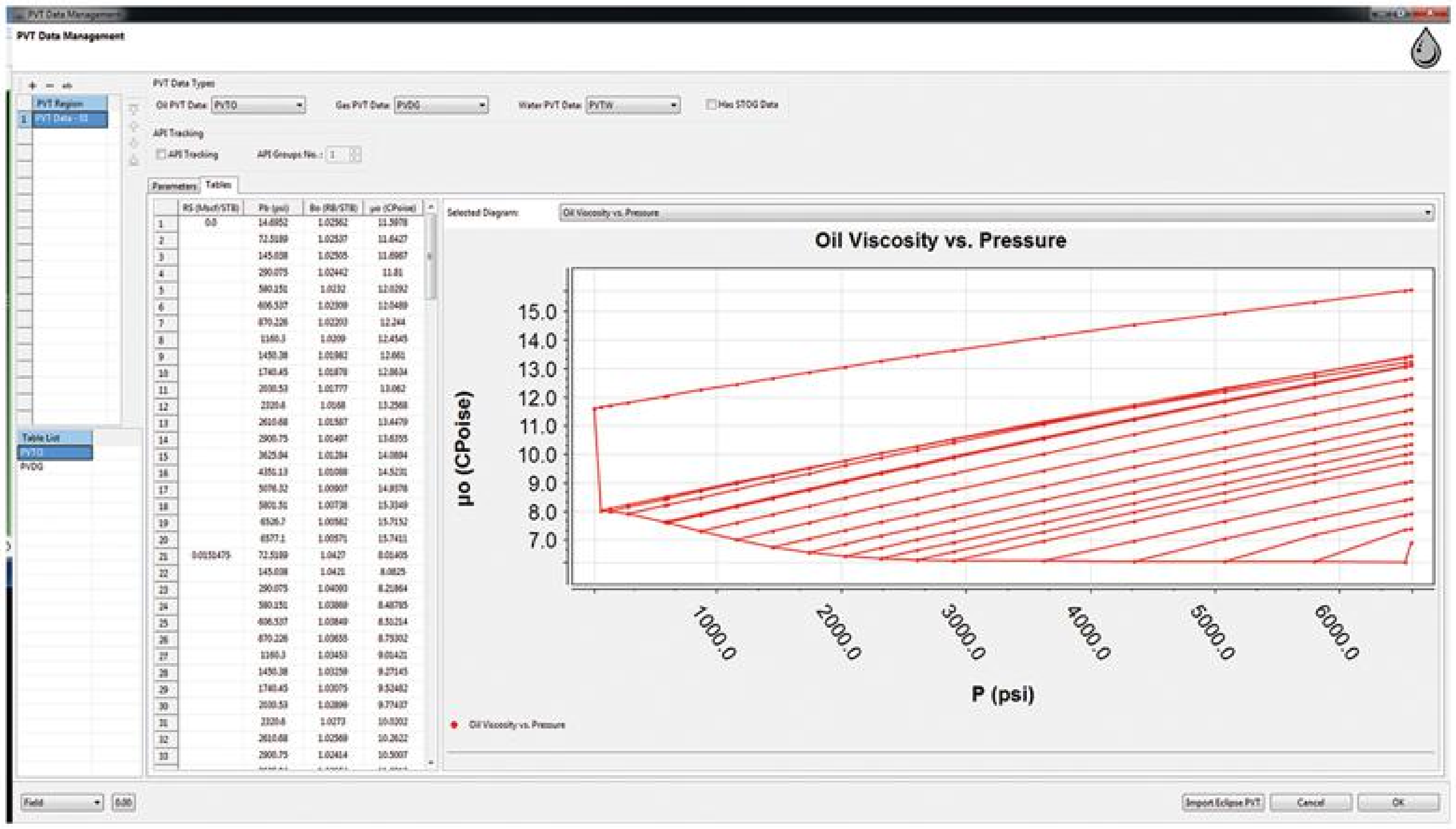
12 All data in the model will be validated before the run.

13 Statistical information for all the data is displayed.

14 Complete control over unit conversion of data on every dialog.

15 Complete control over floating point viewing precision in every dialog.

16 Completely decoupled view and model layers that can be later converted to a Server-Client system



Engineering Support & Technology Development (ESTD)

Key

Simulation

1 Corner-point grid support

2 Full and Quasi Newton non-linear solvers.

3 3D 3 Phase Black Oil single and dual medium formulation

4 BiCG-Stab linear solver

5 ILU0, ILU1 and AMG pre-conditioner

6 Well and group control features

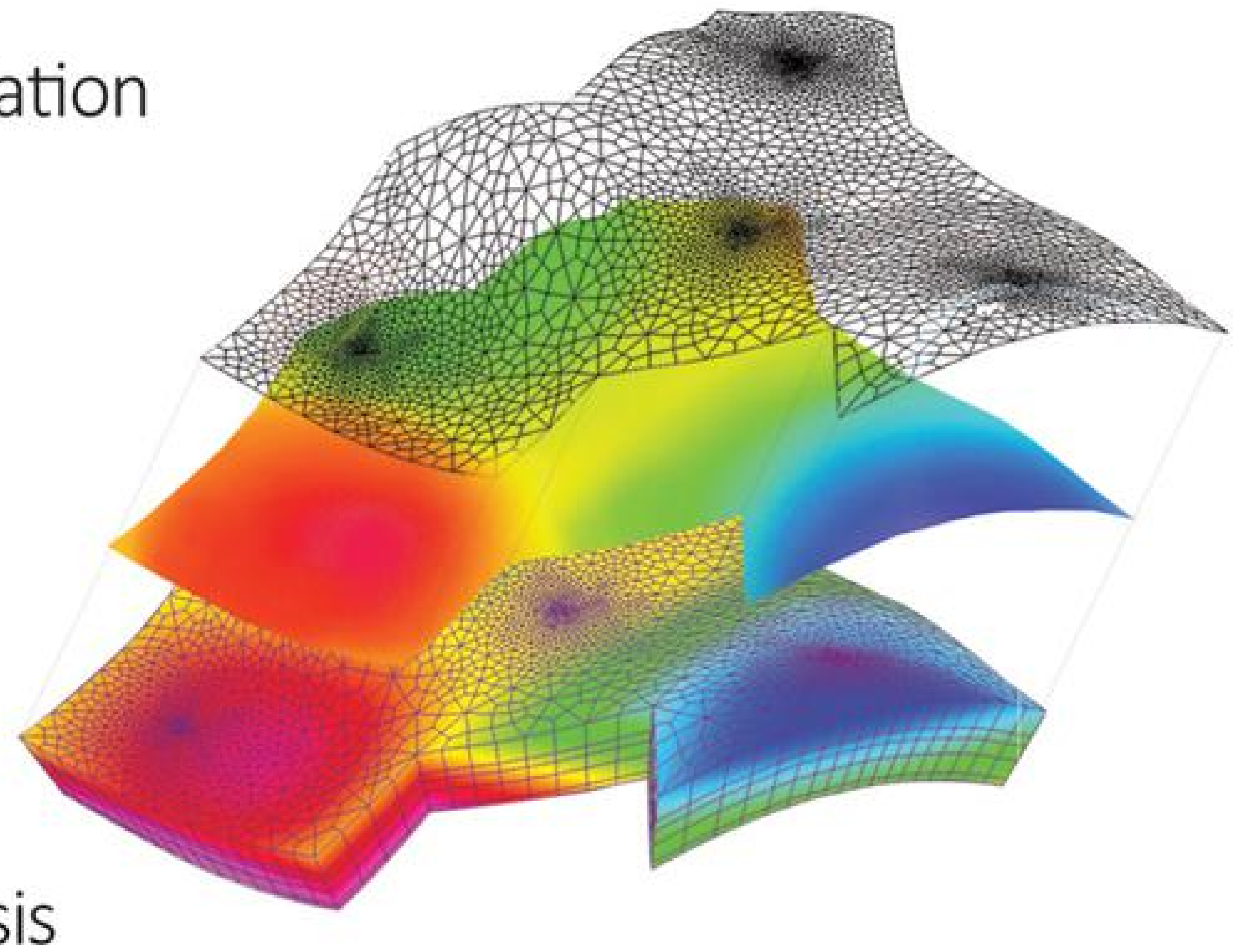
7 Well auto completion

8 Sonier et. al. Matrix-Fracture transfer function

9 Relative permeability and capillary pressure hysteresis

10 Full segregation and stone type 3-phase models

11 2 and 3 point Horizontal and Vertical end point scaling



features

12 Changing gas-oil capillary pressure with respect to pressure (inter-facial tension)

13 Multiple saturation functions, PVT, rock compressibility, equilibration and fluid in place regions

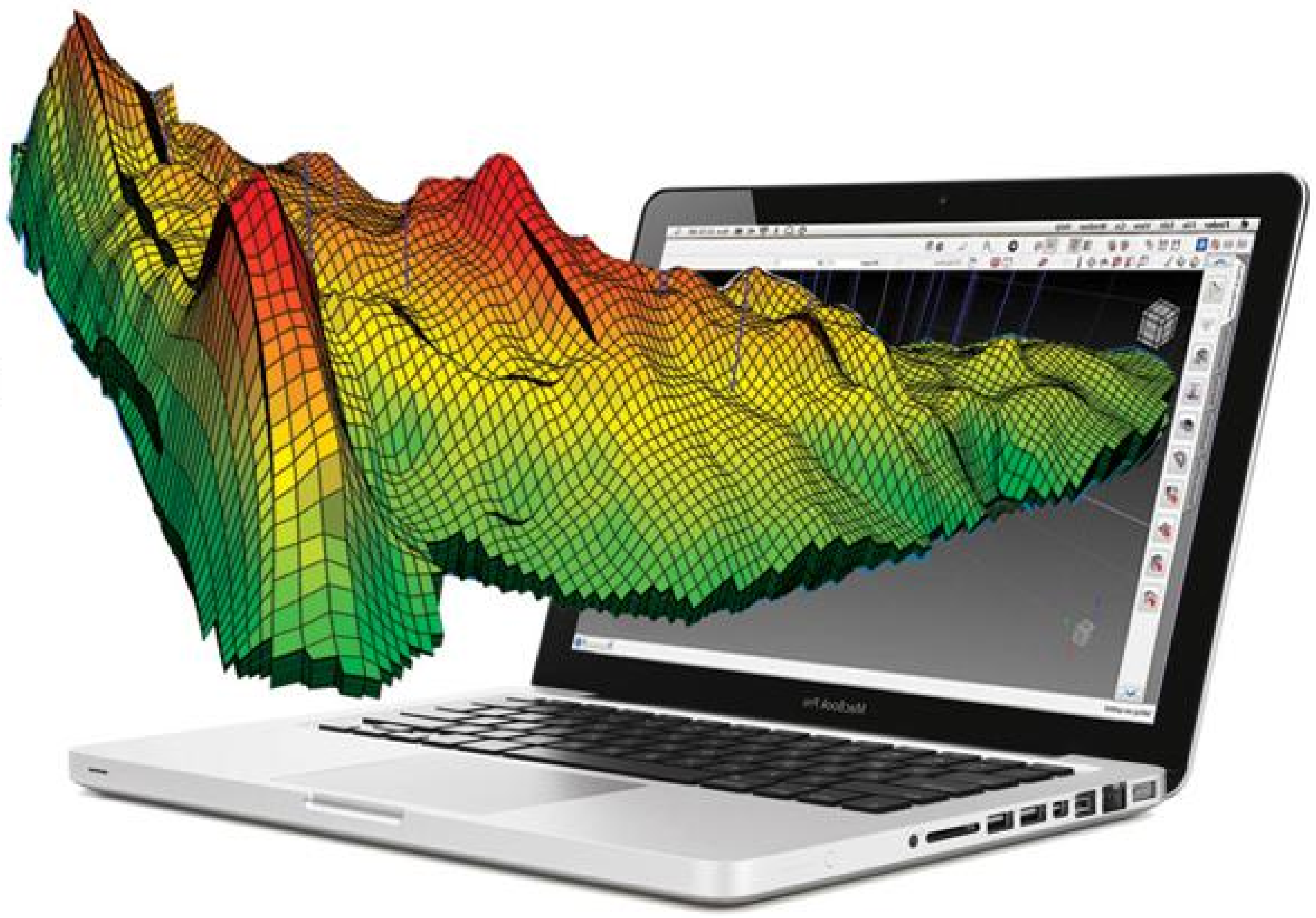
14 VFP table support

15 Multi-threaded parallel support

16 Automatic time step selection algorithm

17 Implicit fully coupled well modeling

18 Fully implicit formulation

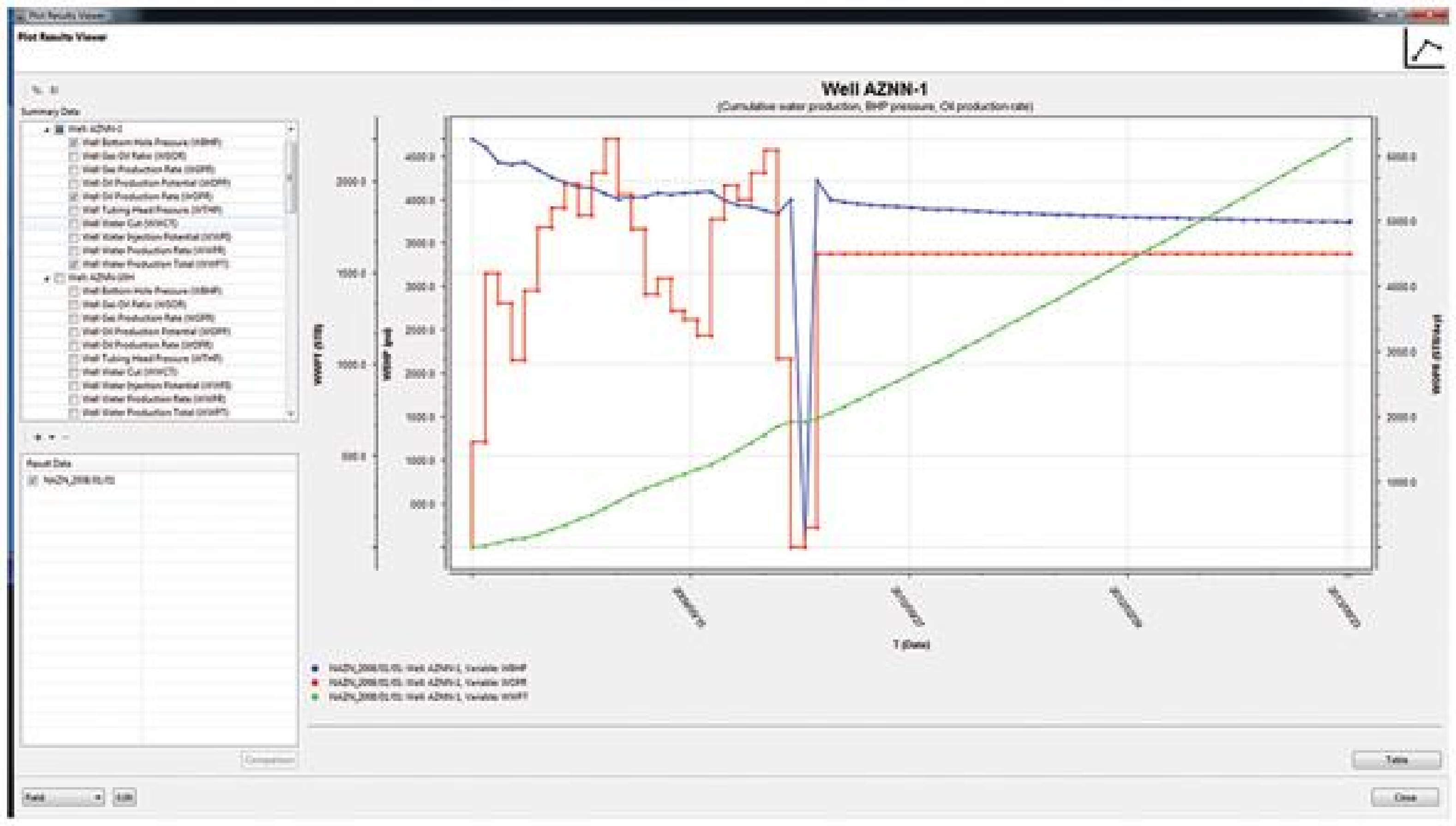


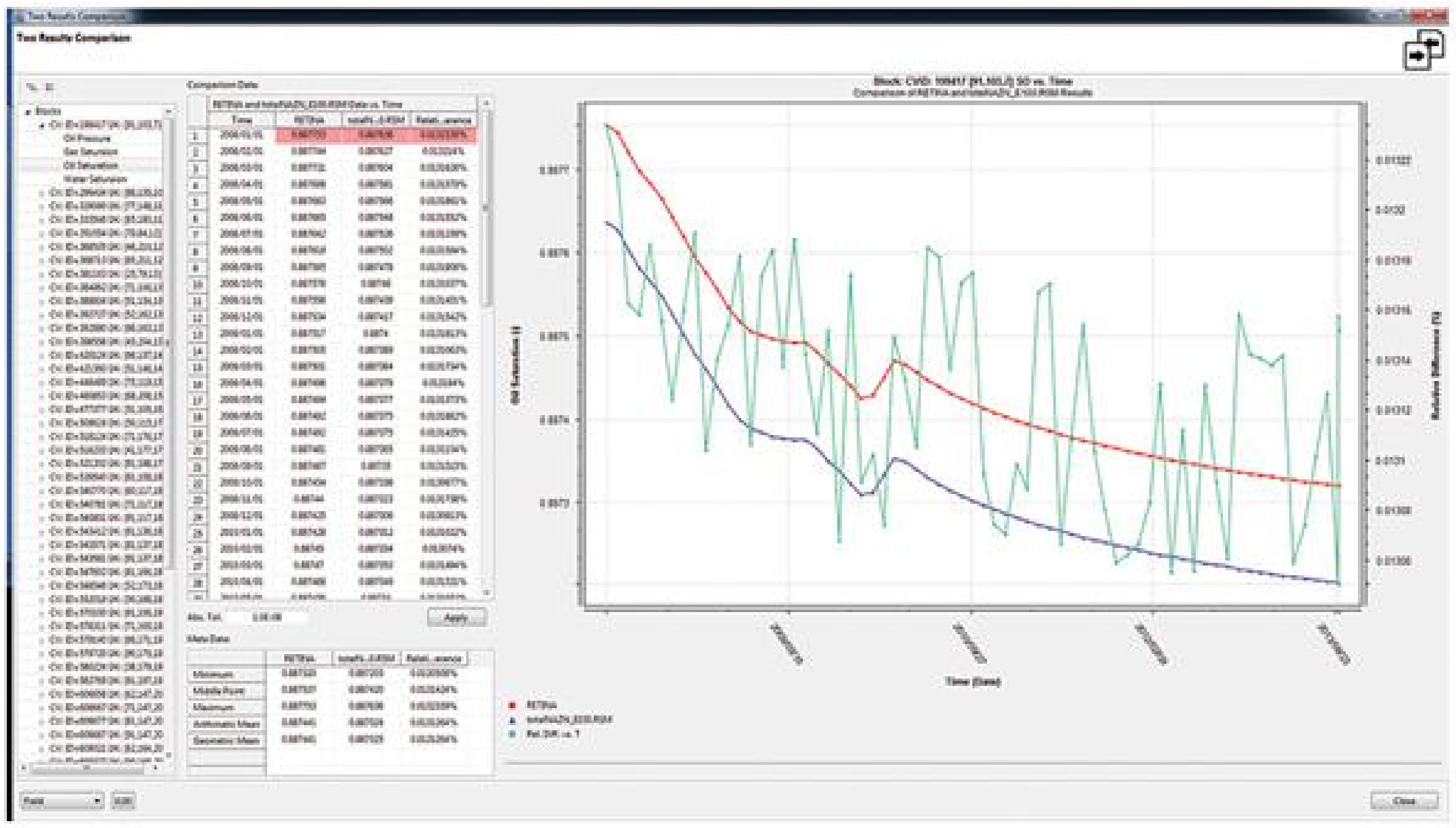
Engineering Support & Technology Development (ESTD)

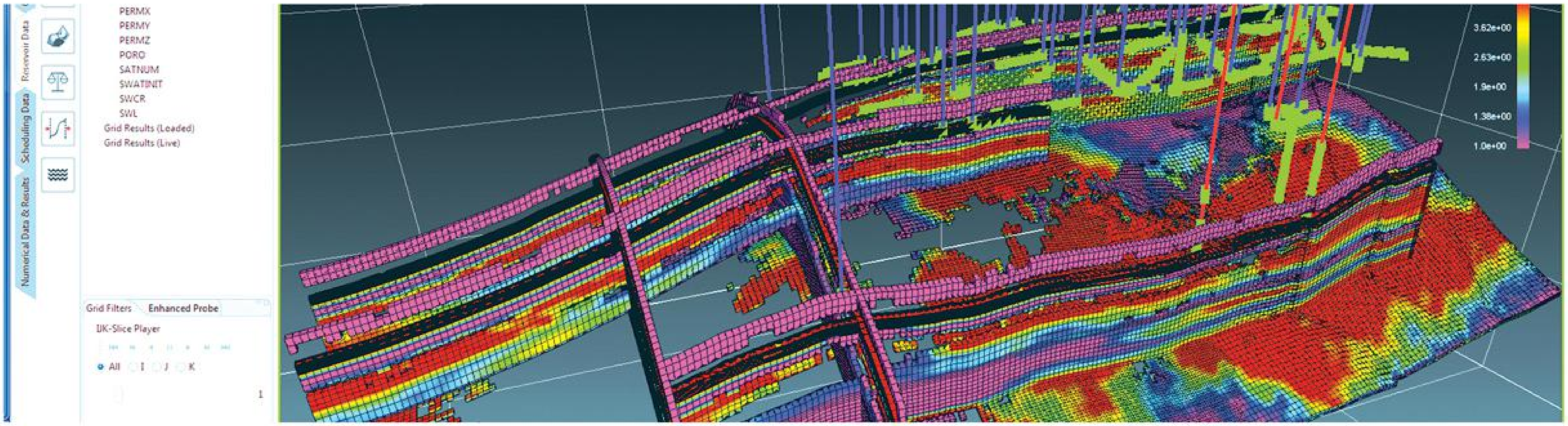
Key features

Post-Process

1. 4D visualization
2. Live summary plot viewing
3. Load RETINA Simulation™ and ECLIPSE summary results and compare the results.

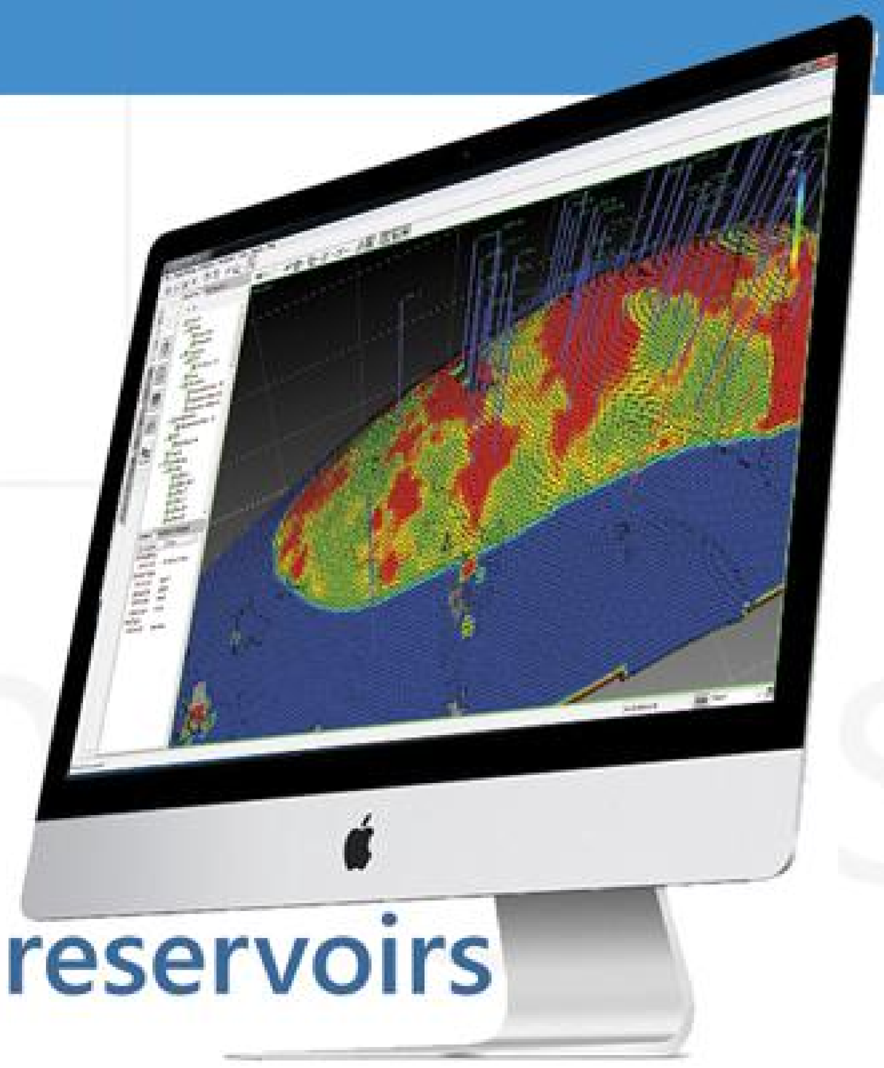






Capabilities and key advantages

Engineering Support & Technology Development (ESTD)



High tech AMG based linear solver brings stable solution to complex reservoirs

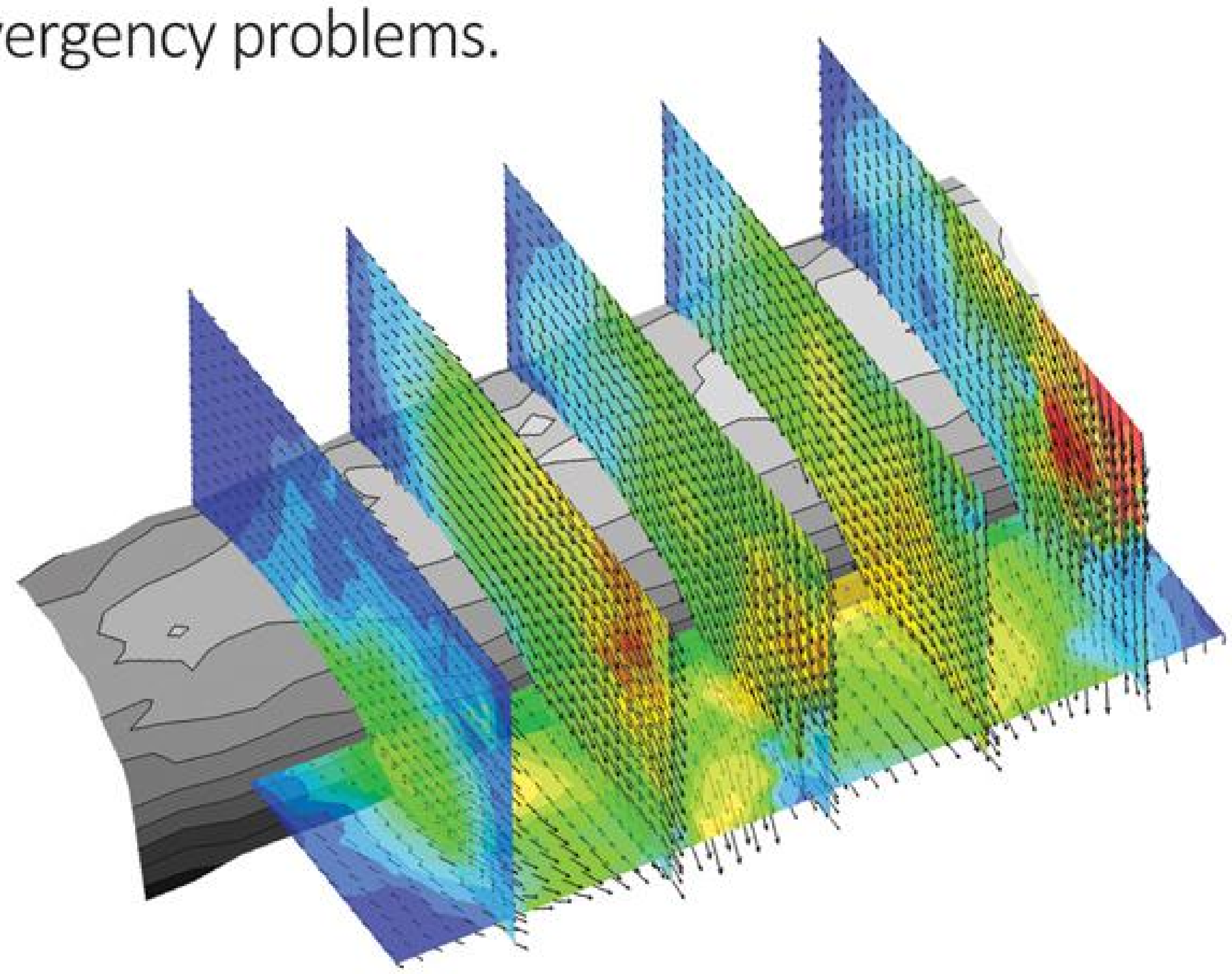
RETINA Simulation™ has the BiCG-Stab standard iterative linear solver which is powered by several pre-conditioners including:

1. CPR-AMG-ILU0
2. ILU0
3. CPR-AMG-ILU1
4. ILU1

The solver and all the pre-conditioners have been developed and tested by ESTD and are fully customized for reservoir simulation needs.

Among them, the CPR method is the cutting-edge pre-conditioner in numerical sciences which is based on the AMG technique. Using the AMG technique along with the CPR method to solve the pressure equation is at the heart of RETINA Simulation™ powerful numerical solver . Especially considering the fact that using the CPR method without the AMG technique will present no industrial benefit.

The linear solver of well-known commercial simulators that utilize the Nested-Factorization method as the pre-conditioner are almost the fastest solvers in the market which are mainly suited for models with a dominant directional behavior (mostly z direction) and make use of the nearly structured shape of corner point grids. Therefore using Nested Factorization for simulation of models with high heterogeneity and/or large number of non-neighbor connections (either of which usually occur in giant fractured reservoirs) can result in severe convergency problems.



The AMG technology is one of the most recent strategies for solving matrices generated in elliptic partial differential equations that can produce suitable solutions for complicated problems.
RETINA Simulation™ has its own customized AMG based solver which is fully tested on 4 sets of data from real-world fields, 5 SPE samples, and many synthetic models. This solver has the power of solving very complex, large and heterogonous models without linear convergency problems. This fact gives RETINA Simulation™ the power to solve models that are simply not solvable using known commercial simulators.

Large time steps and more stable solution in dual porosity/permeability models

One of the most valuable outcomes of using cutting-edge scientific methods and technologies in RETINA Simulation™ s that, RETINA Simulation™ can solve dual porosity/permeability models much faster and more reliable than known commercial simulators. RETINA Simulation™ usually has larger time steps with more realistic results in the case of dual porosity/permeability models. It can also solve these models with less time step cut back and has far less non-linear and linear convergency problems. The main reason for RETINA Simulation™ remarkable stability is its cutting-edge AMG based linear solver along with an improved non-linear iteration scheme.

Improved non-linear Newton iterations

In order to tackle the complexity of the non-linear system with cross variable dependencies, RETINA Simulation™ uses a new and creative method to reduce the number of non-linear iterations. RETINA Simulation™ uses higher order terms in its Jacobian matrix in addition to the Newton's basic linear terms to account for cross variable dependencies. This scheme leads to a smaller number of non-linear iterations compared to basic Newton iterations. The number of Newton iterations in RETINA Simulation™ non-linear solver is now comparable to other known commercial simulators with larger time-steps. All the aforementioned features allow RETINA Simulation™ numerical solver to be among the best solver technologies available to date.

Multi-threading based on OpenMp Parallel technology

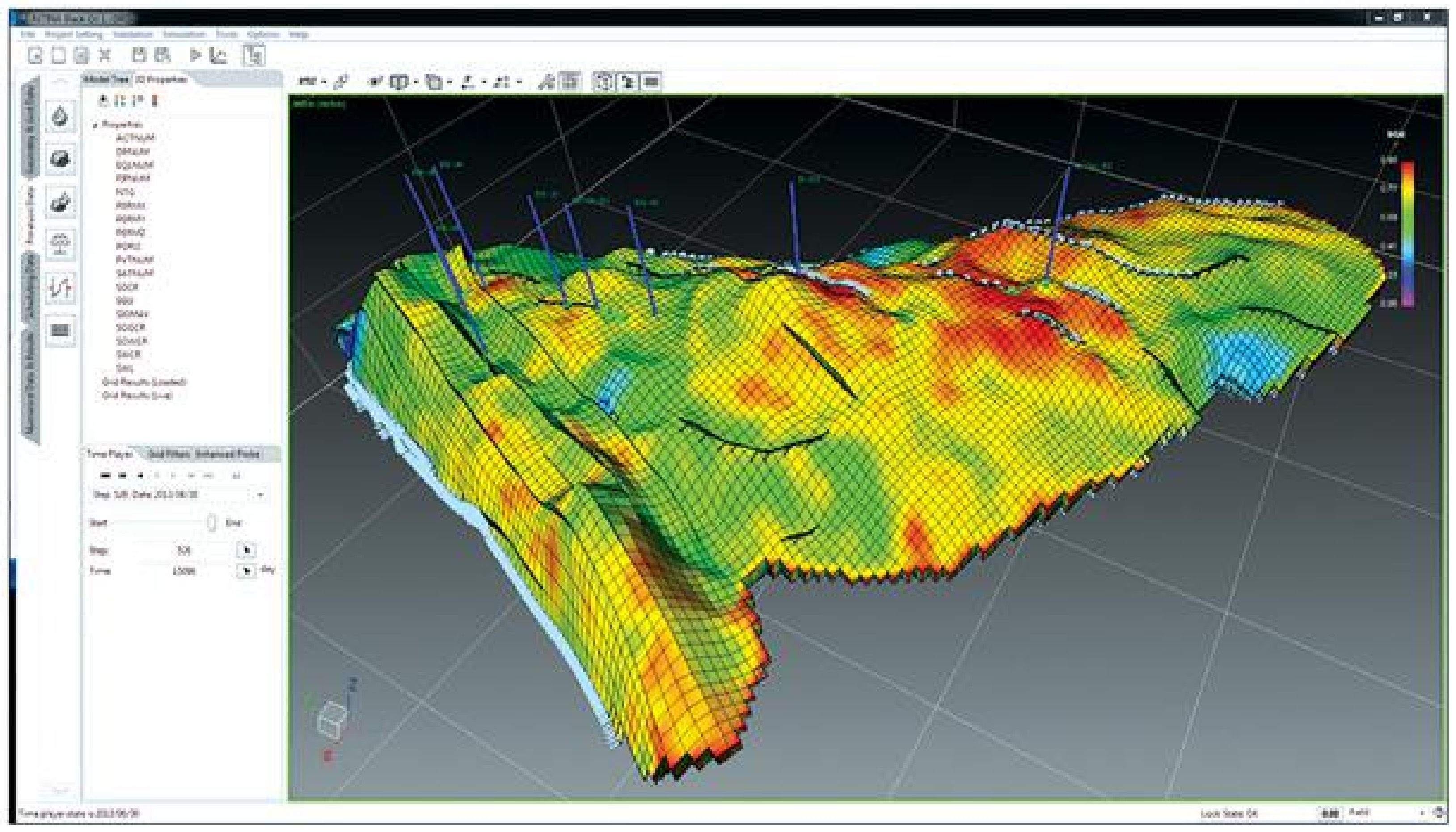
RETINA Simulation™ utilizes a multi-threading algorithm that inserts no approximation in the solution and therefore is fully stable for large and complex models. This algorithm can utilize all or any user defined number of CPU cores efficiently. In parallel simulations, the solution does not change from the single core case and follows the exact same path. This however is not the case for other simulators that use domain-decomposition techniques. These techniques change the solution of the original system and therefore decrease the accuracy of the solution. This is the main reason why parallel accuracy of commercial simulators is decreased especially in cases with a large number of CPUs.

Advanced well equations which are solved for all the variables just like regular cells

RETINA Simulation™ uses a 3-equation and 3-variable well model and solves well equations in saturated and under-saturated states just like ordinary cells which is not the case in known commercial simulators.

RETINA Simulation™ solves well equations for the following set of variables:

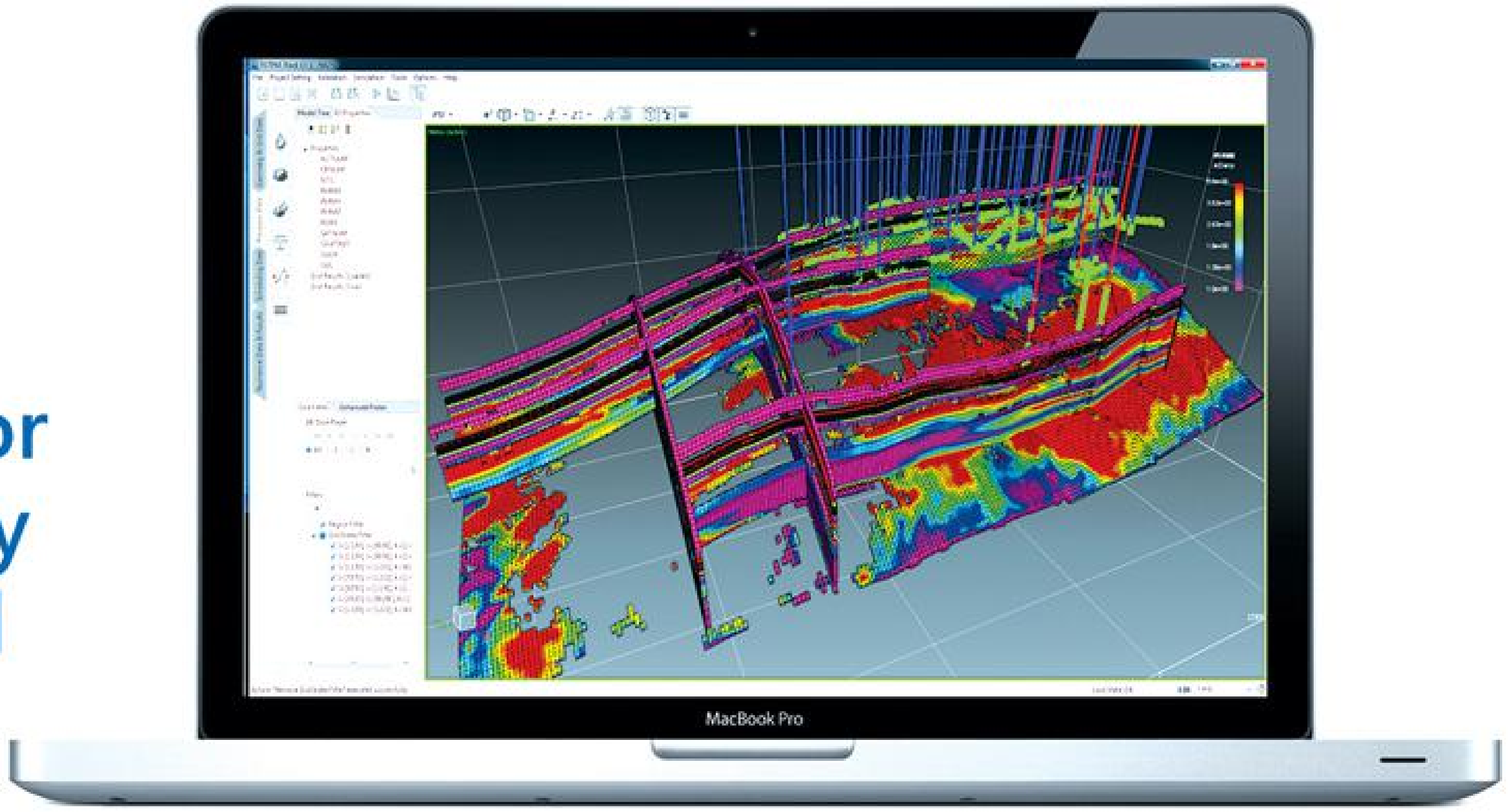
- BHP, Sw and Sg for saturated wells
- BHP, Sw and Rs for under-saturated wells



Whereas known commercial simulators always solve the well for three variables: BHP, Fw and Fg regardless of the state of the well. Therefore for under-saturated wells, Rs of well is not calculated and hence is not correct.

Wrong Rs causes the wrong oil mobility especially for injection connections. This also causes the wrong reservoir volume rate calculation for under-saturated wells.

Well inner iteration for stable solution of fully coupled well and grid equations



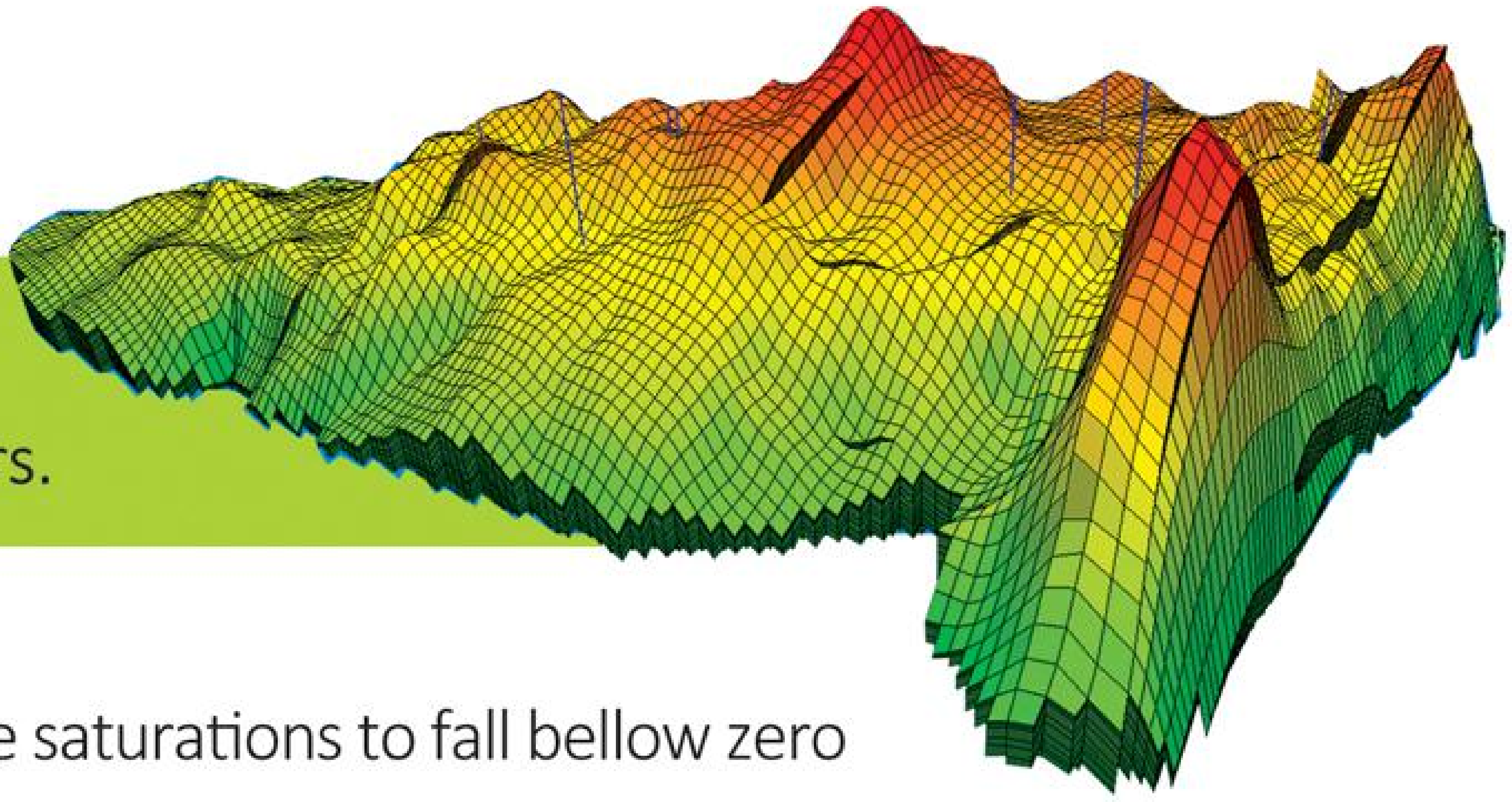
RETINA Simulation™ solves well equations fully implicitly and fully coupled with grid equations. This is the most stable scheme to solve the reservoir equations. However, unstable wells need a large number of non-linear iterations to converge. For these special cases, there is a better solution. Well equations can be decoupled from the grid equations altogether before each Newton iteration and iterated separately to converge. All the equations are then coupled together and iterated again to reach the final solution.

This is the default scheme used in known commercial simulators and causes a more stable well solution. In some rare cases however, this method causes some stability problems and increases computational cost. Therefore it's better to be an optional feature in the simulator. This facility is optional in RETINA Simulation™ so that the user can test its effectiveness without being forced to use it.

Capabilities and

RETINA keeps everything in physical range while maintaining high numerical efficiency

Saturations will never go out of bound, cells with low oil saturation do not have an unrealistic Rs and combining oils with different Rs does not result in unrelistic free gas saturation when DRSDT is zero.



All the above situations could happen in known commercial simulators.

1 Known commercial simulators allow phase saturations to fall bellow zero or grow above one. This behavior is not realistic and should be avoided. The only way to make sure this numerical constraint is satisfied is to use algebraic constraints during non-linear iterations. RETINA Simulation™ applies these numerical constraints in all the possible cases so that no variable can take an unrealistic value.

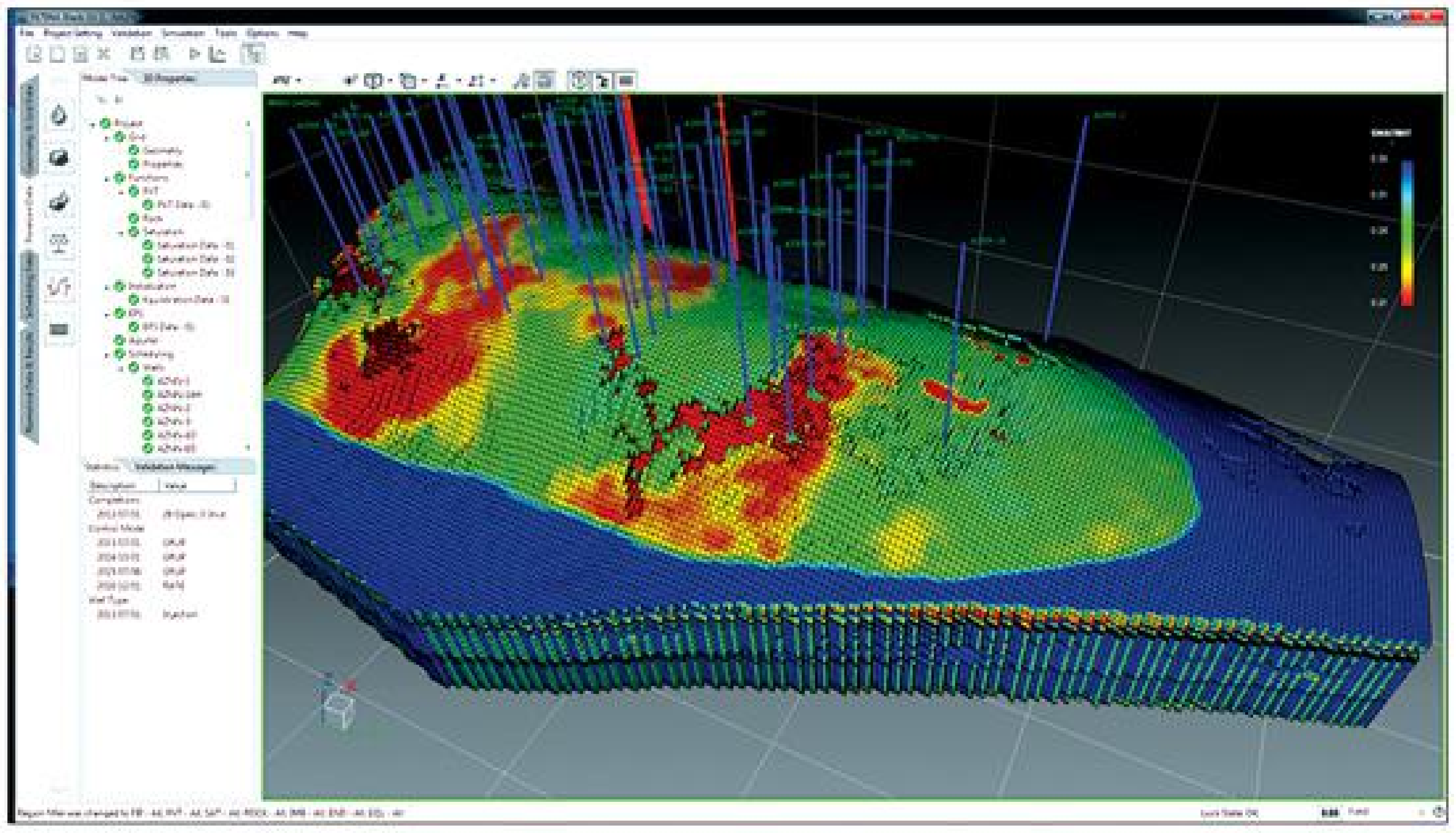
RETINA Simulation™ also controls the constraints to prevent any numerical inefficiencies.

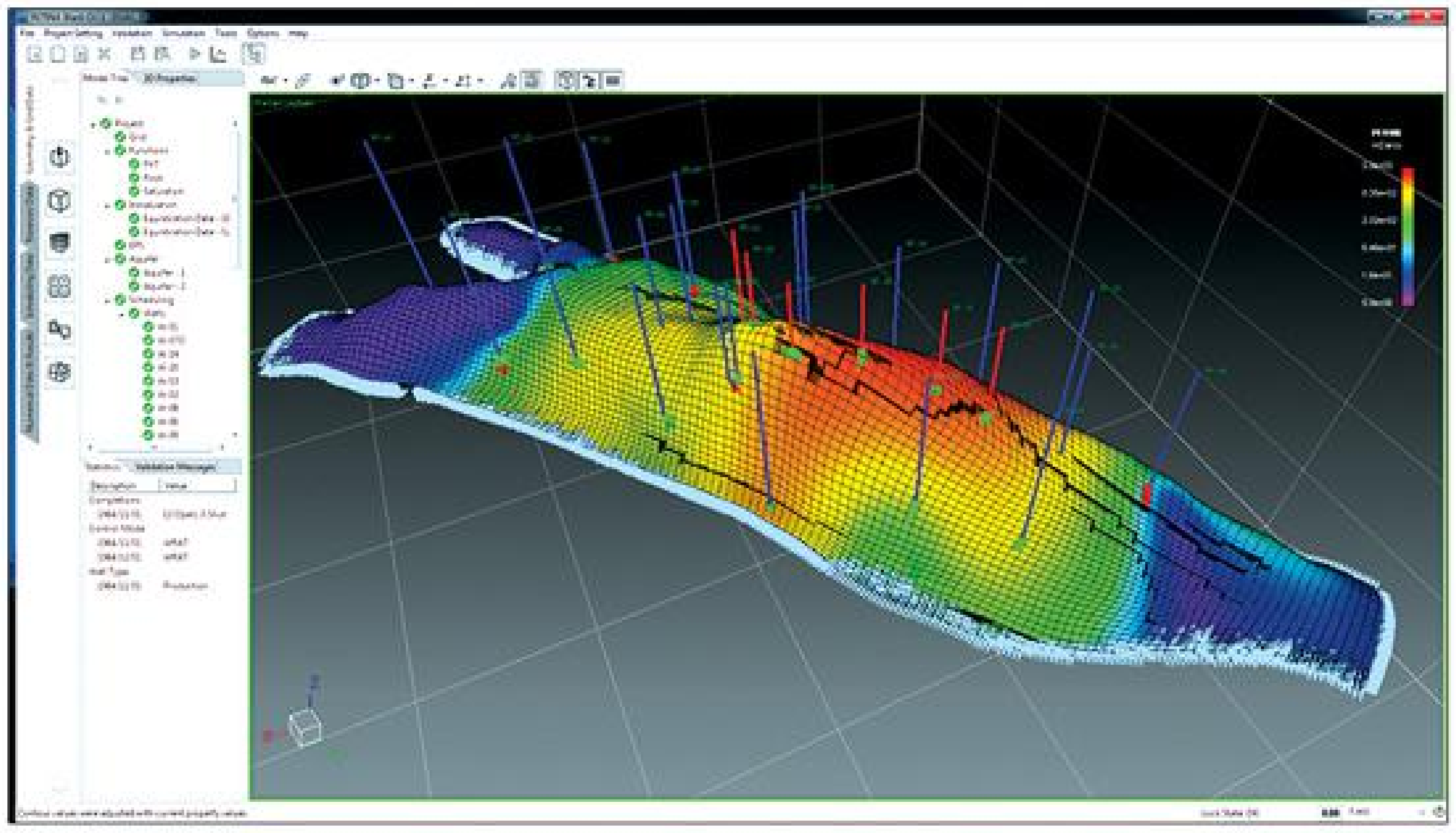
key advantages

2 Under-saturated cells with very low oil saturation are very difficult to solve for Rs.

Known commercial simulators solve this problem with a non-physical assumption. They solve these cells as saturated and therefore solve for Sg and not Rs. In some cases this can result in small values of free gas saturation below the WOC. It also causes the bubble point pressure of cells below WOC to be equal to their oil pressure which in turn leads to large values of Rs especially in highly under-saturated reservoirs.

As it happens, these cells with large Rs can be located right next to other cells with regular (and hence much less) values of Rs. This can cause numerical instability in known commercial simulators. RETINA Simulation™ however does not solve under-saturated cells with low oil saturation as saturated cells, but rather, treats them as regular under-saturated cells with some numerical enhancements. Therefore, cells have a correct value of Rs below WOC and no instability occurs in RETINA Simulation™ due to this issue. Moreover, RETINA Simulation™ solves these cells with almost no numerical difficulty.





DFN modeling

The DFN feature allows RETINA Simulation™ to solve fully unstructured fractured grids (i.e. modeling fractures as 2D surfaces between 3D matrix cells). This feature is fully implemented and tested with several synthetic cases, however, due to the fact that DFN is not used in industry, real-world cases are not available for further testing.

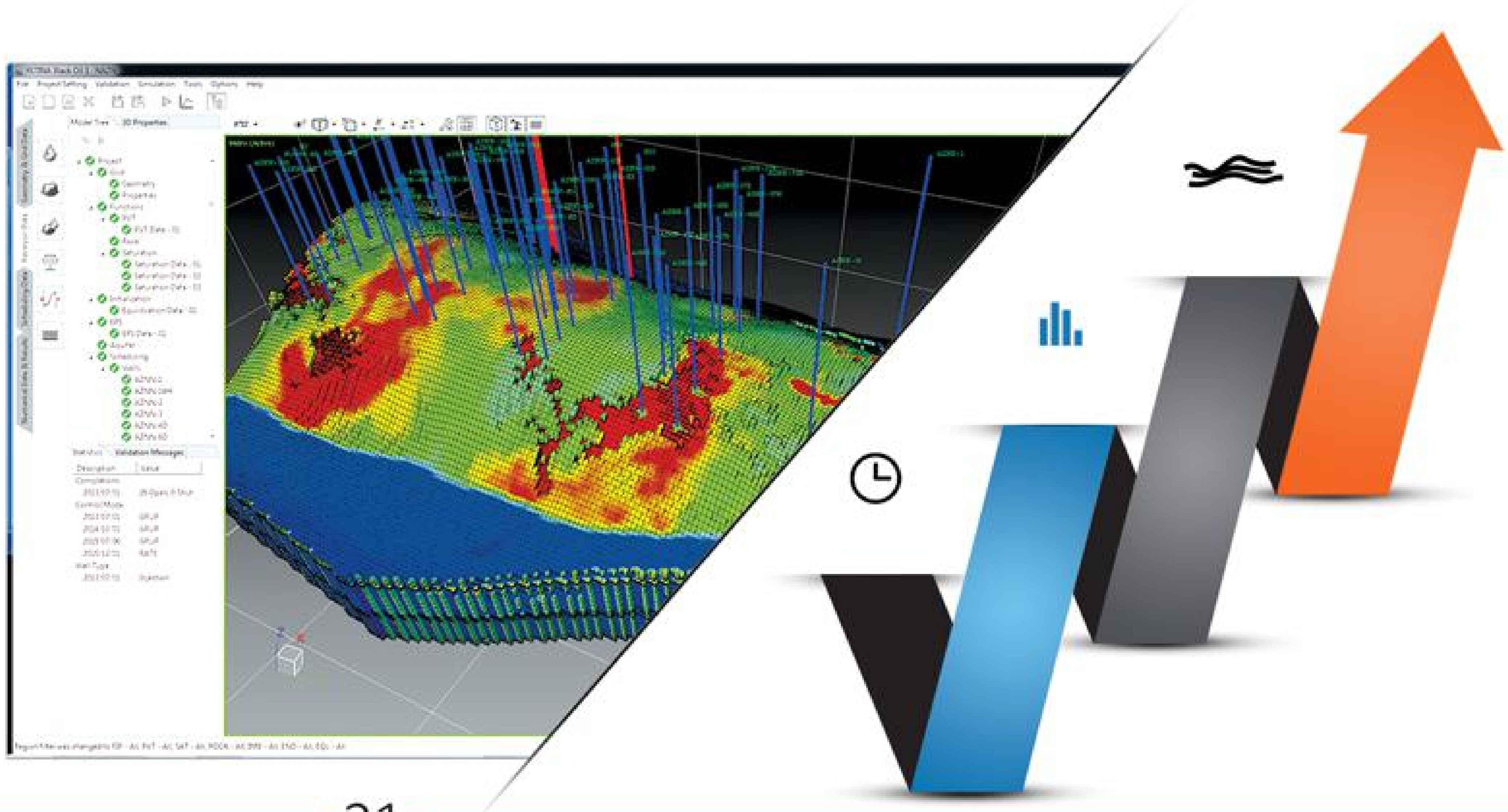
List of dual-porosity transfer functions and shape factor formula

RETINA Simulation™ includes the following transfer functions:

- Kazemi (1976)
- Gilman-Kazemi (1983)
- Quandalle and Sabathier (1989)

The following shape factor calculation formulae are implemented in RETINA Simulation™:

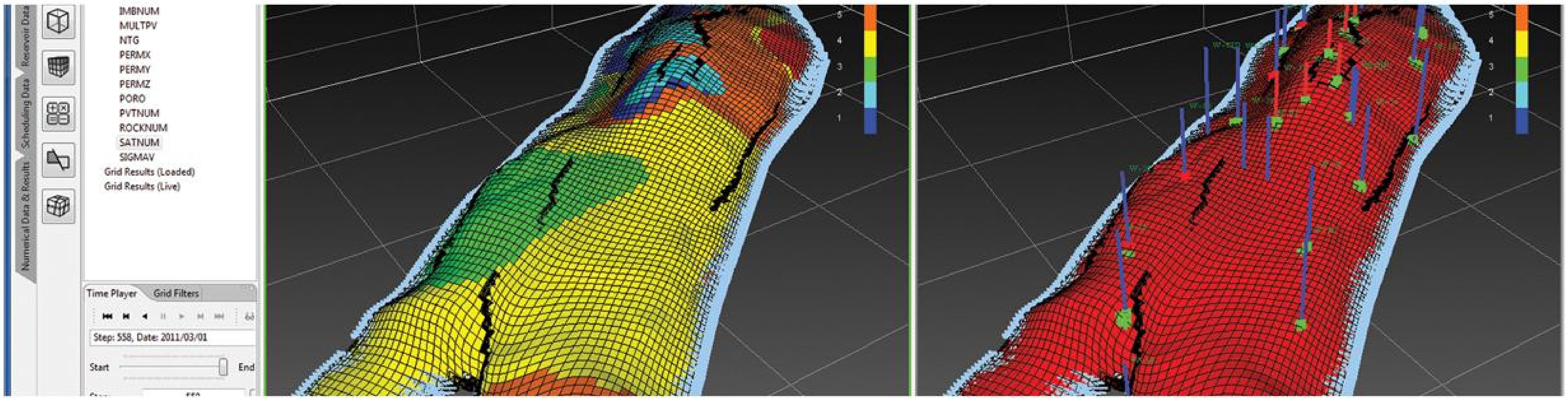
- Warren and root
- Kazemi et al. (1976)
- Gilman, Kazemi (1983)
- Coats (1989)
- Chang (1993)
- Lim and Aziz (1995)



Full field simulation of unconventional reservoirs (tight oil / shale gas)

RETINA Simulation™ has magnificent ability to simulate unstructured and hybrid DFN models. Technically speaking, using RETINA Simulation™, engineers can model the volume around the wells using an unstructured DFN grid while using the conventional structured single or dual porosity grid for the rest of the reservoir volume. This ability comes in handy especially in case of wells stimulated using Hydraulic Fracturing.

The current solution for predicting performance of unconventional reservoirs is to perform the following two simulations:



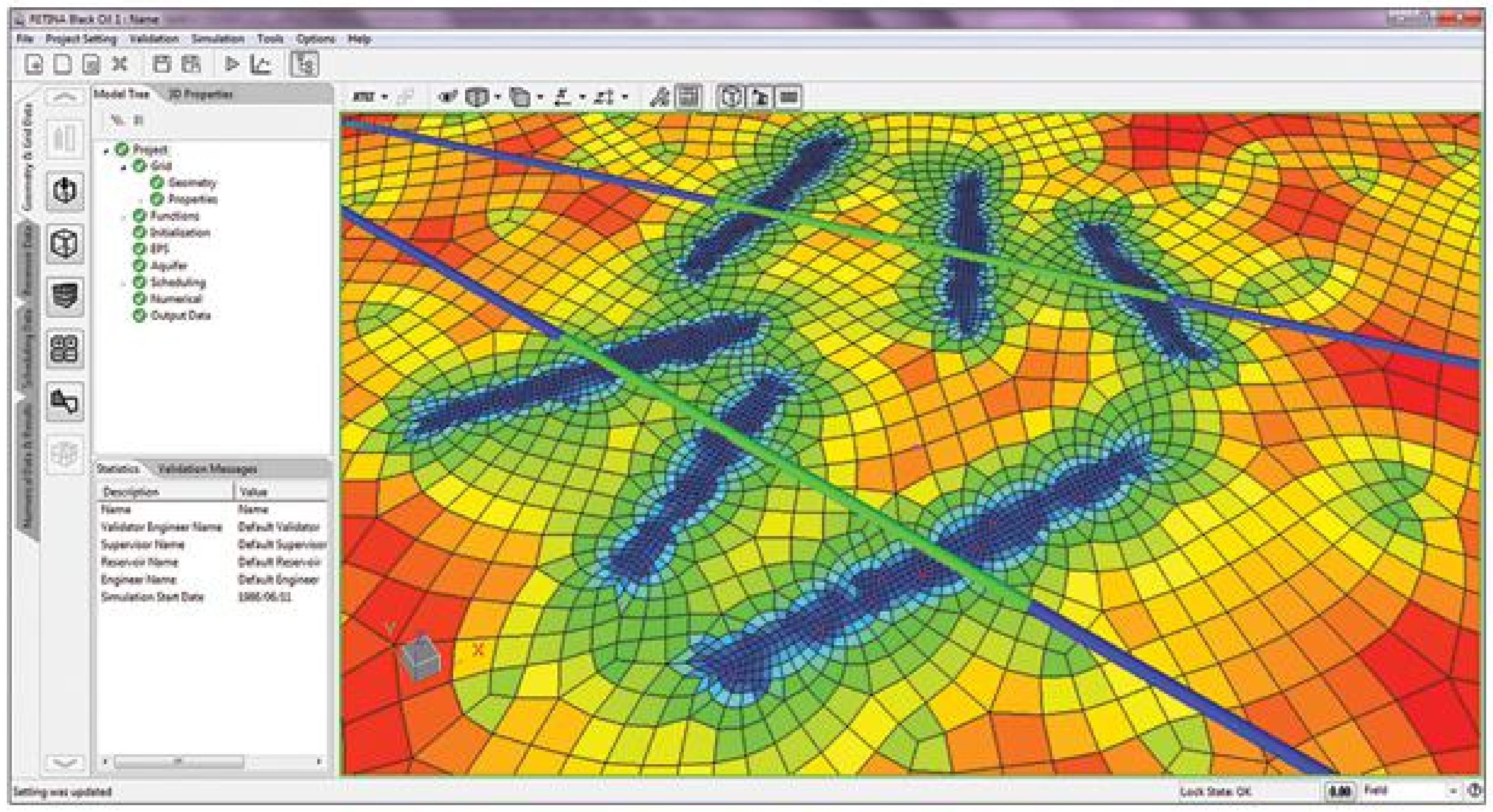
1. Single well simulation using explicit DFN model to predict the well performance. The results of this simulation are usually used to design the Hydraulic Fracturing operation and predict the future performance of wells. An overall skin factor is also estimated for full field studies.

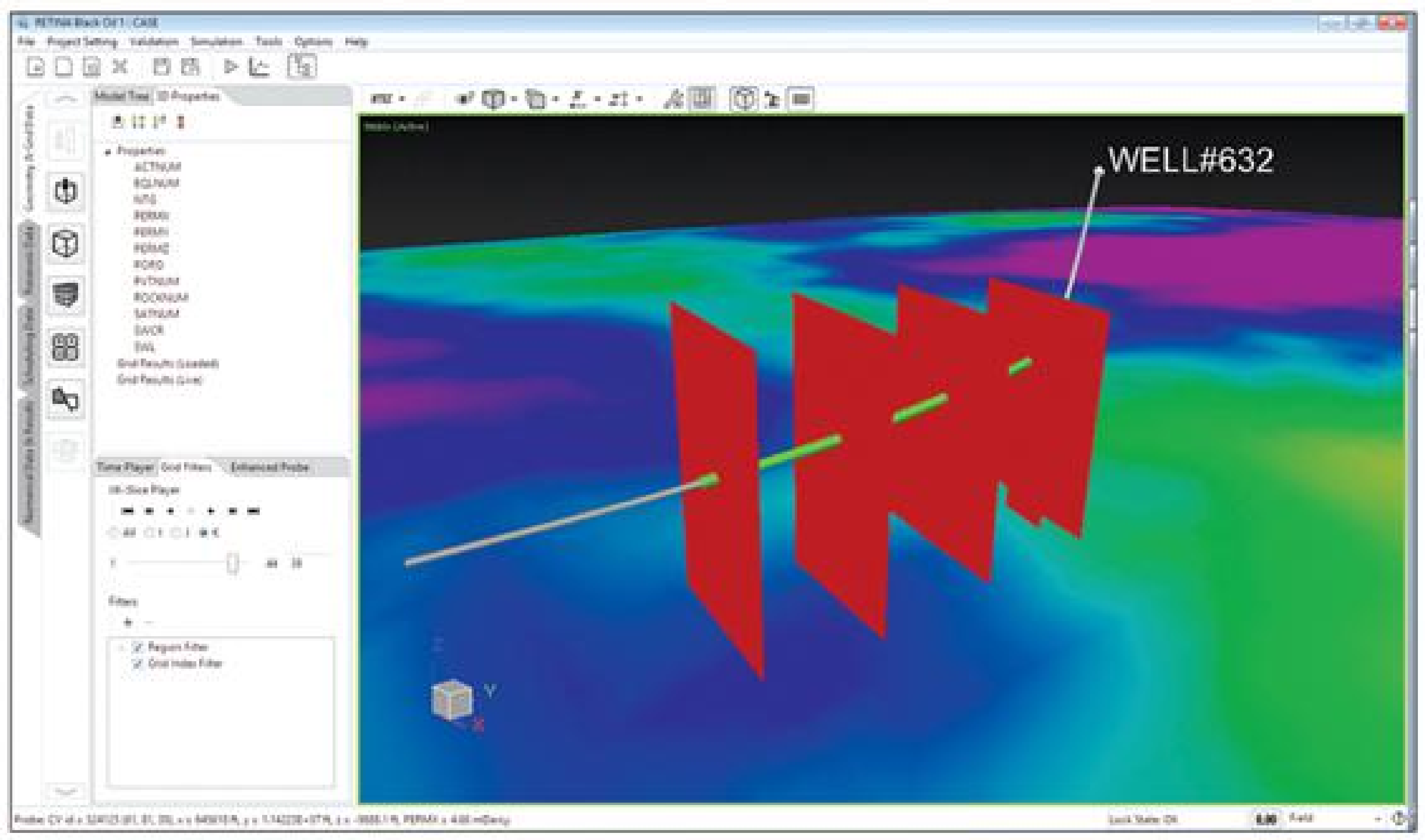
2 Full field simulation with a conventional approach using a prevalent industrial simulator. The results are used to predict the overall (usually qualitative) performance of the field. Simulation is done using single or dual porosity approach according to rock properties of the field. In this simulation, hydraulically fractured wells are represented either by an overall skin or adjusting properties of cells surrounding each well.

RETINA Simulation™ is able to combine the DFN model with the full field simulation to create a model that includes all the details needed to predict full field performance as well as single well results.

RETINA Simulation™ has a toolbox that can generate unstructured or hybrid grids for the mentioned simulation approach. The overall full field study workflow for unconventional reservoirs is as follows:

1. Importing conventional grid (static fine grid) for the model along with the well deviations.
2. Entering hydraulic fracturing parameters for each well. (These parameters could be estimated using Hydraulic Fracturing Design module of RETINA Stimulation™)
3. Generating suitable grid for the reservoir and around wellbores according to well paths and fracture geometry.
4. Transferring data from the conventional grid to the newly generated grid.
5. Perform simulation using RETINA Simulation™





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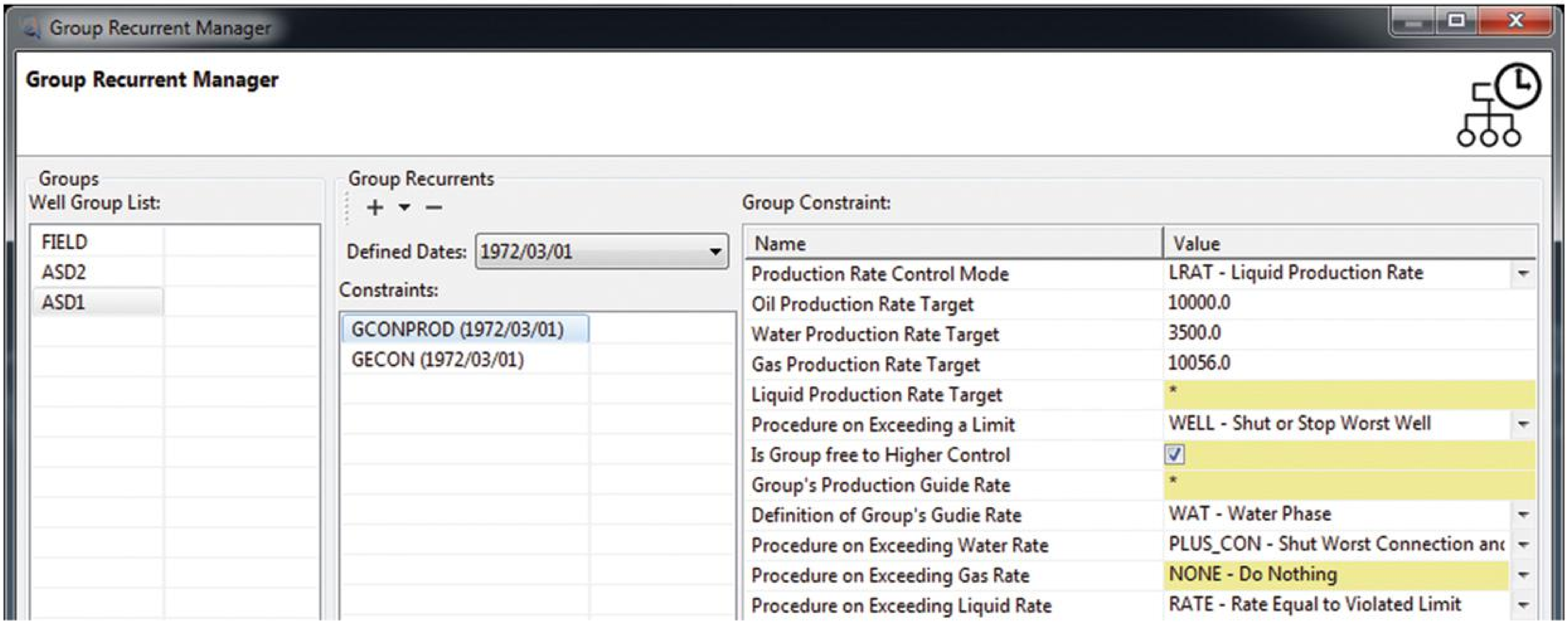
Running this kind of full field models has multiple numerical difficulties. The first issue is high heterogeneity of these models; and the second issue is high throughput nature of DFN models. Two dimensional fracture cells with small pore volume and high speed of flow are a great challenge for numerical solvers. These are the two main issues that prevent current industrial simulators from handling full field DFN models. By contrast, RETINA Simulation™ benefits from a modern and robust linear solver that is easily capable of handling the mentioned issues. Using RETINA Simulation™, DFN models are simulated smoothly and with large time-steps while other simulators face severe problems while simulating such models.



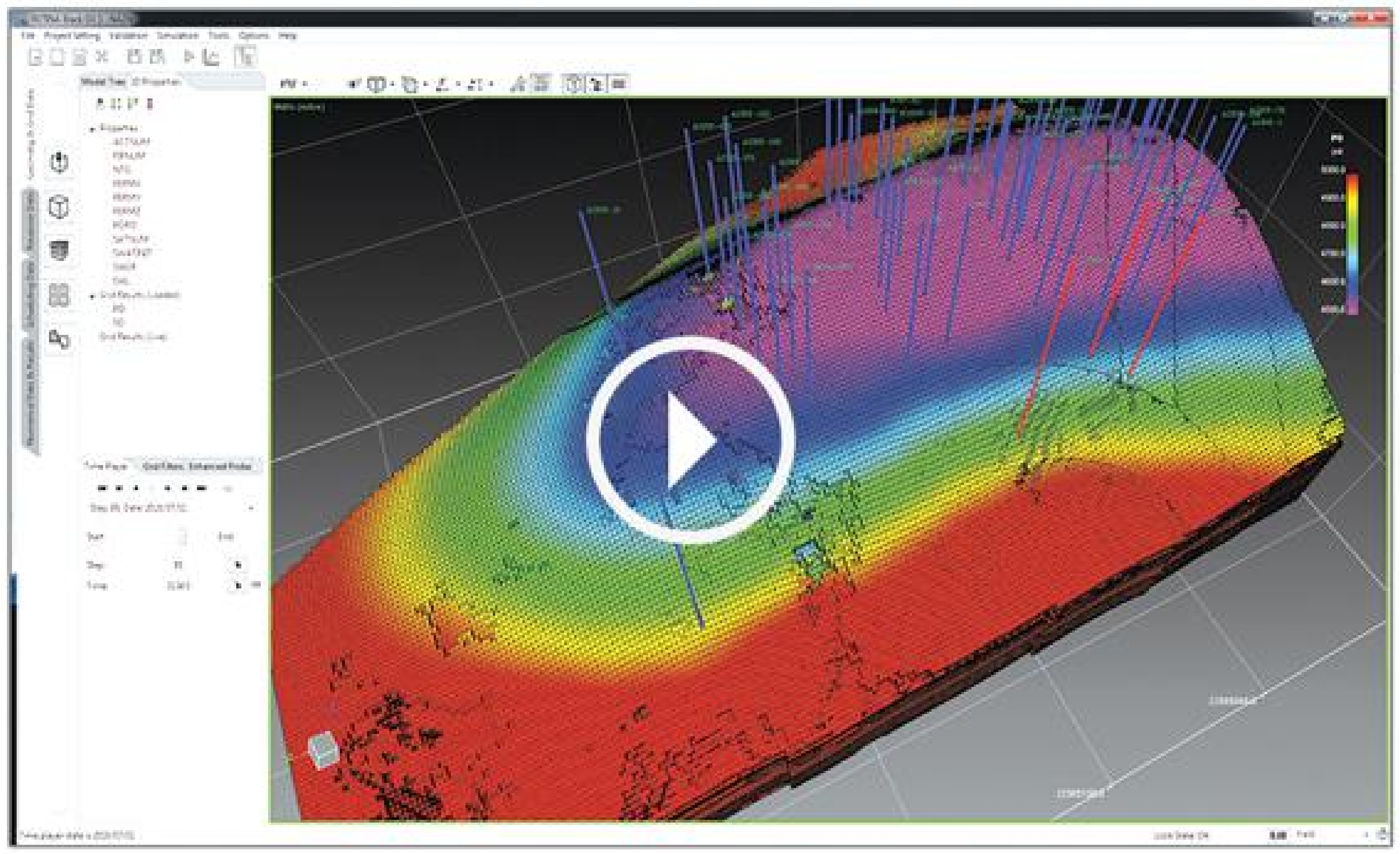
List of group control facilities for prediction runs

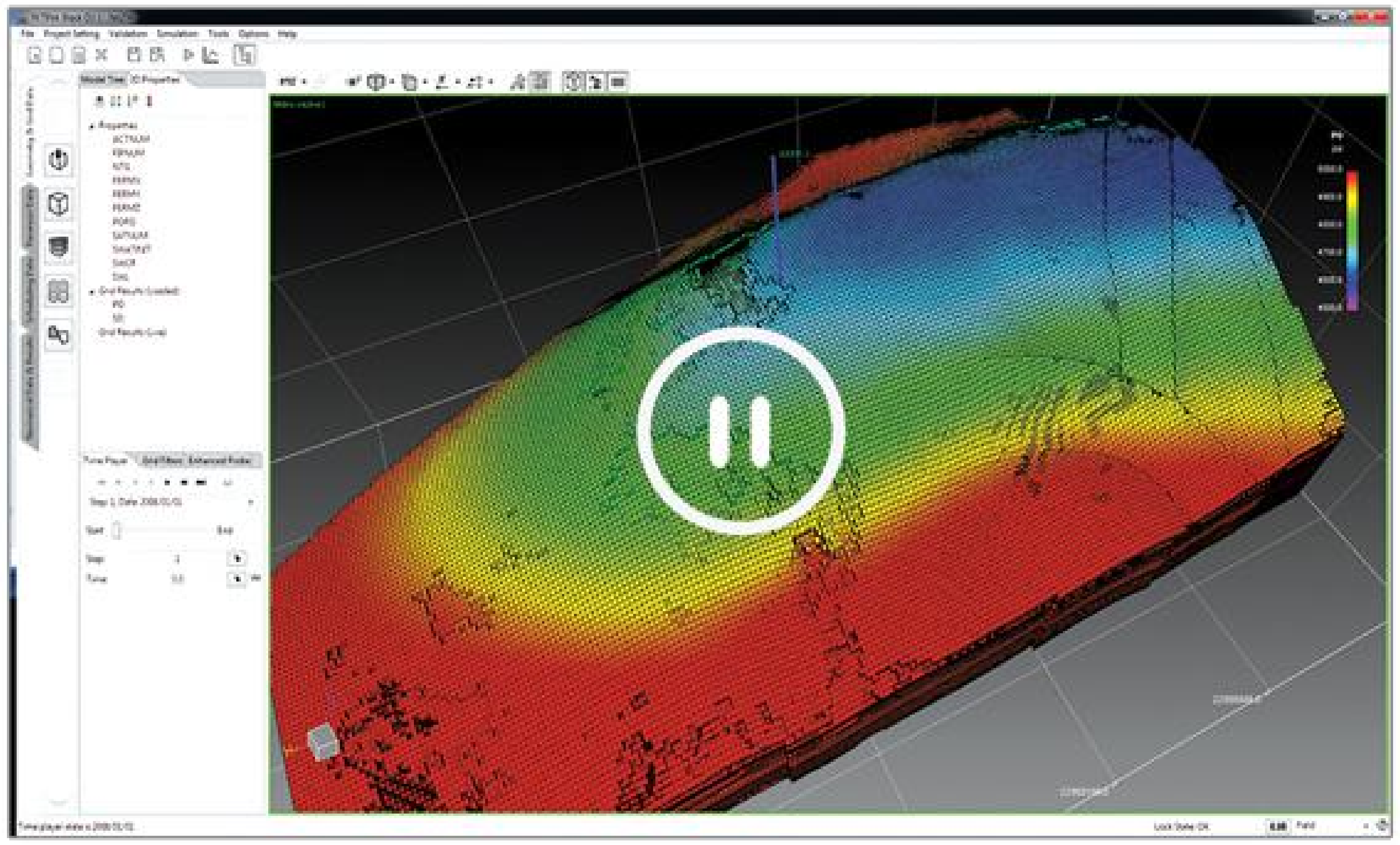
All the usual group control facilities are available in RETINA Simulation™:

1. Multi-level hierarchical fully implicit production and injection group control
2. Re-injection and voidage replacement of the production group to injection wells
3. Auto work-over and economic limit handling
4. Auto drilling and completion facilities
5. Limiting the drilling and work-over rigs
6. Drilling wells in sequential or prioritized queues
7. Group guide rate calculation formula

Live result presentation (4D visualization)

Simulation graphs and 3D results can be animated in real-time during the simulation. Results are loaded automatically as they are written on disk in a smooth and efficient manner.





Changing the model during simulation

Simulation can be paused at any time, which allows the user to change the data for the upcoming time steps. When the simulation is resumed, RETINA Simulation™ will load the new data for corresponding steps.

key advantages

Interactive and user friendly interface

- Grid property editing
  - All the grid properties are defined and edited
- Graphs for PVT, SCAL, End-Pint Scaling and other data
  - PVT, SCAL and other data are plotted automatically as soon as they are defined in
- RETINA Simulation™ Import capabilities
  - Grids with formats: GRID, EGRID, FEGRID, FGRID, GRDECL and RESCUE to and exported from RETINA Simulation™.
  - PVT table
  - SCAL keywords
  - Aquifer keywords
  - VFP tables
  - Schedule keywords
  - Equilibration keywords
  - EPS keywords
  - ECLIPSE DATA file
- Well path import
- Well recurrent manager
- Easily define multiple wells and connections (one click)
- VFP table generator
- Multiple (RETINA Simulation™ and ECLIPSE) cases result viewer

Case study: An Iranian oil field

The case is an Iranian offshore oil field located beneath the Karg island 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[1] and ESTD aimed at validating and certifying RETINA Simulation™.

The model is dual porosity with some single porosity layers (DPNUM). It is an under-saturated reservoir with a moderate aquifer as its boundary condition. during these years 8 oil producing wells are activated.

1 Iranian Offshore Oil Company (Offshore division of NIOC)

More details about the model are described at 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 E100 2010.1 32-bit" are used for comparison and validation.

The two simulators were allowed to select their own time steps as they see fit and no special tunings were 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 study are compared from two aspects:

accuracy and speed

Accuracy

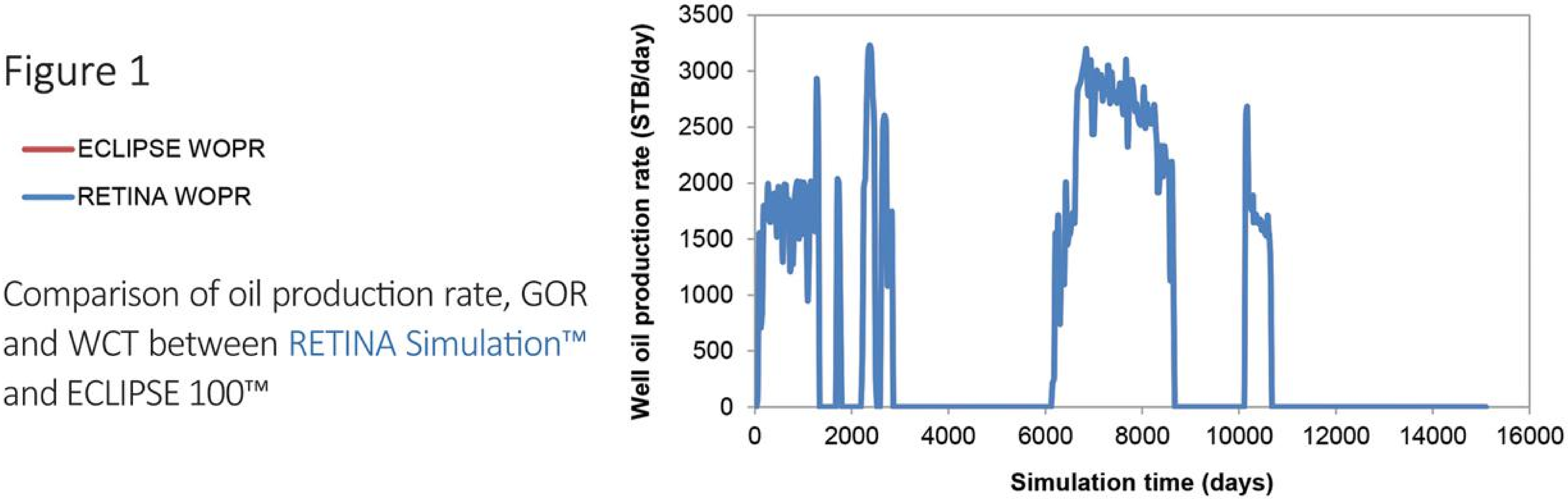
Figure 1 and 2 show the comparison between RETINA Simulation™ and ECLIPSE 100™ for one of the wells only for the reason of confidentiality of data. All the results match almost perfectly and this is the case for all the other wells and vectors. The selected well is the first producing well and hence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

Table 2

Simulation result	Max. of relative difference (percent)
Field average pressure (FPR)	0.051%
Field oil production rate (FOPR)	0.000025%
Field gas production rate (FGPR)	0.5%
Field water production rate (FWPR)	4.7%
Wells gas production rate (WGPR)	0.83%
Wells water production rate (WWPR)	5.1%
Wells bottom-hole pressure (WBHP)	0.98%
Wells average block pressure (WBP9)	0.78%
Aquifer rate	2.7%

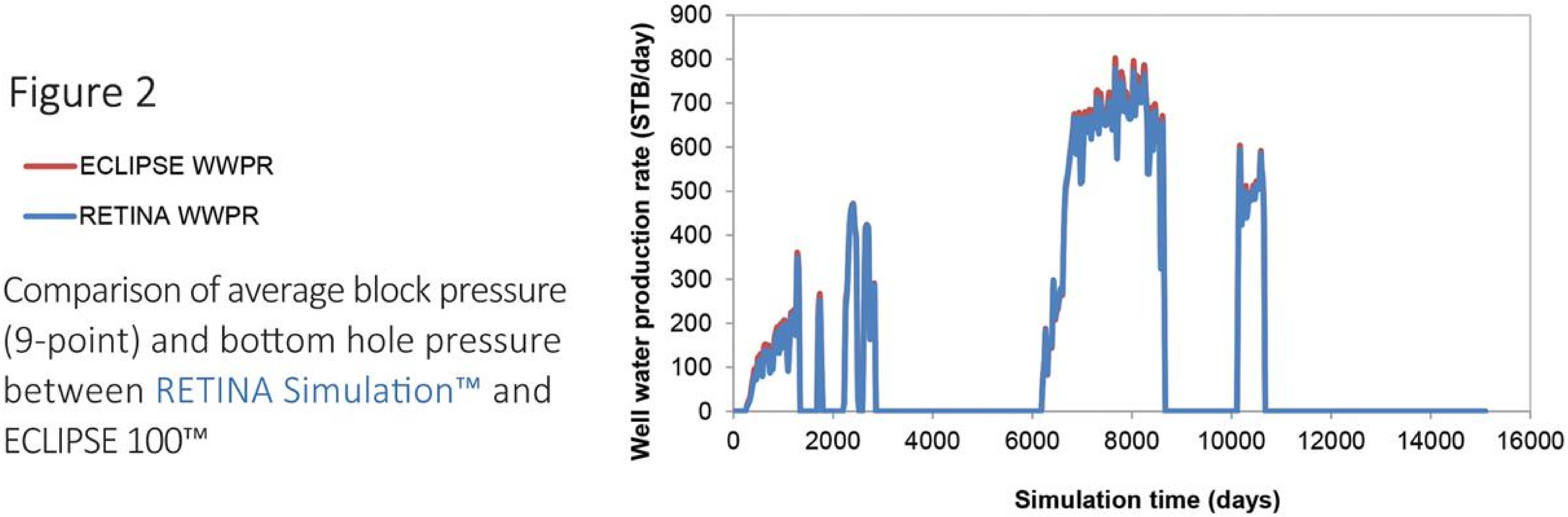
Summary of simulation results comparison between RETINA and ECLIPSE

Figure 1



Comparison of oil production rate, GOR and WCT between RETINA Simulation™ and ECLIPSE 100™

Figure 2



Comparison of average block pressure (9-point) and bottom hole pressure between RETINA Simulation™ and ECLIPSE 100™

Speed

As it is seen in figures 3 and 4, RETINA Simulation™ can take larger time steps in this model and therefore it has less simulation run 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 a better linear solver pre-conditioner used in RETINA Simulation™ . Hence, in this case (as a typical dual porosity model), we expect a better performance compared to ECLIPSE 100™. More detail on speed comparison is explained in the following sections.

1 Simulation elapsed time in seconds.

This is the time taken to run the model from time 0 to the specified simulation time (days). Figure 3 shows that RETINA Simulation™ has less elapsed time and can run the model almost two times faster than ECLIPSE 100™. RETINA Simulation™ takes 16615.70 seconds where ECLIPSE 100™ needs 27185.98 seconds to run the entire model. RETINA Simulation™ solves the model with 957 time steps and 5499 non-linear iterations and ECLIPSE 100™ with 7588 time steps and 42587 non-linear iterations.

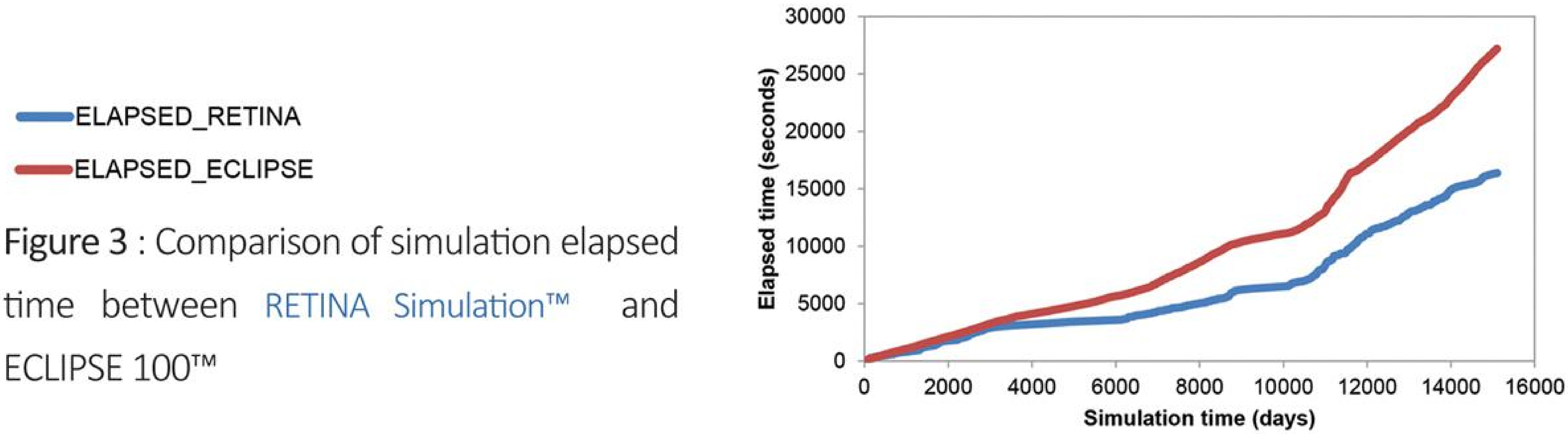


Figure 3 : Comparison of simulation elapsed time between RETINA Simulation™ and ECLIPSE 100™

1 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 (time at which the well rates are entered for the model) is the limiting factor for time steps in RETINA Simulation™ in most of the time steps; whereas ECLIPSE 100™ faces trouble taking large time step in the size of report step size. Average size of time steps in RETINA Simulation™ is 21.69 days where ECLIPSE 100™ has the average of 5.34 days time steps. And from the accuracy comparison it is evident that, large time step sizes do not lead to higher time truncation error in RETINA Simulation™ .

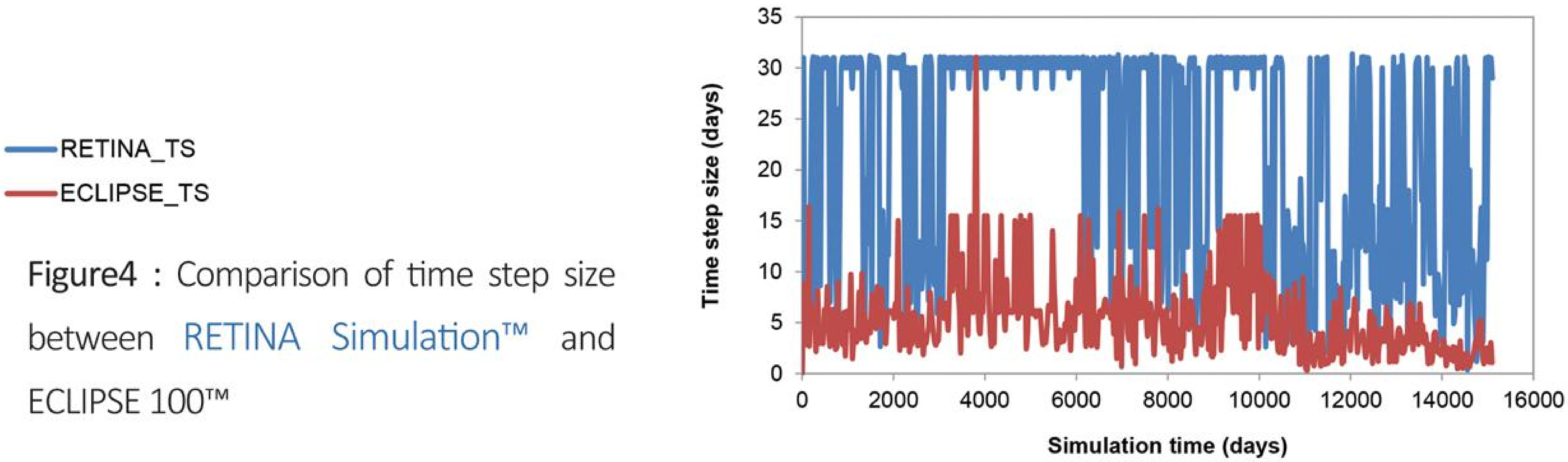
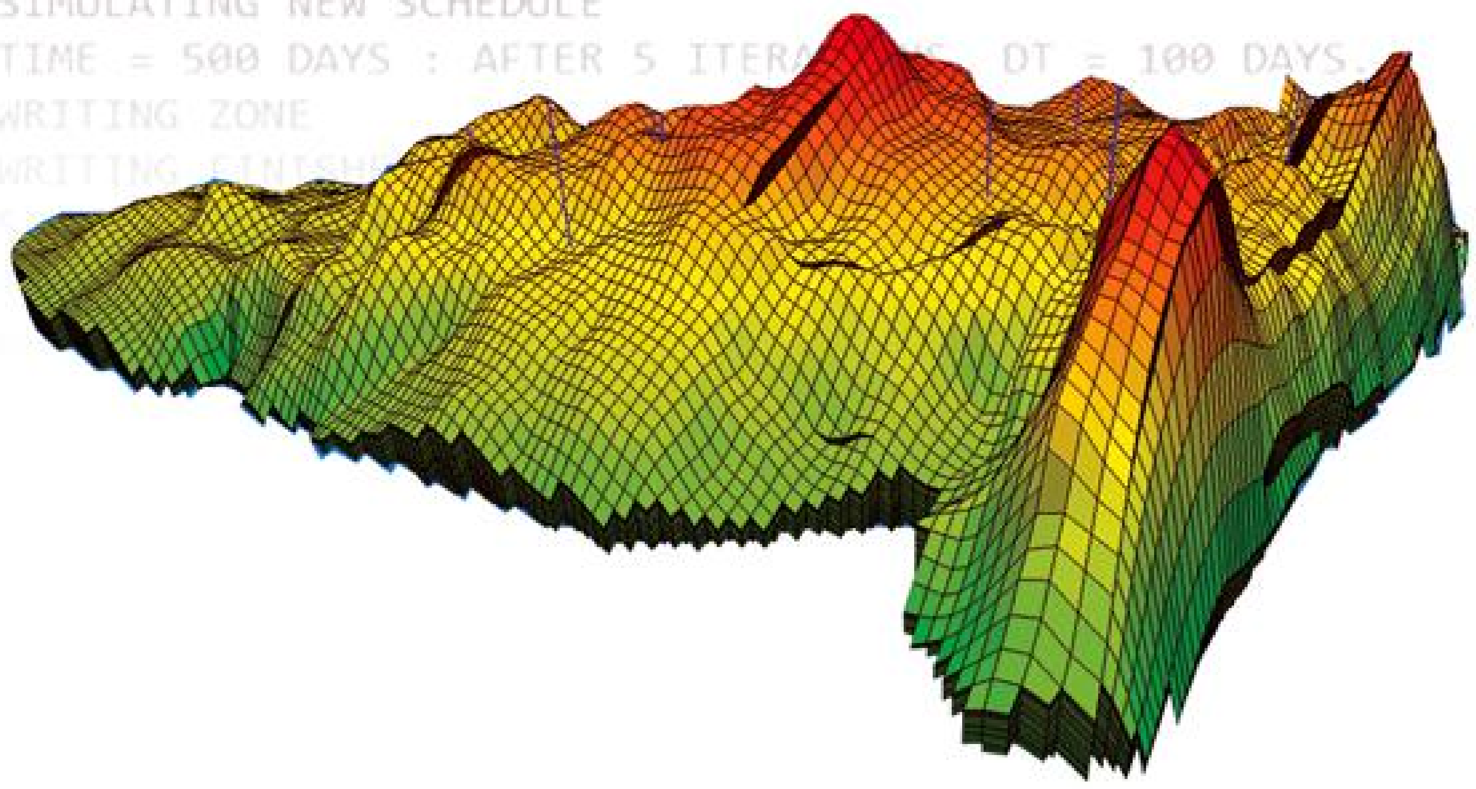


Figure4 : Comparison of time step size between RETINA Simulation™ and ECLIPSE 100™

```
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
```



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