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CARBON CAPTURE, UTILIZATION, AND STORAGE
THE INDUSTRY'S LEADING EVENT FOR CCUS MANAGEMENT AND DEVELOPMENT
3-5 MARCH 2025
HOUSTON, TEXAS

Uncertainty Assessment Methodology for Defining the Area of Review (AoR) in CO_2 Injection Wells

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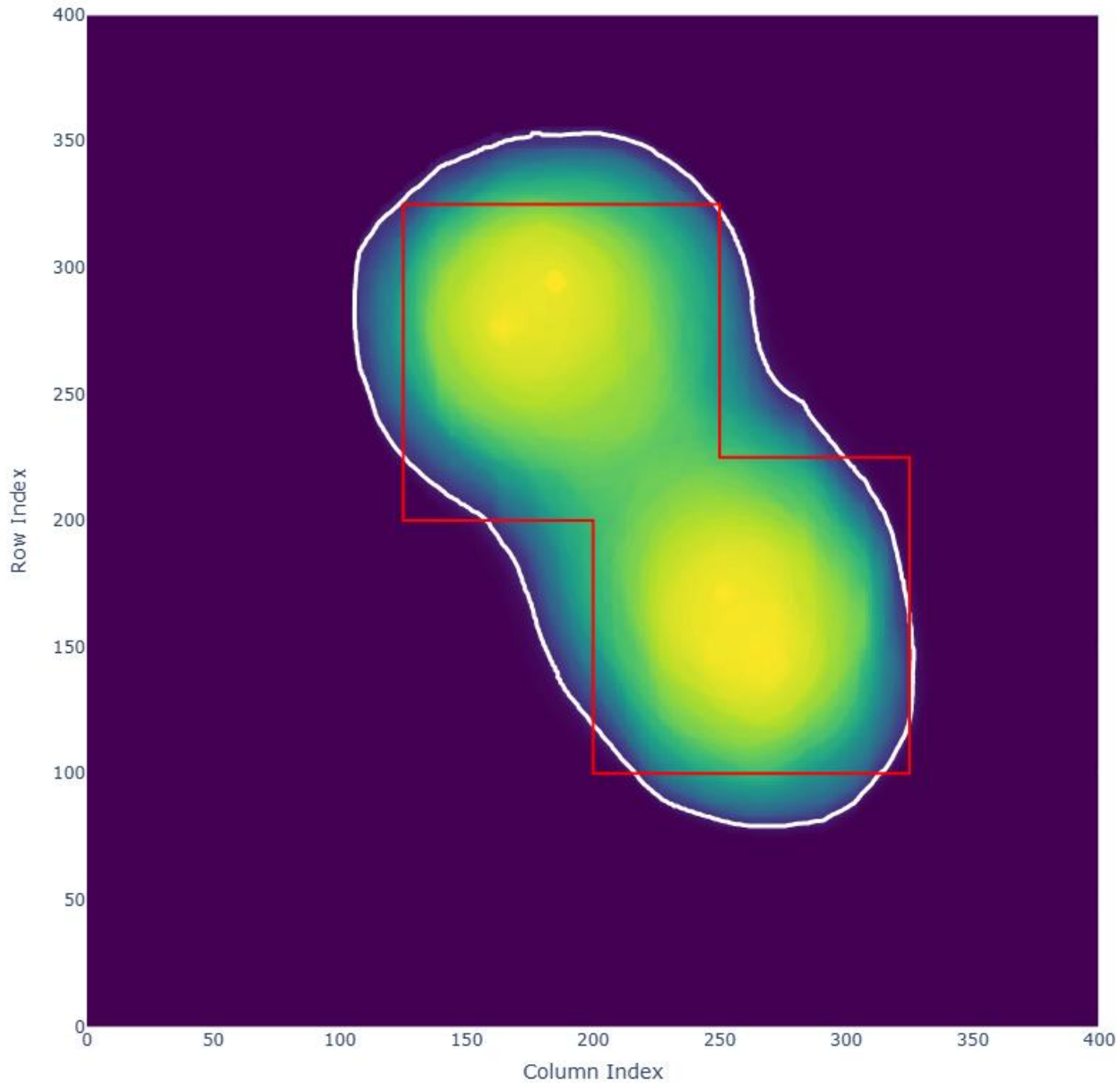
Agenda

- Objectives
- Overview
- Methodology
- Case Study
- Conclusions



Objectives

Develop methodology to support:

- Develop a robust methodology to support regulatory compliance, including EPA Class VI well requirements, CARB, and other relevant frameworks, domestics and internationals.
- Implement an uncertainty assessment approach to accurately evaluate the Area of Review (AoR) for CO_2 storage projects.
- Optimize CO_2 injection strategies to maximize storage efficiency while mitigating risks.

Challenges

- Ensure safe and efficient CO_2 injection while minimizing uncertainties and risks.
- Maintain project integrity by preventing CO_2 migration beyond the lease area and ensuring long-term containment.

Overview

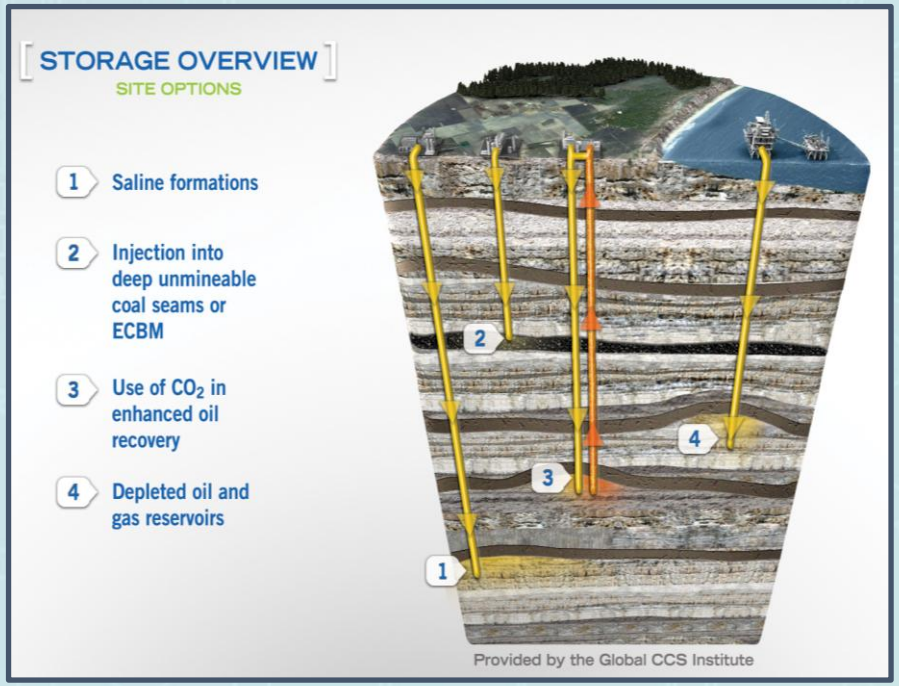
CO_2 storage is focused on long-term geological storage to keep it separate from atmosphere for 1000`s years

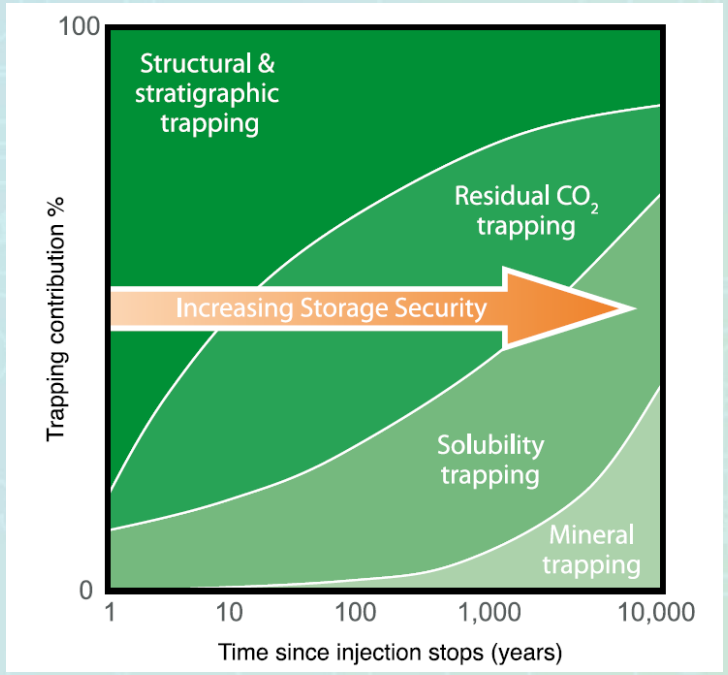
Storage options:

- Saline aquifers
- Depleted oil/gas reservoirs
- Enhanced oil recovery
- Coalbeds
- Basalt
- Others...

Trapping mechanisms:

- Structural trapping
- Hysteresis
- Solubility
- Mineral trapping





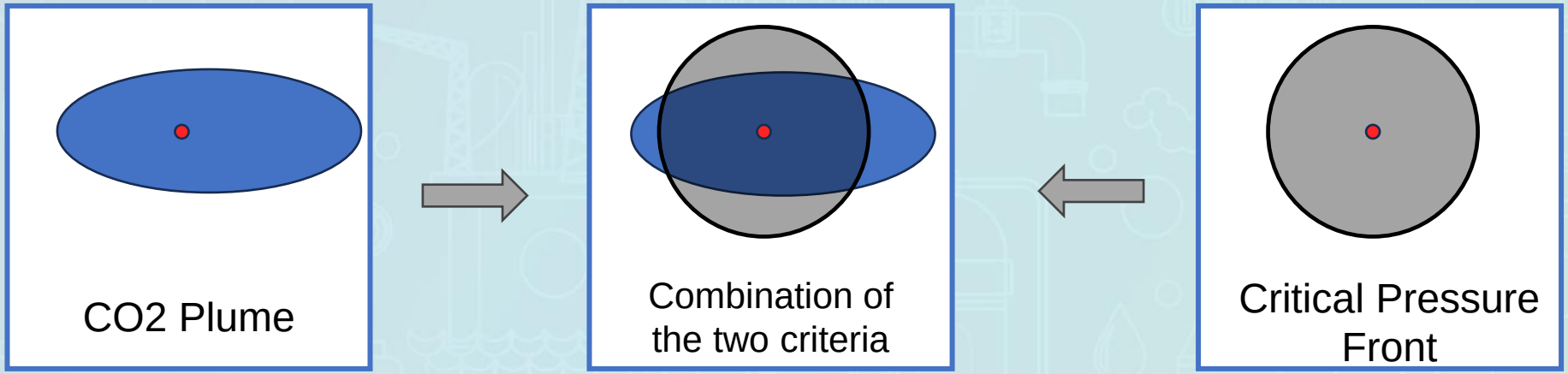
Area of Review-AoR

Area of Plume

- Considers the area of the CO_2 plume in gas/supercritical conditions.
- Due to buoyance effects, it will leak if caprock sealing is compromised.

Area of Critical Pressure

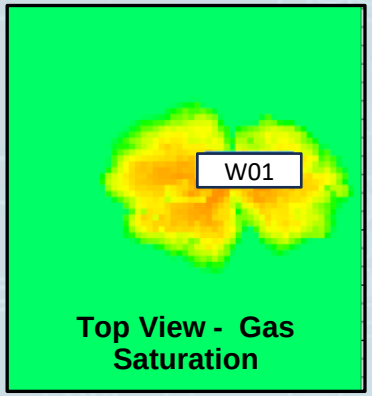
- Area where the Δp is higher than critical pressure.
- Critical pressure is the minimum pressure that can make the carbonated water to reach the closest USDW (underground sources of drinkable water).



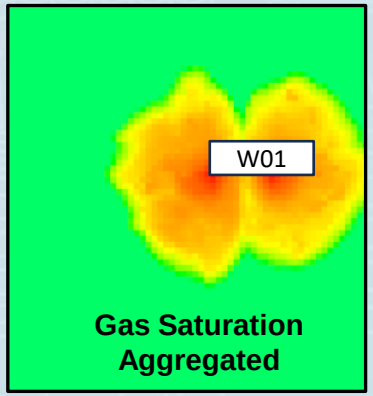
Area of Review-AoR

Bandilla et al., 2017

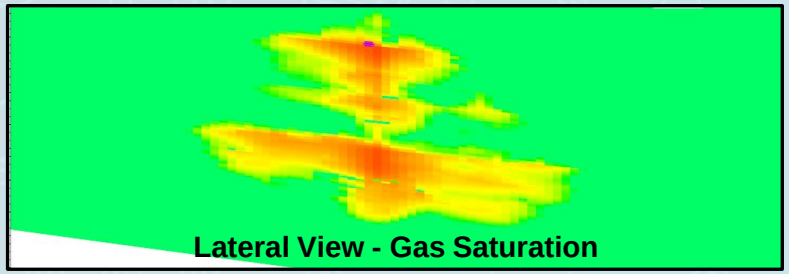
AoR calculation and features in a Simulation Model



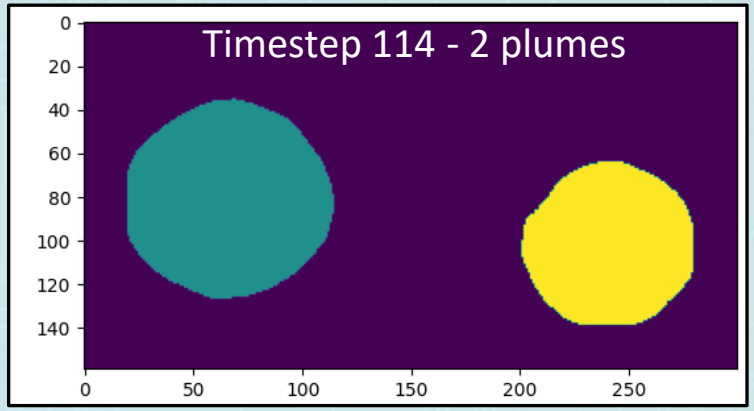
Top View - Gas Saturation

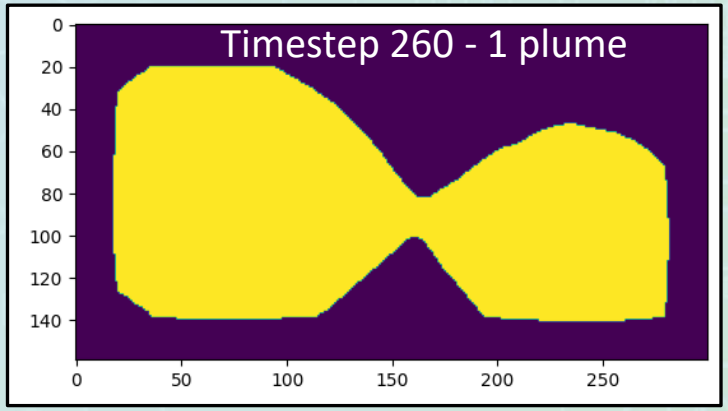


Gas Saturation Aggregated


Lateral View - Gas Saturation

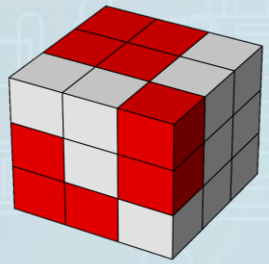
- The AOR boundary should be measured considering all layers through vertical aggregation
- The block will be added to the AoR group if it meets any of the conditions (plume or critical pressure)
- Multiple AoR can be tracked for analysis or optimization purposes (i.e. keeping AoR separated for different well sites)



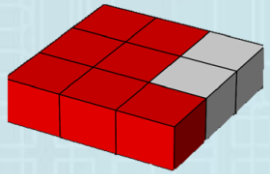


AoR calculation

1. Binary array based on parameter cut-off*

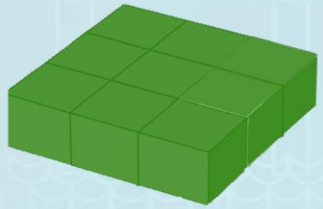


2. Aaggregate vertically with max value



3. Get number of non-connected bodies (n cluster)

4. Calculate block area in a reference layer



5. Multiply step 2 with 4

6. Sum values from step 5 in each cluster

Total Area (ft^2)

*For saturation and critical pressure, if block value for at least one of the conditions if higher than cutoff, 1 is defined if not 0.

Uncertainties

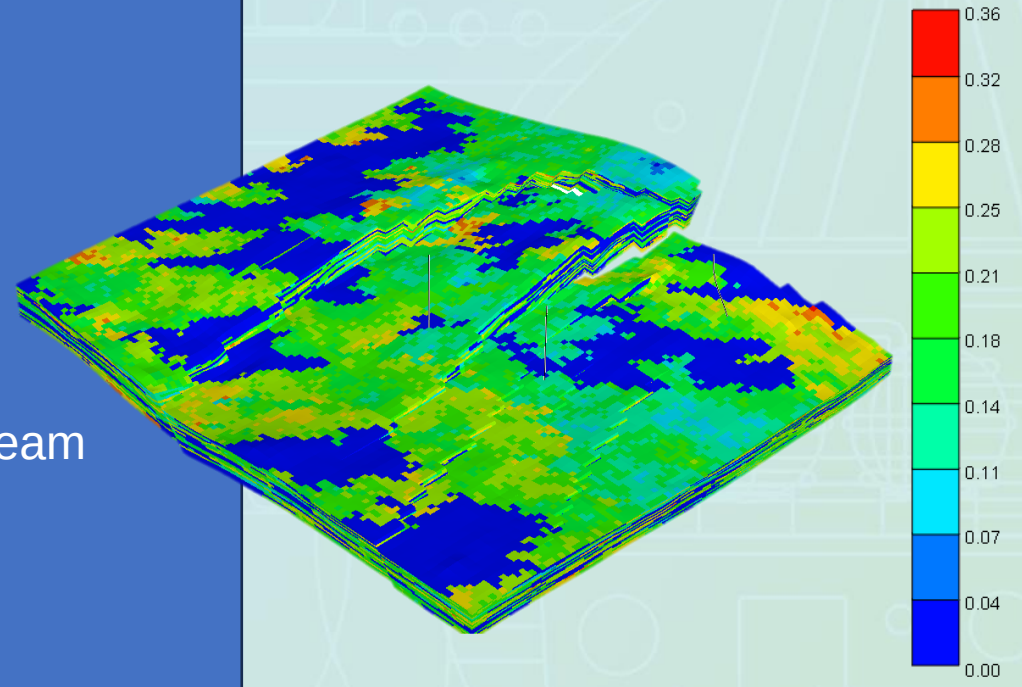
AoR size and shape will depend on multiple factors

Uncertainties regarding reservoir characteristics:

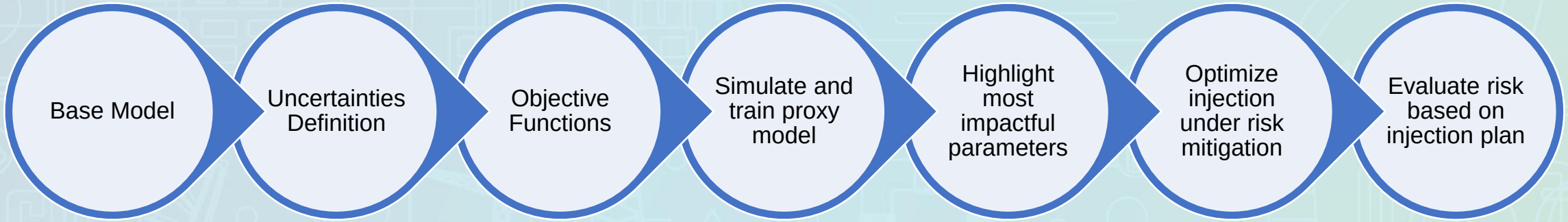
- Heterogeneity:
  - Porosity
  - Permeability
  - Preferential flow paths
- Fluid
  - Miscibility (depleted oil reservoirs)
  - Salinity (saline aquifers)
- Rock-fluid
  - Relative permeability tables
  - Capillary pressure
  - Hysteresis
- Reservoir Conditions
  - Temperature
  - Pressure

Uncertainties regarding operational conditions and subsurface:

- Individual gas rates
- Injection pressure at surface/bottom-hole
- Perforation interval
- Facility capacity
- Gas deliverability
- Impurities in the gas stream
- …



Methodology



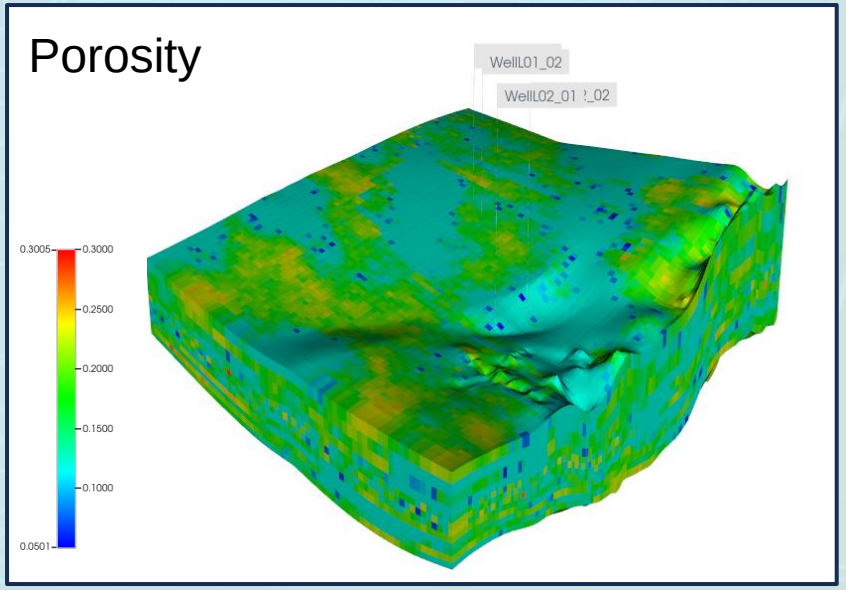
Case of Study

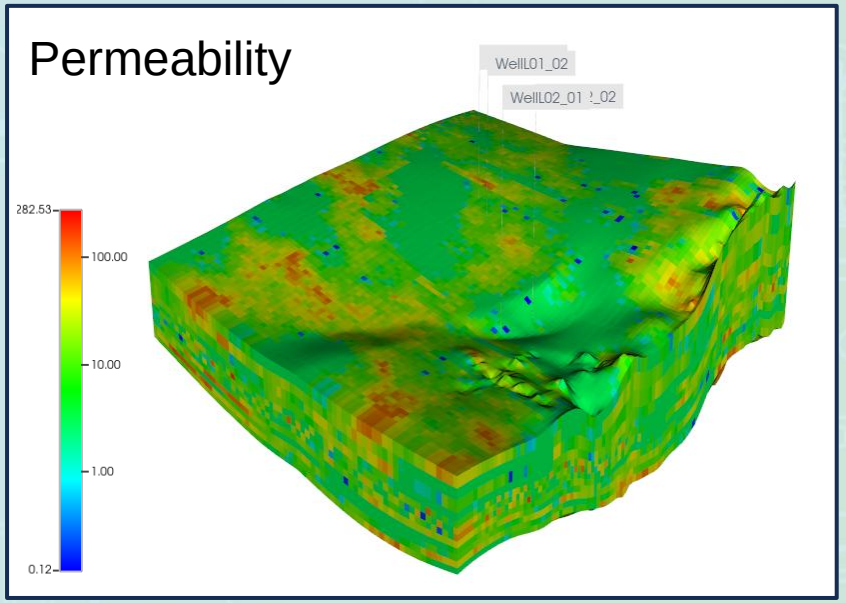
Base Case

- 400x400x96 cells (>15 M grid cells)
- 400x400x7 ft
- Injection depth 4400 ft (super critical conditions)
- 2 injection site (W01, W02)
- 4 injection wells

Uncertainties:

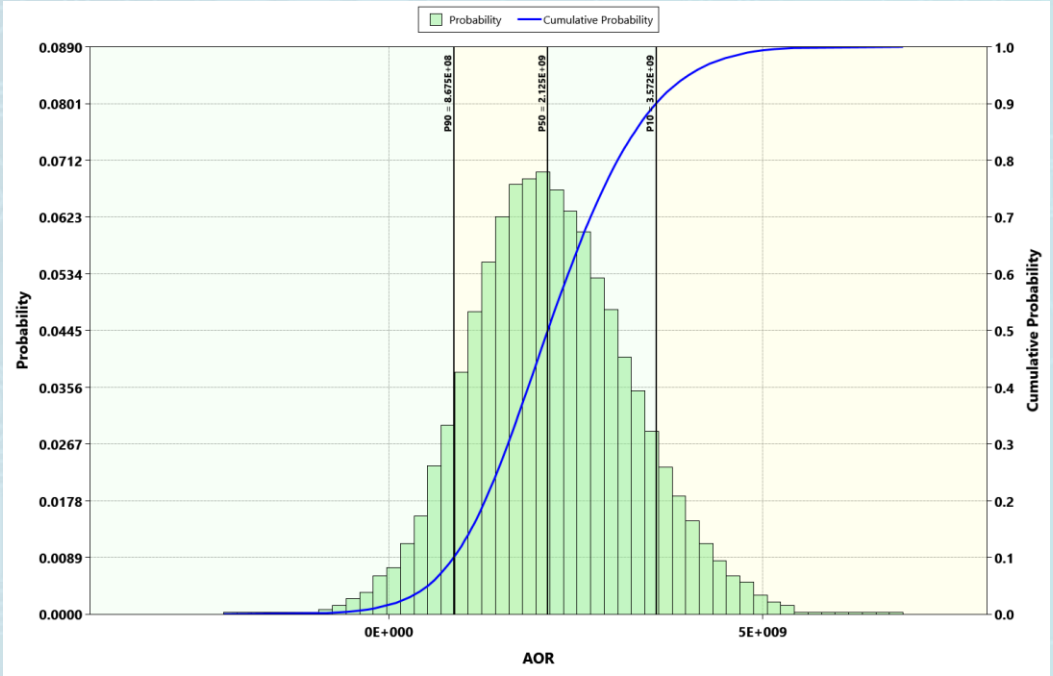
Uncertainty	Parameter Name	Base	Min	Max
Porosity Multiplier	PHIE	1.0	0.9	1.1
Permeability Coefficient $K_{coef}(\emptyset^b)$	PERM3	52496	25000	72000
KvKh	KvKh	0.5	0.0075	0.5
Maximum Pcap	PCWMAX	51.9	10	100
Individual Gas Rates (ft^3/day)	GasRateW0x_0x	60E+06	5	95E+06

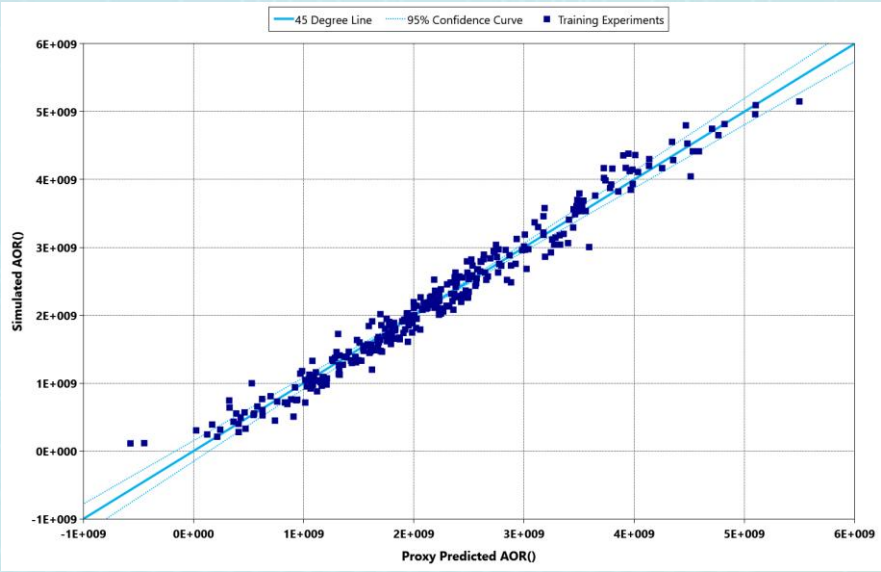


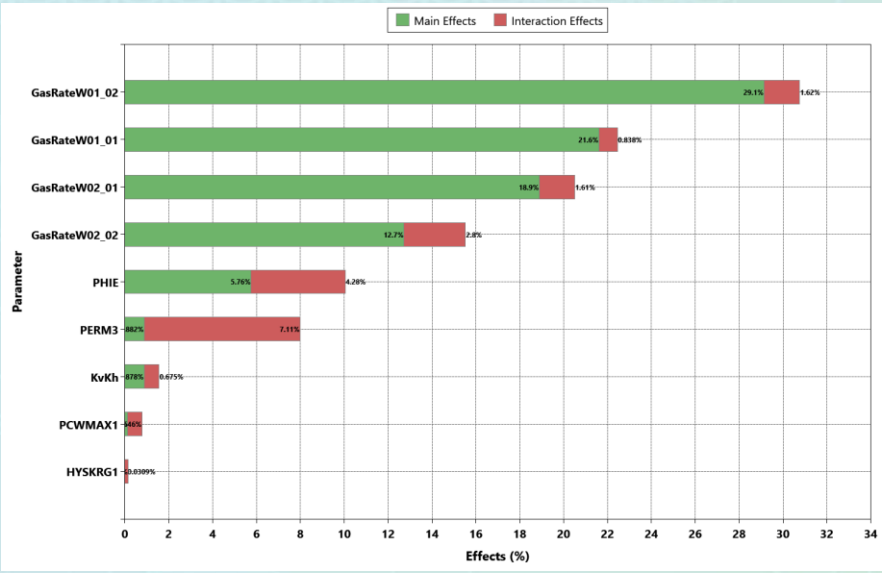


Results

- Results show that proxy model has a good accuracy to predict AoR
- AoR probability distribution and cumulative probability provide a quantitative measurement of the AoR
- Most impactful uncertainties (reservoir modeling and operation conditions are highlighted)





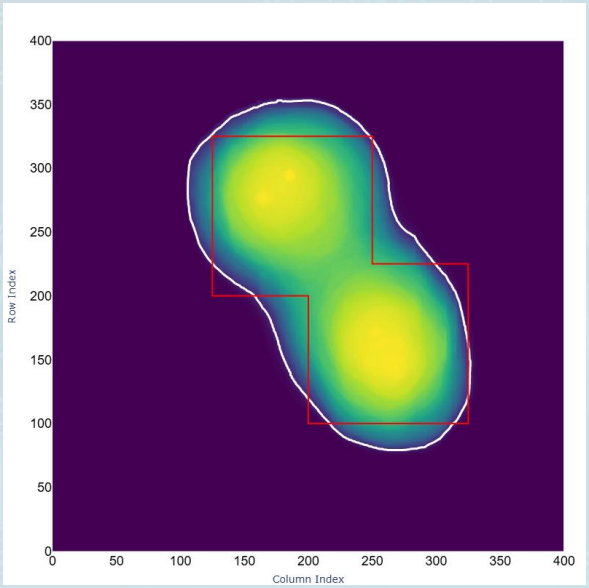


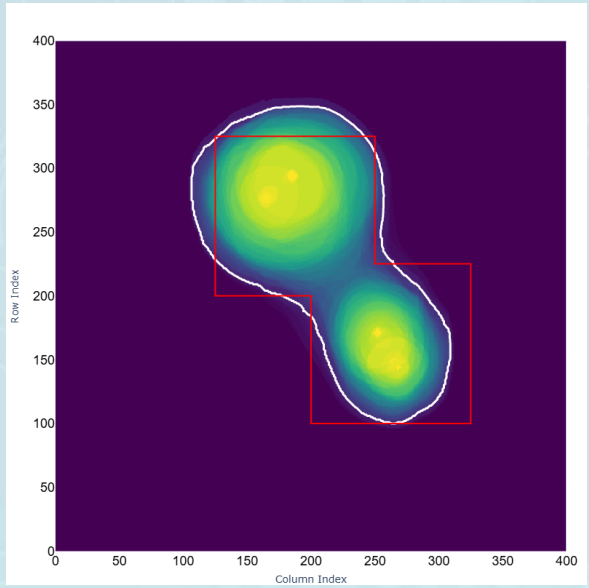
AOR=−2.67E+10+2.59∗**GasRateW01_01**+20.41∗**GasRateW01_02**−28.24∗**GasRateW02_01**−55.29∗**GasRateW02_02**−6.43E+09∗**HYSKRG1**+5.34E+09∗**KvKh** ...

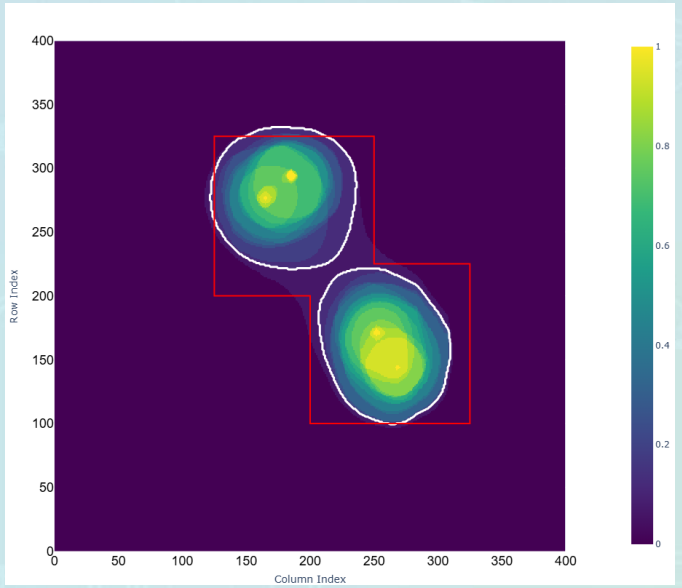
AoR under uncertainties

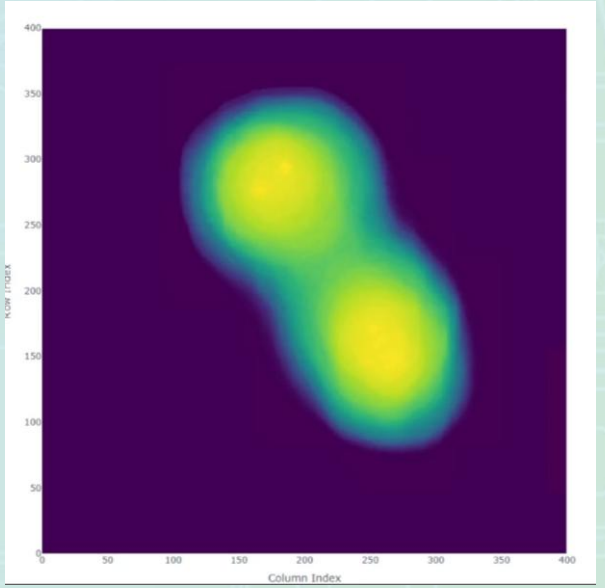
- A useful tool to understand the impact that operational conditions can have on the AoR is to have real-time updates based on filtered constraints
- Inputs: lease area (red boundary), gas saturation cutoff, critical pressure cutoff

Original rates variability | Reduction in W01 CO2 rate | Reduction in W01/W02 CO2 rate | Real time changes







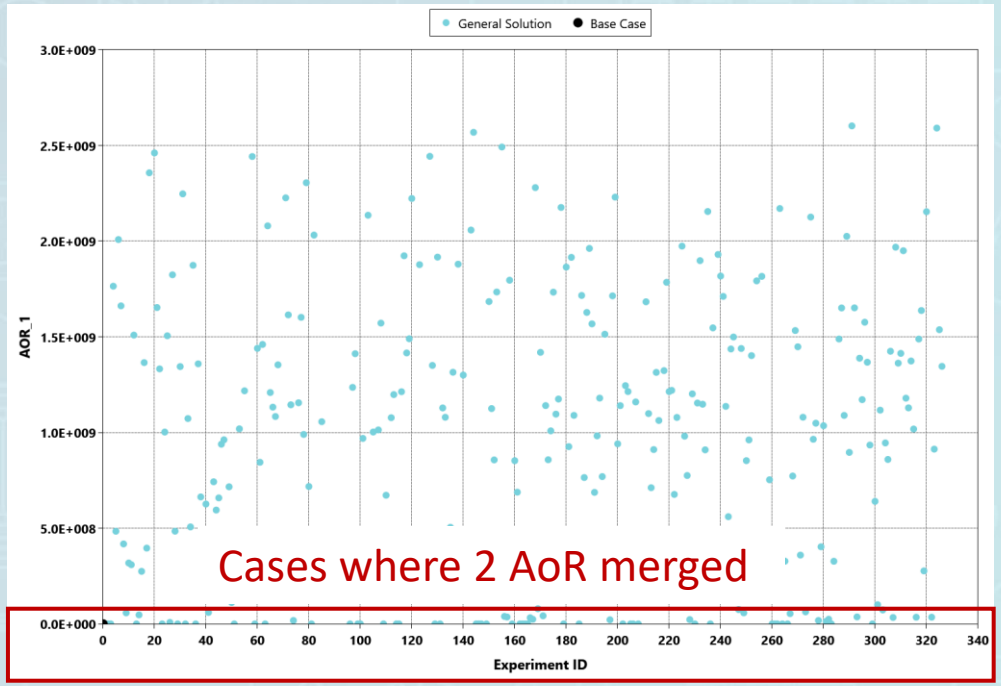


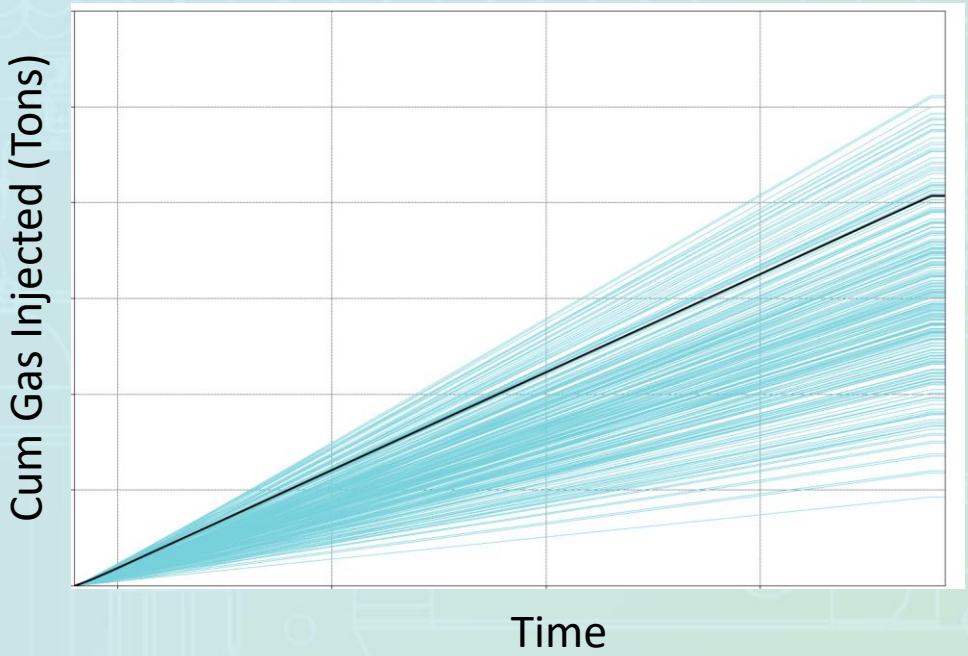
P_{crit} = 160 psi S_g = 0.01

Optimization Study while conducting Risk Mitigation

CMOST allows multiple objective functions to be considered in the process. A practical example of objective functions to be used simultaneously on a (robust) optimization are:

- Cumulative injection volume (**maximize**)
- Number of AoR (**maximize** to avoid injection site interference)
- Volume of CO2 outside the lease area (**minimize**)





Conclusions

- The current methodology provides and efficient and interactive way to evaluate the Area of Review under uncertainties
- Results obtained can come as timeseries, data and 2D visualization
- The outcomes can be used to improve new CCS projects approval, including EPA's Class VI well permit requirements
- Multiple objective functions can be used to maximize CO2 injection volume while de-risking projects