MOZAMBIQUE LNG

The Benefits of Stochastic Subsurface Uncertainty Assessment in a Complex Greenfield LNG Development

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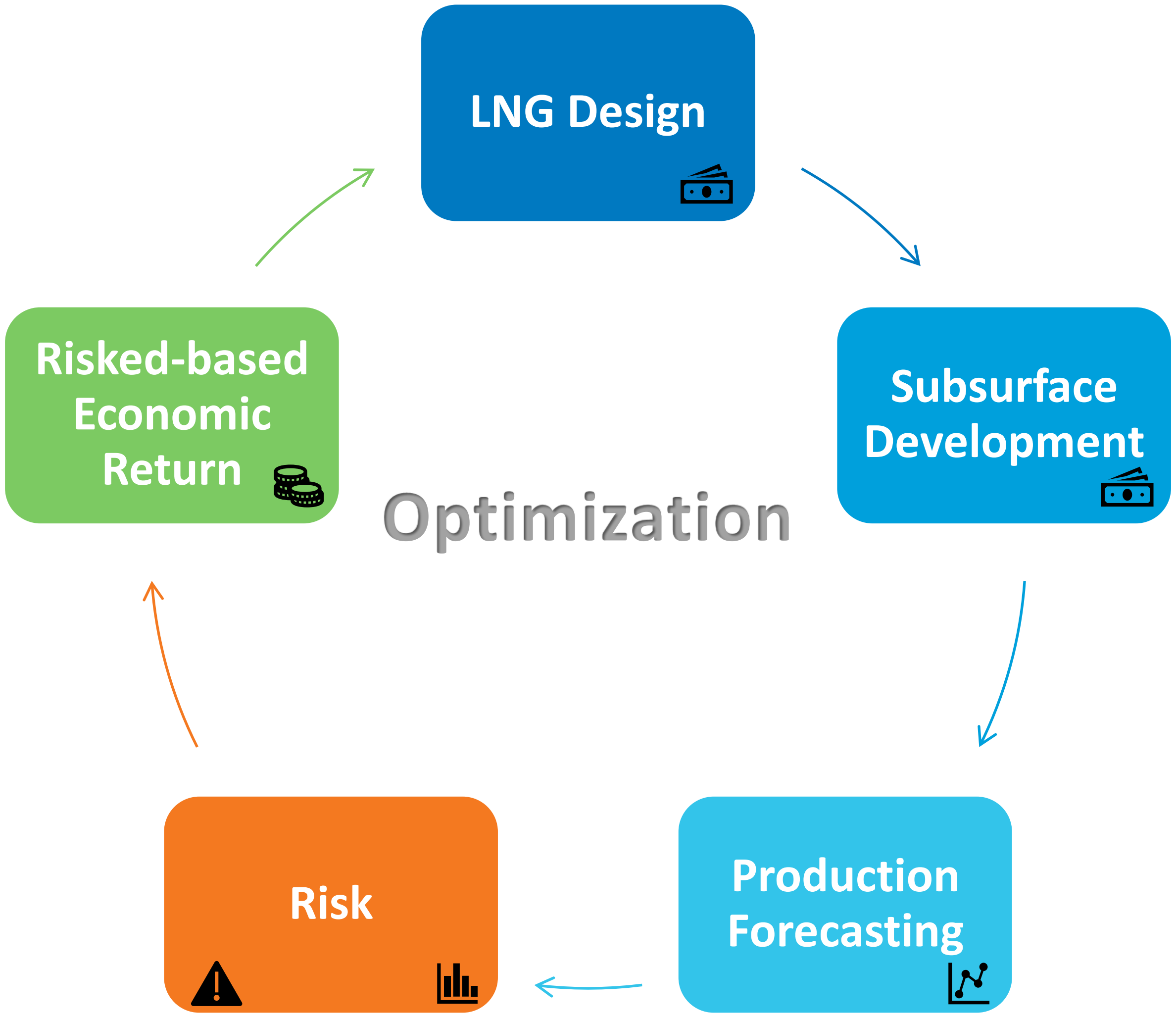
Decision Challenges in Field Development

- **Uncertainty**
  - Production forecasts
- **Decision**
  - LNG-Train capacity
  - Offshore development
- **Objective**
  - Maximize economic return

<u>CHALLENGES with Probabilistic Decision Making Analysis</u>

1. Process
2. Tools
3. Training
4. Communication



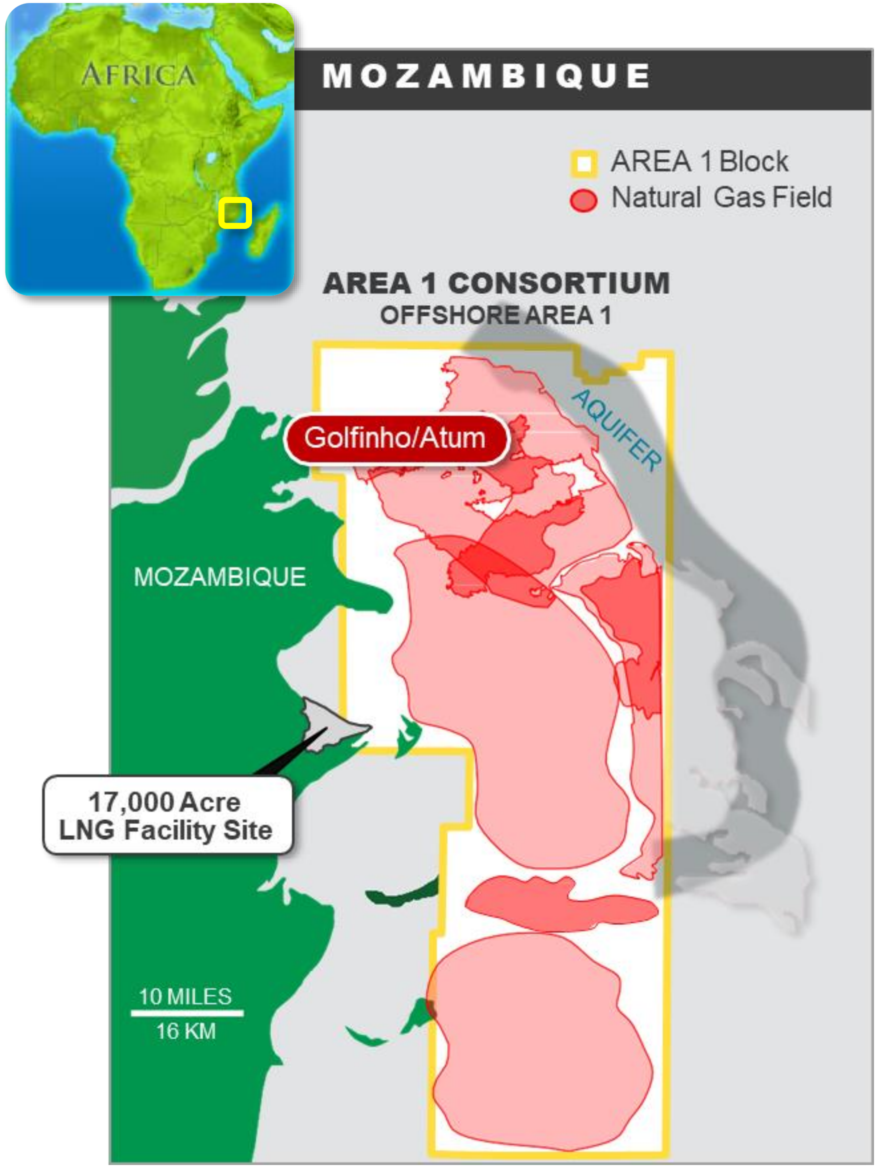
Paradigm Shift – Adopt an Alternative Methodology

A. Initial field development decisions were based on a deterministic assessment (the Base case)

- Develop an initial well count and locations with large amount of redundancies (*what if reservoir is poorer than base case or poor completion or well failure…*)
  - $AOF_{well} \gg Max(Rate_{well})$
  - $Nb_{wells} * Max(Rate_{well}) > 2 * Avg_{LNG\ throughput}$
- Subsea gathering system with dedicated 1Bscf/d trunkline per train
- Simple workflow: G&G interpretation ⇨ reservoir model ⇨ dynamic model ⇨ production forecast

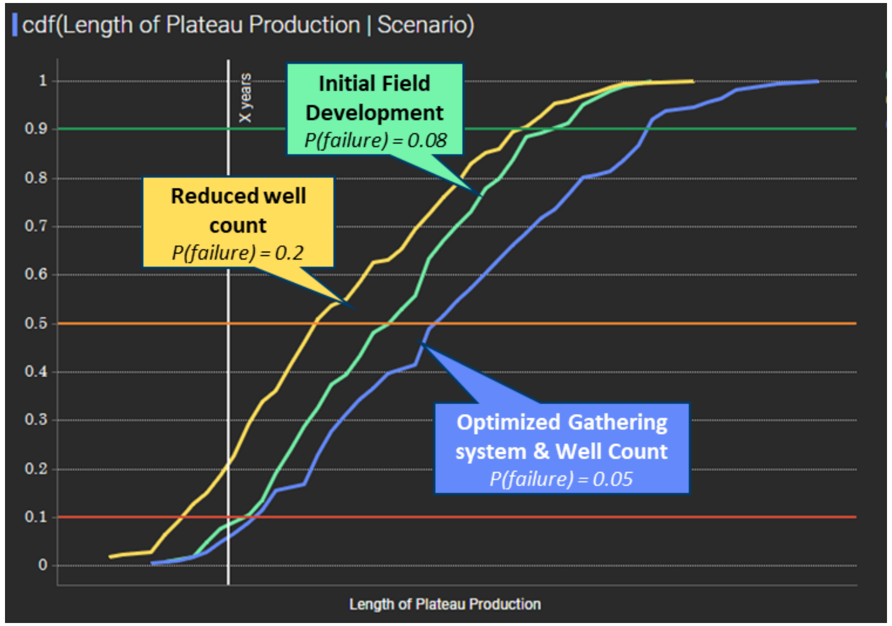
B. Alternative methodology from management's motivation to quantify risks (gas contracts in form of SPA = production obligation) and reduce cost in a low commodity price environment (capital efficiency)

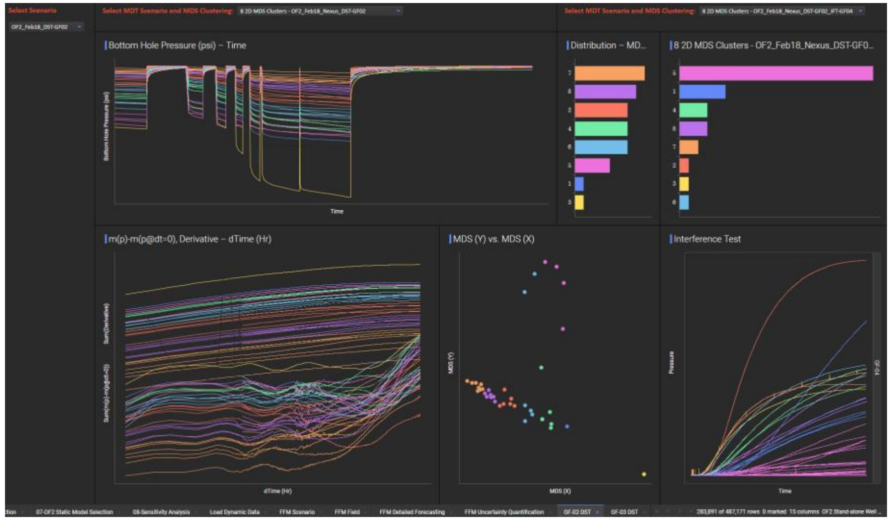
- Provide probabilistic production forecasts and reserves
- Can we reduce well count and differ wells to future drilling campaign?



Key Learnings

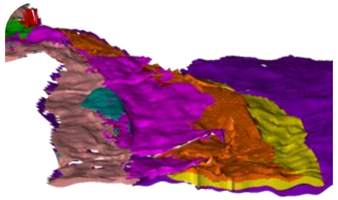
- **Making decision under uncertainty is difficult and requires careful and thoughtful framing**
  - Move from an aspiration (minimize cost & maximize production) to a quantifiable risk tolerance goal - P(Max(Gas Rate) < X years) < 0.05
- **Science of uncertainty assessment is complex**
  - Statistics and modeling knowledge
- **Importance of workflows, software and hardware**
  - Integrated multi-disciplinary workflows
  - Modeling tools with probabilistic assessment modules, ideally running realizations in parallel
  - Tool capable of gathering data from multiple platforms, software and disciplines for data integration and analysis





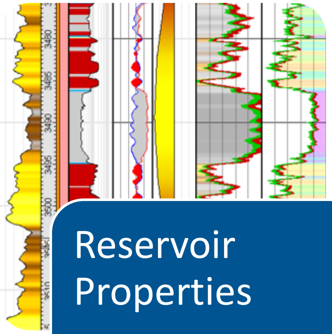
Quantitative Stochastic Uncertainty Assessment

1. Large number of stochastic realizations using Monte-Carlo sampling of uncertain parameters
2. Dynamic model screening of each static model using a fast proxy
3. Model selection using distance-based technique, multi-dimensional scaling (MDS) and clustering
4. Dynamic model selection from stand-alone reservoir simulation
5. Full field simulation of selected model combinations

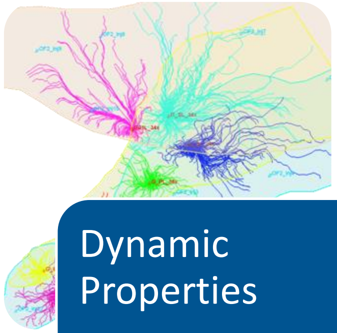


Reservoir Container
- Seismic Interpretation
- Seismic velocity
- Seismic resolution

Reservoir Sand Fraction
- Geological Scenario



Reservoir Properties
- Petrophysical Model
- Compaction
- Diagenesis

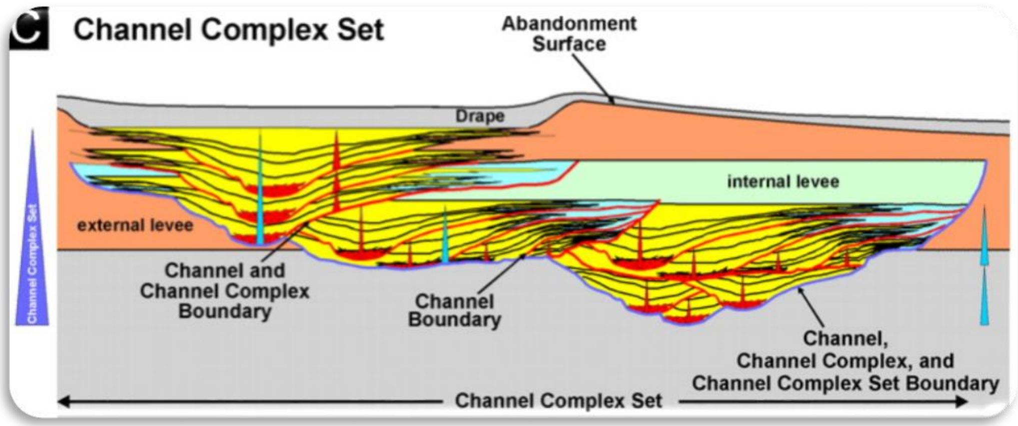


Dynamic Properties
- Relative Permeability
- Aquifer Strength

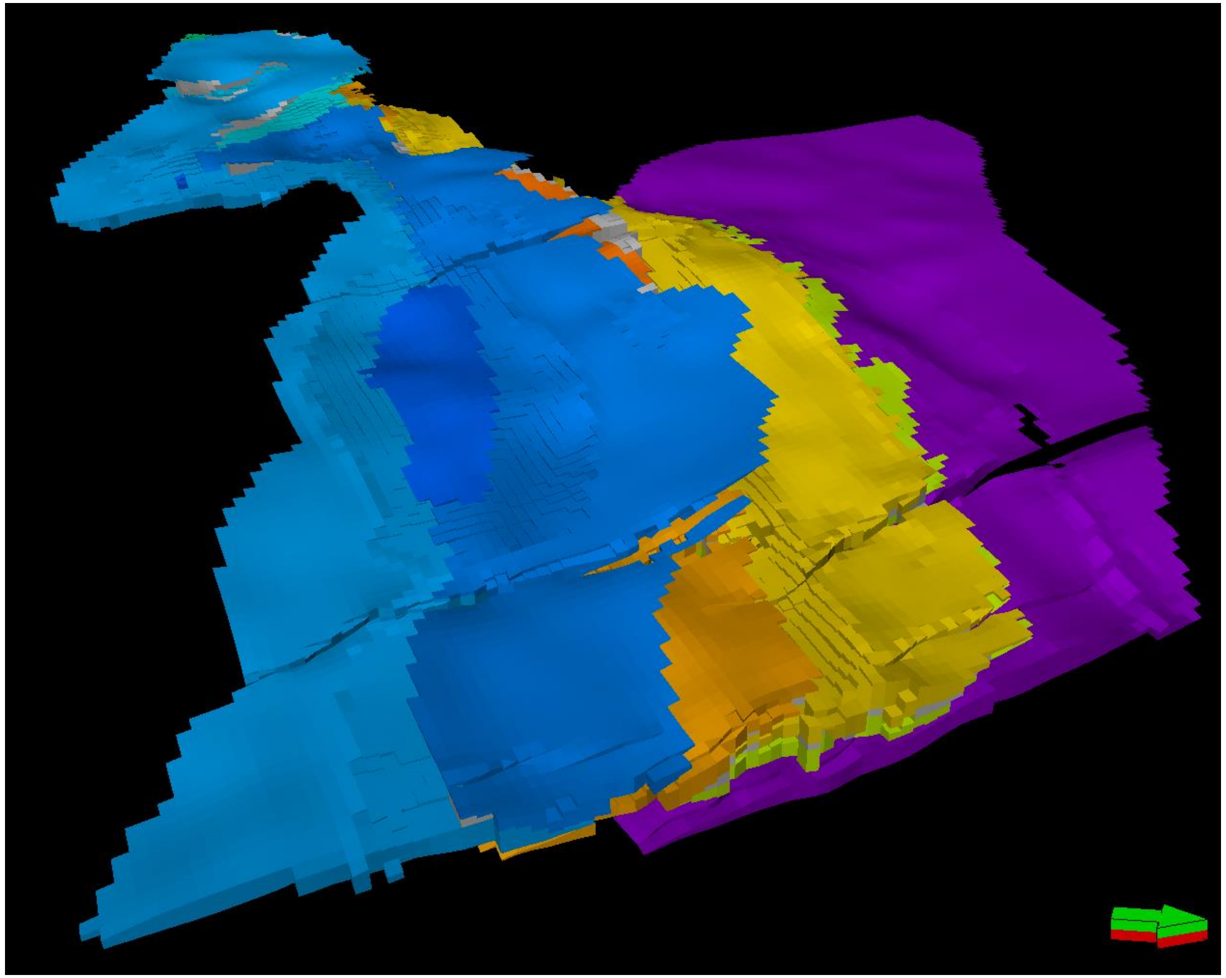
Model Selection
- Well production measure
- Pair-wise distance
- MDS
- Clustering

Deepwater Stratigraphic Complexity

- **Giant deepwater clastic reservoirs with complex stratigraphy – impacts reservoir connectivity**
  A. Amalgamated deepwater slope channel elements
  B. Channel complexes, imaged seismically
  C. Channel complex set
- **Uncertainty in reservoir thicknesses and location / transmissibility of internal boundaries (channel, channel complexes and channel sets)**



**from Campion et al. (2005), Sprague et al. (2005) and Di Celma et al. (2011)*



An Efficient Strategy to Provide Probabilistic Forecasts

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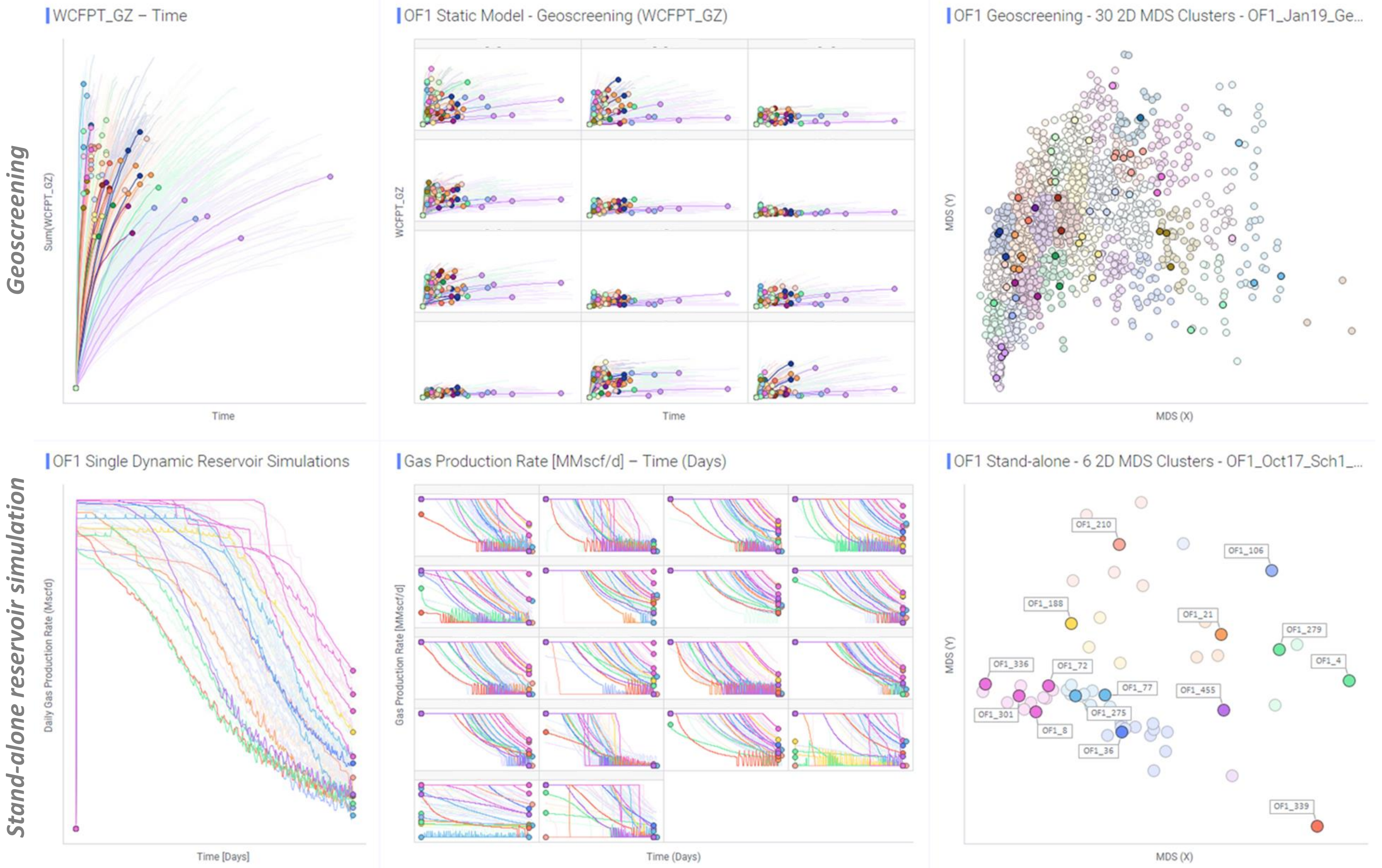
- **Production is sensitive to connected hydrocarbon pore volume**
- **Probabilistic forecasts require large number of samples – stochastic spatial variables**
- **Number simulations from coupled models is unmanageable:** $N_{FFM} = N_{OF1} * N_{OF2}$
    1. Create large sample of single reservoir static models (Monte-Carlo sampling)
    2. Screen models using dynamic connected volume, then dynamic simulation
    3. Compare all model pairs and measure the difference
    4. Multi-dimensional scaling, clustering and selection

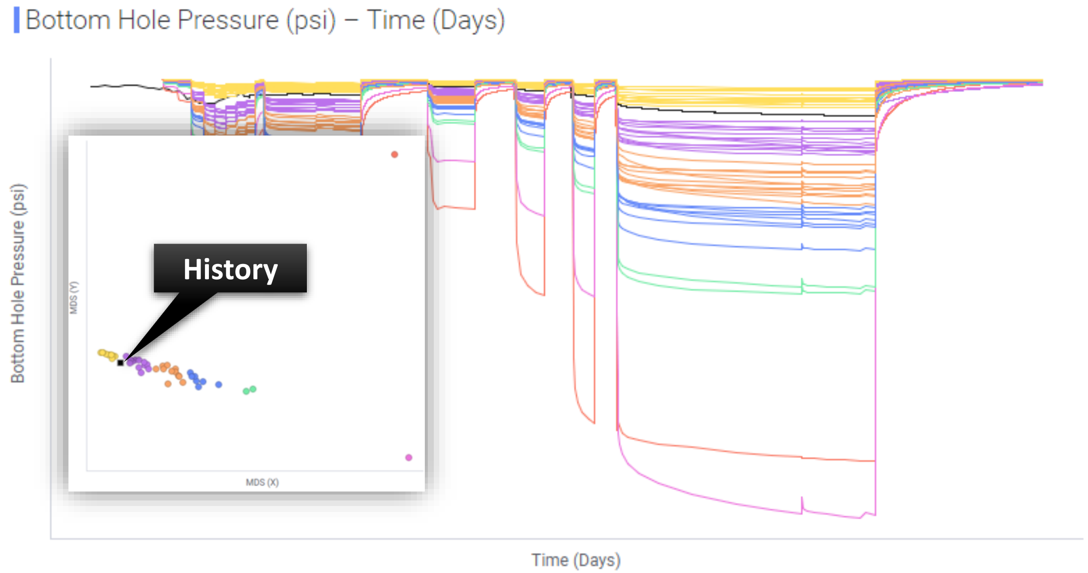


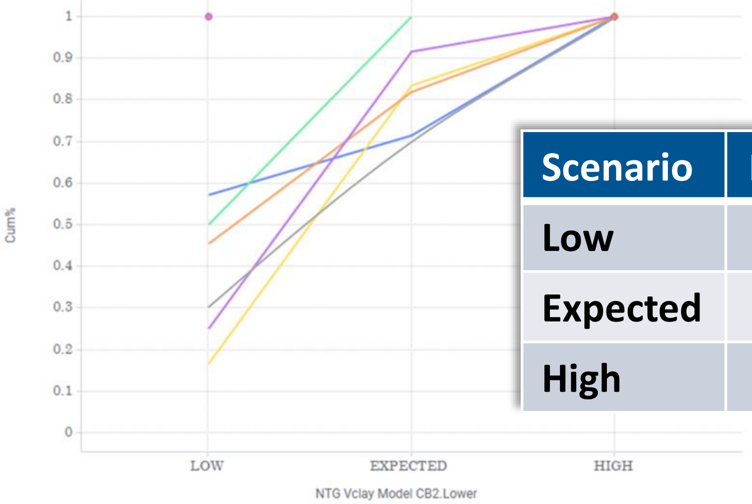
Prediction – Communicate Probabilistic Results

- **Improve communication and make informed decisions from quantitative uncertainty assessment**
- **Generate probabilistic prediction on many levels:**
  - Field production, water breakthrough
  - Wells: Net Pay, HcPV, BHP(t)
  - Maps: P(net pay > 30m)
- **Provide management with calibrated values for portfolio models, planning, risk management and reserves**

Benefits – Model Rejection, Fast Learnings and Updates

- **Stop traditional history matching techniques with ad-hoc model changes to match history, which generally leads to poor predictivity**
  - Most history matching problems are non-unique
  - Does not provide uncertainty assessment
  - Slow process
- **Model rejection techniques with additional information provide**
  - Instant update to prior distribution of uncertain parameters (posterior distribution - Bayes)
  - Learnings
  - Reduction of uncertainty
  - Additional matched models using resampling techniques

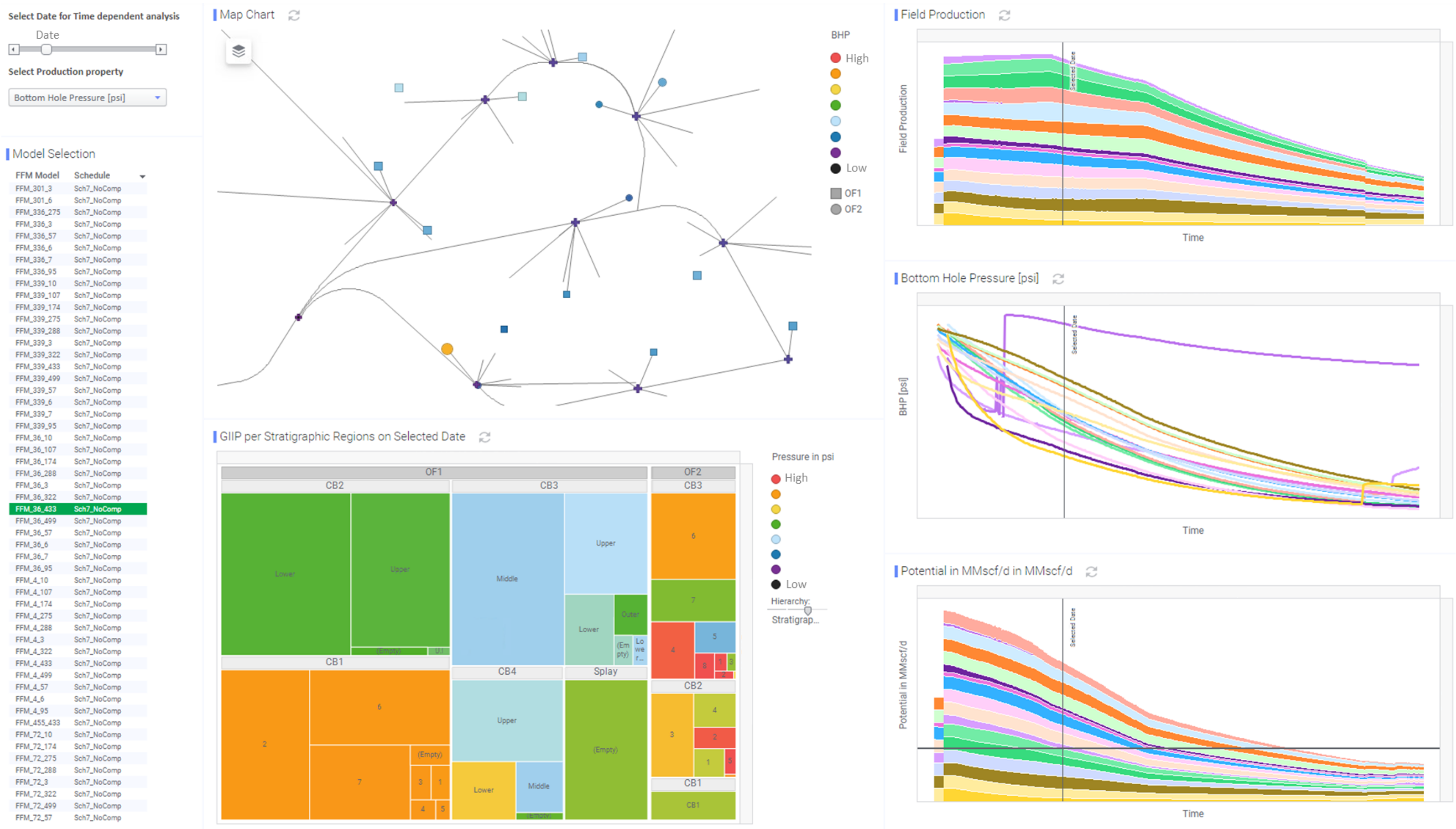




Scenario	Prior	Posterior
Low	0.3	**0.20**
Expected	0.4	**0.68**
High	0.3	**0.12**

Development of Efficient Visualizations & Analytics Tools

- **Challenge:**
  - Large amount of data from various sources
  - Data stored in various locations
  - Multi-disciplinary
- **Solution**
  - Create a central data store (SQL) linked to original data locations and properly managed
  - Establish links between data tables
    - *Model parameters – static volume – connected volume(t)*
    - *Well location – static prediction - dynamic forecast*
  - Develop dashboards to query and visualize the data in one common location
  - Data analytics



Limitations of Tools Employed for this Study

- Pillar-based grids are not ideal to construct complex stratigraphic models where internal surfaces representing geologic boundaries are driving gas recovery ⇨ evaluation of depo-grid underway
- Inability to properly handle structural uncertainty near faults to preserve or modify fault throw
- Sequential built of reservoir model – parallelization is hindered by tool and licensing structure
- Model export for integrated subsurface-surface, coupled reservoir simulation
- Limited access to cluster technology for faster delivery
- Streamline simulation used in geoscreening is not a direct proxy to primary gas depletion

Acknowledgments

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THANK YOU