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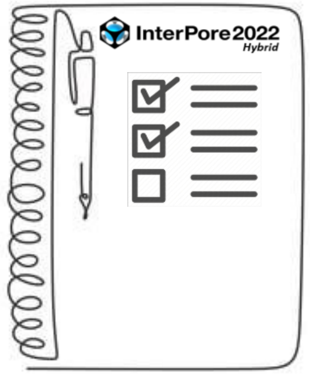
An Uncertainty Quantification Workflow for Naturally Fractured Reservoirs using Proxy Modelling based on Poro-mechanically Informed Flow Diagnostics Simulations

Lesly Gutierrez Sosa, Heriot-Watt University
Sebastian Geiger, Heriot-Watt University
Florian Doster, Heriot-Watt University

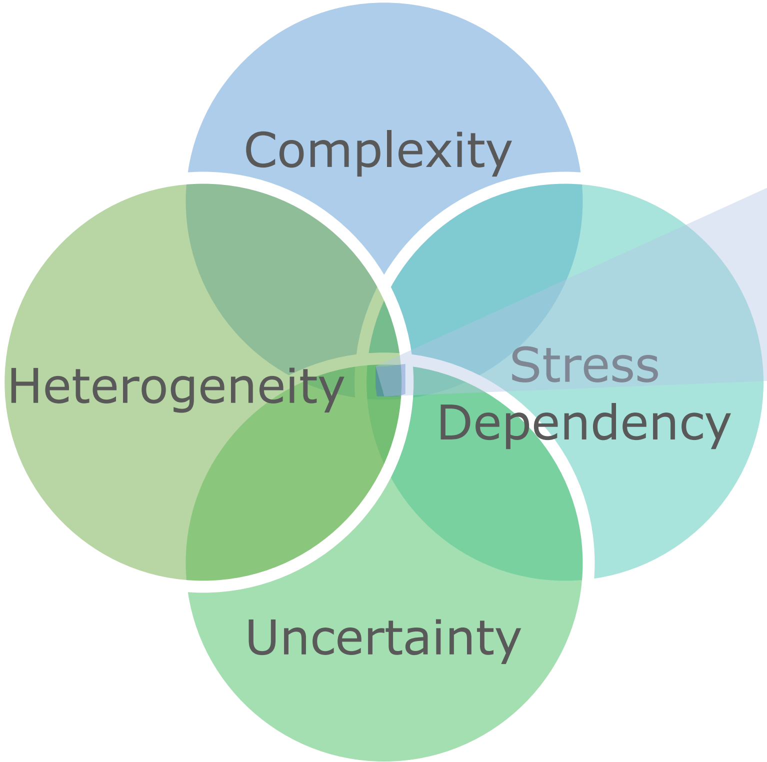
Agenda

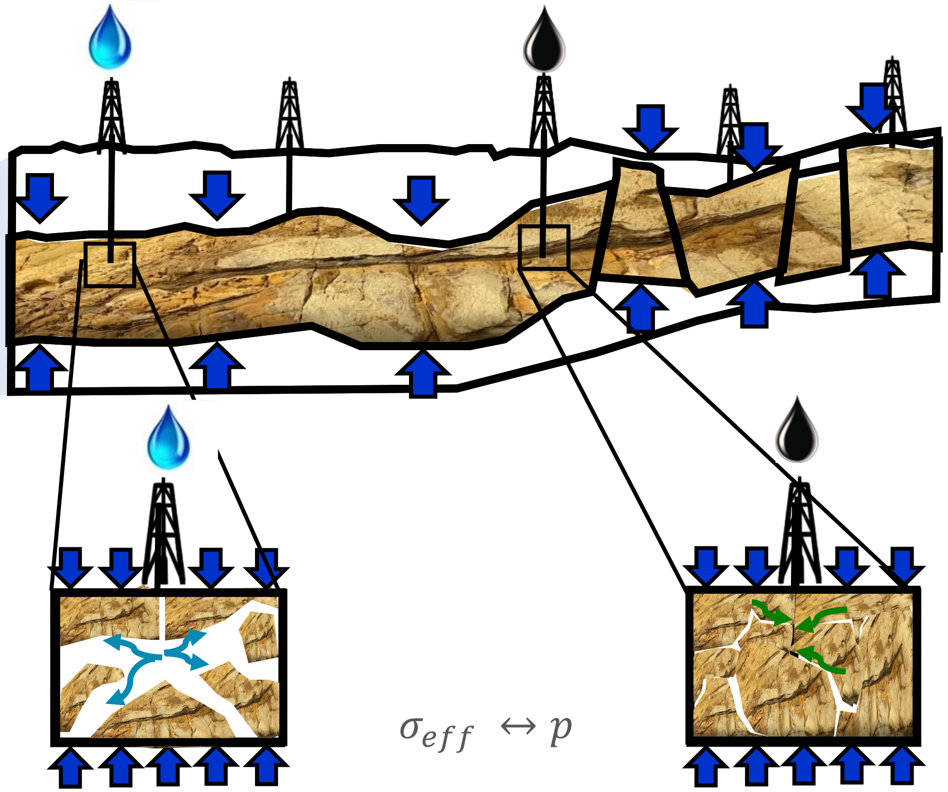
- Introduction
- Objective
- Implementation
- Application – Case Study : Carbonate Reservoir Model
- Conclusions



Introduction

Reservoir Performance Prediction is a challenge





Petrophysical properties changes

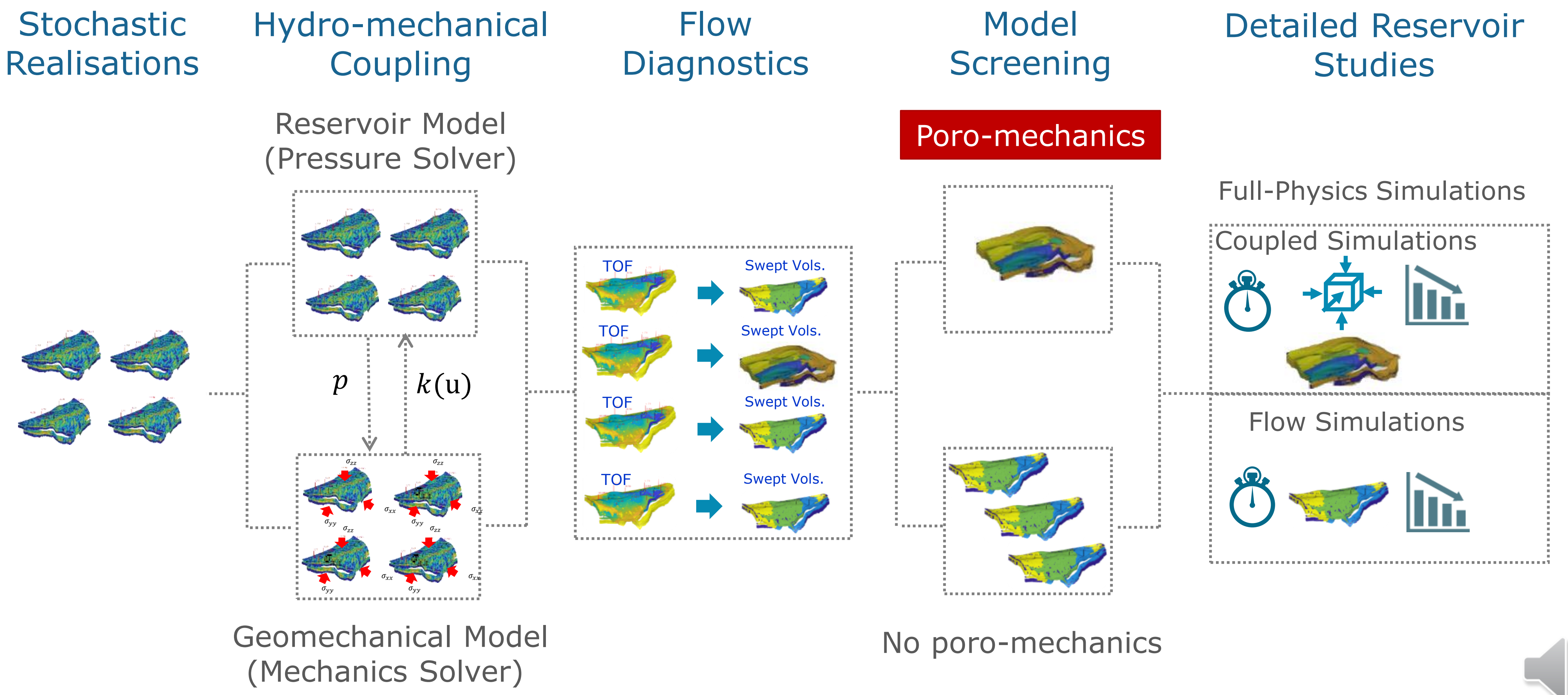
- ☑ Change in Flow Paths
  Reservoir connectivity
- ☑ Change in Dynamics
  Productivity and injectivity
- ☑ Challenge
  - Screening poro-mechanics
  - Reducing CPU cost

Simpler Practical Approach
Poro-mechanically-informed flow diagnostics

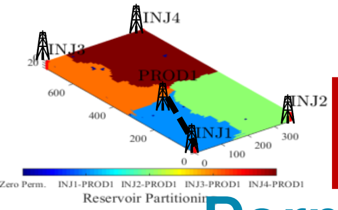
To Be Considered

- ☑ High computational overhead
- ☑ Limited uncertainty quantification

Objective


Stochastic Realisations
Hydro-mechanical Coupling
Flow Diagnostics
Model Screening
Detailed Reservoir Studies
Reservoir Model (Pressure Solver)
p
$k(u)$
Geomechanical Model (Mechanics Solver)
TOF
Swept Vols.
TOF
Swept Vols.
TOF
Swept Vols.
TOF
Swept Vols.
Poro-mechanics
No poro-mechanics
Full-Physics Simulations
Coupled Simulations
Flow Simulations

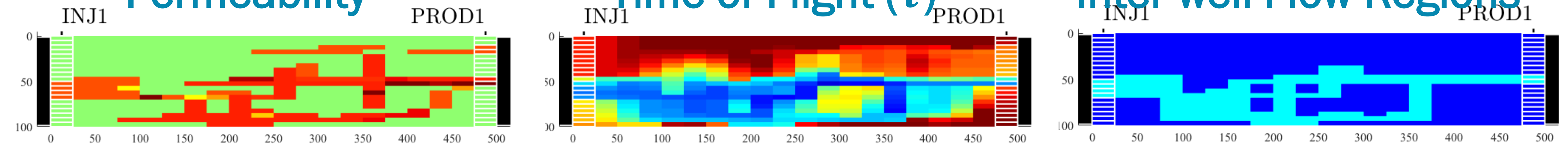
Poro-mechanically Informed Flow Diagnostics (FD)



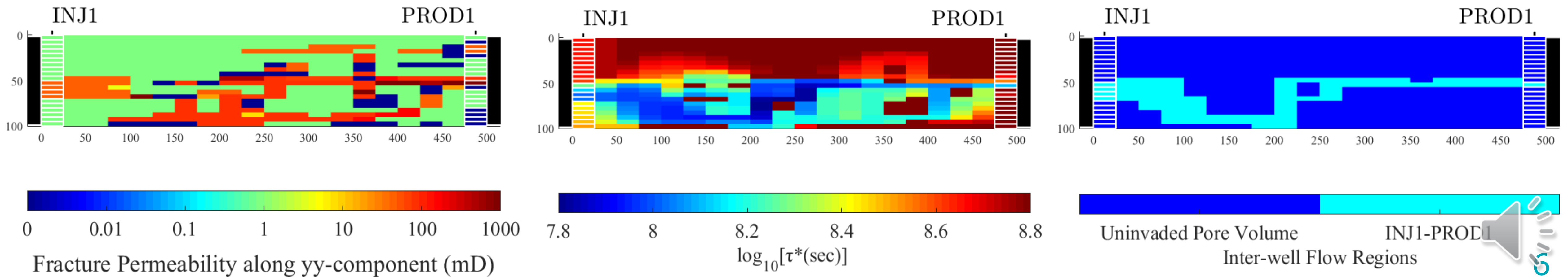
Production – Injection Operation (0.5 PV injected)

w/o Poro-mechanics

Permeability | Time of Flight (τ) | Inter-well Flow Regions

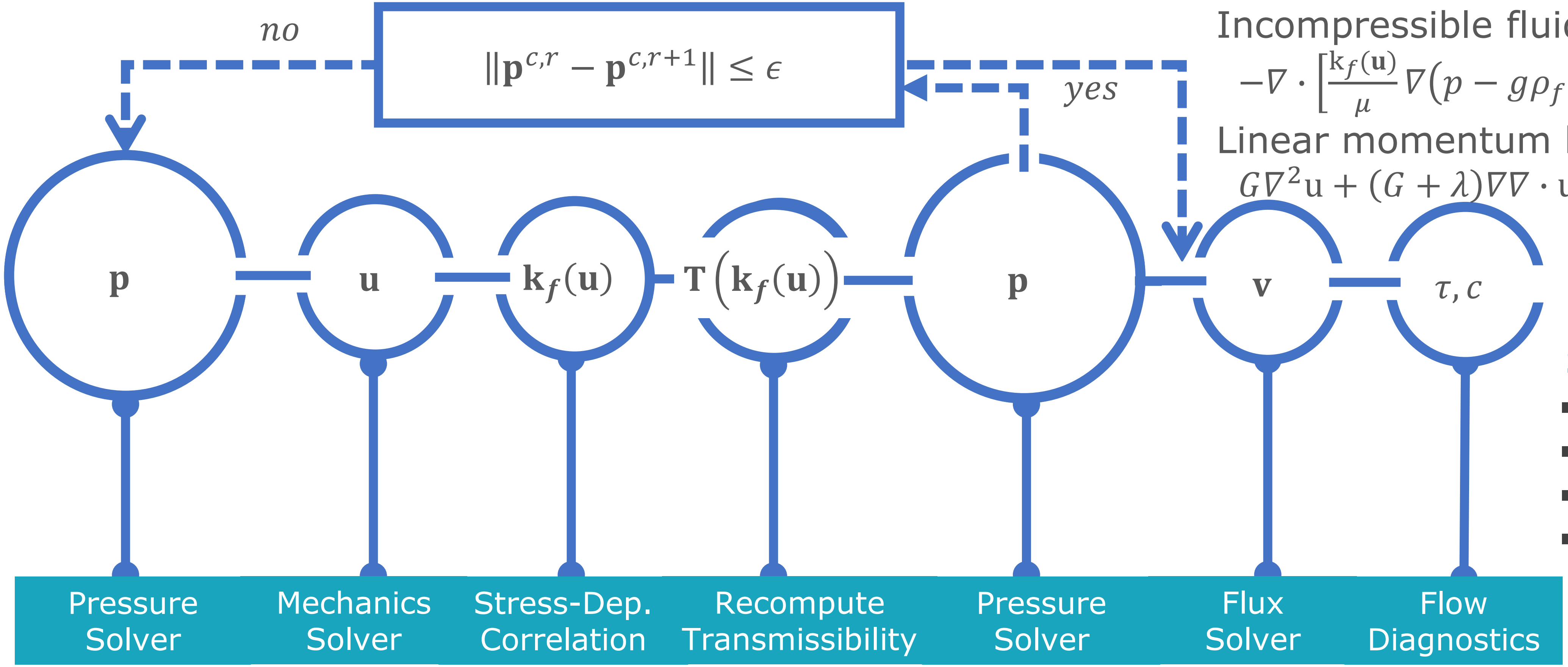


w/ Poro-mechanics



Poromechanics in FD Framework

Sequentially Coupled Solution – Implemented in open source MRST



Incompressible fluid pressure equation

$$-\nabla \cdot \left[\frac{\mathrm{k}_f(\mathbf{u})}{\mu} \nabla (p - g\rho_f z)\right] + q = 0$$

Linear momentum balance equation

$$G\nabla^2 \mathrm{u} + (G + \lambda)\nabla\nabla \cdot \mathrm{u} = -\alpha\nabla p - \rho b$$

Stress dependency

- $\mathbf{k}_m(\mathbf{u}), \phi_m(\mathbf{u})$
- $k_r(\mathbf{u}), P_c(\mathbf{u})$
- Matrix-Fracture
- transfer rate

Discretised macroscale constitute model

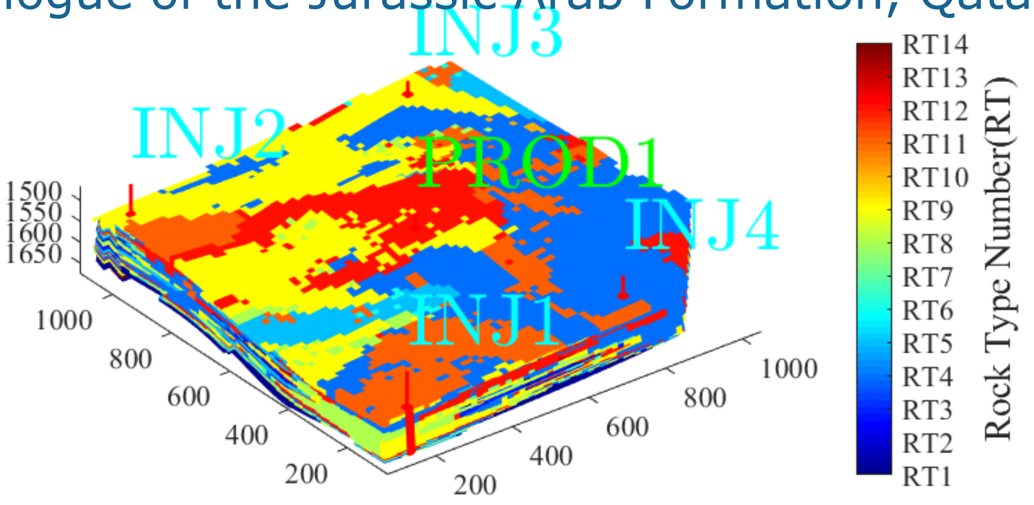
$\mathbf{T}(\mathbf{u}^{c,r})\mathbf{p}^{c,r+1} = \mathbf{f}_p$ where $\mathbf{k}_f(\mathbf{u}^{c,r})$

$\mathbf{K}\,\mathbf{u}^{c,r+1} = \mathbf{f}_u + \mathbf{Q}\mathbf{p}^{c,r+1}$ then $r = r + 1$

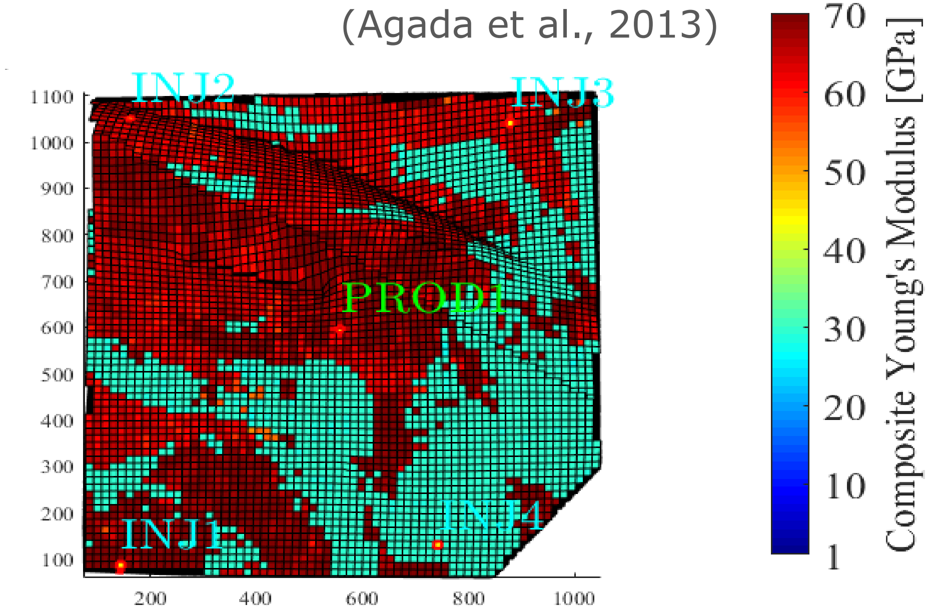
(Gutierrez Sosa et al., 2020)
(Gutierrez Sosa et al., 2022)

Application – Amellago Model

Analogue of the Jurassic Arab Formation, Qatar



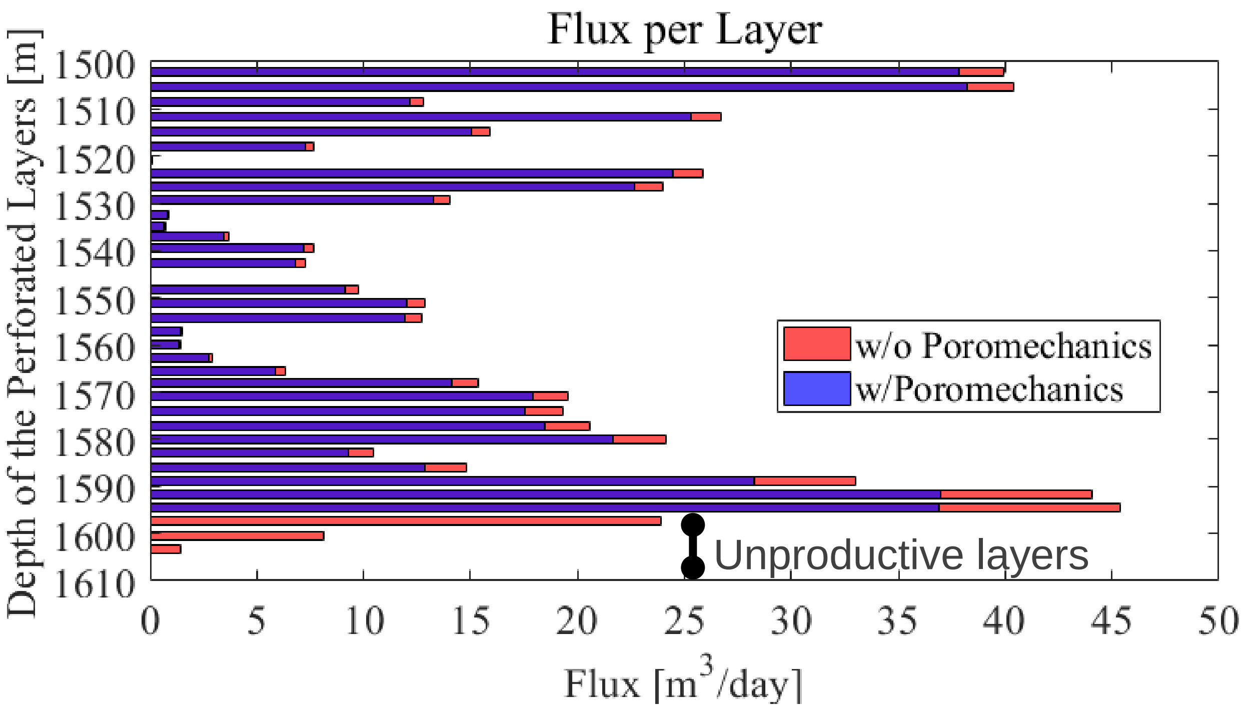
(Agada et al., 2013)



Subjected to production induced changes and gravity load

- Continuous and thin fractured carbonate bodies
- Heterogeneous petrophysical properties
- Heterogeneous matrix stiffness

Effect on Permeability and Productivity



When accounting for poro-mechanics

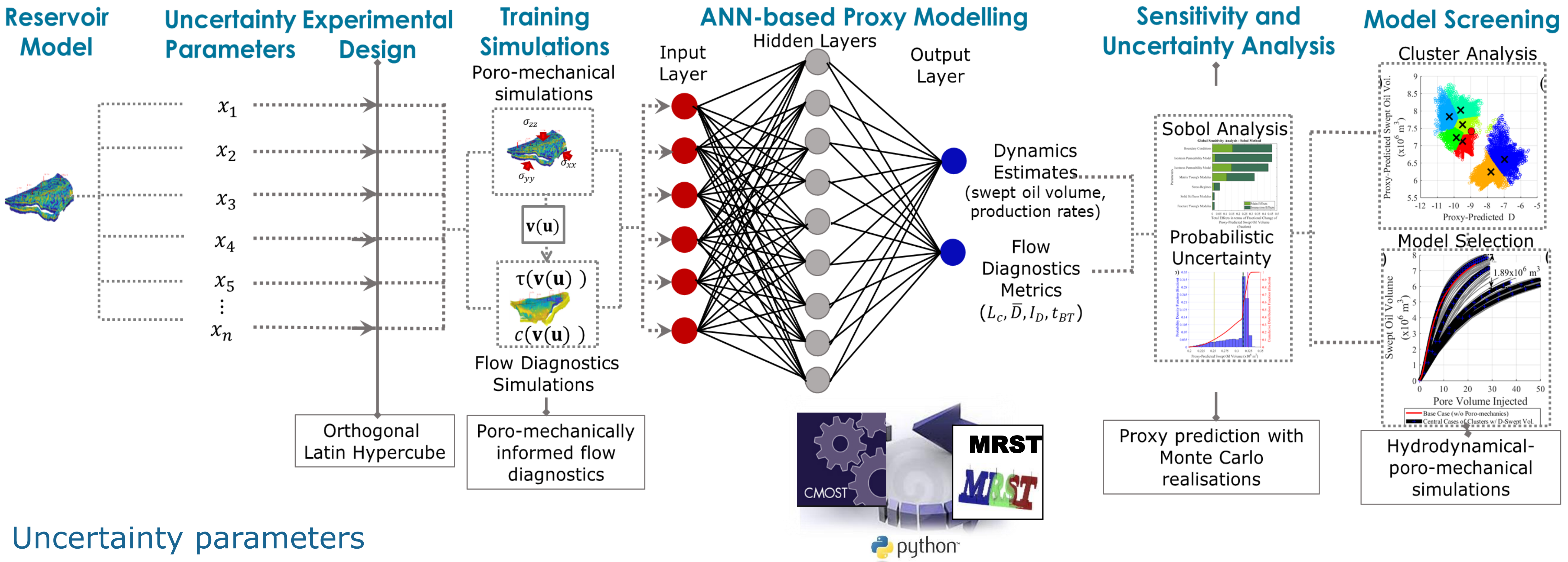
- Subtle permeability reduction
- Substantial reduction of productivity
- Addition of unproductive layers

Comparison of cases w/ Poro-mechanics

- Differences in reservoir connectivity, recovery and injectivity profiles, breakthrough time

Computational efficiency: whole workflow took 20 min

Proposed Uncertainty Quantification Workflow



Uncertainty parameters

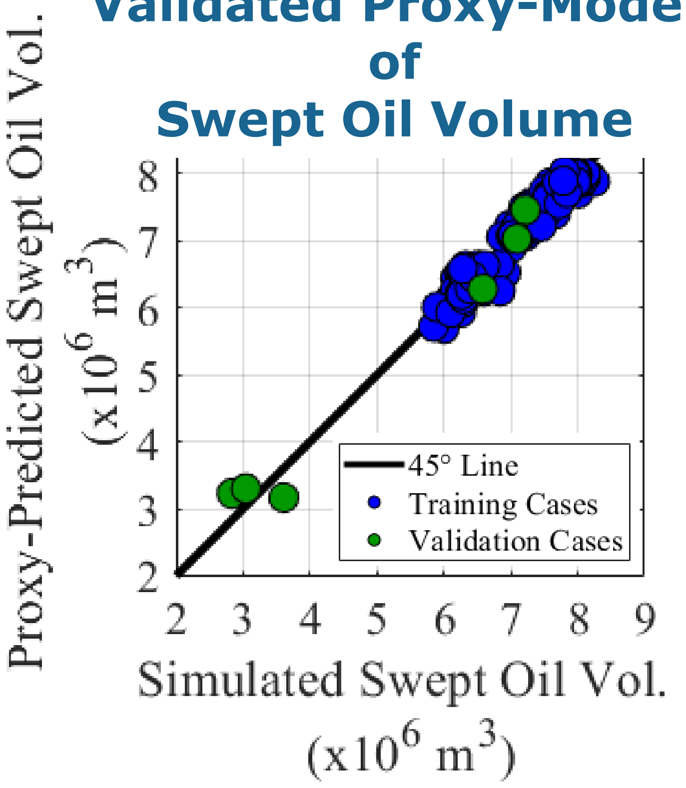
- Boundary conditions, permeability model, stress regimes and some mechanical Moduli

ANN-based proxy model

- 335 poro-mechanically informed FD – 3.5 days

Proxy-based Sensitivity Analysis

Validated Proxy-Model of Swept Oil Volume

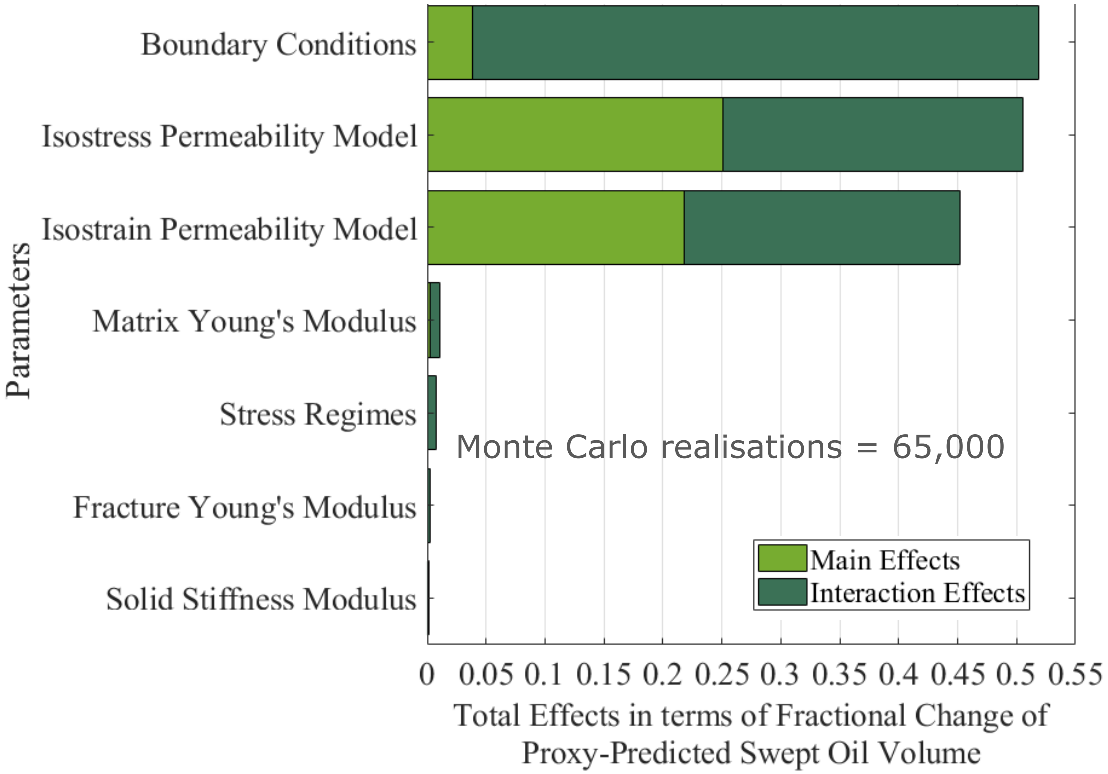


ANN Neural Network

R^2-Training = 0.987

R^2-Validation = 0.975

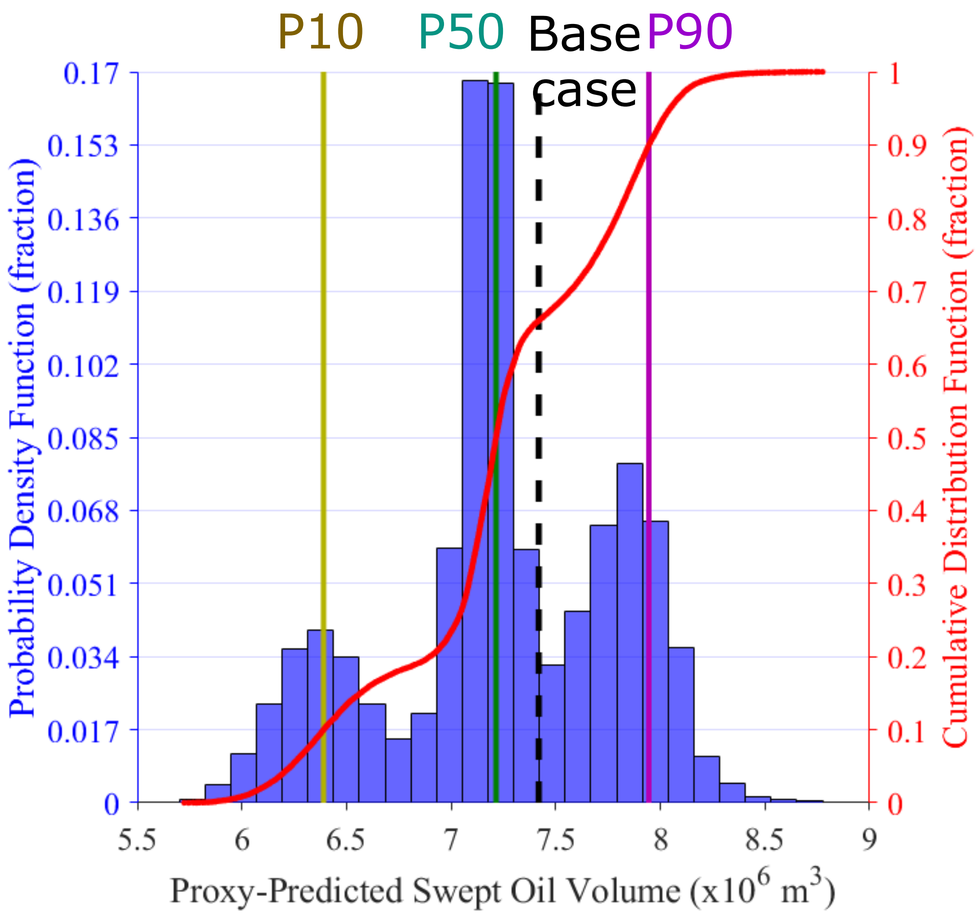
Sobol (Global) Sensitivity Analysis



- Non-linear and interaction relationship between input parameters
- Identification of most influential parameter
- Guiding further experimental designs

Proxy-based Uncertainty Quantification

CDF and PDF functions of Swept Oil Volume



Monte Carlo Realisations = 65,000

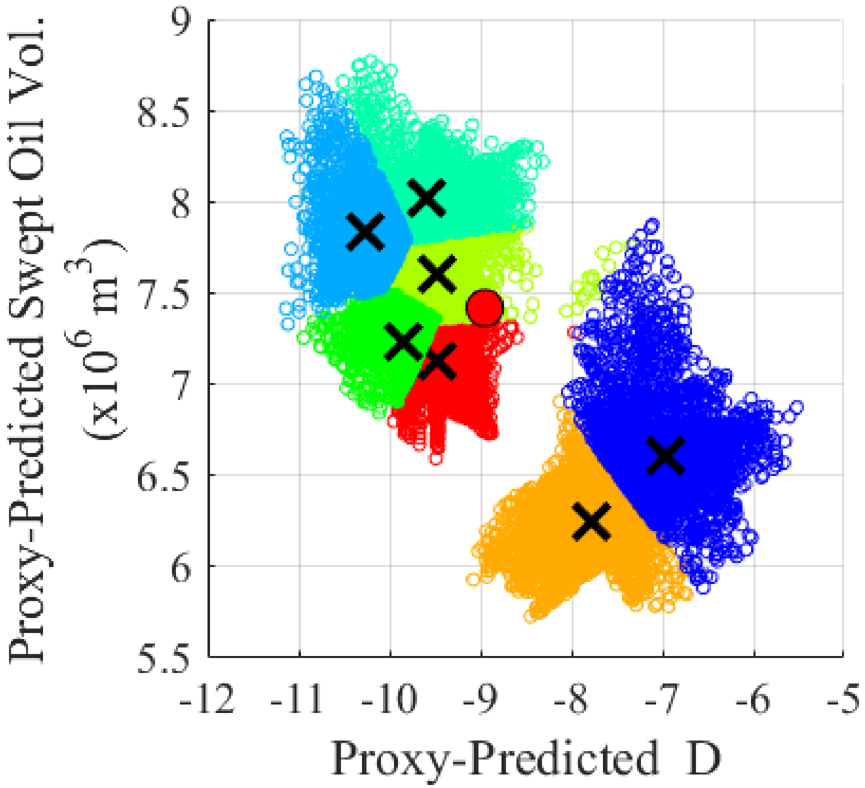
Monte Carlo Realisations w/ Fracture-Dominated Flow = 40,068

- PDF of Proxy-Predicted Swept Oil Volume
- CDF of Proxy-Predicted Swept Oil Volume
- Base Case (w/o Poro-mechanics) Swept Oil Volume= 7.418 x10^6 m^3
- P10 Swept Oil Volume$_{\text{Proxy-Prediction}}$ = 6.39 x10^6 m^3
- P50 Swept Oil Volume$_{\text{Proxy-Prediction}}$ = 7.215 x10^6 m^3
- P90 Swept Oil Volume$_{\text{Proxy-Prediction}}$ = 7.945 x10^6 m^3

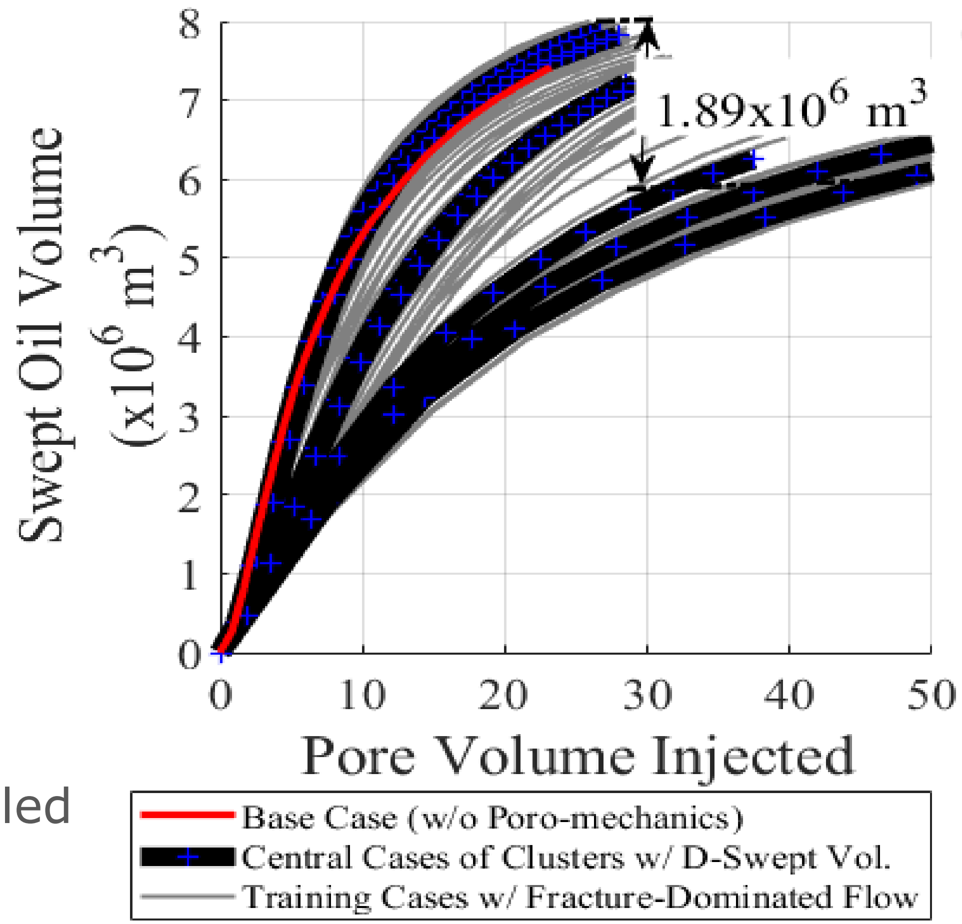
- Broad exploration using 1000’s MC realisations

Clustering and Model Screening

Cluster Analysis



Selected cases (simulated)



- Identification of candidates to be studied in more detailed
- Candidates that cover the full range of uncertainty

Conclusions

Integration of Poromechanics in Flow Diagnostics Framework

- Feasible and computationally efficient
- Quick screening of poromechanical effects
- Complement to reservoir simulations workflows

Application of Poromechanical informed Flow Diagnostics

- Amellago carbonate model
- Assess of petrophysical and mechanical heterogeneity

Involvement in an Uncertainty Quantification Workflow

- Decision-making workflows

Thank you / Questions

Lesly Gutierrez Sosa, PhD Student, Heriot-Watt University
Prof. Sebastian Geiger, Heriot-Watt University
Prof. Florian Doster, Heriot-Watt University

lmg1@hw.ac.uk S.Geiger@hw.ac.uk F.Doster@hw.ac.uk

Thank You!