

TECHNICAL SPECIFICATIONS



CougarFlow®

Uncertainty Analysis

Software Presentation

Through a multiple realizations approach based on experimental design and state of the art optimization algorithms, CougarFlow® aims at reducing the number of simulation runs to properly explore the possible solutions. CougarFlow® is usable for any type of numerical simulation at both basin and reservoir scales. CougarFlow® allows:

- A thorough screening of uncertainties on a given range of input parameters and their influence on key simulation outputs;
- Uncertainty analysis for quantifying parameters impact and associated optimization;
- Rapid and robust Assisted History Match offering both a fast converging gradient method (local optimizer) and a thorough Bayesian approach (global optimizer).

Functionalities and Algorithms

MANAGEMENT OF UNCERTAINTIES

UNCERTAIN PARAMETERS

- Scalars such as end points for KrPc curves, WOC...
- Possibility to group parameters with metaparameter option

EXPERIMENTAL DESIGN AND RESPONSE SURFACE APPROACH

- From the simplest to the more complex: Classical, Full, User defined, Latin Hypercube and D-Optimal designs for uncertain domain sampling
- Responses of interest:
 - Direct outputs of the simulator (pressures, rates...)
 - Customized responses: multi-time/multi-property/multi-object functions, interpolated, scalar and multi-objective functions (decomposition well by well, property by property), composite responses (R script language to create user defined responses, NPV...)

- Algorithms to compute Parametric (Least Angle Regression Square) and Non-Parametric Response Surface Models (Kriging)

- QC tools to analyze and validate the Predictivity of Response Surface Model: Spider and Tornado plots, Cross plot and Quality Indicators such as Predictivity Q2 and Predictivity with confirmation runs Q2 conf (blind tests)

UNCERTAINTY ANALYSIS

- **Global Sensitivity Analysis:** qualitative and quantitative sensitivity analysis to determine the most influential parameters; automatic calculation of interactions between parameters
- **Risk Quantification:** uncertainty propagation and controllable uncertainty optimization
 - **Field Appraisal:** assess the impact of uncertain uncontrollable parameters on the production uncertainty profile
 - > **Bayesian formalism** to constrain the uncertainty by historical data (posterior sampling using Markov Chain Monte Carlo)

- **Field Development Optimization:** determine the optimal production scheme; optimize controllable production parameters
- **Decision Making:** choose the best production scenario with the full knowledge of geological, modeling and financial uncertainties

OPTIMIZATION ALGORITHMS

- Objective-function based optimizations:
 - User defined weight definition, standard deviation
 - Possibility to manage every history point and weight
 - Possibility to create composite objective function
 - Possibility to add water breakthrough time to objective function
- Possibility to define constraints between uncertain parameters
- Possibility to optimize both geological and dynamic models
- Three methods for optimization are available:
 - 2 Gradient-based methods⁽¹⁾
 - Bayesian algorithm⁽²⁾

⁽¹⁾ 2 Gradient based methods: Optim (Cougar's historical method) and SQPAL (to avoid non-physical fluid flow models)
Five algorithms implemented from the simplest to the more complex for local optimizer:

- **Steepest Descent (Optim):** robust, particularly suited for solving non-linear problems, cases where the initial value is far from the optimal solution; may become less and less efficient when it approaches the solution.
- **Gauss-Newton (Optim):** good convergence rate (quadratic), efficient in most cases; less robust for highly non-linear problems and when the initial parameters are too far from the optimal solution
- **Levenberg-Marquardt (Optim and SQPAL):** extension of the Gauss-Newton method; good when the initial point is far from the solution, numerical stability; needs to define a suitable initial value of the Marquardt parameter
- **Powell dog-leg (Optim and SQPAL):** improvement of the previous algorithm; robust and quick; combines the Steepest-Descent and Gauss-Newton solutions according to a trust region in the parameter domain; the radius of the trust region is adjusted with respect to the evolution of the objective function
- **BFGS (SQPAL):** quasi-Newton method of Broyden, Fletcher, Goldfarb, and Shanno; uses the first derivatives only to approximate the Hessian matrix of the used function; good performance for non-smooth optimizations; to use for large datasets only

⁽²⁾ Global optimizer: based on Bayes formula; iterative optimization process based on Response Surface and posterior (parameter distribution that matches the production data); getting a set of matched models.

- Analysis of HM: percentage of matching well by well and property by property, bubble maps

EXTRAS

- Linked to any reservoir simulator: PumaFlow®, Eclipse, Petrel-RE, VIP/ Nexus, CMG, IMEX/GEM/STARS, Powers
- Seamless link with FracaFlow®
- Link with third-party geo-modelers: Petrel
- Link with material balance tool: MBAL
- Flexibility from Uncertainty to AHM workflows
 - Initialize an AHM workflow from the sensitivity analysis results. Only influential parameters can then be optimized to save simulation time
 - Possibility to pursue after an initial optimization adding parameters, modifying the Objective Function
 - Define and analyze several OF before launching the AHM procedure

Results Analysis

- Many viewers are available: histograms, cross-plots, graphs, logs, maps, cross-sections, 3D inherited histograms OpenFlow™ platform
- Filters and graphic settings
- Specific plots for uncertainty analysis: cross-plots, tornado plot, spider plot, Pareto plot
- Objective Function Analyzer (OF contributions, percentage of matching)
- Bubble maps

Data Management

DATA IMPORT/EXPORT

The following formats are available:

- Well paths and logs in ASCII columned, LAS 2.0 and 3.0
- Well/Trap/Group/Reservoir dynamic data (production/injection history, flowmeter, RFT, well tests, etc.) in ASCII, RSM and OFM (.prd)
- Well pressure and perforation data in ASCII
- 3D grid in GRDECL and EGRID format
- Rescue models in ASCII or binary (version 37) and ResQML 2.0 import
- Reservoir simulation results ASCII or binary format
- Templates, preferences and color scales from OpenFlow™
- Groovy scripts & packages
- Data exchange between OpenFlow Suite projects

DATABASE

- MySQL or Oracle database
- Improved data security and integrity, reduced data storage
- User and project administration

OTHER FACILITIES

- Unit system management
- Workflow manager: create, delete, configure, start, stop, load, restart, monitor a workflow...; manual and automatic launch/stop/restart/load
- Help through an online reference manual and contextual information
- Search tool
- Perspectives for display
- Workflow tree
- Host & Activity settings

Extensions and Customization

- Direct link to transfer data between Petrel and OpenFlow™ using an Ocean plugin
- Scripting facility based upon Groovy language
- Scripting facility based upon Freemarker language for customization of the reservoir-simulation input data
- Generate KrPc tables from Corey coefficients, call different property maps, automatic schedule writing to optimize surfactant/polymer injections, generic cycles

System Requirements

- **Operating Systems:**
 - Supported on Windows 10, Compatible with Windows 11
 - Linux Red Hat 7 and Red Hat 8 for calculators only (unavailable GUI)
- **RAM:** 48 Gb or more recommended, 32Gb minimum
- **Minimum free disk space:** 5 Gb (for installation files)
- **CPU:** x86-64 processors (Opteron, CoreDuo, Core2Duo, Xeon & EMT64, Nehalem, Westmere, Sandy Bridge, Core i3, i5, i7)
- **Dualcore or Quadcore:** 2 GHz or more recommended
- **Graphics board:** NVIDIA (except Quadro FX 1000, Quadro FX 3500, Quadro NVS 110 M, Quadro NVS 280 SD, and NVS 300) with recent driver (at least OpenGL 3.3 -driver 330 or later)
- Openmotif rpm package must be installed on Linux
- **Database:** MySQL 5.5, 5.6.X (with X superior to 22), 5.7 or 8.0 and Oracle 12c, 18c or 19c
- FlexLM 11.16.2 server for licensing



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