MRST: MATLAB® Reservoir Simulation Toolbox

A rapid, adaptive solution for poroelastic multi-phase fluid flow analysis and simulation of reservoir models

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MathWorks
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MathWorks®
Accelerating the pace of engineering and science

Outline

- MathWorks® digital solutions
- MRST: MATLAB® Reservoir Simulation Toolbox
  - MRST in a nutshell
  - MRST advantages
  - MRST examples
  - MRST modules
  - MRST resources

MathWorks® Digital Solutions
Fact Sheet Highlights

- MathWorks® is a private company founded in Massachusetts, USA in 1984 to:
  - Provide the ultimate computing environment for technical computation, visualization, design, simulation, and implementation
  - Accelerate the pace of discovery, innovation, development, and learning in engineering and science
- MathWorks® has developed major digital solutions for industry and academia:
  - MATLAB®, the language of engineers and scientists, for algorithm development, data analysis, visualization, and numerical computation.
  - Simulink®, a block diagram environment for model-based design and simulation of multidomain and embedded engineering systems; plus…
  - …over 120 digital products for data analytics, image/signal processing, control systems, robotics, deep learning, digital twins, and many, many more.

MathWorks® Digital Transformation Solutions

Digital Transformation Solutions Ecosystem

Digital Transformation Process

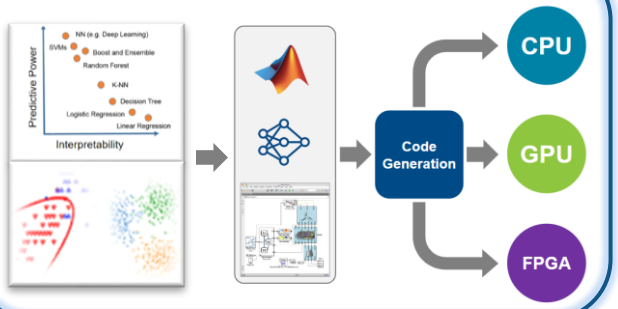
Energy sector demands
- Process optimization
- Sustainability compliance
- Circular economy innovation
- Energy transformation

Digital technology enablers
- AI/ML & HPC computing
- IoT, digital twins & robotics
- Process digitization (modeling, simulation, predictive analysis)

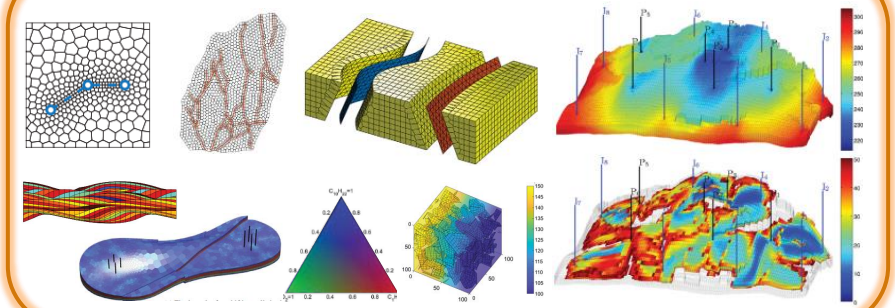
Digital business outcomes
- Prompt big data-driven analysis
- Asset performance optimization
- Value chain automation
- Process optimization & integration

MathWorks® Digital Transformation Solutions

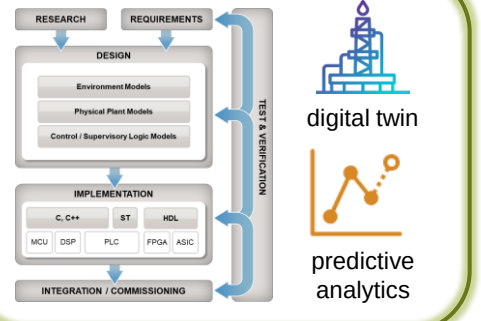
AI/ML & HPC Integration



Computational Modeling & Simulation*



Process Automation



Challenges & Outcomes

Key transformational challenges
- Organizational barriers
- Unclear ROI from digital
- New digital skills and expertise
- Siloed vs integrated digitization

Value of digital technology
- Accelerated decision making
- Preventive decision making
- Agile production optimization
- Adaptive integrated platforms

ROI as a digital business*
- Upstream: $5/boe incr. ROI
- Downstream: $1/boe incr. ROI
- Up to 20% in extra reduction of carbon emissions (scope 1 & 2)

* Sources: Hassmann *et al* (2022) – Technology transformation in oil and gas. McKinsey& Co.
Lie *et al* (2021) – Advanced modeling with MATLAB Reservoir Simulation Toolbox. Cambridge University Press

MathWorks® in Energy Resources
Customizable Digital Solutions for Upstream & Downstream

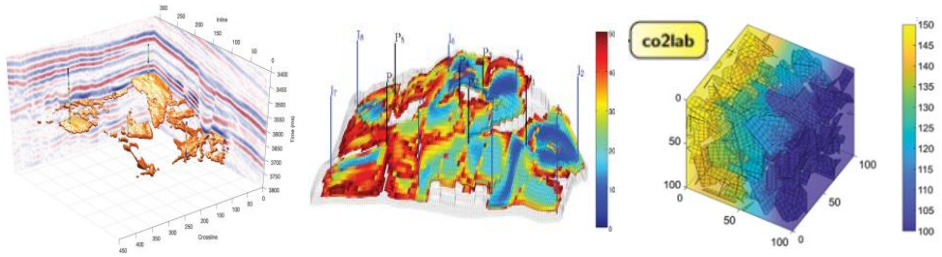
MathWorks® Solutions

Process Modeling & Simulation

Process Optimization & Automation

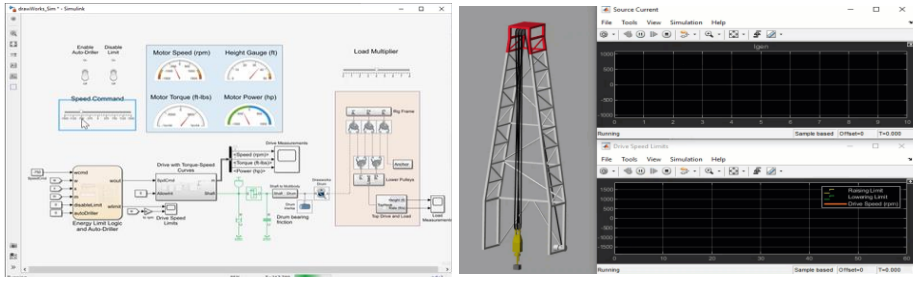
Subsurface

SeReM + MRST
MATLAB® Reservoir Modeling & Simulation



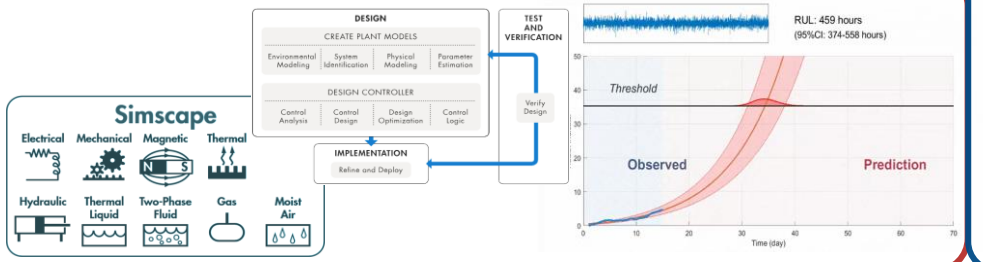
Oilfield

Drilling Digital Twin
Simulink® Surface Drilling Automation



Plant

Plant Digital Twin
MATLAB® & Simulink® Predictive Maintenance



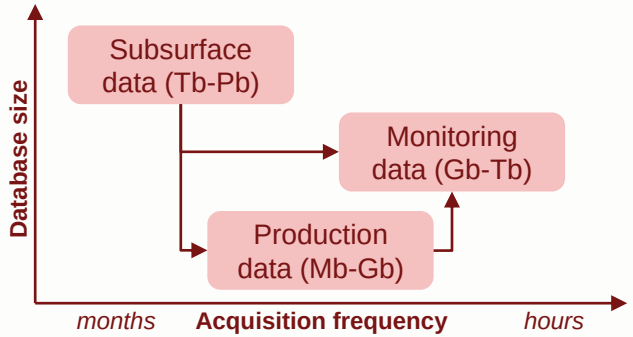
- MATLAB® Production Server
- MATLAB® Cloud Service
- MATLAB® Quantum Computing
- Parallel Computing Toolbox
- GPU Computing Toolbox
- Simulink® Simscape
- Image/Signal Processing Toolboxes
- Computer Vision Toolbox
- Machine Learning Toolbox
- Deep Learning Toolbox

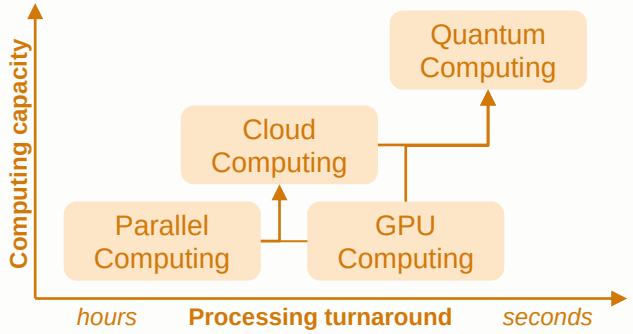
MathWorks® in Energy Resources
Data Science Workflow for Big Data Analysis

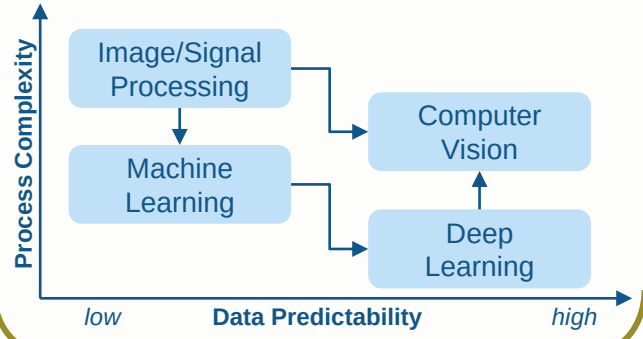
Data Processes

- **Big-Data Gathering**
- **High-Power Computing**
- **Predictive Analytics**

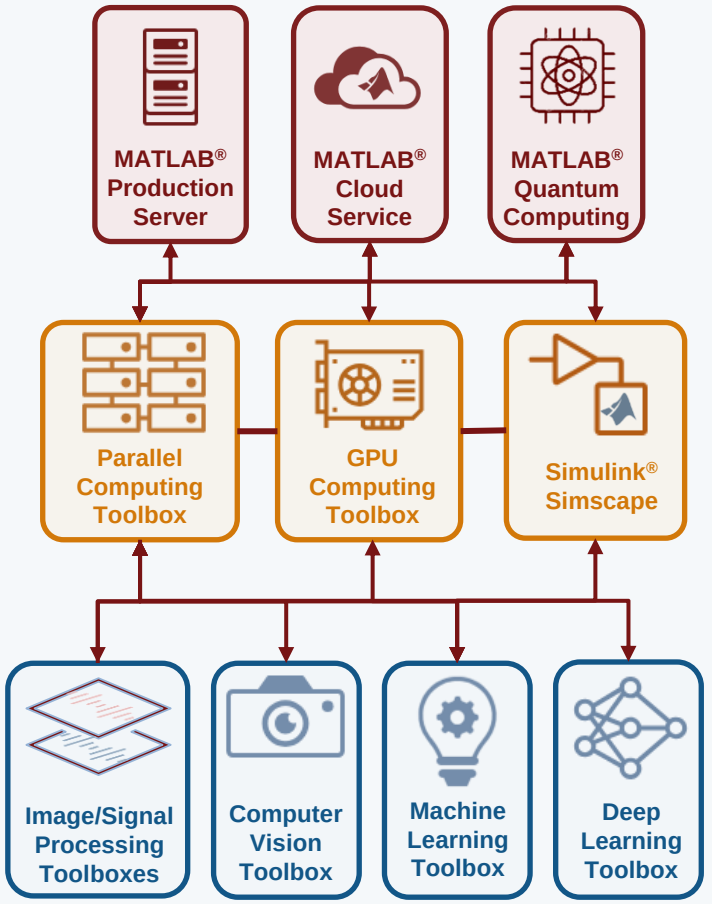
Technical Requirements







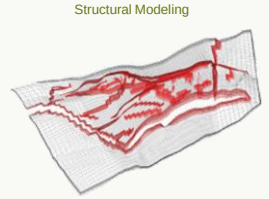
MATLAB® & SIMULINK®

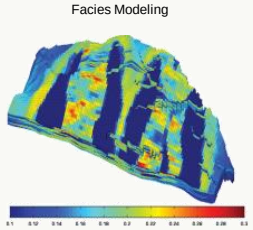


Business Applications

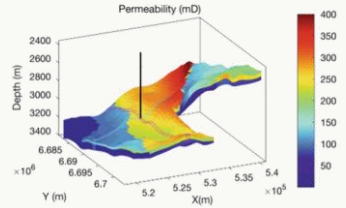
UPSTREAM

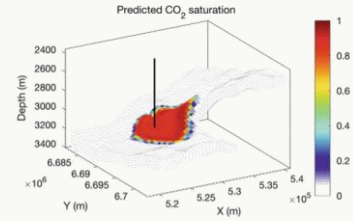
Subsurface Process Modeling





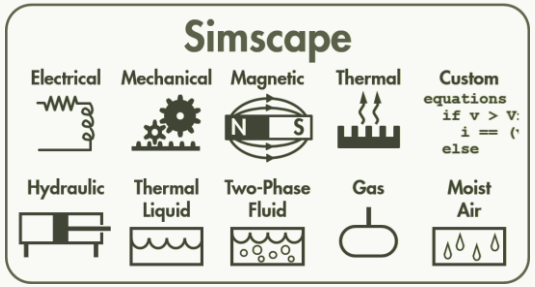
Subsurface Process Simulation



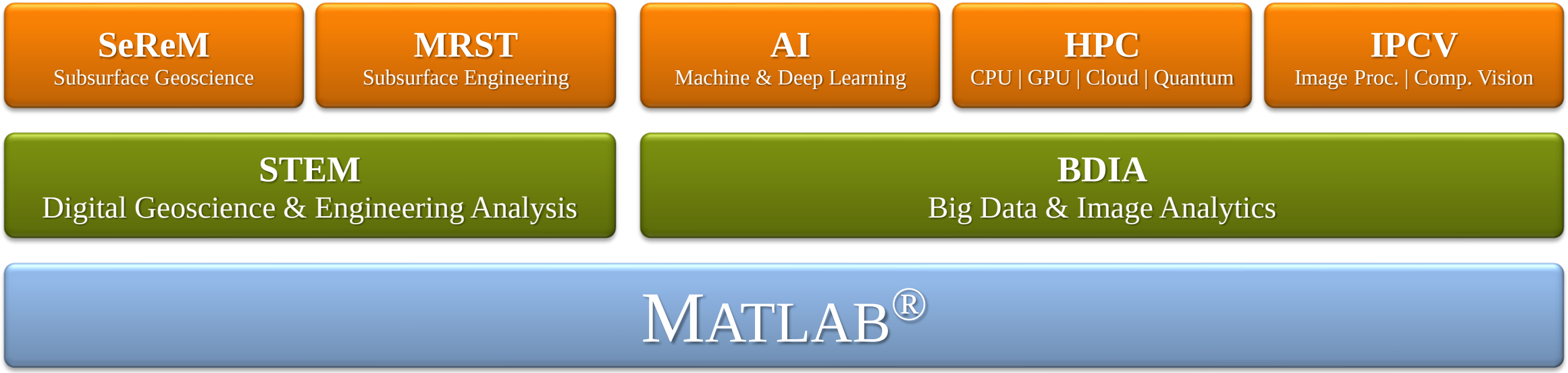


DOWNSTREAM

Dynamic Process Modeling & Simulation



MathWorks® – Digital Subsurface Toolset (v2023)



Key technology differentiators

- Customizable STEM and BDIA toolboxes developed and fully interconnected on MATLAB® platform
- Model-based and data-driven geoscience & engineering workflows to maximize data & image usage
- MathWorks® support, training, and development of data science, engineering, and analytics solutions
- Adaptive digital solutions to assess and integrate new energy processes using high-end technologies
- Low-cost, high-quality software solution to maximize technical expertise, IT infrastructure, and budget
- 200+ energy companies globally currently use MATLAB® solutions across upstream and downstream

MRST: MATLAB® Reservoir Simulation Toolkit

- MRST is a MATLAB®-based toolbox with building blocks necessary to design, prototype, and build simple and complex dynamic reservoir models

- Developed by the Computational Geosciences group at SINTEF Digital, a research consortium based in Norway sponsored by industry leaders (CVX, XOM, RDS, SLB, ECP, ENI), renowned academia (TNO, TU Delft, Heriot-Watt, NTNU), and more than 25,000 users worldwide.

- Enables rapid prototyping of reservoir simulation concepts

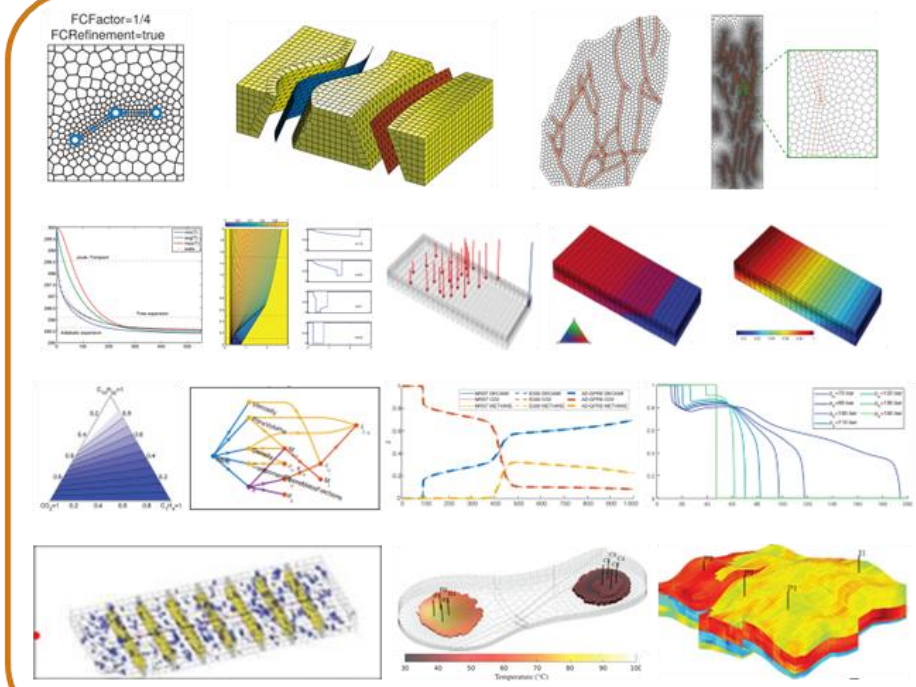
- Offers a wide range of data structures and algorithms that can be combined to create customized simulation workflows

Key Advantages of MRST

- MATLAB®-based modular design compatible with ECLIPSE decks
- Customized black-oil and compositional model solvers
- Exhaustively validated against industry-standard benchmark cases
- Automatic Differentiation (AD) framework with extensive diagnostic tools
- Optimized linear and nonlinear solvers

MRST in a nutshell
Reservoir simulation grids, operators, diagnostics, and models

MRST
MATLAB Reservoir Simulation Toolbox

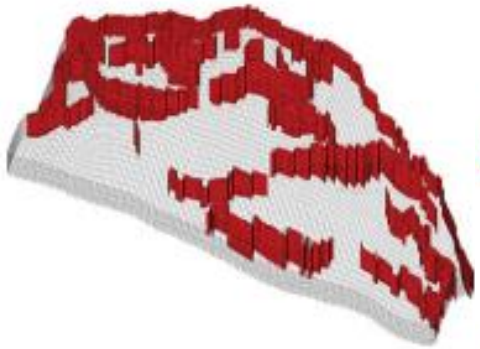


- Structured, unstructured, and optimized grids including perpendicular bisector (PEBI) and conformable, adaptive facies/fault/fracture/borehole-centric CFD grids
- Single and multi-phase, non-linear fluid flow via object-oriented-automatic-differentiation (AD-OO) simulations
- Black-oil and compositional fluid simulation and diagnostics including compressibility, thermal expansion, and miscibility
- Non-fractured, fractured, geothermal, or unconventional reservoirs with poroelastic processes including unsaturated, EOR/CCS, coupled geomechanical modeling, *and more…*

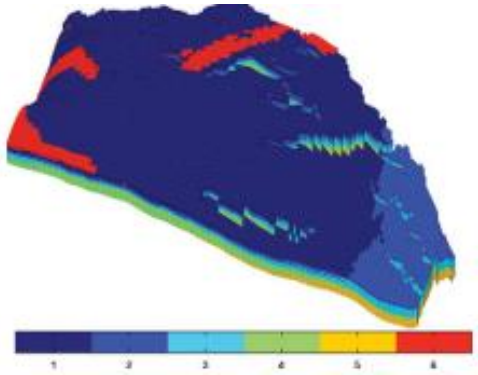
MRST highlights

Structured, unstructured, and optimized grids including perpendicular bisector (PEBI) and conformable, adaptive facies/fault/fracture/borehole-centric CFD grids

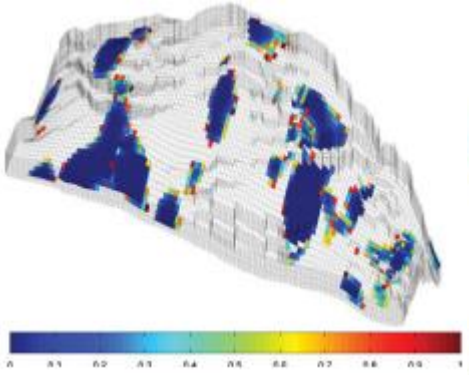
structure



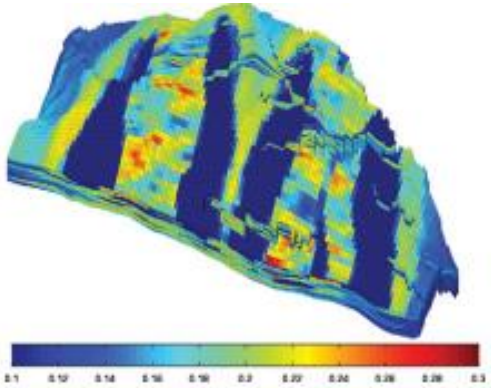
facies



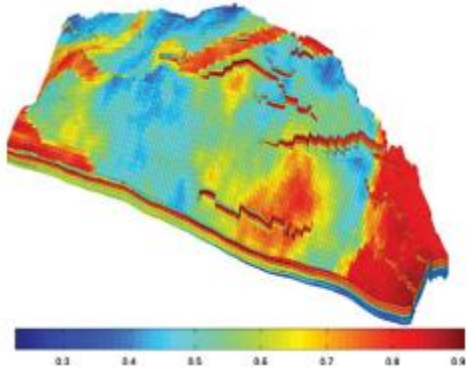
baffles



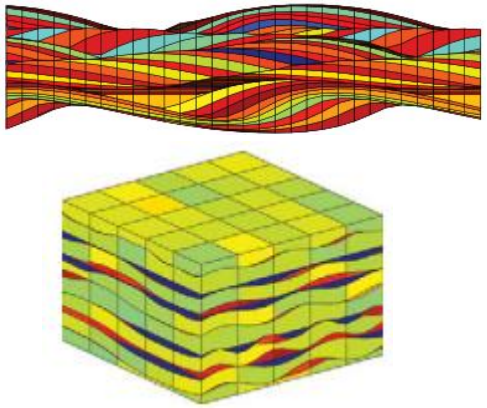
porosity



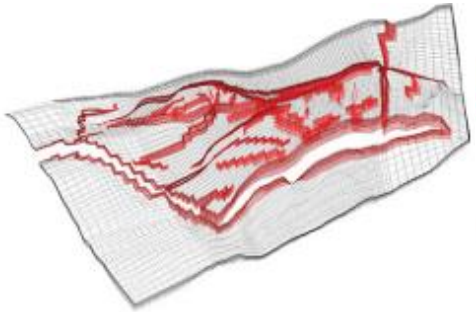
permeability



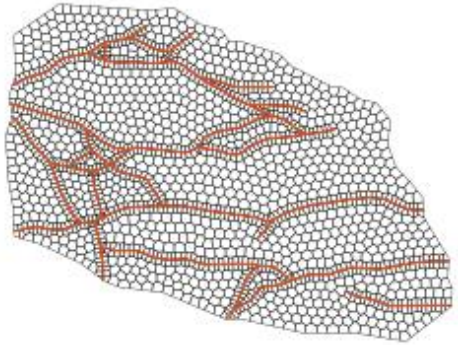
sedimentary beds



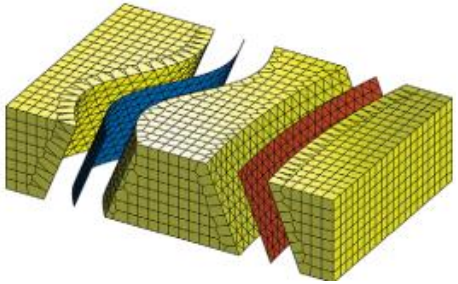
faulted grid



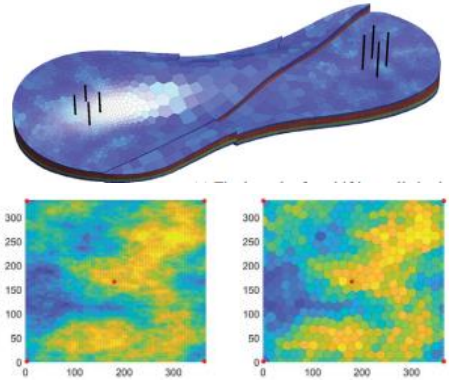
composite PEBI grid (1)



composite PEBI grid (2)



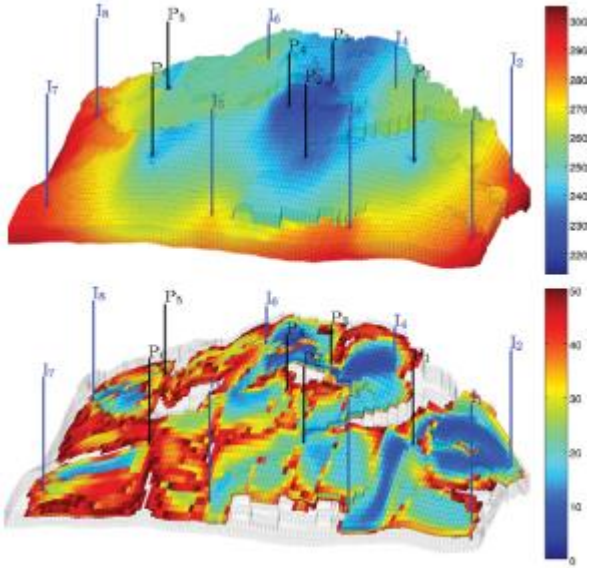
composite PEBI grid (3)



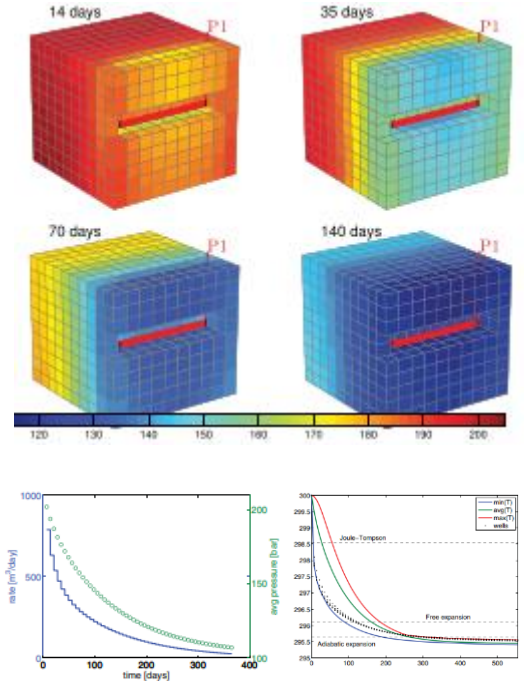
MRST highlights

Black-oil and compositional simulation and diagnostics on compressibility, thermal expansion, and miscibility fluid flow via automatic-differentiation (AD-OO) (1)

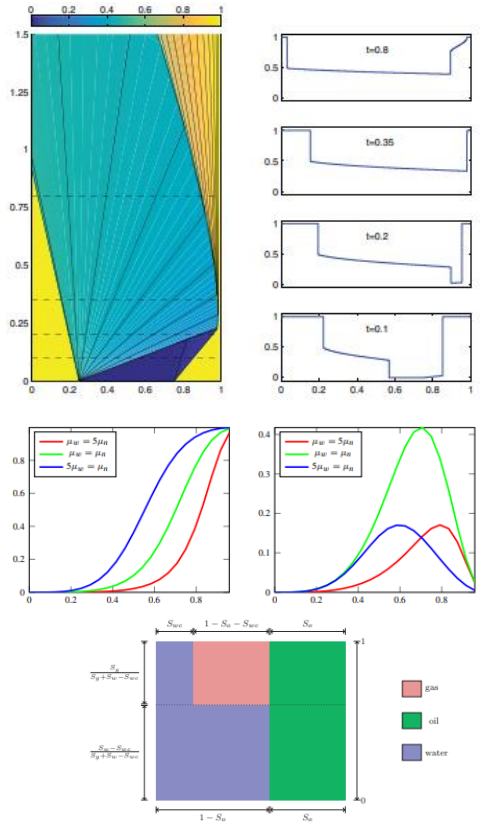
Incompressible, single-phase simulation *(pressure, ITT)*



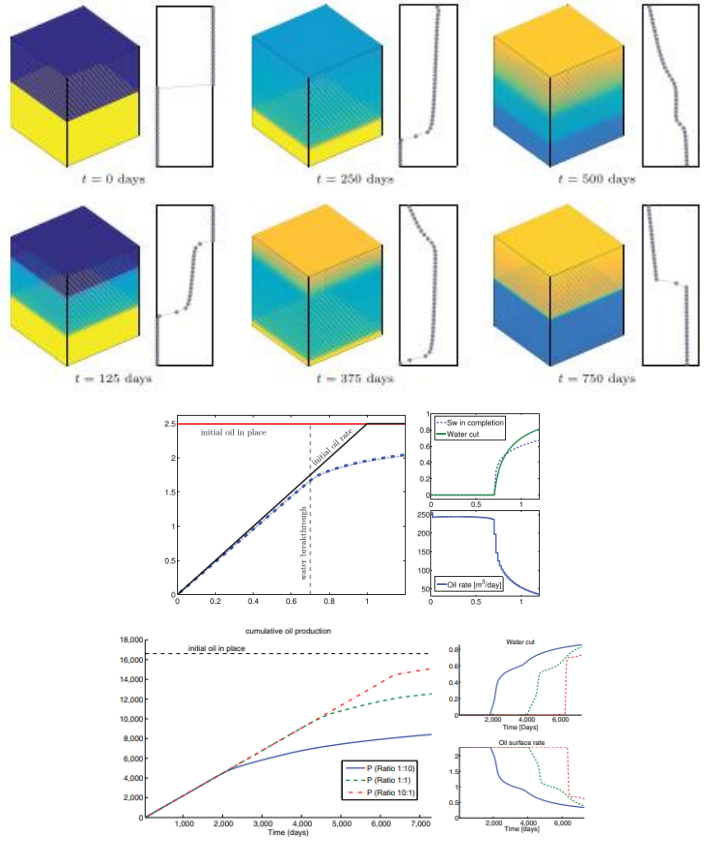
Compressible, thermal flow *(rapid prototyping)*



Multi-phase flow and CO2 displacement



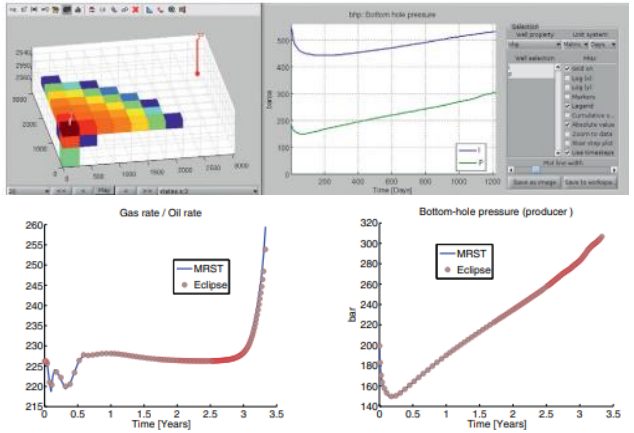
Incompressible & inmiscible Water + CO2 (WAG) flow *(homogeneous & heterogeneous)*



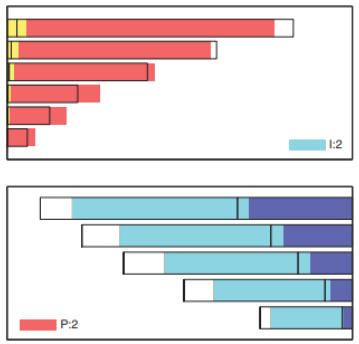
MRST highlights

Black-oil and compositional simulation and diagnostics on compressibility, thermal expansion, and miscibility fluid flow via automatic-differentiation (AD-OO) (2)

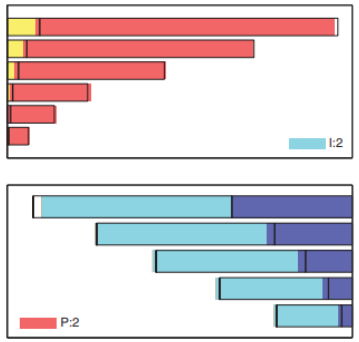
Black Oil AD-OO Modeling, Upscaling, and Diagnostics
(MRST vs. Eclipse)



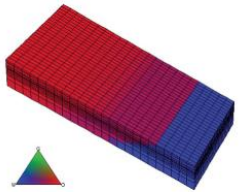
Permeability upscaling



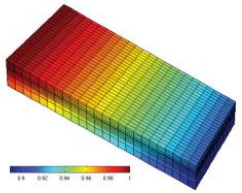
Transmissibility upscaling



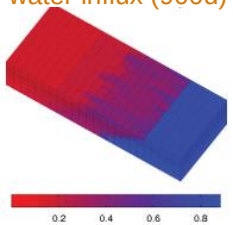
fluid distribution



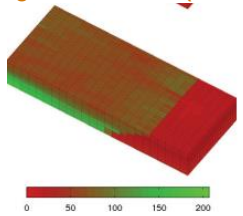
degree of saturation



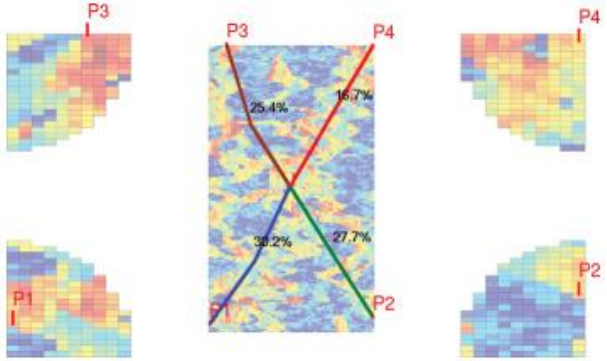
water influx (900d)



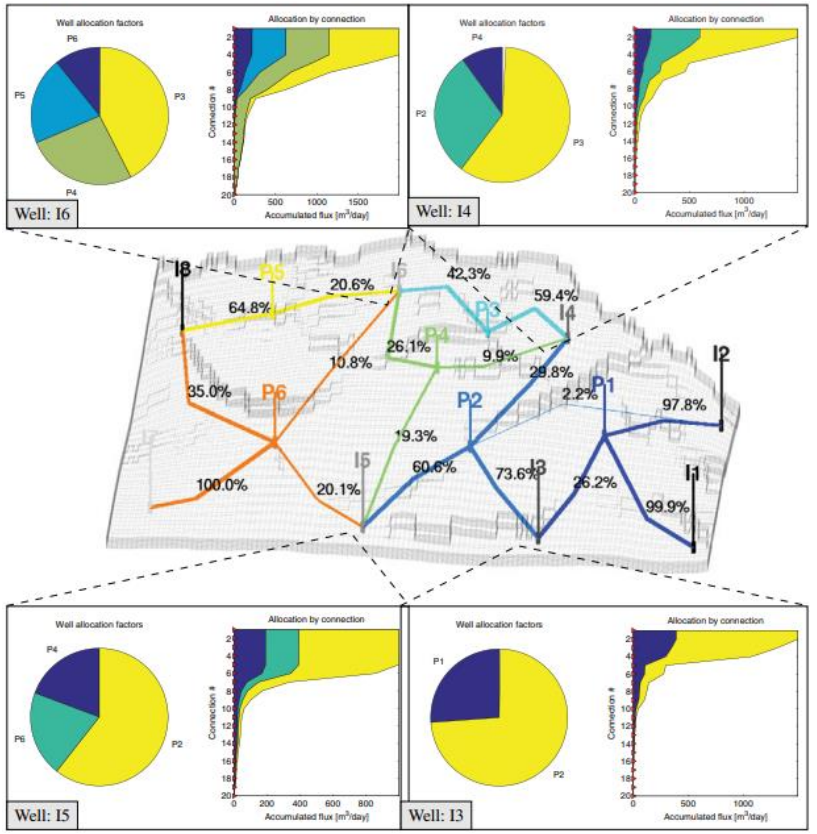
gas dissolved (900d)



flow distribution diagnostics



Flow simulation diagnostics
(SAIGUP model example)

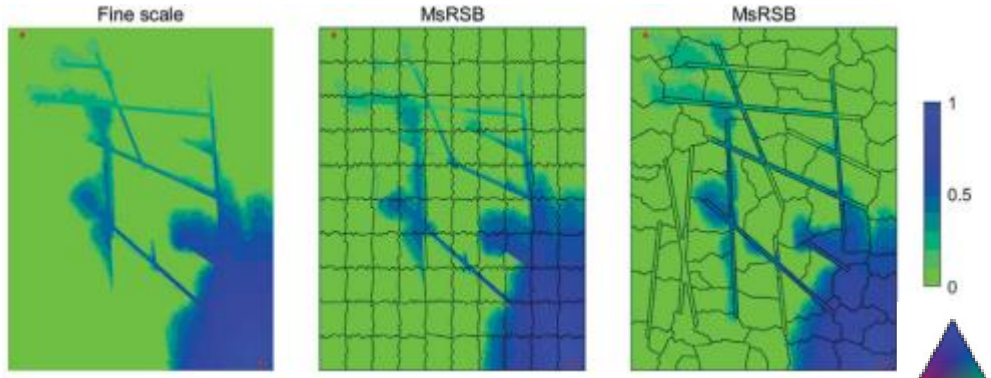


MRST highlights

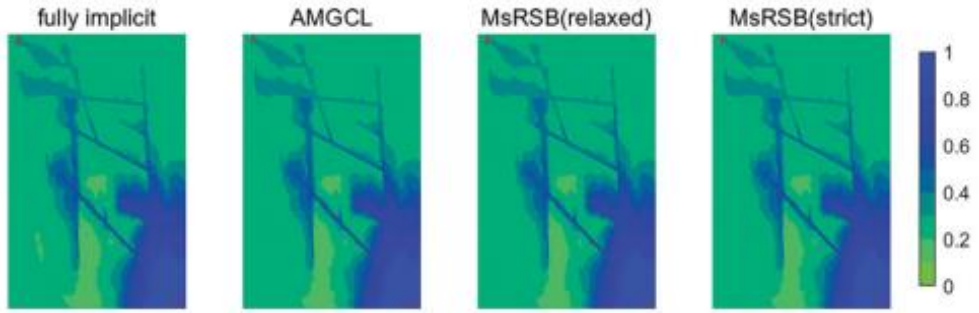
Multi-phase, fractured, geothermal, or unconventional reservoirs with poroelastic processes including unsaturated, EOR/CCS, coupled geomechanical modeling

Fracture-bound compositional (CO2+CH4+H2O) flow

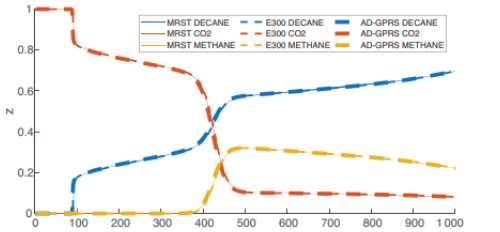
Fault-bound saturation profiles (511d)

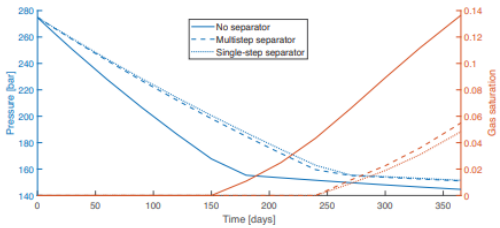


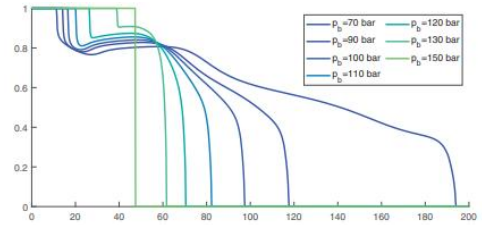
Fault-bound hydrocarbon saturation profiles (600+d)



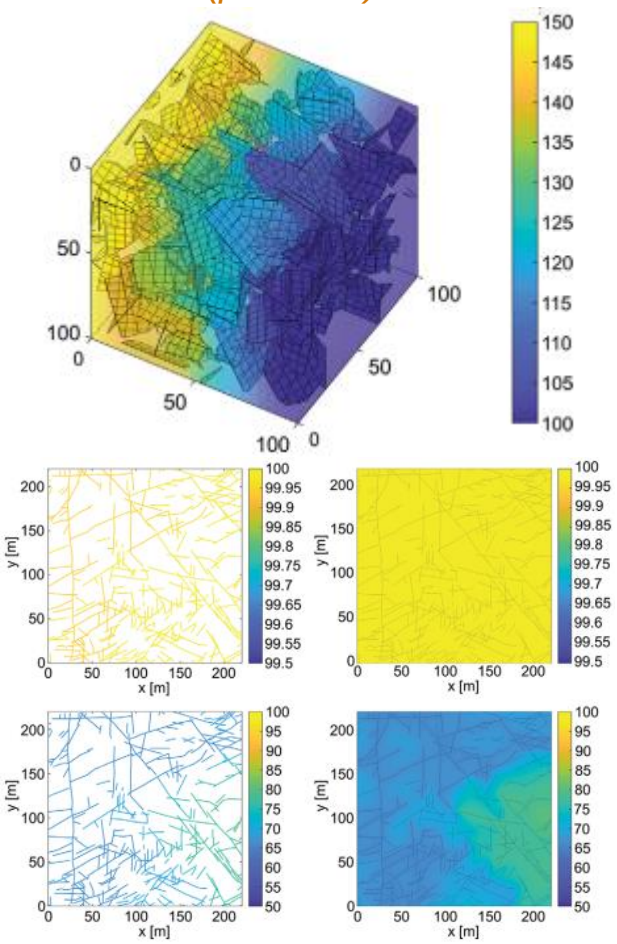
Miscible, compositional (CO2+CH4+CH10) modeling



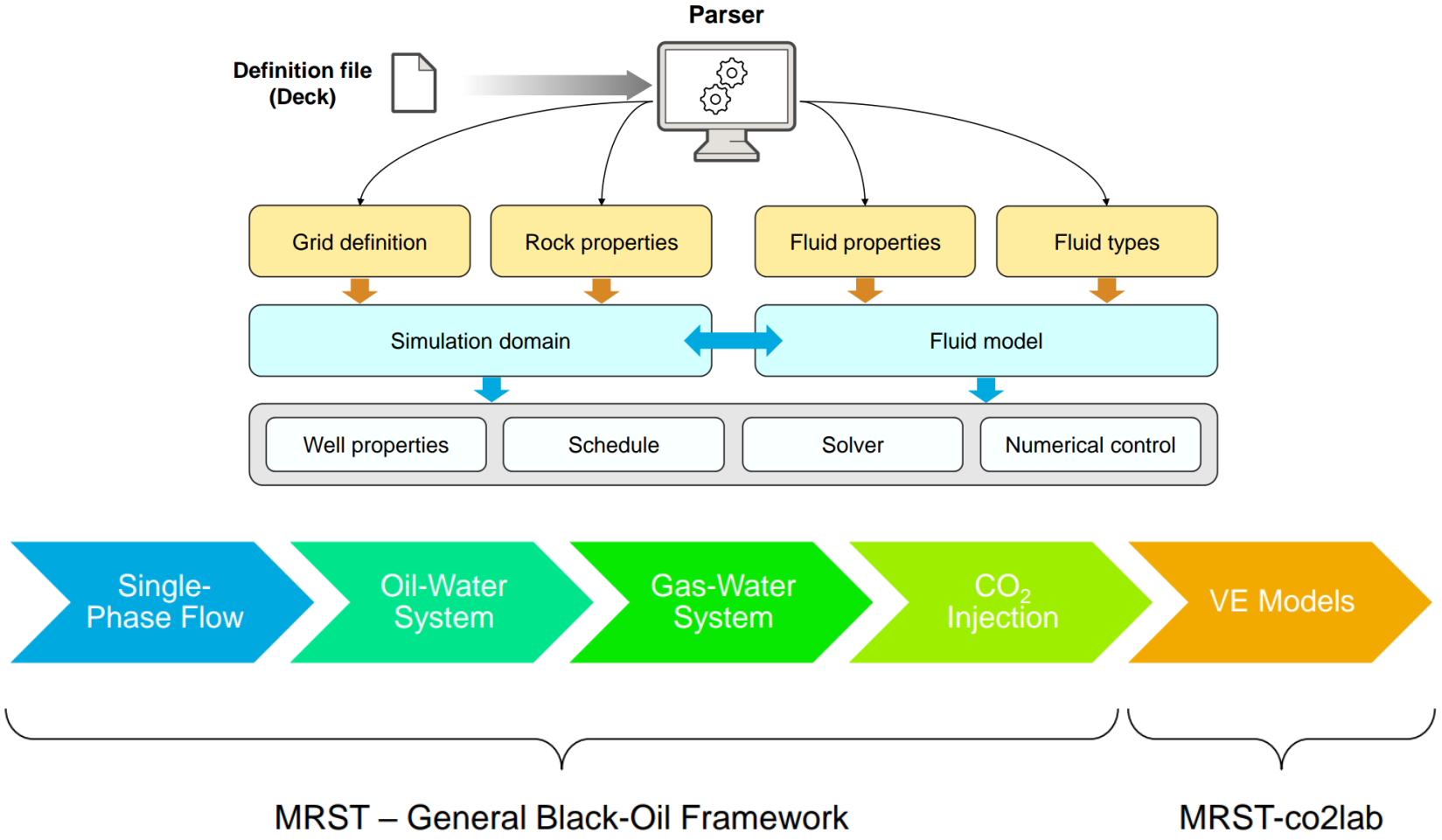




Discrete fracture modeling *(pressure)*

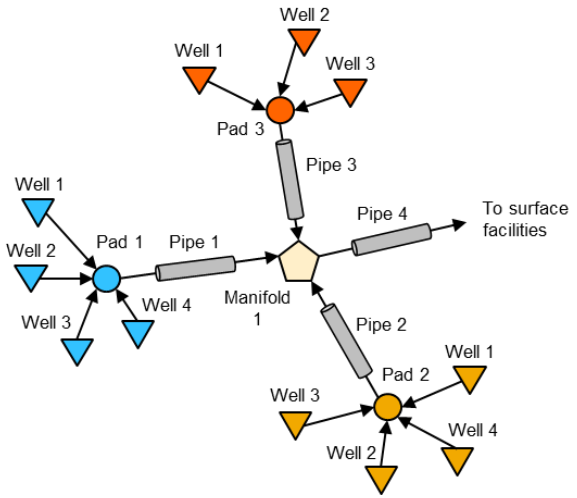


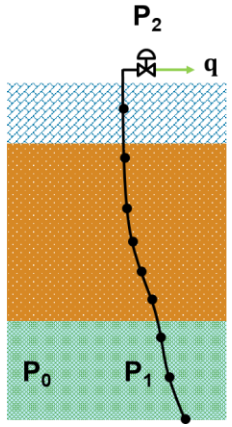
MRST Example:
Dynamic model building of Black Oil+CO2 fluid flow



MRST Example – Nonlinear Production Optimization

Solve IPR/VLP problem to optimize production from multiple wells





IPR:

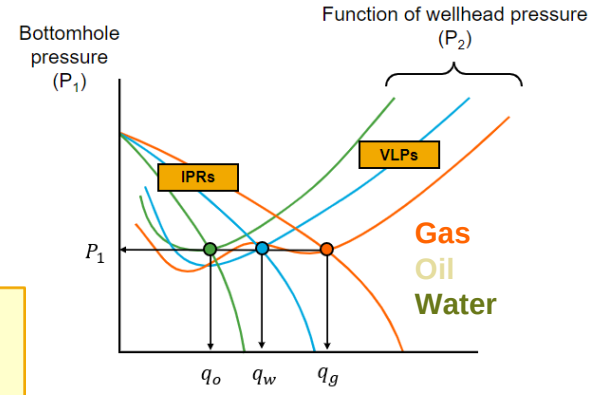
$$q_g = f_g(P_1)$$
$$q_o = f_o(P_1)$$
$$q_w = f_w(P_1)$$

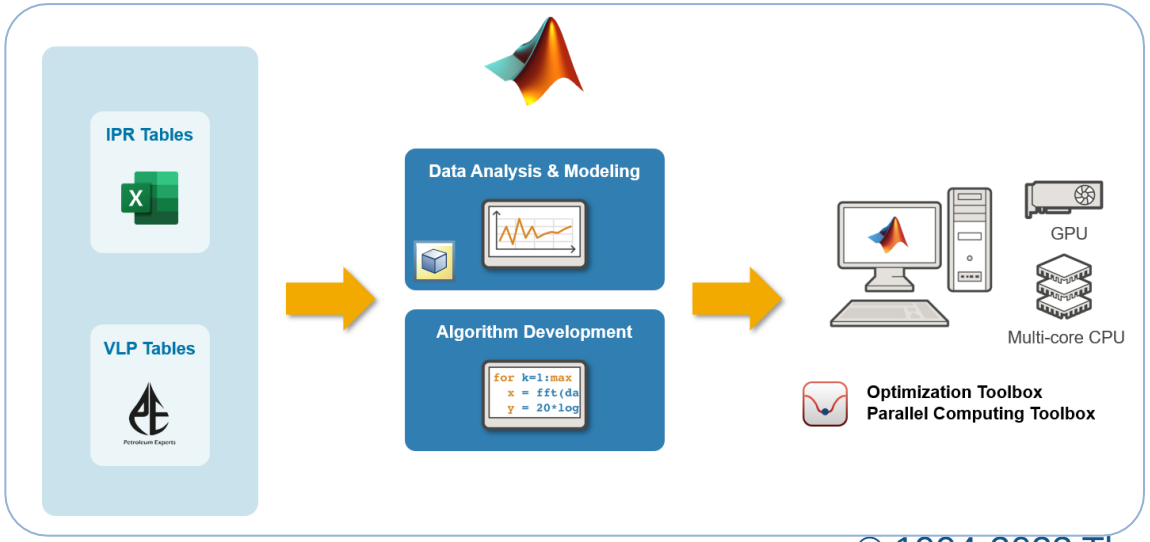
VLP:

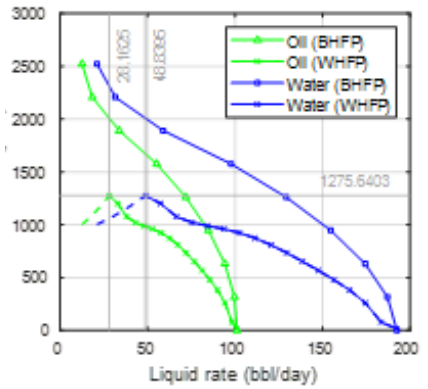
$$P_1 = f_p(q_o, q_g, q_w, P_2; \mathbf{\Gamma}_p)$$

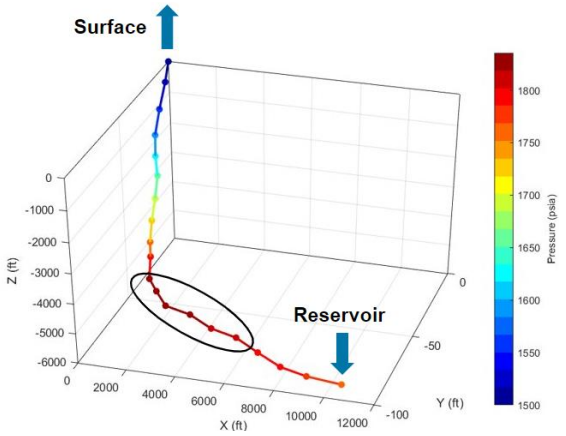
Problem:
For a given q_g, find $P_2 \rightarrow R(P_2) = 0$

$$R(P_2) = p_1 - f_p(f_o(P_1), q_g, f_w(P_1), P_2; \mathbf{\Gamma}_p)$$









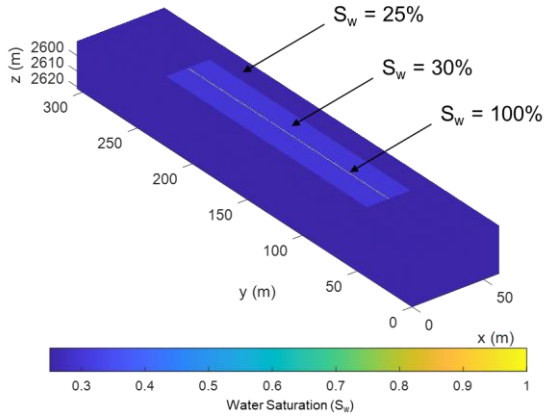
Key takeaways:

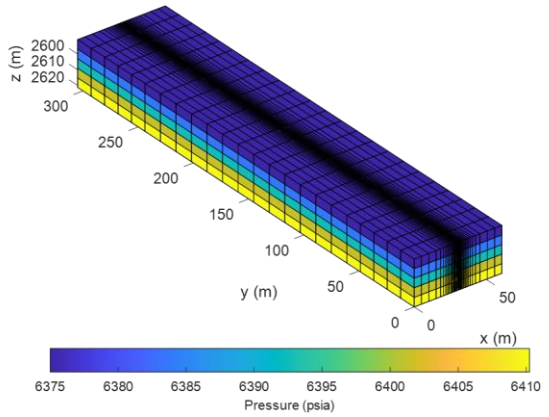
- MATLAB is efficient and robust solving complex nonlinear optimization problems
- MATLAB solved the IPR/VLP problem to optimize production from multiple wells

MRST Example – Sequential Geomechanical Simulation

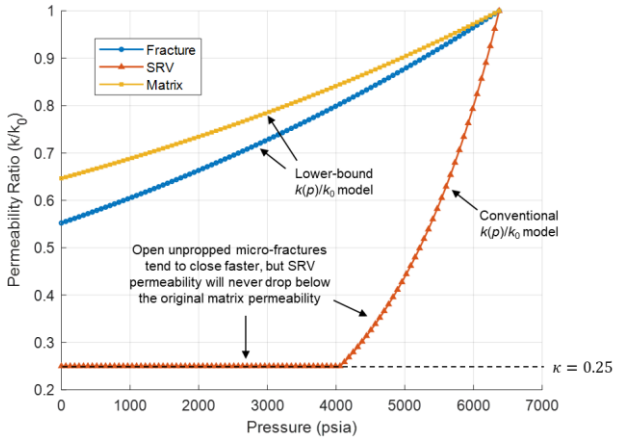
Solve for realistic fractured unconventional reservoir production

Fluid Flow Model
(PVT properties, ode23 solver)

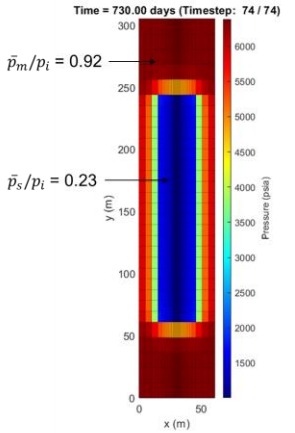




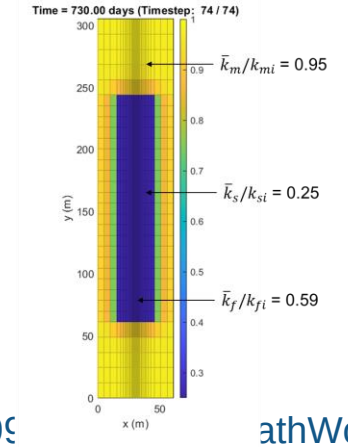
Matrix & Fracture Permeability
(sequential geomechanics)



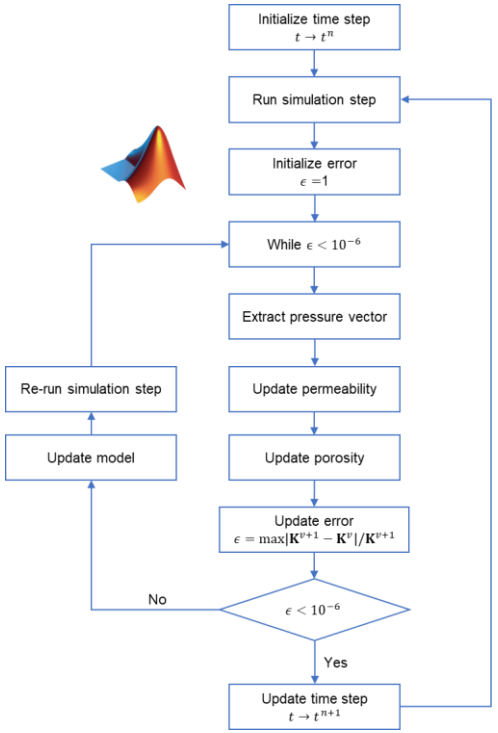
Pressure Distribution



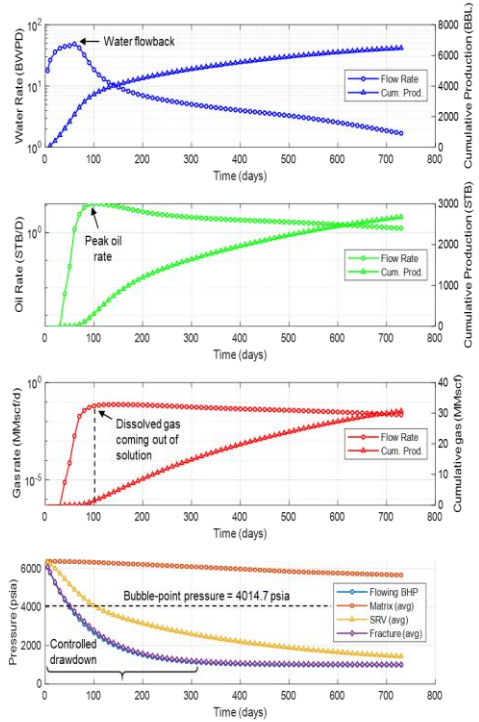
Permeability Retention



Hydro-Mechanical Solver
(sequential geomechanics)



Production Metrics
High Matrix Permeability
Low SRV conductivity



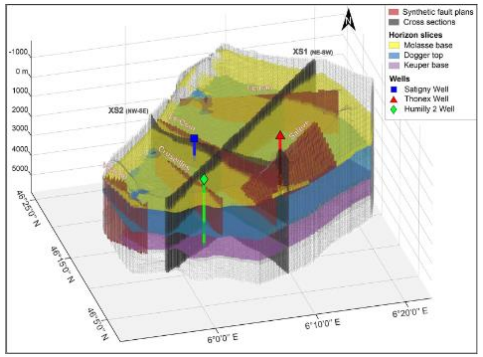
Key takeaways:

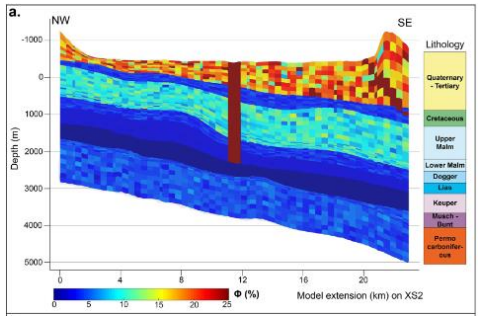
- Pressure-drawdown is the most significant early impact on the productive life of a well.
- Geomechanics can delay, or suppress, impact of long-term production of released gas.

MRST Example – Groundwater Geothermal Simulation

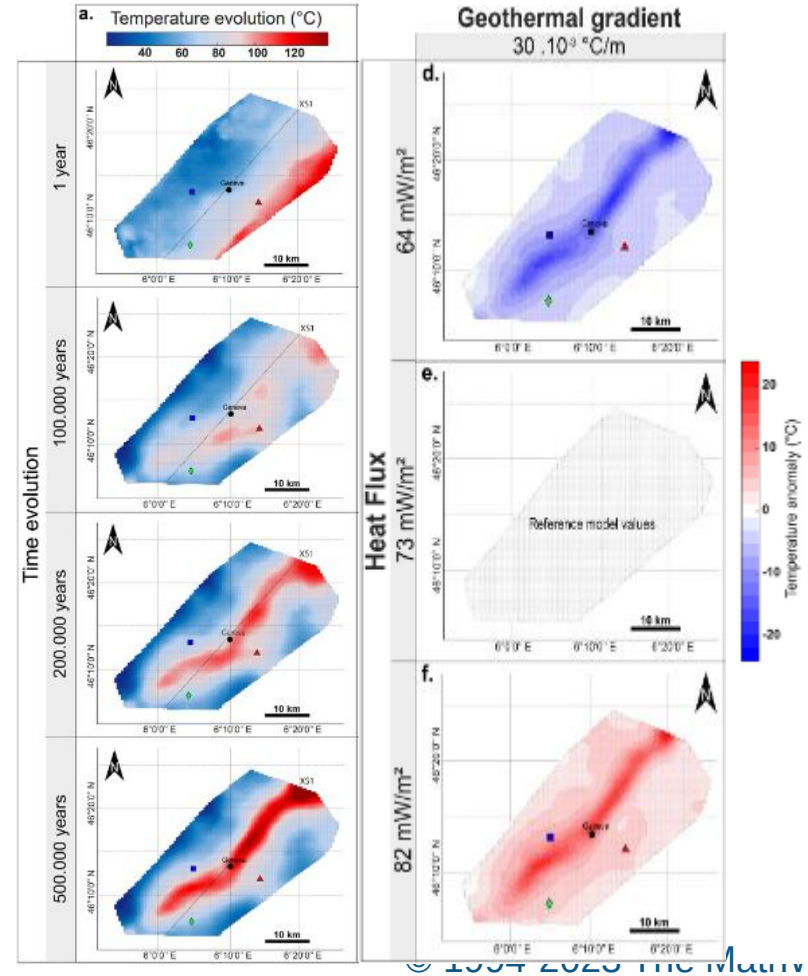
(Geneva Basin, Switzerland | Alcanie et al, 2021)

3D Geological Model
(0.5M cells)

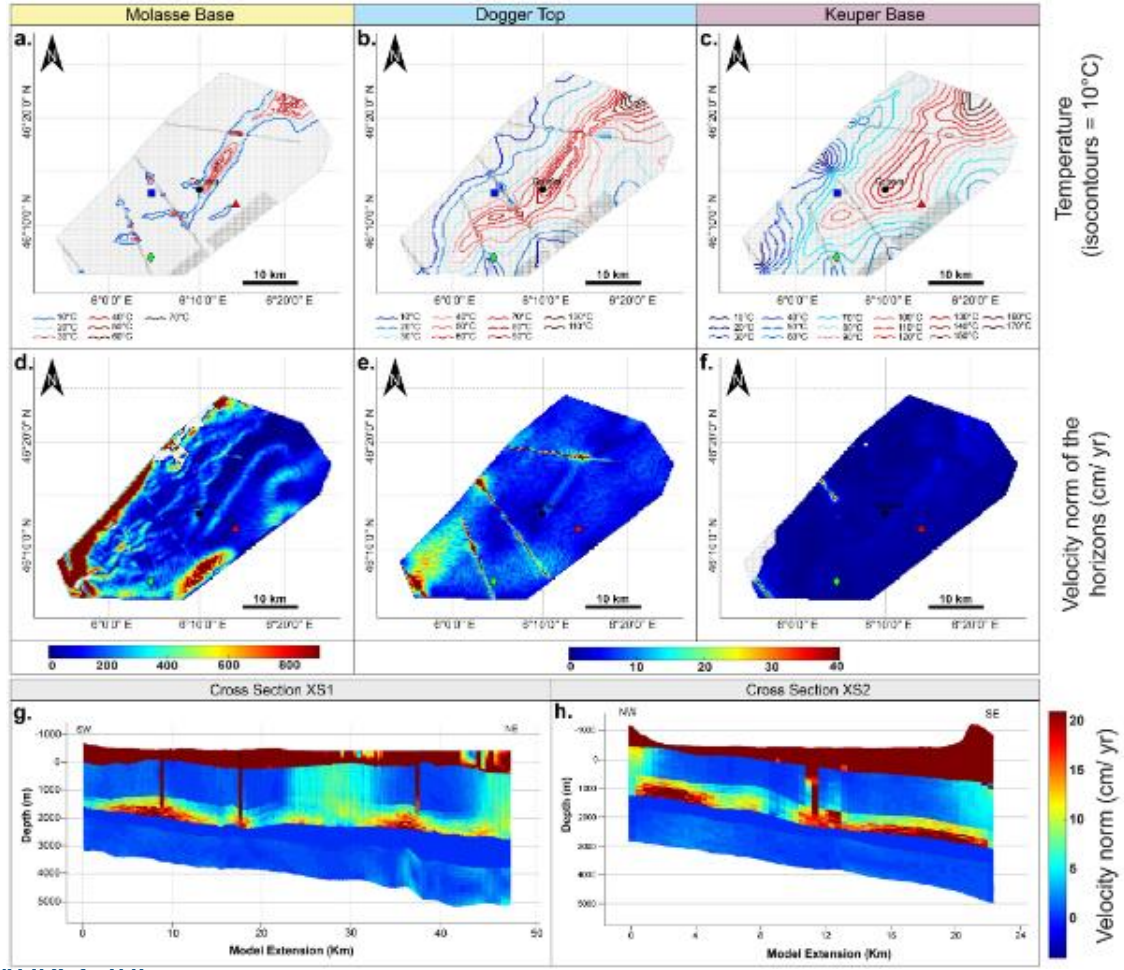




Geothermal Gradient & Heat Flow Models
(4,000 time stamps, 3 formations)

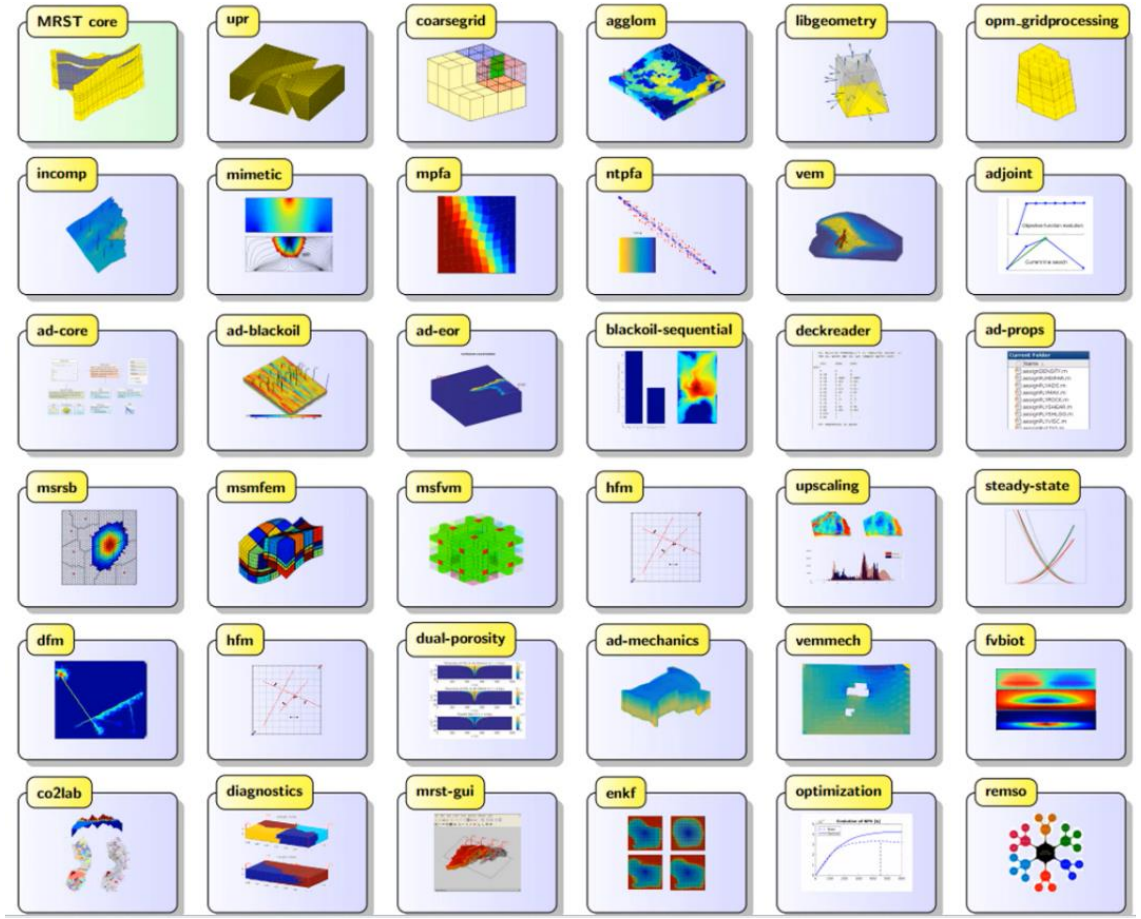


Final Geothermal Simulation Models
(thermal, structural, and petrophysical parameters)

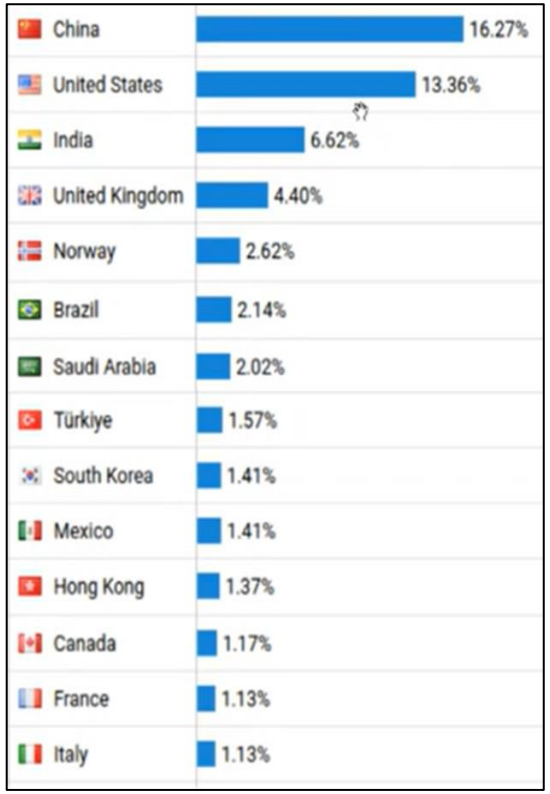


MRST modules usage (2022)

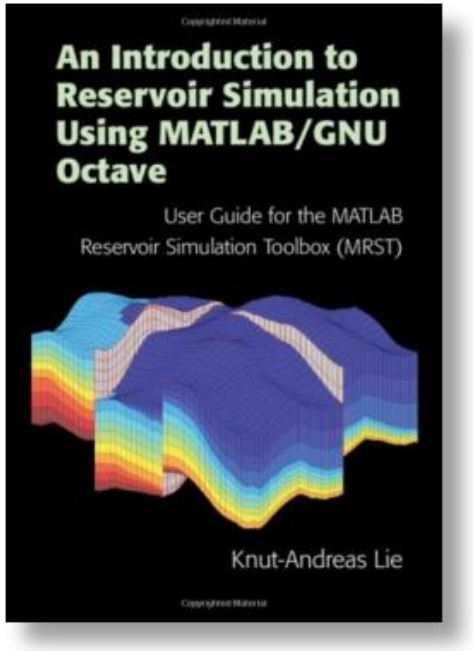
- Unstructured grids
- ECLIPSE I/O interface
- Multi-scale solvers
- Black oil & compositional
- Fractured media (DFM, EDFM, DPDP)
- Geothermal, geochemical, geomechanical modeling
- Unsaturated media
- Unconventional segments
- CO2 process (WAG/CCS)
- Flow diagnostics



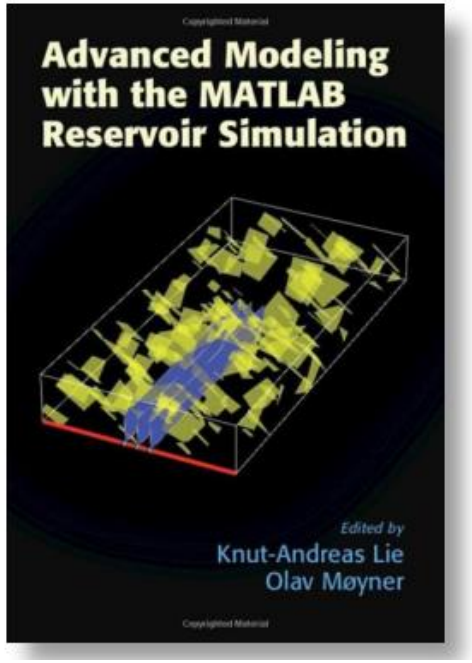
MRST usage worldwide
(EOY2022)



MathWorks MRST Resources



Introductory Guide to MATLAB® Reservoir Simulation Toolbox (MRST)



Advanced Modeling with MATLAB® Reservoir Simulation Toolbox (MRST)

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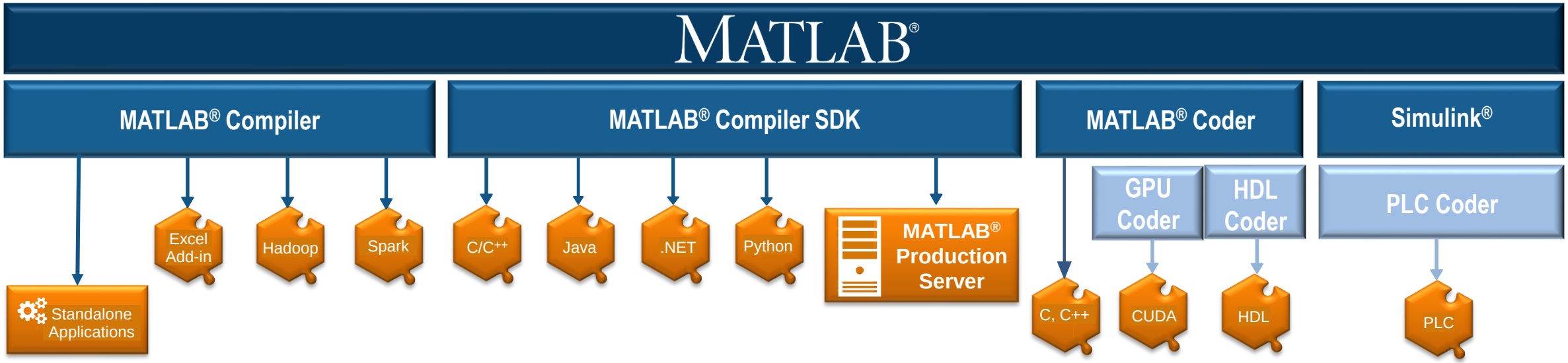

Interactive Petrophysics
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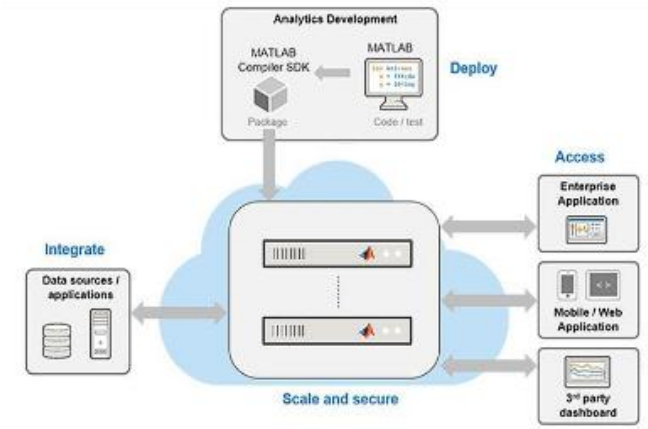
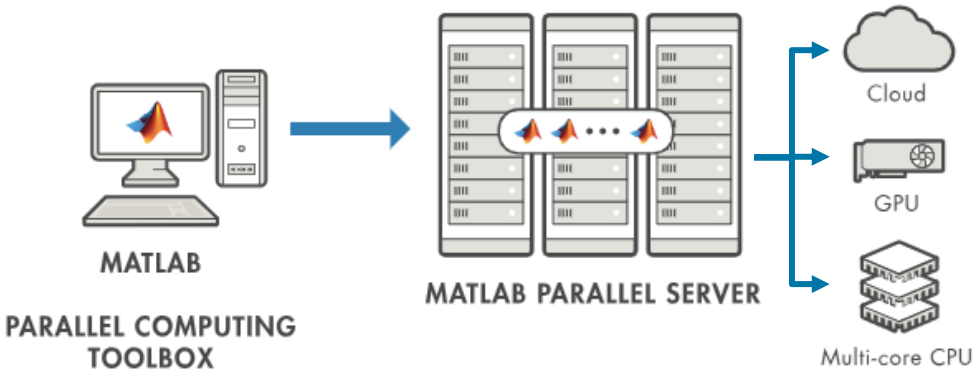
MATLAB® Production Server



HPC capabilities: Parallel | GPU | Cloud | Quantum Computing



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Azure
NVIDIA
Google Cloud
CLOUDERA
Spark
hadoop
databricks
HORTONWORKS
cloudstack

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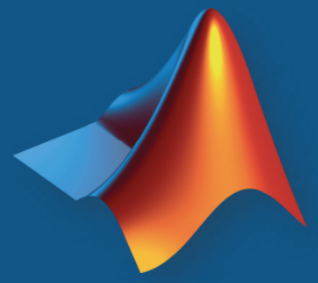
Artificial Intelligence | Big Data Analysis | Deep Learning | Machine Learning | Reinforced Learning | Predictive Analytics | Internet of Things | Process Optimization | Process Digitization | Process Automation | Value Chain Integration



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