

Integrated static and
dynamic modeling
from reservoir to
surface network

tNavigator®

Open windows

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 - VPC

Wells Table					
	Well Name	X0, m	Y0, m	Z0, m	Trajectory
1	1	486911	7,87563e+06	20	(...)
2	10	468344	7,8675e+06	20,8	(...)
3	11	483076	7,87388e+06	-22,8	(...)

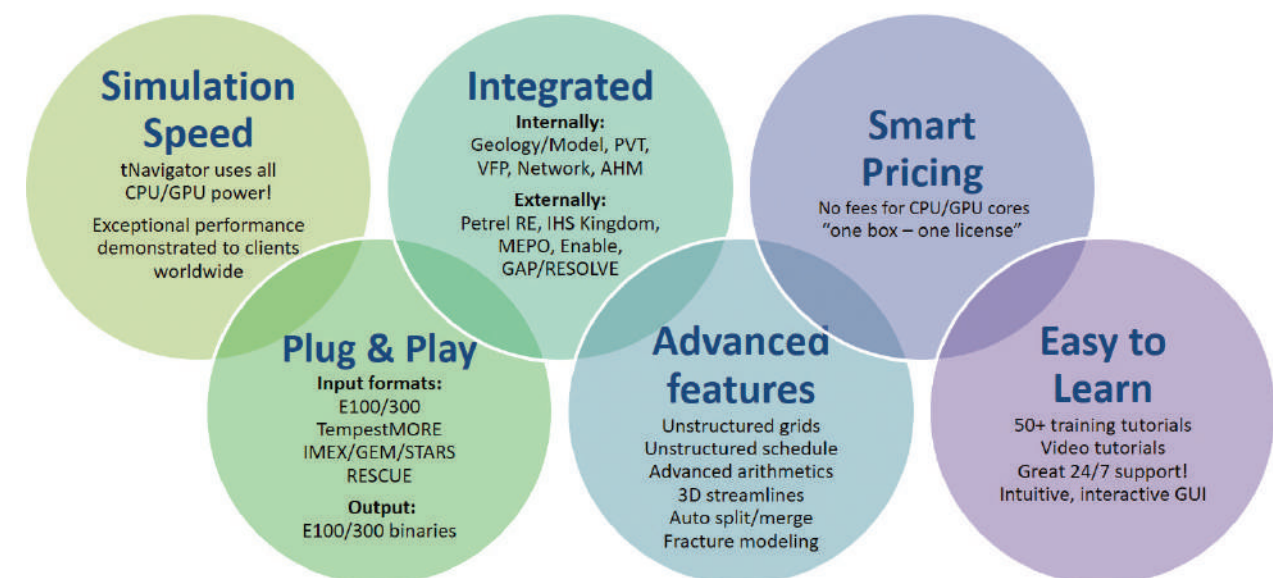
Simple facts on Rock Flow Dynamics and tNavigator

Rock Flow Dynamics is offering high performance tools for integrated static and dynamic modeling from reservoir to surface networks.

- It took 12 years to develop tNavigator.
- There are 4 tNavigator releases per year.
- tNavigator is a set of numerical algorithms written in C++/CUDA with more than 3.7 million lines of code, using all advantages of up-to-date CPU/GPU processors, memory and chipsets.
- With 85 staff software engineers Rock Flow Dynamics is a software development powerhouse.
- International support staff includes 35 reservoir engineers in 18 offices in 13 countries.
- Super-computer facilities worldwide: 175 cluster nodes (3404 CPU, 35840 GPU cores).
- tNavigator community includes 120+ commercial clients in 23 countries and 40+ universities in 18 countries.

More information about Rock Flow Dynamics, tNavigator technology, support videos, tutorials, client's testimonials are available on-line via <http://www.rfdyn.com>

What makes us different?



tNavigator Modules Available

tNavigator is a software package, offered as a single executable, which allows to build static and dynamic reservoir models, run dynamic simulations, calculate PVT properties of fluids, build surface network model, calculate lifting tables, and perform extended uncertainty analysis as a part of one integrated workflow. All the parts of the workflow share common proprietary internal data storage system, super-scalable parallel numerical engine (tested up to 4096 CPU and 35840 GPU cores with model sizes exceeding 1 billion active grid blocks), data input/output mechanism and graphical user interface.

tNavigator is a multi-format simulator natively supporting E100/300, TempestMORE, IMEX/GEM/STARS, RESCUE input data formats. The format converters are embedded into the executable and provide on-the-fly conversion of input data decks into the internal data storage system.

tNavigator is a multiplatform software application written in C++, CUDA and can be installed on Linux, Unix, Windows (64-bit) OS and run on systems with shared and distributed memory layout as a console or GUI (local or remote) based application.

tNavigator parallel technology takes full advantage of multicore CPU and GPU processing units. The domain decomposition between computational threads for shared and distributed memory systems, as well as load balancing is done automatically. tNavigator can be run on any laptop, any single, dual (or higher) CPU based workstations with one or multiple GPUs, and HPC clusters. Cloud based solution with full graphical GUI capabilities and cloud side postprocessing via remote desktop is also available.

tNavigator licensing is enabled for local and network environments. Local licenses are provided for standalone workstations and laptops and require USB dongle and a corresponding license file.

Network licenses for LAN and WAN networks are provided by a license server installed on Linux or Windows computer systems (physical or virtual). The license server requires access to USB dongle and its license file. The license server is based on open-source Apache server and could provide usage statistics for FlexNet and OpenIT monitoring systems.

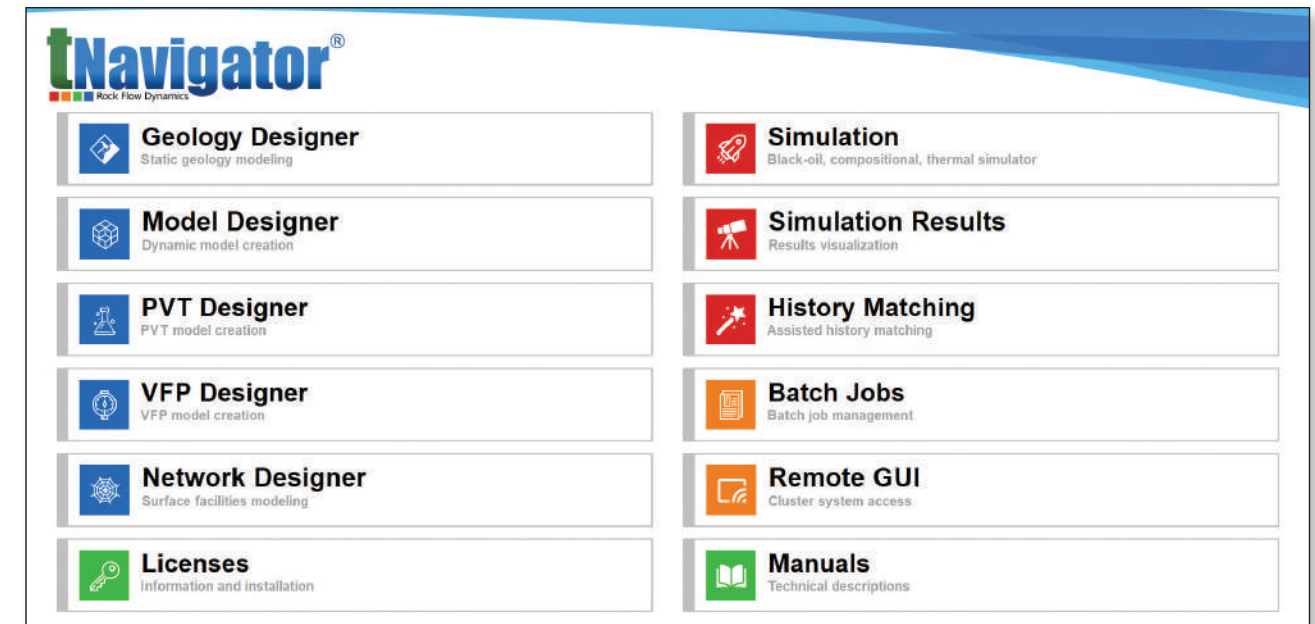
tNavigator package contains the following functional modules offered separately:

- **Geology Designer** for building static reservoir model
- **Model Designer** for building dynamic reservoir model
- **PVT Designer***
- **VFP Designer***
- **Network Designer**
- **Simulation engines:**
 - o Blackoil
 - o Compositional
 - o Thermal compositional
- **Simulation Results** GUI for post-processing
- **History Matching** for assisted history matching and uncertainty analysis

* The following two modules are included in other modules and don't require special license:

- **PVT Designer** (included in Geology Designer, Model Designer, Network Designer)
- **VFP Designer** (included in Geology Designer, Model Designer, Network Designer)

tNavigator GUI shown below lists all the modules listed above and includes additional features like **Remote GUI, Batch Job Manager, License Manager and Manuals** available at no extra charge.



Blackoil, Compositional and Thermal Compositional are full physics finite difference simulators with upstream flux approximation, molar densities, and pressure used as principal variables. All the simulators use general mesh formulation and support fully unstructured grids including non-neighborhood connections, layers with pinchouts and thin layers. Corner point input format for the model grid is supported. Multiple local grid refinements and grid coarsening are allowed. Support for naturally fractured reservoirs is provided via dual porosity dual permeability (DPDP) mechanisms. tNavigator supports trajectory and (I, J, K) defined wells of arbitrary shapes and supports multi-lateral wells, ICDs, connection based fractures, and wells with multi-segmented densities. Simulation of BHP, THP, hierarchical group controls, and control by rates is supported. At each time step, the coupling between the well and the reservoir is resolved by solving a fully implicit well equation that takes into account possible crossflow between well connections. The resulting system of non-linear equations is resolved using Newton's method using a common Fully Implicit (FI) or Adaptive Implicit (AIM) solver. The simulation results can be exported to standard E100/300 binaries and RSM files. The simulators don't require any other external software tools and can be used within integrated static, dynamic, and uncertainty workflows available in tNavigator. In some special cases, to satisfy existing corporate workflows, tNavigator can be integrated with some legacy third-party tools: MEPO, Enable, Petrel RE/IHS Kingdom, GAP/RESOLVE, and some others.

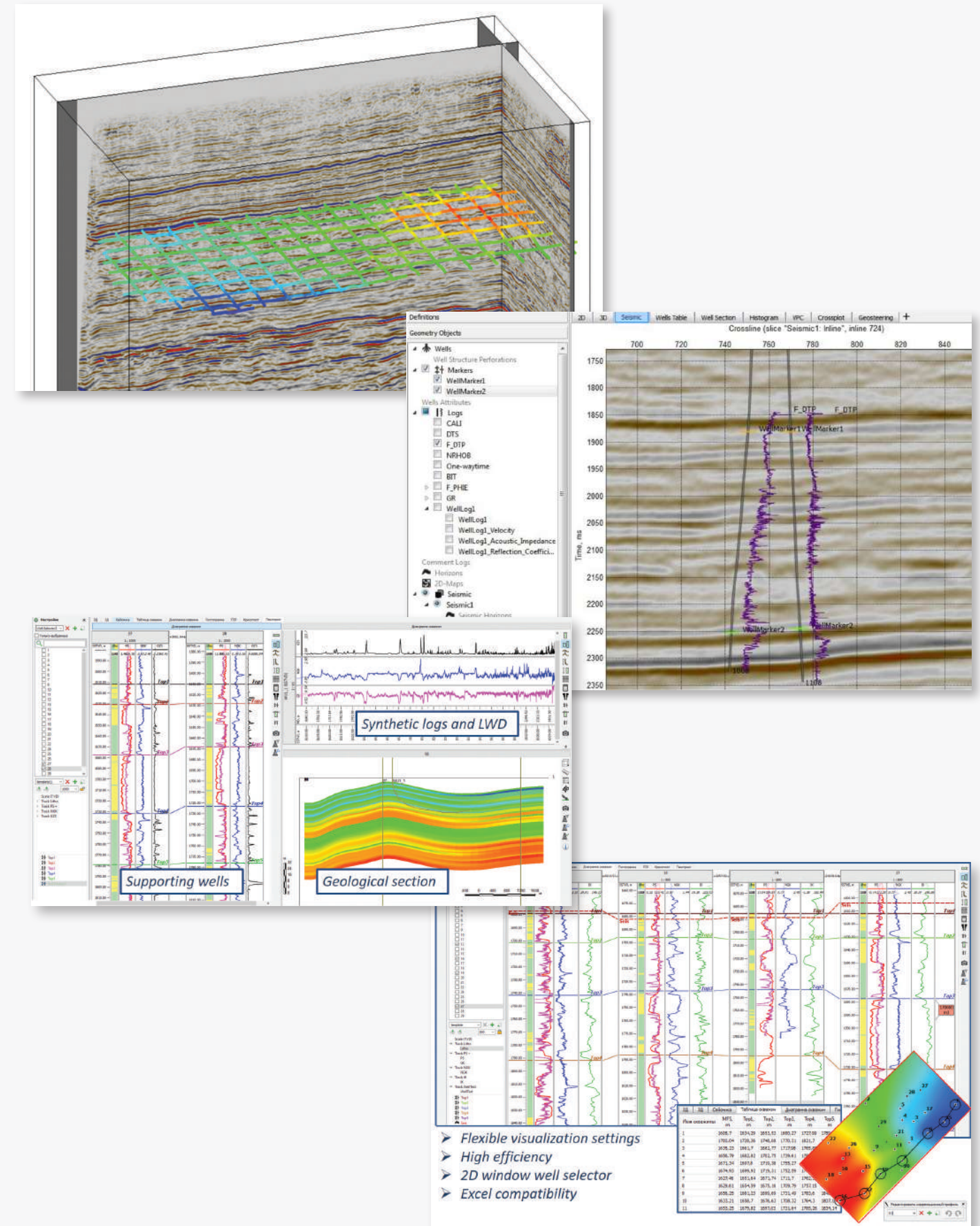
Geology Designer

Geology Designer allows to build static model from scratch.

- Load and edit interpreted seismic surfaces, well trajectories, logs and well picks, facies properties, rock properties, petrophysical information, point sets and other objects. Formats exported from IHS Kingdom can be loaded to Geology Designer.
- 3D seismic. Import of SEG-Y format, creation and visualization of in-lines, cross-lines and time-slices. Seismic interpretation. Time-to-depth conversion relation. Display of wells, well logs and markers on the Seismic tab (2D). Calculation of synthetic velocity curve, synthetic acoustic impedance, reflection coefficient and interval velocity curves to compare it with the seismic data. Palette, wavelet, reflection, lines visualization.
- Support for coordinate reference systems by country or EPSG codes.
- 2D and 3D visualization, Histograms, Crossplots, VPC.
- Well correlation window allows to work with many wells at the same time. Automatic and manual well correlation. Ghost curve.
- Build 3D grid with faults. Loading faults in standard formats, faults creation via polygons.
- Structural modeling. Local grid editing.
- Facies analysis. Variograms. Property interpolation: least-squares, inverse distance weighing (IDW), kriging, Gaussian simulation (SGS).
- Fluid-in-place.
- Calculator to work with all project objects.
- Workflows implemented using Python scripts.
- Geosteering.
- Big loop. Variables in workflow to run AHM and uncertainty analysis, and other options.

All the calculations related to grid generation, properties interpolation and others are accelerated with parallel algorithms run on all available cores of the workstation.

Integration. Usage of the combination of modules Geology Designer, Model Designer, PVT Designer, VFP Designer, Simulator (blackoil, compositional or thermal), Assisted History Matching and Uncertainty provides the possibility to create in one graphical interface static and dynamic model, run simulations, analyze results, do assisted history matching (big loop), uncertainty analysis.



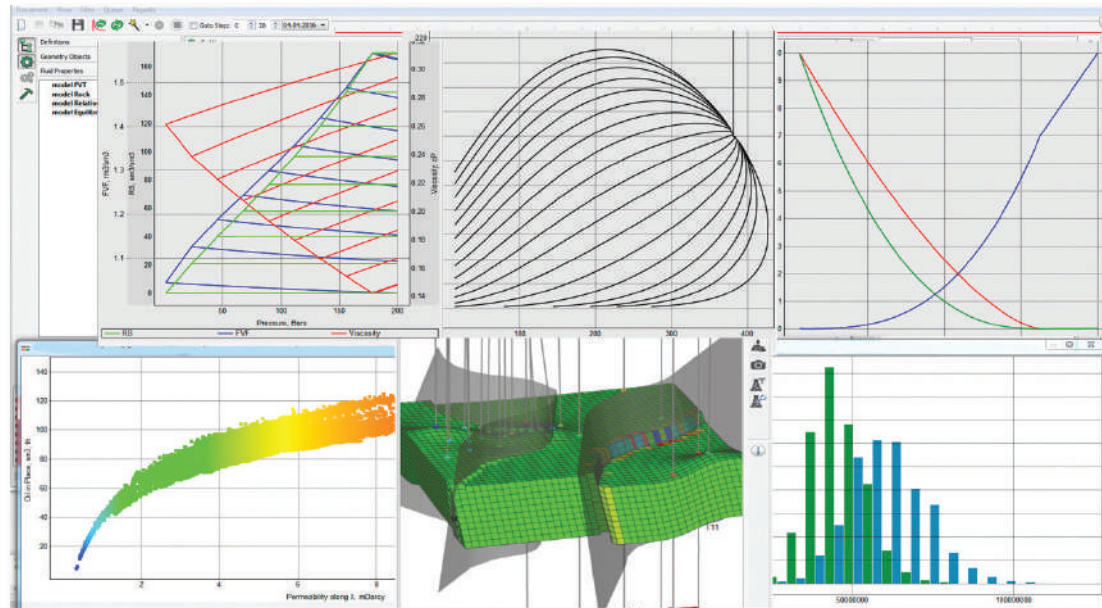
Model Designer

Model Designer (pre-processor) allows to create dynamic model (blackoil or compositional). This module provides local editing, loading new data and maintaining of the relevant up-to-date geological and hydrodynamic model.

- Loading grid in standard formats, loading RESCUE files.
- Property calculator. Local grid editing. Aquifers.
- Load well history and events.
- Well Rule: well groups, limits and control modes, groups limits, economical limits and other rules for wells. Well Filters.
- Field development planning. Forecast scenarios.
- 2D and 3D visualization, Histograms, Crossplots, Graphs.
- Relative permeabilities (Corey and LET correlations, import).
- PVT and EOS. Integration with PVT Designer.
- VFP tables. Integration with VFP Designer.
- Rock properties.
- Equilibrium and nonequilibrium initialization.
- Start from existing dynamic model. Property editing, PVT, RP, well production data update.
- other options are available.

All the calculations related to grid generation, properties interpolation and other are accelerated with parallel algorithms run on all available cores of the workstation.

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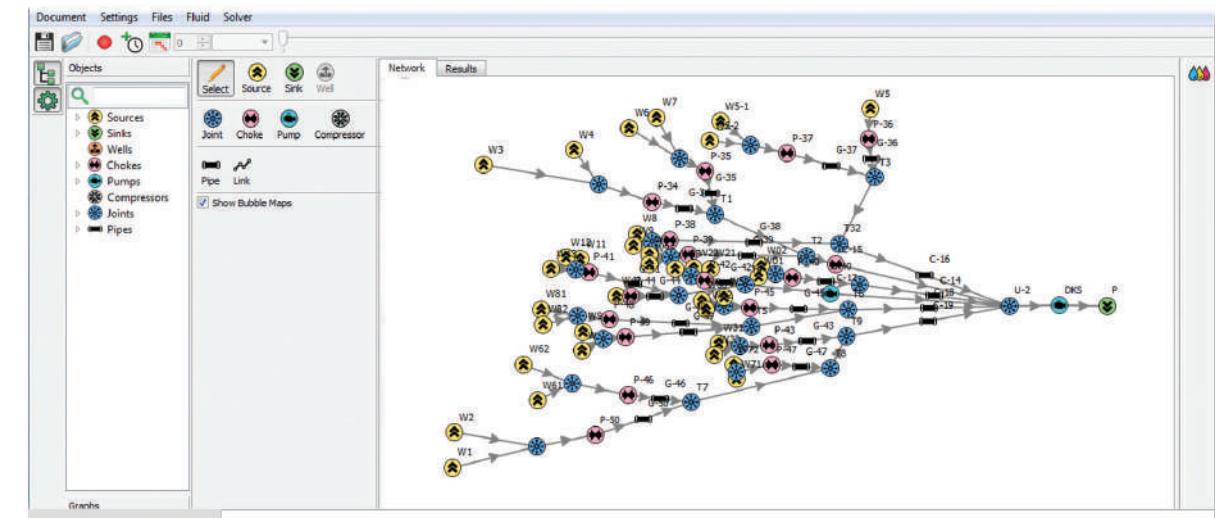
Network Designer

Network Designer allows to create and calculate the surface network. Network Designer models the standard network objects: well, source, link, pipe, joint, pump, choke, compressor, separator, sink, and provides various tools to analyze results in graphical interface.

- The possibility to create and calculate the surface network is available (find network characteristics in the internal points based on data specified at the boundary objects of the network). Steady-state problem is considered.
- Integration with PVT Designer is provided. Fluid composition: compositional properties or blackoil.
- Elements Library: well, source, link, pipe, joint, pump, choke, compressor, 2-phase and 3-phase separators, sink. Flow looping.
- Control of network correctness (Detection of network's parts, where a flow is absent, before running calculation; detection inconsistency of heights of pipe end-points at pipe joints; control of sufficiency of the number of boundary conditions (pressure, mass flow rate); control of setting equipment characteristics required for calculations).
- Integration with VFP Designer is provided. Create VFP and IPR tables for wells.
- Results visualization. Graphs, bubble maps and other tools.
- Other options are available.

All the calculations related to network calculation are accelerated with parallel algorithms run on all available cores of the workstation.

Integration. Usage of the combination of modules Network Designer, PVT Designer, VFP Designer provides the possibility to model surface network from wells to sink.

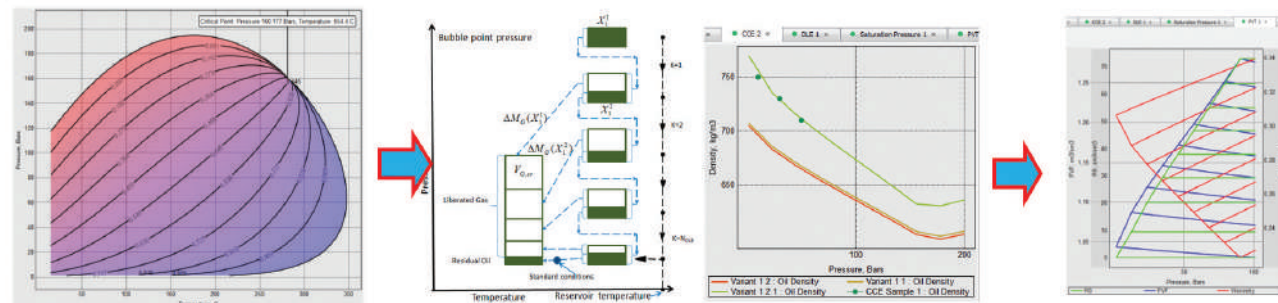


PVT Designer

PVT Designer allows to create fluid model (PVT, EOS). It doesn't require special license. PVT Designer is included in Geology Designer, Model Designer, Network Designer license.

- Components library, enter user components, calculate component properties via correlations.
- Saturation pressure curve, Phase envelope.
- Supported lab experiments: CCE, DLE, CVD, Swelling test, Grading test, Separator test, Blend.
- Enter samples (laboratory data). Run regression (Matching) - Match points of experiments data (samples). Set weights for sample points and for experiments independently. Quality check.
- Lumping (create pseudo-components). Use Matching for lumping.
- Swelling test.
- Initialization data. Grading test: composition with respect to depth.
- Create PVT. Export PVT tables to create blackoil model.
- EOS. Export EOS data to create compositional model.
- Create PVT tables via correlations for blackoil cases.

All the calculations related to phase envelope calculation, experiments, regression are accelerated with parallel algorithms run on all available cores of the workstation.



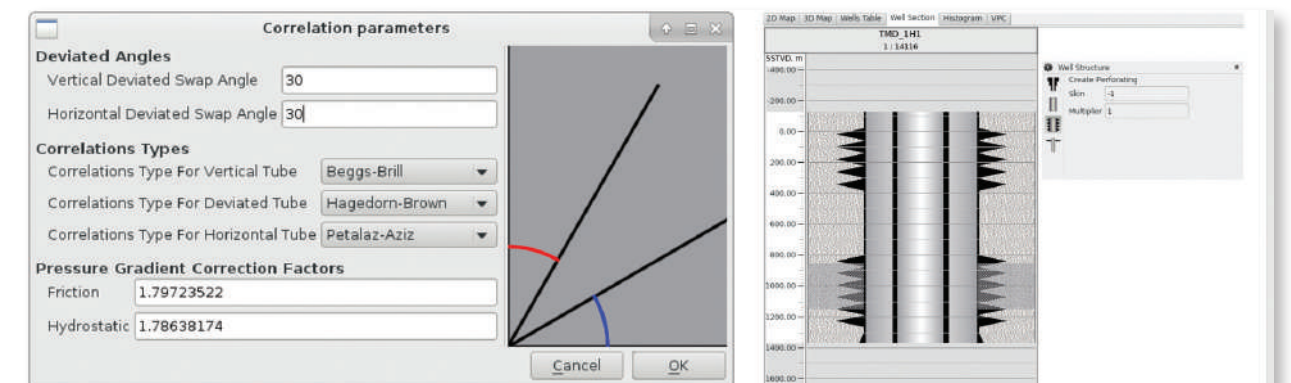
VFP Designer

VFP Designer allows to create lifting tables for wells and pipes. It doesn't require special license. VFP Designer is included in Geology Designer, Model Designer, Network Designer license.

- Well geometry. Load well trajectory in standard formats (Well Path/Deviation, LAS, GWTD, etc.). Manual editing of a trajectory. Well geometry visualization (TVD and Deviation Survey).
- Well construction specification. Casing, tubing, perforation, squeeze, packer. Creation and import of custom object catalogs. Selection of parameters of well construction objects as variables for matching experimental data (pressure drop measurements).
- Integration with PVT Designer. Fluid composition: compositional properties or blackoil.
- Creation of lifting tables (VFP). Creation of tables by correlations (Beggs & Brill, Hagedorn & Brown, Orkiszewski, Gray, etc.). Different correlations for vertical, deviated and horizontal parts of the wellbore. Friction multiplier and Hydrostatic component.
- Normalization of VFP tables.
- Entering the experimental data (pressure drop measurements). Visualization of the experimental measurement along with the created VFP tables.
- Matching of tables by selected measured parameters and variables (network component settings, Friction and Hydrostatic components).
- Export of VFP tables to a file or to Network Designer.

All the calculations are accelerated with parallel algorithms run on all available cores of the workstation.

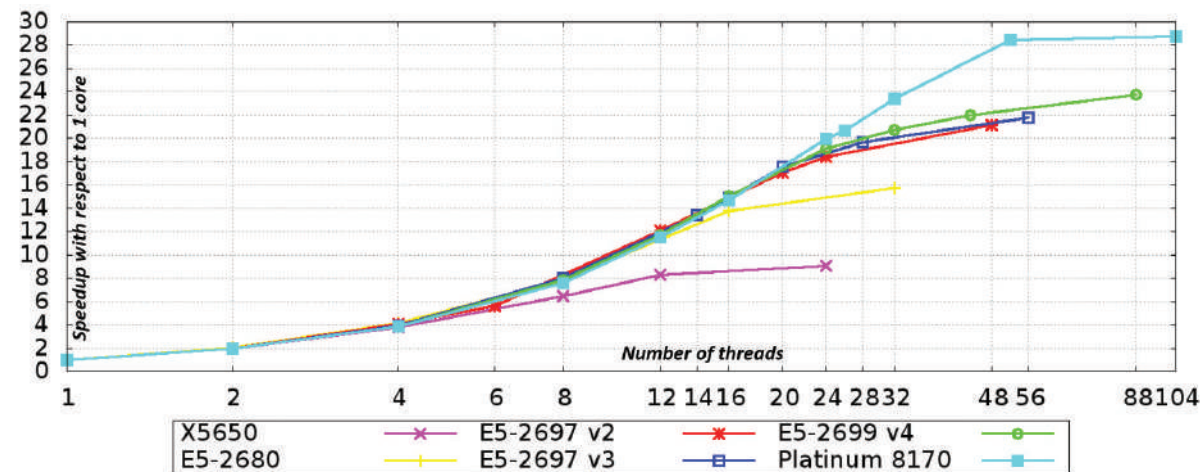
Integration. Usage of the combination of modules Network Designer, PVT Designer, VFP Designer provides the possibility to model surface network from wells to sink.



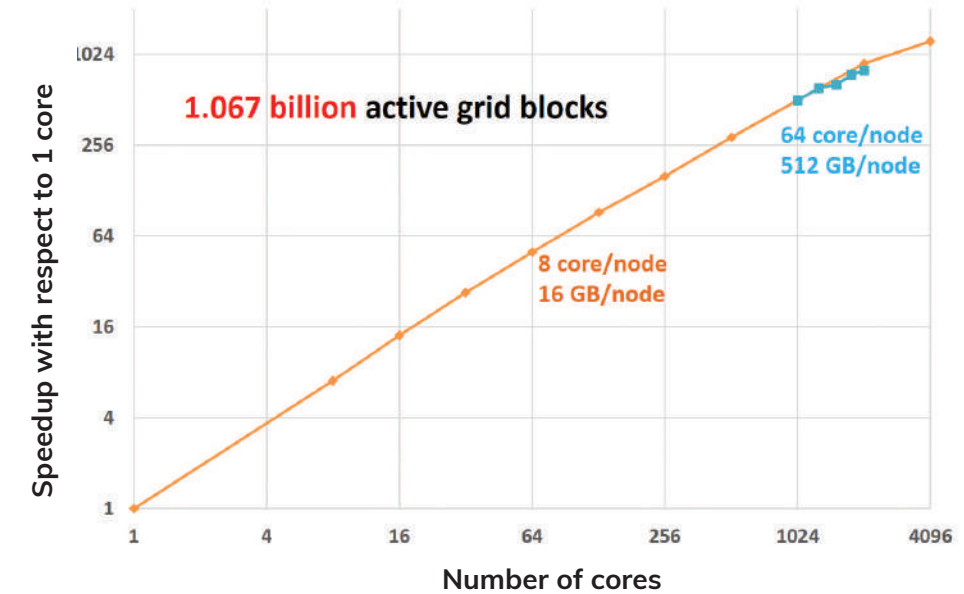
Black Oil Simulator

Console (blackoil) simulator doesn't consider changes in composition of the hydrocarbons as the field is produced. The typical use cases include simulations of light oil and gas production. It supports all industry standard functionality including standard functionality – live oil, dead oil and wet gas. This module can be used with Graphical Interface module or separately as a console version on the PC workstations or HPC clusters. Input data formats supported are E100, E300 (option "blackoil"), TempestMORE and IMEX.

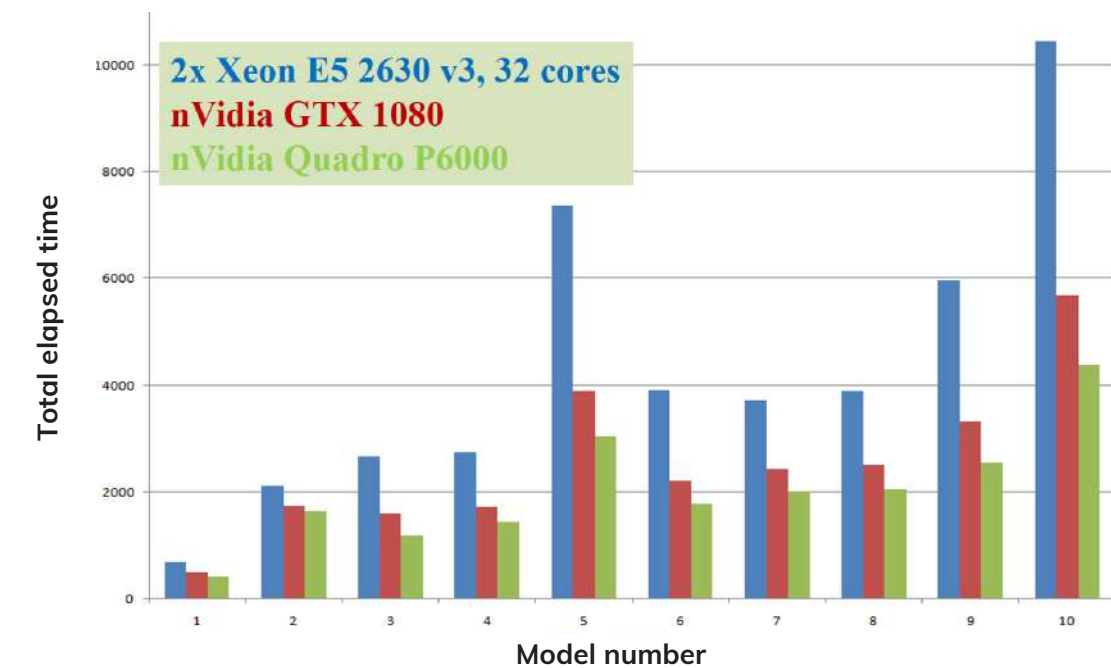
- 3-phase permeabilities with end-point scaling, gravitation, capillary effects, multiple filtration, PVT, equilibrium regions.
- General mesh formulation (NNC, LGR and coarsening, faults, pinchouts, etc.), corner point, unstructured grids.
- Dual porosity, dual permeability.
- API tracking, gravity drainage, nano-polymer flooding, desalination.
- Tracer analysis, waterflood optimization, aquifers, waters with different salinities.
- Polymers, surfactants, ASP injection, Bright Water polymers.
- Hysteresis, diffusion, adsorption, desorption.
- Hydraulic fractures.
- Multi-segment wells, group controls, aquifers including constant flux, Fetkovich, Carter-Tracy, numerical extended surface network option.
- Temperature extension of blackoil to model cold water injection.
- D-factor, GPP controls, VFP lifting tables and correlation functions, ACTIONS, auto-drilling, support of user defined variables, arrays, extended arithmetics.
- Fully implicit and adaptive implicit algorithms.
- Reservoir coupling.
- And other options are available.



The simulation speed-up shown as a function of computational threads (physical and logical) plotted for a workstation with dual Xeon CPUs.



The simulation speed-up shown as a function of physical computational cores plotted for two different HPC clusters with significantly different core densities per computing node.

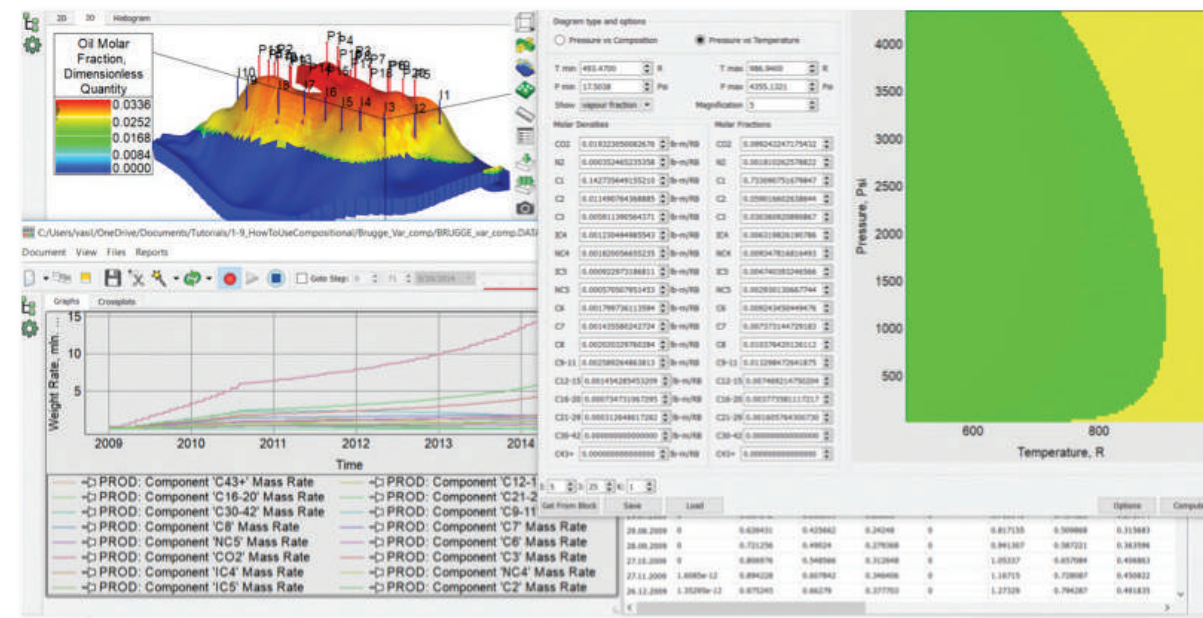


The simulation speed-up shown for 10 different models, where the linear solver is calculated using GPU instead of CPU. Comparison is shown for two different types of GPU cards.

Compositional Simulator

This module is designed to simulate compositional models, where PVT properties of oil and gas phases are fitted to an equation of state (EOS), as a mixture of components. Only isothermal cases are supported. Conventional syntax of input deck can be used: E300, GEM, TempestMORE. This module can be used with Graphical Interface module or separately as a console version on the workstation or cluster.

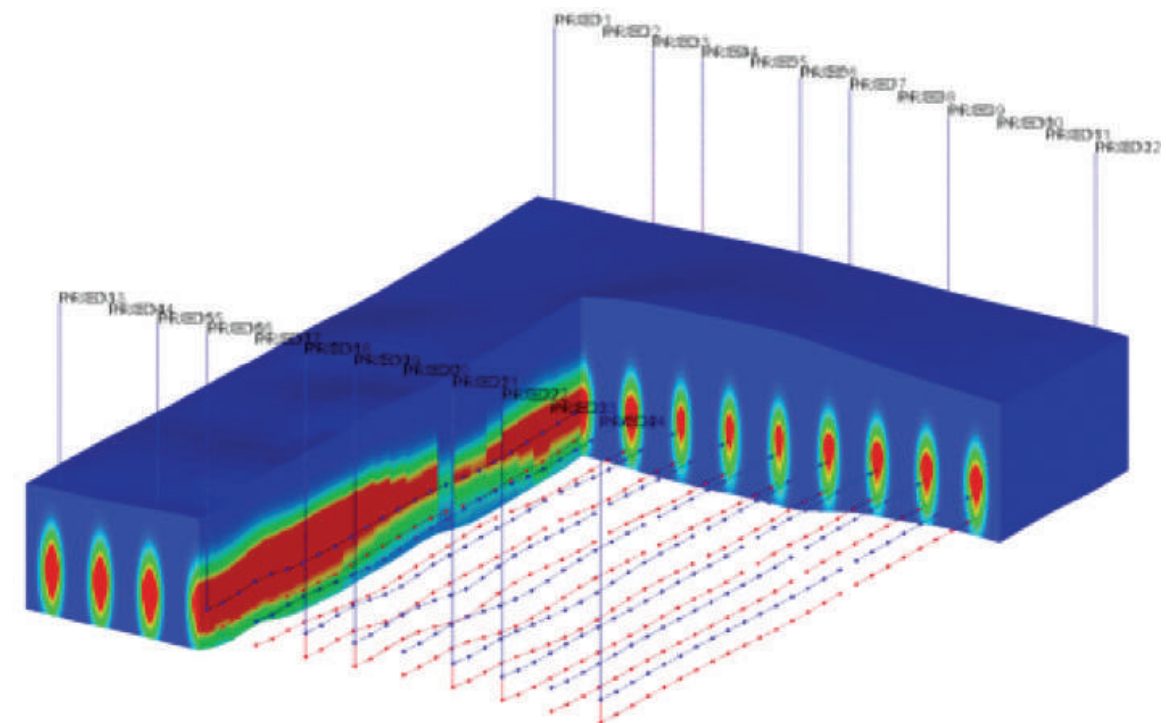
- Multiple EOS (Peng-Robinson, Redlich-Kwong, Soave-Redlich-Kwong) regions.
- CO2 injection, cycling water-gas injection.
- Molecular diffusion, adsorption and desorption, coal bed methane (CBM).
- Relative permeability scaling with respect to composition.
- Special treatment for oil and gas relative permeabilities near the critical point.
- Velocity dependent relative permeabilities.
- Gas plants, gas fuel, sales and re-injection, multistage separators.
- Gas field model (gas Daily Contracted Quantity – DCQ).
- Mixture injection (multicomponent and multiphase – WAG).
- Production and injection surface networks.
- Segments of multi-segment wells that represent sub-critical valves.
- Pressure maintenance regions.
- Reservoir coupling.
- And other options are available.



Thermal Compositional Simulator

Thermal compositional includes temperature in compositional simulations and is typically used for hot water and steam injection simulations. Conventional syntax of input deck can be used: E300 thermal, STARS. This module can be used with Graphical Interface module or separately as a console version on the workstation or cluster.

- K-values for hydrocarbon components via tables or via correlation formulas (surface).
- Four phases: oil (hydrocarbon components), gas (hydrocarbon components, water), water and the solid phase. Phase transitions: evaporation, condensation, dissolution, combustion, modeling of chemical reactions.
- Support for solid phase and chemical reactions for in-situ combustion process.
- Steam injection, mixture injection (multicomponent and multiphase (WAG)).
- Liquid phases individual component densities, viscosities as functions of T and P.
- Enthalpies of hydrocarbon components and rock as functions of temperature.
- Porosity dependence of temperature and pressure.
- Thermal conductivity dependence on conductivities of mobile phases, solid phases and rock.
- Analytical, semi-analytical and numerical aquifers.
- Relative permeabilities scaling with respect to composition and temperature.
- Analytical model of heat exchange with the environment.
- Electrical heaters, thermal aquifers.
- Steam injection, mixture injection.
- Dual porosity, dual permeability.
- Steam Assisted Gravity Drainage technology (SAGD).
- Support of full cluster MPI and GUI functionality.
- Reservoir coupling, and other options are available.



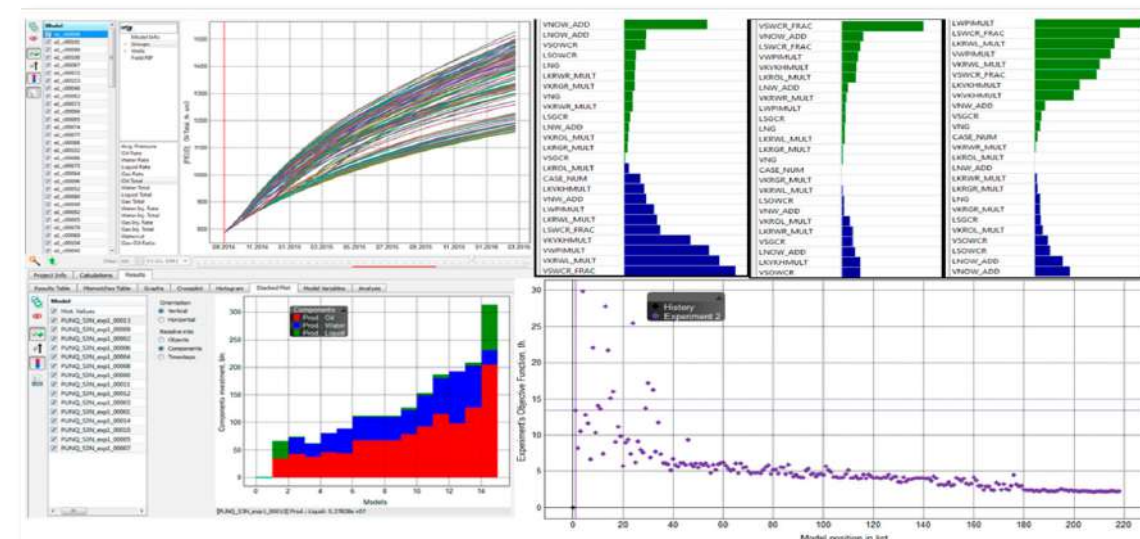
Assisted History Matching and Uncertainty Analysis

This module provides assisted history matching and uncertainty analysis. Any parameter of the model data deck can be replaced with a variable with an initial base value and the range of uncertainty or arithmetic expression. The module includes GUI for run control (workstation or cluster) and runtime statistical analysis of the simulation results.

- Experimental design: Latin Hypercube, Grid Search, Tornado, Plackett-Burman.
- Optimization algorithms: Differential evolution, Particle swarm optimization (PSO), Simplex method (Nelder-Mead), Response surface (Proxy models).
- Arbitrary objective function, taking into account RFT/MDT measurements, NPV optimization, UDQ objective function.
- Graphical interface: graphs, tables, histograms, crossplots to compare model variants.
- Analytics: Pareto chart, Pearson correlation, Tornado plots, multidimensional scaling (MDS), R2 table, stacked plot.
- P10, P50, P90 and other quantiles.
- Forecast optimization, optimization of well position and trajectory.
- Workflows from Geology Designer.
- Big loop. Variables in workflow to run AHM and uncertainty, workflows are Python based.
- And other options are available.

This module is integrated with Job Queue. Calculations on the workstation or cluster are available. Mouse control of cluster calculation and Remote graphical interface.

Integration. Usage of the combination of modules Geology Designer, Model Designer, PVT Designer, VFP Designer, Simulator (blackoil, compositional or thermal), Assisted History Matching and Uncertainty provides the possibility to create in one graphical interface static and dynamic model, run simulations, analyze results, do assisted history matching (big loop) and uncertainty analysis.



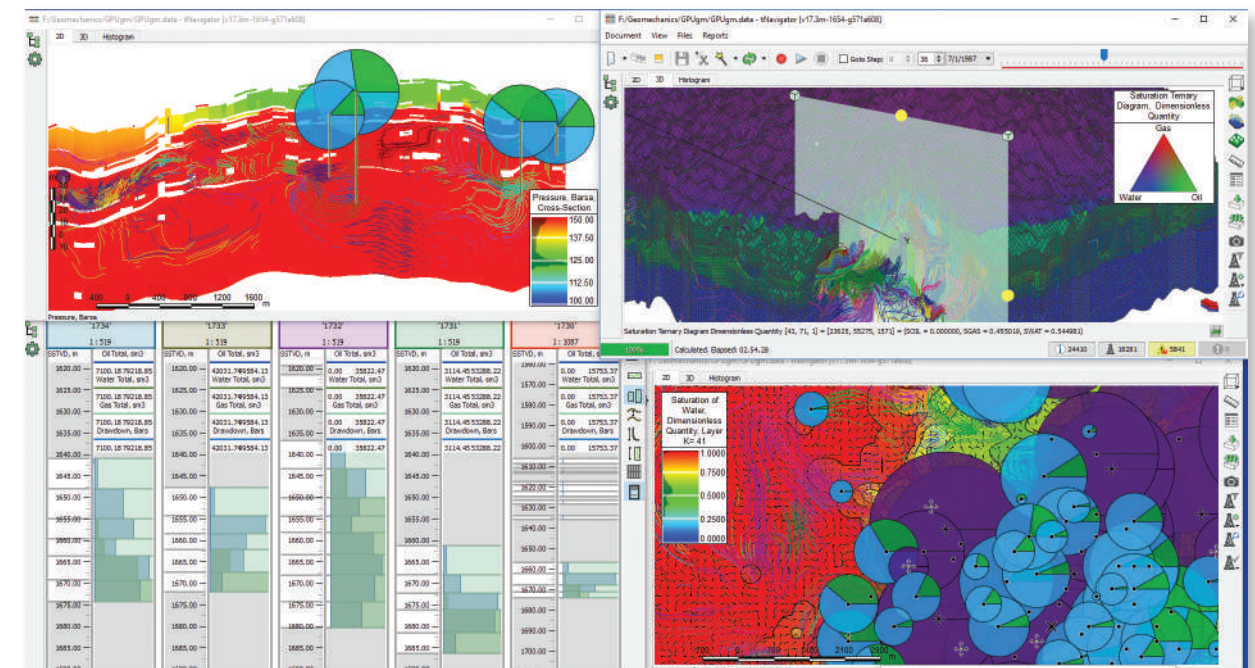
Graphical User Interface

tNavigator GUI is a universal data analysis and visualization application, which can be used standalone for viewing existing simulation results generated by tNavigator and some others (E100/300, TempestMore), or being integrated with one of the tNavigator simulation engines to provide interactive run control and instant results monitoring at calculated time steps. The distribution of initial and calculated model grid properties can be viewed as 2D, 3D maps, cross-sections, well fences, and 1D, 2D histograms. Calculated and historic production data at the field (when available), group, well, perforation levels can be viewed as graphs, cross-plots, summary tables, bubble maps, contours, and profiles along well trajectories. Interface allows loading of LAS data, trajectories, and comparison with dynamic well profiles. At each time step, the calculated pressure in the grid blocks is used to generate 2D and 3D streamlines traced using projectile technology. The streamlines are used to calculate injector-producer allocation factors summarized in the form of a drainage table or visualized as 2D drainage network. The 2D map of any grid property can be overlaid by a set of contour lines.

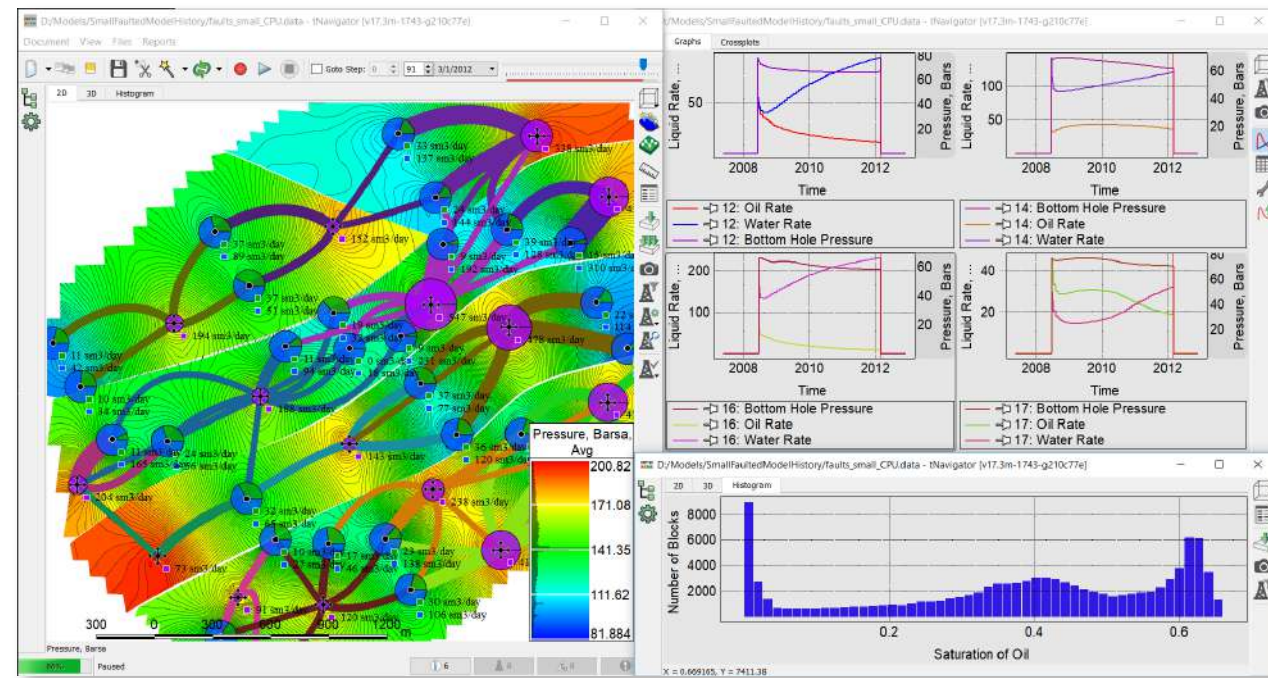
Preprocessing, run monitoring, and simulation result postprocessing are done using a single multi-window graphical interface.

- Mouse control simulation: start, pause, restart.
- Visualization of 2D, 3D dynamic maps and graphs during calculation.
- Graph templates, bubble maps, contours, cross-plots, 1D, 2D histograms, well profiles, reports.
- Field development planning: add vertical and horizontal wells, hydraulic fractures.
- Load history and events tables to update model automatically.
- Waterflood optimization: interactive tracers, streamlines, drainage graphs and colored tables.
- Sector modelling: automatic split and merge.
- Advanced user map calculator: build any maps and filters to analyze data.
- And other options are available.

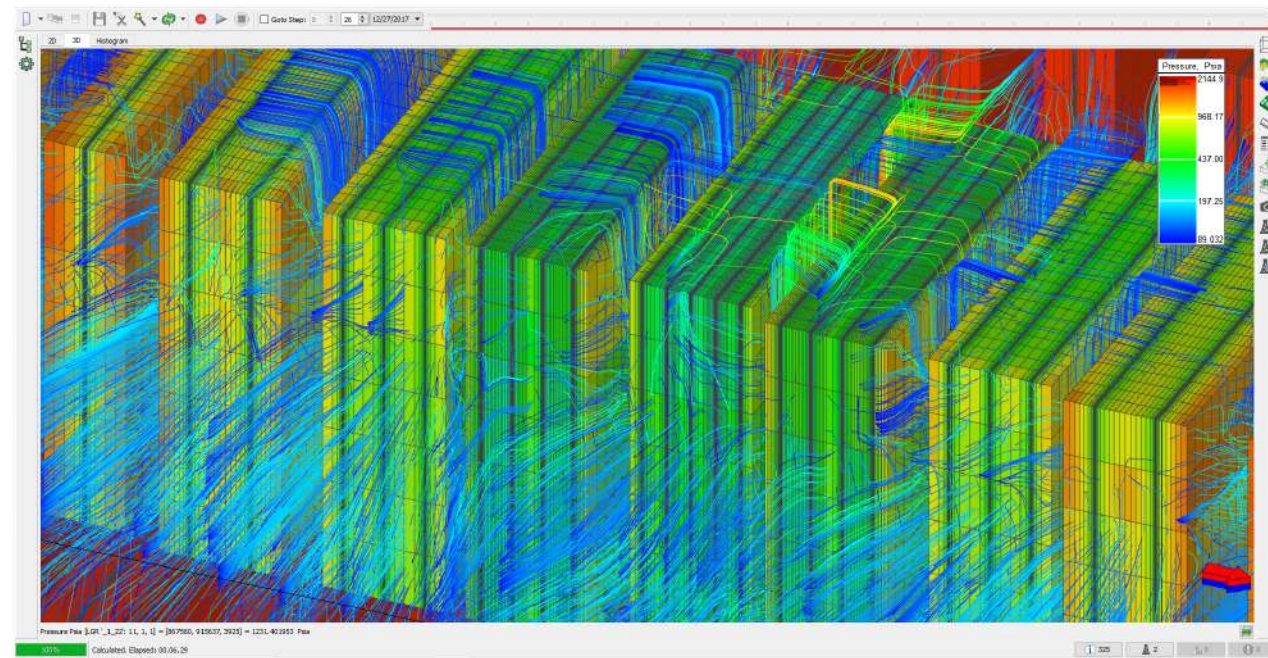
Additional option Remote Graphical Interface is available to control calculations running on cluster.



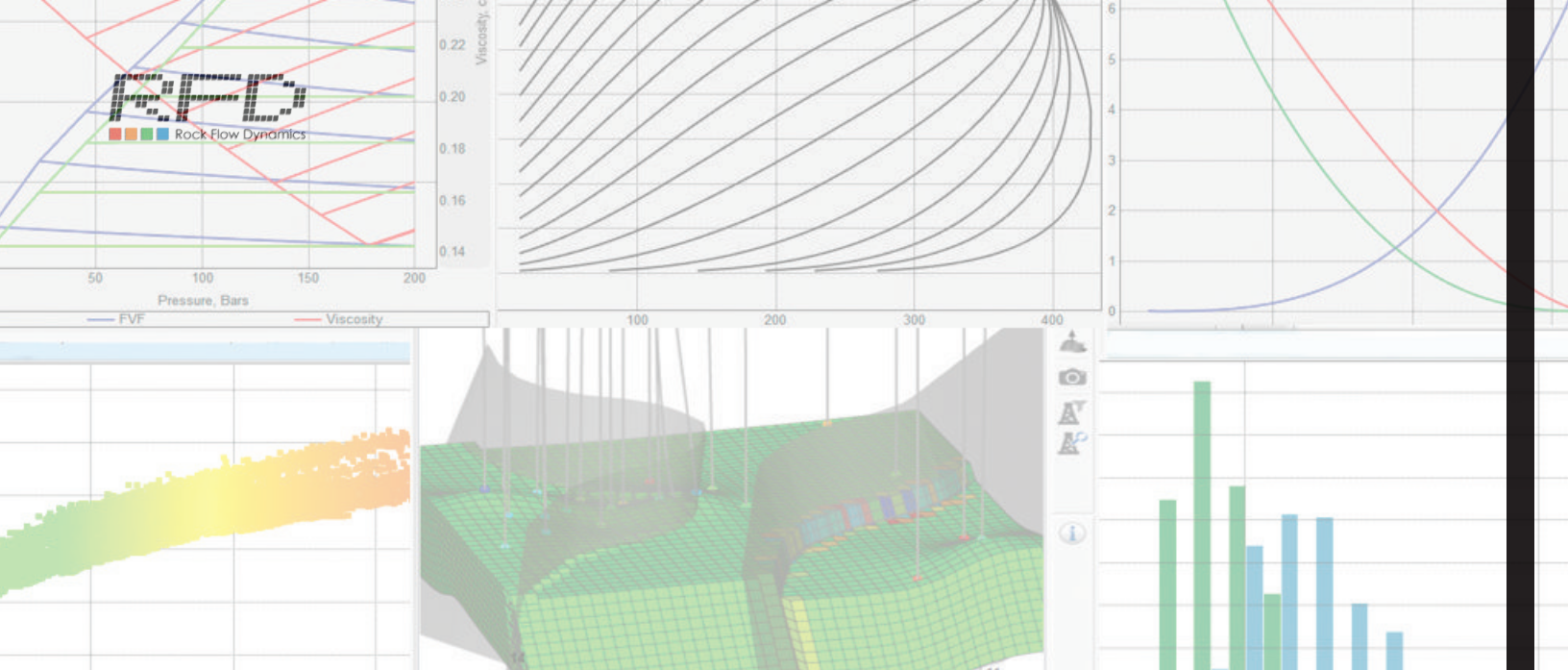
Graphical User Interface (continued)



Runtime visualization of drainage matrix, contours, bubble maps and injection allocation factors, production graphs template for multiple wells, and 1D histogram of oil saturation distribution.



Simulation of multi-stage, multi-cluster fracture dynamics with 3D streamlines overlaid plotted for shale reservoir.



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Dynamic Model "model"

- Regions
- User Maps
- Zones
- Dynamic Model "model"

3D
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VPC
Crossplot
Geosteering

Wells Table

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