The Evolution of Reservoir Simulation

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APRIL 11-12, 2023

MONTANA TECH 29TH ANNUAL JOHN “JOCKO” EVANS SPRING TECHNICAL SYMPOSIUM

Evolution of Reservoir Simulation

Then:
"Mathematical simulation of reservoir behavior may be used to help understand reservoir processes and predict reservoir behavior … in addition simulation can be used as a tool for reservoir description to learn more about the physical nature of the reservoir … this use is essential in most reservoir studies and represents one of the more significant applications of simulation."

This comment was from an article nearly 55 years ago (James H. Peery and E. H. Herron, Jr., 1969) in which the authors described development of an "accurate, efficient, and economical prediction of the reservoir flow of three phases in two-dimensional geometry". Their "large" (800 block) model ran 100 time-steps in 100 minutes on an IBM 360.

www.geologypage.com

Now:
"The present work indicates that models with tens of millions of cells can now be easily simulated by combining HPC systems and high-resolution simulators"

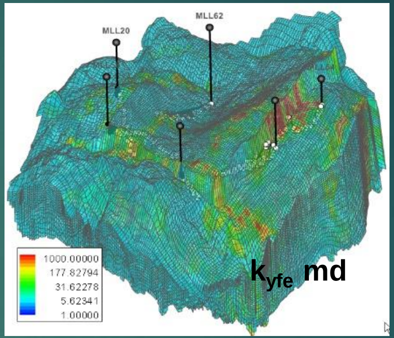
SPE 175633-MS " *Latest Advances in Simulation Technology for High Resolution Reservoir Models: Achievements and Opportunities For Improvement*" Cascianco, Cominelli and Bianchi (2015)

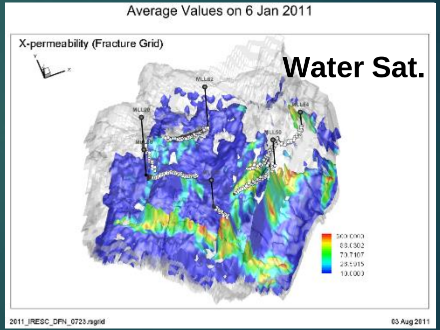
The Evolution

- Software capabilities/algorithms
  - Simulators, geomodeling, visualization, auxiliary software
- Data quality/quantity
- Hardware performance
- 3D geomodelling

Dynamic Simulation

- Combine various models/interpretations to “validate”/ “constrain” reservoir characterization and fluid interpretations
- Ensure model consistency with static and dynamic data/interpretations
- Considerations
  - Scale of data / interpretations
  - Uniqueness of interpretations
  - Computational constraints
  - Physics of flow process

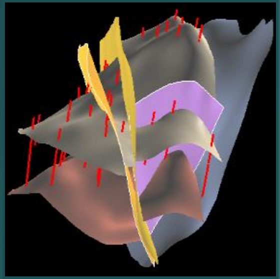




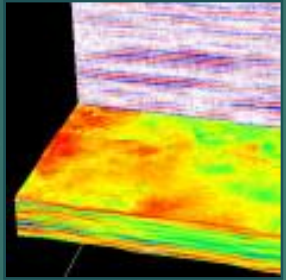
Reservoir Characterization Research Laboratory
iReservoir.com e-solution for global energy
SEISPETRO Geoconsulting

Integrated 3D Reservoir Modeling

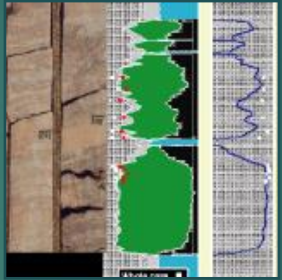
Structural & Stratigraphic Frameworks



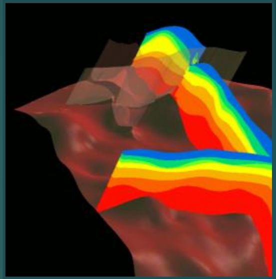
Seismically Conditioned Rock Properties



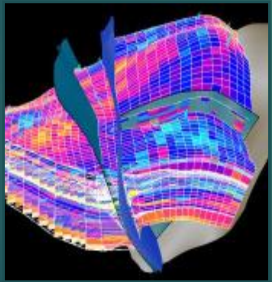
Petrophysics, Lithology, & Facies Mapping



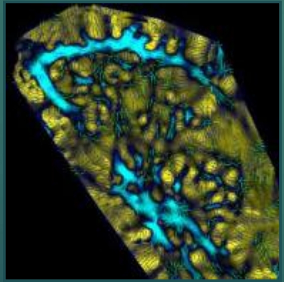
Stratigraphic Gridding



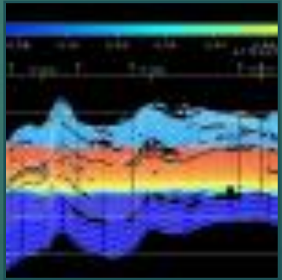
Matrix Properties & Connectivity



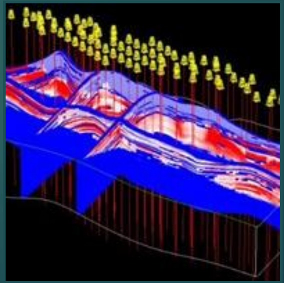
Fracture Network & Stress Field



Reservoir Fluids &Flow-Calibration

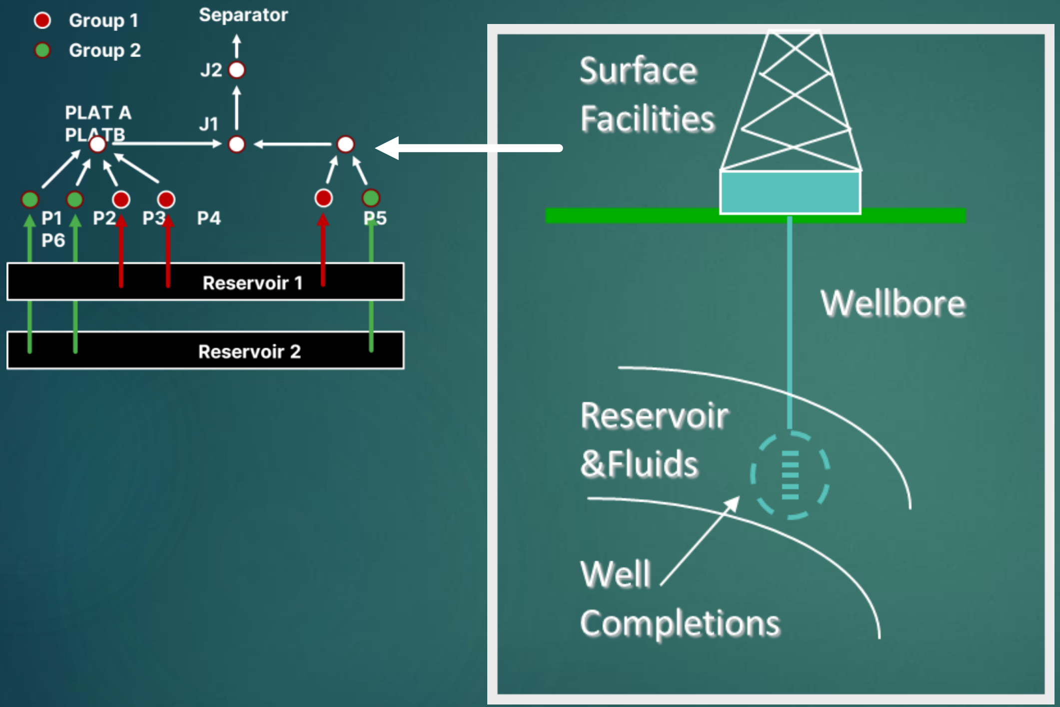


Dynamic Response Forecasts-Sensitivity



A significant concern with many modeling studies is that the focus is on getting a history match. The purpose of a 3D characterization/simulation study is not to match history, but to understand the reservoir to optimize recovery processes. Integration of disciplines is a key.

Reservoir Model Subsystems

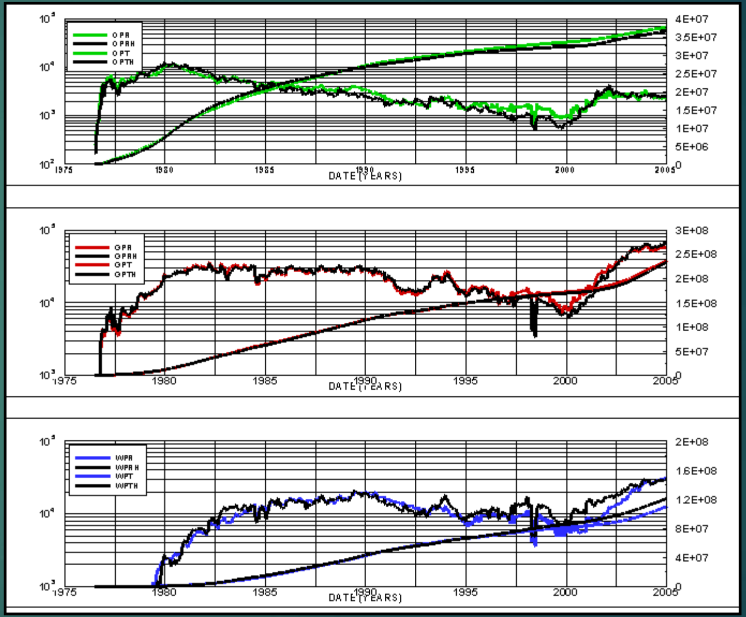


- Reservoir & Fluids – understand / predict flow of fluids/heat within the reservoir (includes fluid behavior)
- Well Completions – include efficiency and dynamics of reservoir-well interface
- Wellbore – understand flow of fluids between reservoir and surface
- Surface Model - surface fluid handling facilities / constraints impact on reservoir dynamics

History Matching/ “Validating" the Model

- *The process by which a reservoir simulation model is altered in some way to minimize the difference between model performance and historical performance*

See SPE REE Apr. 1988 by Williams et. al “The Stratigraphic Method: A Structured Approach to History-Matching Complex Simulation Models”.



"When things don't work as planned"

- Harts E&P July 2004

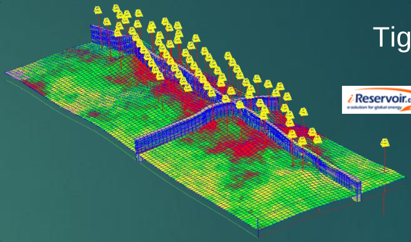
- *A technical re-appraisal of the field suggests a substantial write down of the asset to the tune of nearly $128 million – nearly all the development cost.*

- "It is clear from the performance of the producing wells that deliverability from the reservoir is much poorer than had been predicted"
- "The field's performance since production commenced and subsequent technical work suggests that this key conclusion upon which the reservoir model used for planning the development and for reserves estimates was based is erroneous"
- "…it is now thought that the … reservoir is more compartmentalized, and that the five production wells on the field are connected to lower gas volumes"
- "Work is already underway on developing a revised reservoir model, which … will take several months to complete. … this will be an important tool for reassessing the field's recoverable reserves and designing a future work program."

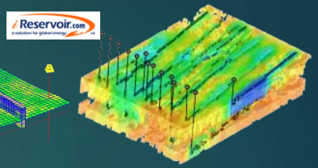
State-of-the-Art

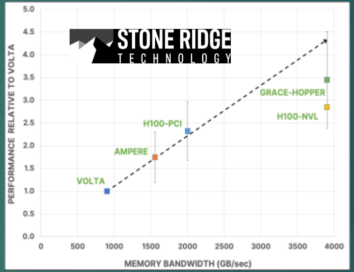
- Physics based simulation has long been used to estimate field performance based on input from geologic, structural, petrophysical and fluids characterization
- We continue to have a conflict between the limits of data, the ability to describe the reservoir and the limits of computational capabilities when modeling the physics and capturing the important details of dynamic behavior
- We desire to more rigorously address uncertainties while optimizing field development/recovery techniques
- Reservoir simulation on Graphical Processing Units (GPUs) is providing the ability for much higher model resolution with reduced run time
- AI/ML/DA methods are being developed/applied to improve characterization, simulation model inputs and modeling workflows

Depletion Gas Saturation



Tight Oil Reservoir Pressure



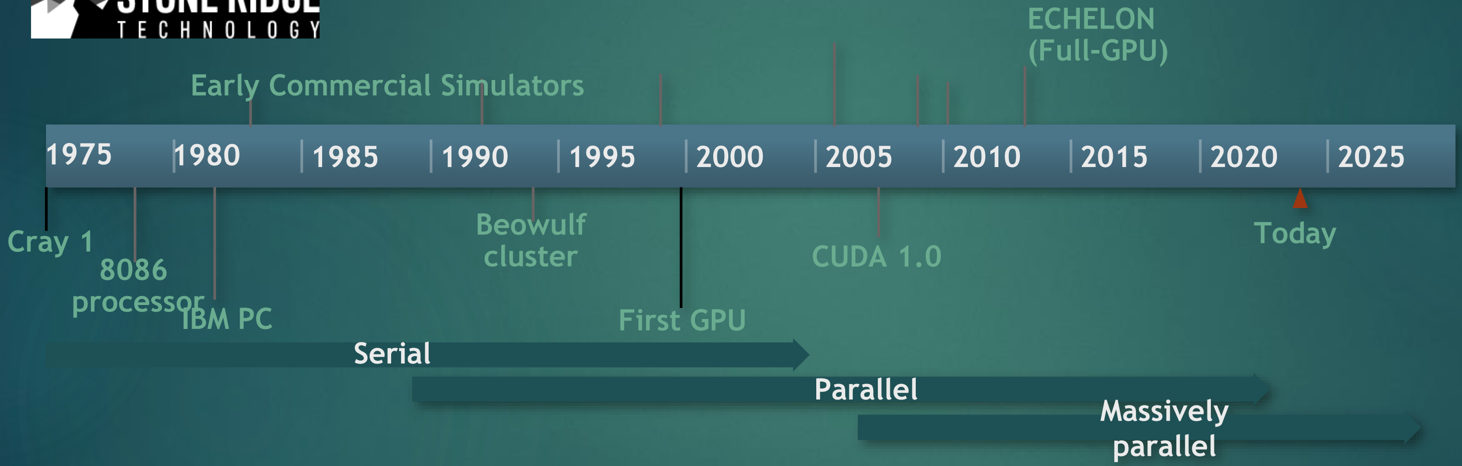


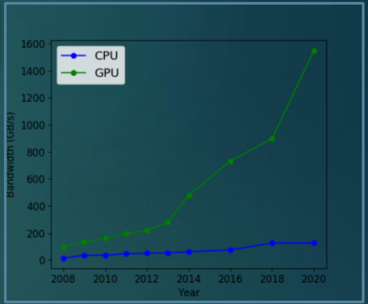
GPU Bandwidth

https://vinodsblog.com/2017/10/01/artificial-intelligence-as-a-service/

HPC Evolution in Reservoir Simulation

STONE RIDGE TECHNOLOGY





"Accelerated computing certainly starts with GPU, and if that's all there was, I might also be of the opinion that NVIDIA's day is coming. On top of the silicon, NVIDIA layers its CUDA software stack, which is *as important to accelerated computing as the GPU." - Why NVIDIA Wins and Will Continue To Win. Zeus Kerravala, eWeek.*

AI/Machine Learning Opportunities

- LLM to answer questions about data setup / model choices
- Review model input, suggest solvers, locate data errors and suggest changes, suggest options for better run time, review SCAL, PVT well input for consistency
- Review simulation output as above
- AI for history matching
- AI for uncertainty
- AI for optimization

AI/Machine Learning Opportunity/Examples

Core-based machine learning characterization of Wolfcamp XY and Third Bone Spring Formation across the Delaware Basin, Texas

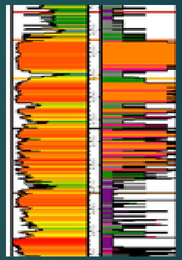
•

This study applies machine learning tools to characterize Wolfcamp XY and Third Bone Spring 'sand' chemofacies using high resolution X-ray fluorescence core-based measurements from the Delaware Basin in west Texas. …The distribution and abundance of the siltstone and organic matter-rich mudstone facies are consistent with the Wolfcamp XY submarine fan complex developed in Loving and Reeves County and can be used to differentiate stacked reservoirs that have excellent potential to store migrated oil vs good unconventional shale-oil targets. This study demonstrates the importance of informing basin models using core-based data and represents an important breakthrough in upscaling core-based data to wireline logs.

https://www.beg.utexas.edu/events/core-based-machine-learning-characterization-of-wolfcamp-xy-and-third-bone-spring-formation-across-the-delaware-basin-texas

Core facies

(sample 0.01 m)



Log facies

(sample 0.152 m)

AI/Machine Learning Characterization

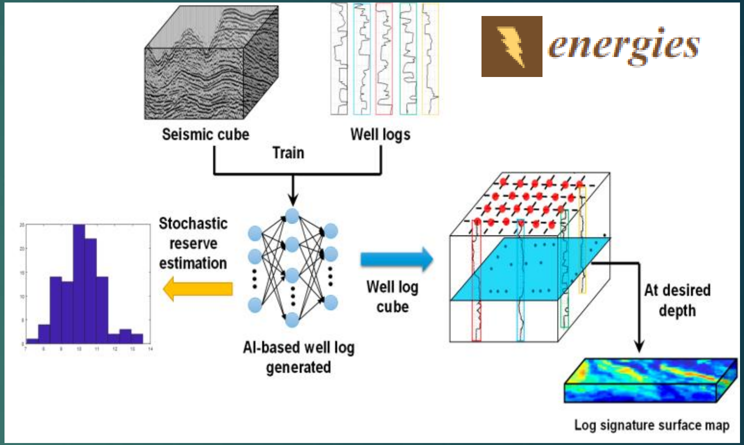
Artificial Intelligence Applications in Reservoir Engineering: A Status Check

Turgay Ertekin and Qian Sun

Energies 2019, *12*(15), 2897;
Published: 27 July 2019
https://doi.org/10.3390/en12152897

This article provides a comprehensive review of the state-of-art in the area of artificial intelligence applications to solve reservoir engineering problems. Research works including proxy model development, artificial-intelligence-assisted history-matching, project design, and optimization, etc. are presented to demonstrate the robustness of the intelligence systems. …

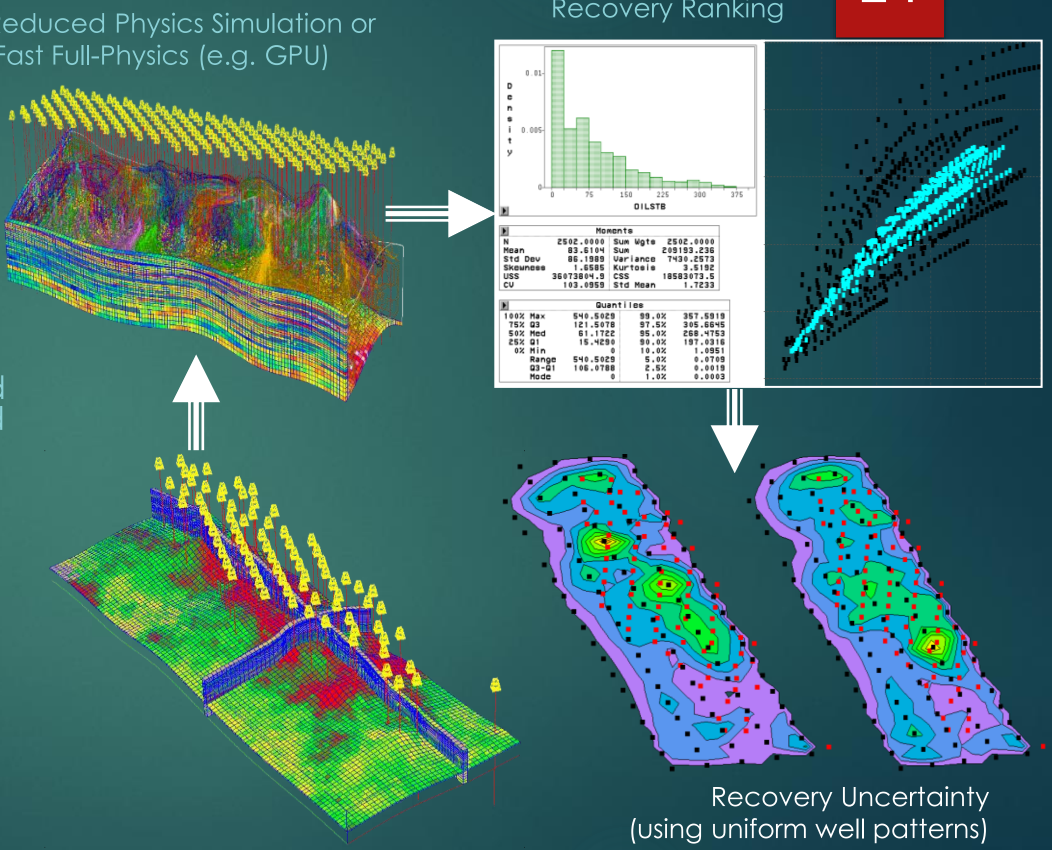
…the implementation of intelligence models enables reservoir engineers to accomplish many challenging and time-intensive works more effectively. However, it is not yet astute to completely replace the conventional reservoir engineering models with intelligent systems, since the defects of the technology cannot be ignored.



General workflow that uses forward-looking intelligent models to accomplish computationally intensive reservoir engineering analysis.

AI/Machine Learning Uncertainty

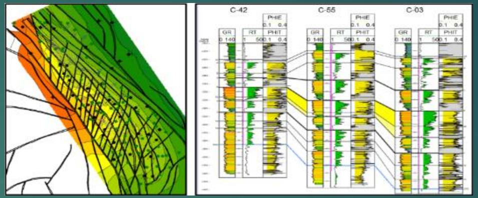
- Well/Field Controls
  - Linking to Surface Networks
- Multiple Sensitivities / Scenarios
- Uncertainty
  - In addition to the geologic model, simulation results depend on many factors. These factors have some degree of uncertainty and should be addressed through data gathering and long-term performance monitoring and simulation sensitivities
- Optimization (total production, net present value, etc)
  - Well locations, Completion Intervals, Well function (Producer, Injector, EOR Injector), Well Rates



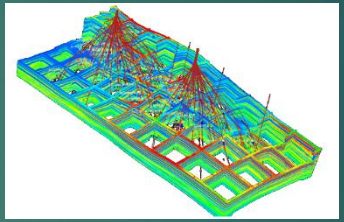
SPE 77374, "Statistical Ranking of Stochastic Geomodels Using Streamline Simulation: A Field Application"

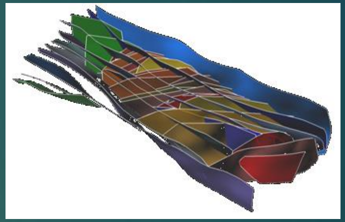
AI/Machine Learning History Matching

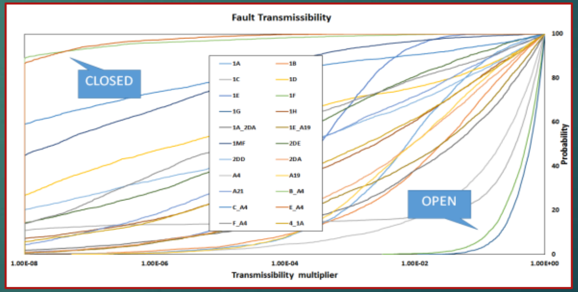
- Ill-conditioned mathematical problem
  - Multiple solutions
  - Highly non-linear interactions
  - Numerical errors in solutions
- Constraints not bounded
  - Uncertainties in variables unknown
- Key parameters are not always apparent
- Input variables are stochastic
- Production data inherently uncertain (bias)



- 787 thousand active cells
- 308 possible compartments
- 140 wells, 30+ years of history
- 145 variables for HM/prediction
- 7 minutes per simulation (GPUs)
- Good HM 's emerge after 140 runs
- Probabilistic uncertainty → 225 runs



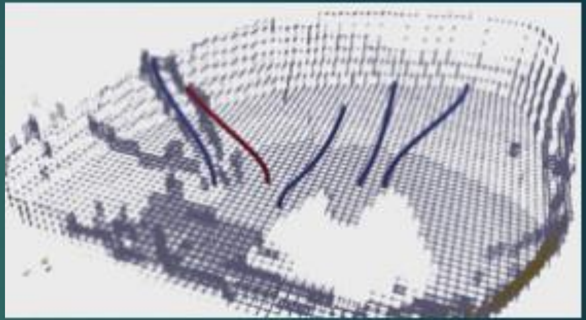




N. Goodwin, K. Esler, M. Ghasemi, K. Mukundakrishnan, H. Wang, J.R. Gilman, B. Lee: "Probabilistic Uncertainty Quantification of a Complex Field Using Advanced Proxy Based Methods and GPU-based Reservoir Simulation", SPE-182637-MS presented at the SPE Reservoir Simulation Conference, Feb. 20-22 2017, Montgomery, TX

AI/Machine Learning: Optimization

- Upstream endeavors normally demand an extensive team of geologists, petro-physicists, reservoir engineers, mathematicians and more, working together to construct models that take several months, or even years, to complete. It's a necessity for such models to capture expert input, as well as statical and dynamic data from considerably high-value assets. Historical human knowledge, experience, and expertise are crucial at almost every stage of interpreting historical performance and data.
- One of the challenges for the upstream oil and gas sector is the optimization of well placement in oil and gas reservoirs (field planning).
- By leveraging NVIDIA A100 Tensor Core GPUs, Beyond Limits is developing a deep reinforcement learning (DRL) framework that provides high-performance computing (HPC) infrastructure to support novel AI frameworks making the strategic moves necessary to simplify this intricate field.

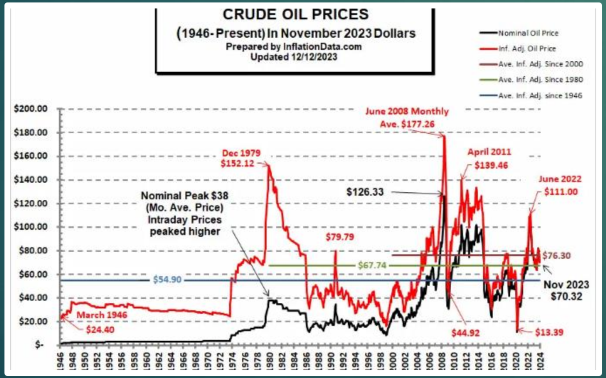


BEYOND LIMITS

https://www.beyond.ai/news/nvidia-case-study-optimizing-well-placement-in-oil-gas-reservoirs-with-ai/

Final Thoughts

- Reservoir simulation is an important part of reservoir hydrocarbon recovery optimization
- Reservoir characterization and simulation studies have many opportunities for improved workflows, improved understanding and uncertainty estimation
- In addition to petroleum recovery, modeling flow in underground reservoirs can be important for $CO_2/H_2/CH_4$ storage, geothermal systems, aquifers, and brine mining



[Historical Oil Prices Chart (inflationdata.com)](https://inflationdata.com)

The current price of WTI crude oil as of March 29, 2024 was $83.17 per barrel.

[Crude Oil Prices Today | OilPrice.com](https://oilprice.com)

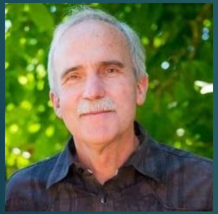
Oil left in the world 1.376 Trillion bbl (2/20/24). 47 years current consumption

[World Oil Statistics - Worldometer (worldometers.info)](https://worldometers.info)

Questions?

The Evolution of Reservoir Simulation, April 2023

Solution to reservoir engineering problems using reservoir simulation has historically been a very time consuming and iterative process of building geologic models through interaction with geoscientists and laboratory experimentalists. This talk will summarize those developments from improved physics to better reservoir descriptions. Modern developments, such as high memory/high bandwidth GPUs plus artificial intelligence and machine learning algorithms may further improve our ability to 1) more rapidly build models 2) more accurately simulate reservoirs and 3) more readily capture the associated uncertainty.



Jim Gilman is a Reservoir Engineering and Simulation consultant. He is a part-time advisor to a consulting company (iReservoir.com, Inc.) and a software company (Stone Ridge Technology). His expertise includes specialization in application and development of numerical simulators for fluid flow in petroleum reservoirs. His first industry job was at Marathon Oil Company's Technology Center where he was involved in reservoir simulation, training, and other reservoir engineering services. Jim has authored or co-authored over 50 articles primarily dealing with reservoir characterization and simulation.
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