

# The 2020's: A Decade of Confidence-Building for Commercial-Scale CO<sub>2</sub> Storage in Deep Geological Formations

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# Development of Geological Storage of CO<sub>2</sub>

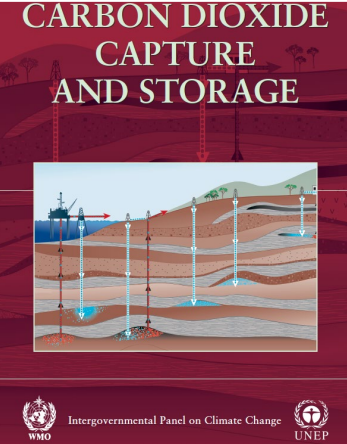
1990's



Courtesy of Statoil

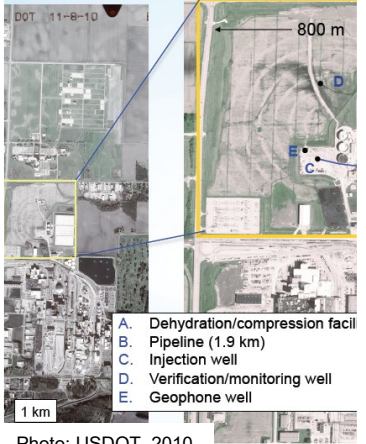
Pioneers

2000's



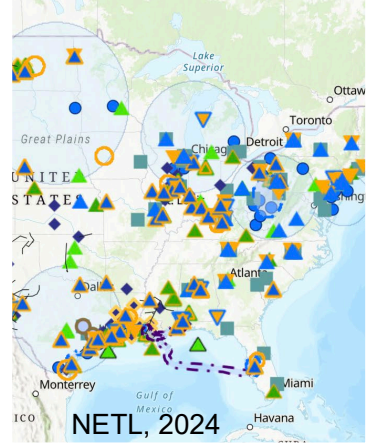
Foundations

2010's



Early Deployment

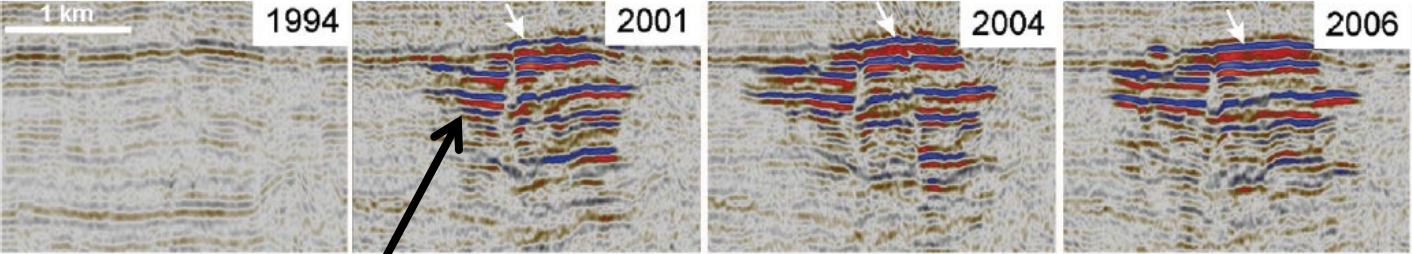
2020's



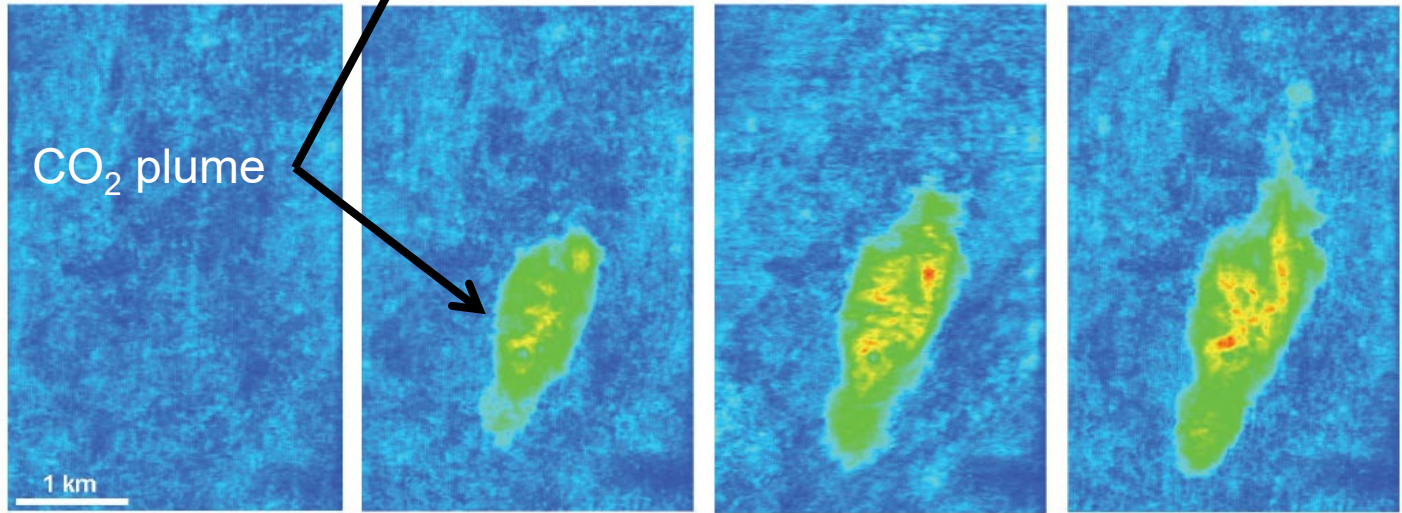
Confidence Building

# Seismic Monitoring at Sleipner Demonstrates Imaging and Containment of the CO<sub>2</sub> Plume

Cross  
Section  
View



Map  
View



[Chadwick et al., GHGT-9, 2008]

# Multiple Trapping Mechanisms Contribute to Storage Security

## Solubility trapping

- CO<sub>2</sub> dissolves in water

## Residual gas trapping

- CO<sub>2</sub> is trapped by capillary forces

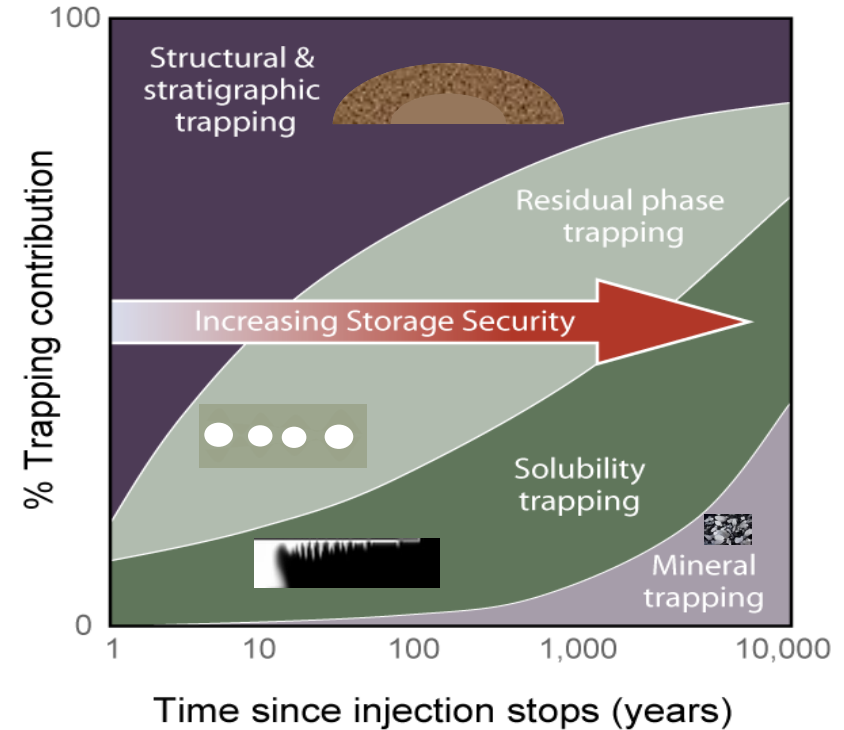
## Mineral trapping

- CO<sub>2</sub> is converted to minerals

## Adsorption trapping

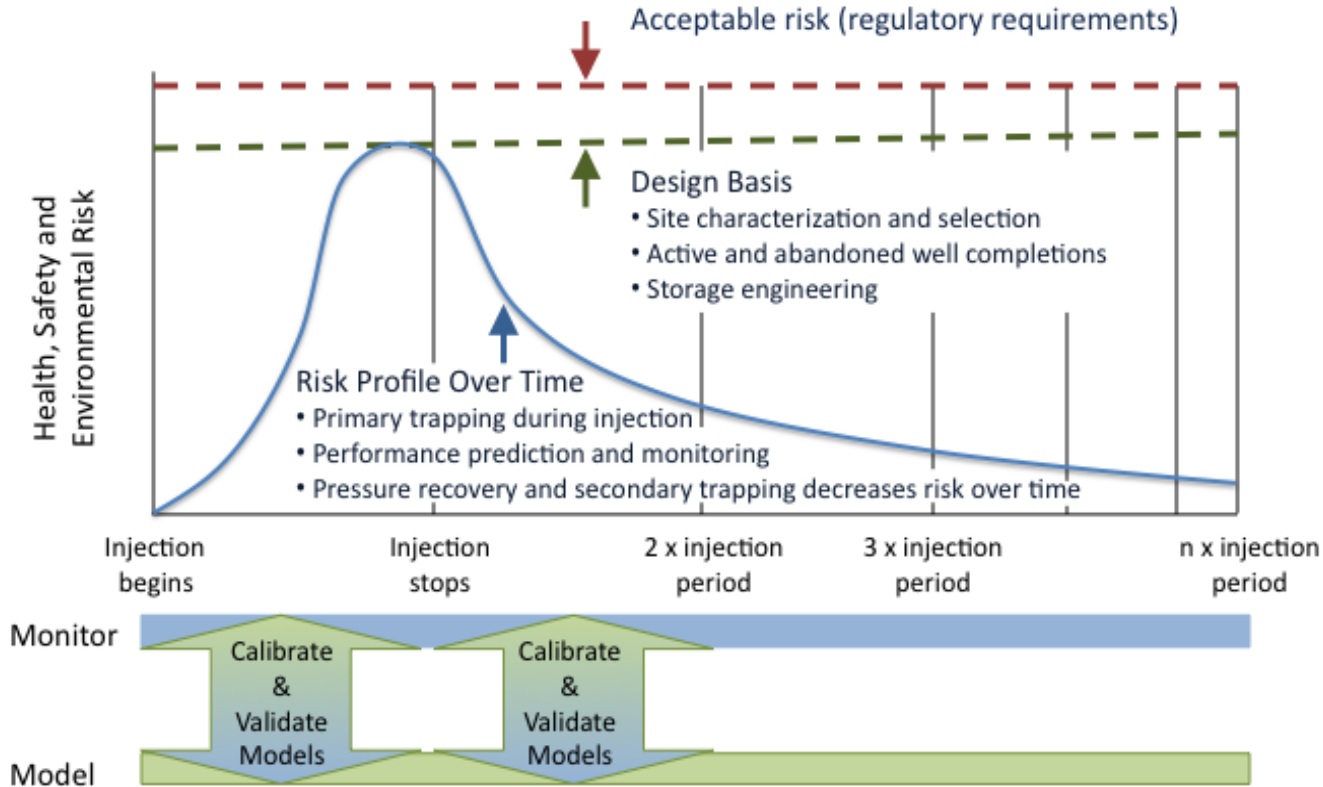
- CO<sub>2</sub> adsorbs insoluble organic matter in shale and coal

Storage security increases over time!

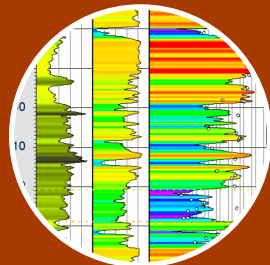


IPCC, 2005

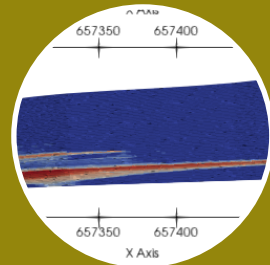
# Risk Profile Over Time for Geological Storage



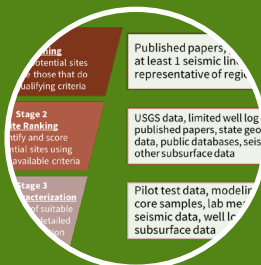
# Confidence Building Toolkit



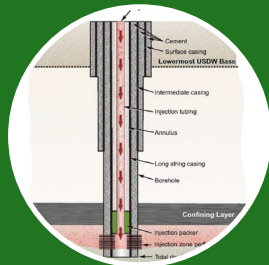
Site characterization technology



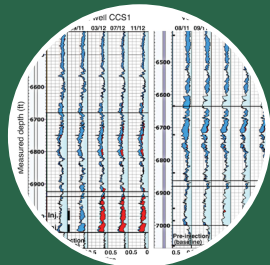
Static and dynamic storage reservoir modeling



Site selection frameworks



Well construction protocols

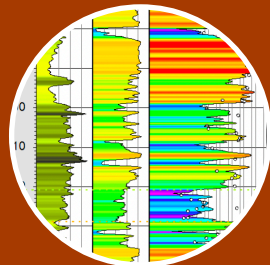


Monitoring methods and requirements

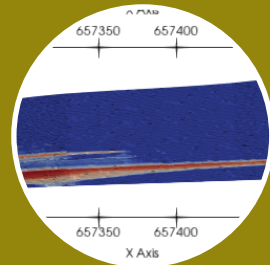
Tested and Validated Methods Build Confidence for Developers, Investors, and the Public



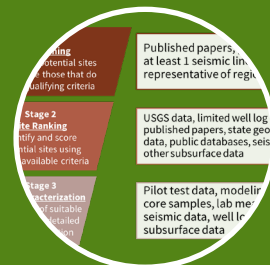
# 2020's: AI Assisted Storage Assurance



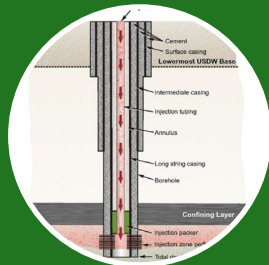
Site characterization technology



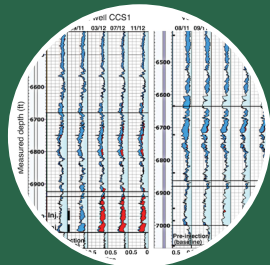
Static and dynamic storage reservoir modeling



Site selection frameworks



Well construction protocols

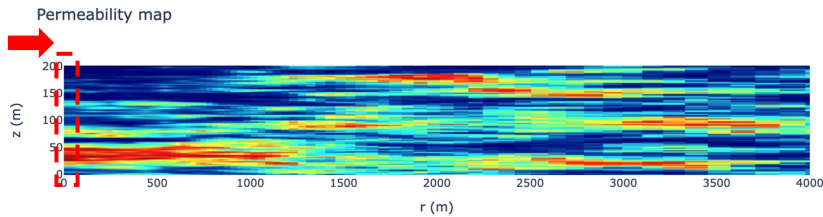


Monitoring methods and requirements

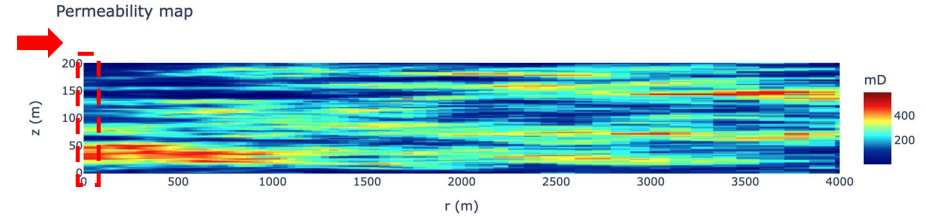
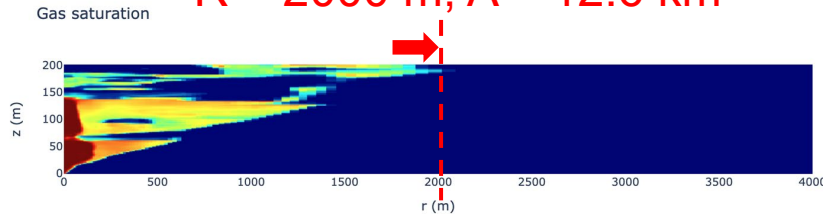
Faster, more accurate and probabilistic prediction of project performance and assurance.

# AI Assisted Work Flows Quantify Uncertainty Associated With Geological Heterogeneity

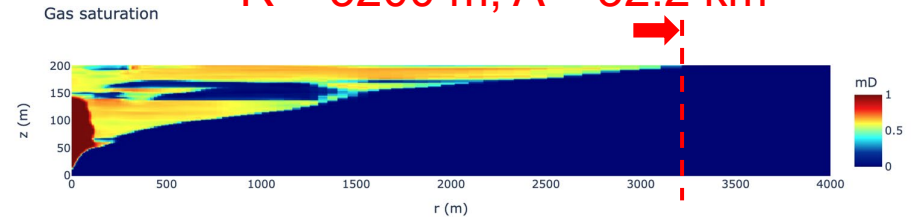
Same permeability at well, same correlation lengths, different realizations



$R = 2000 \text{ m}, A = 12.6 \text{ km}^2$

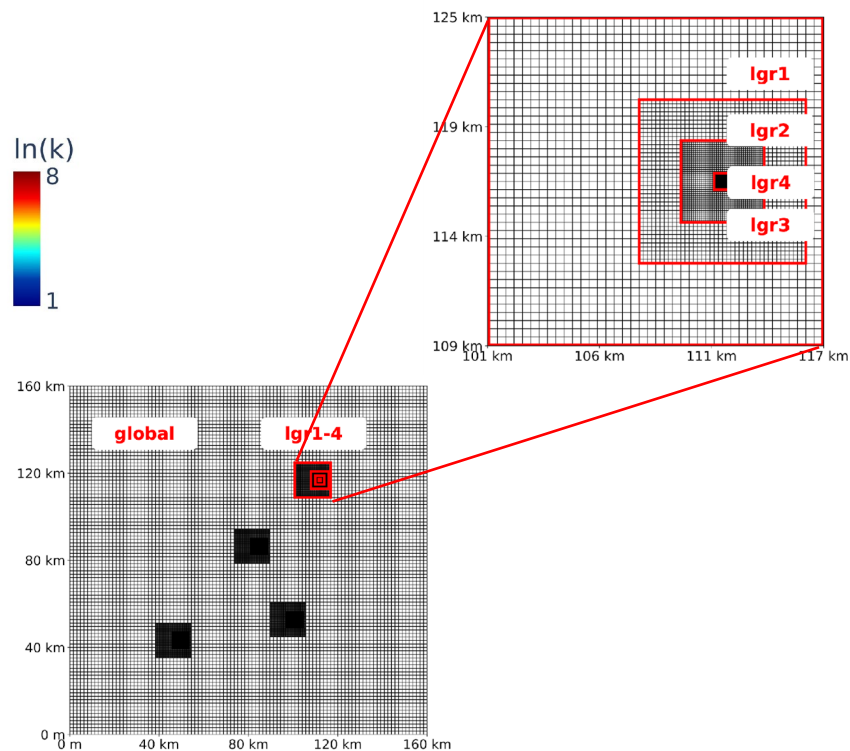
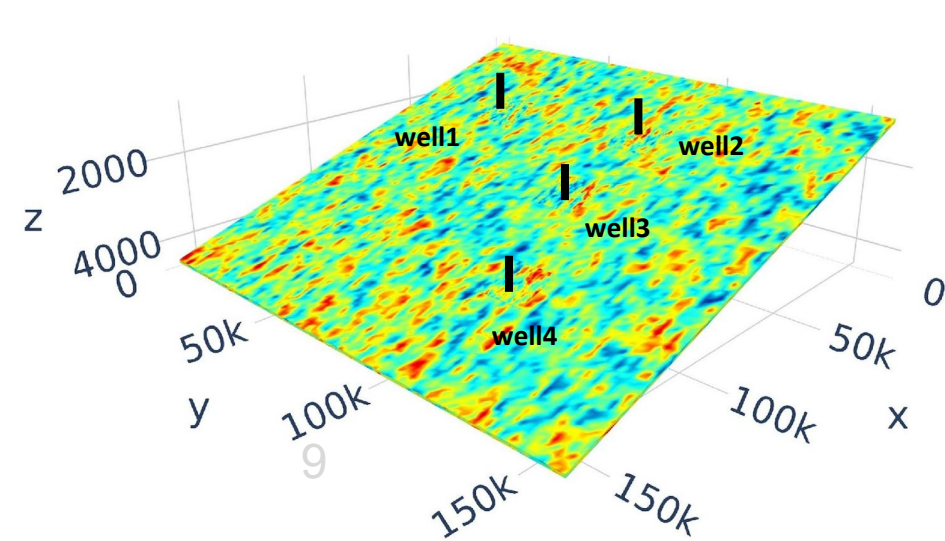


$R = 3200 \text{ m}, A = 32.2 \text{ km}^2$





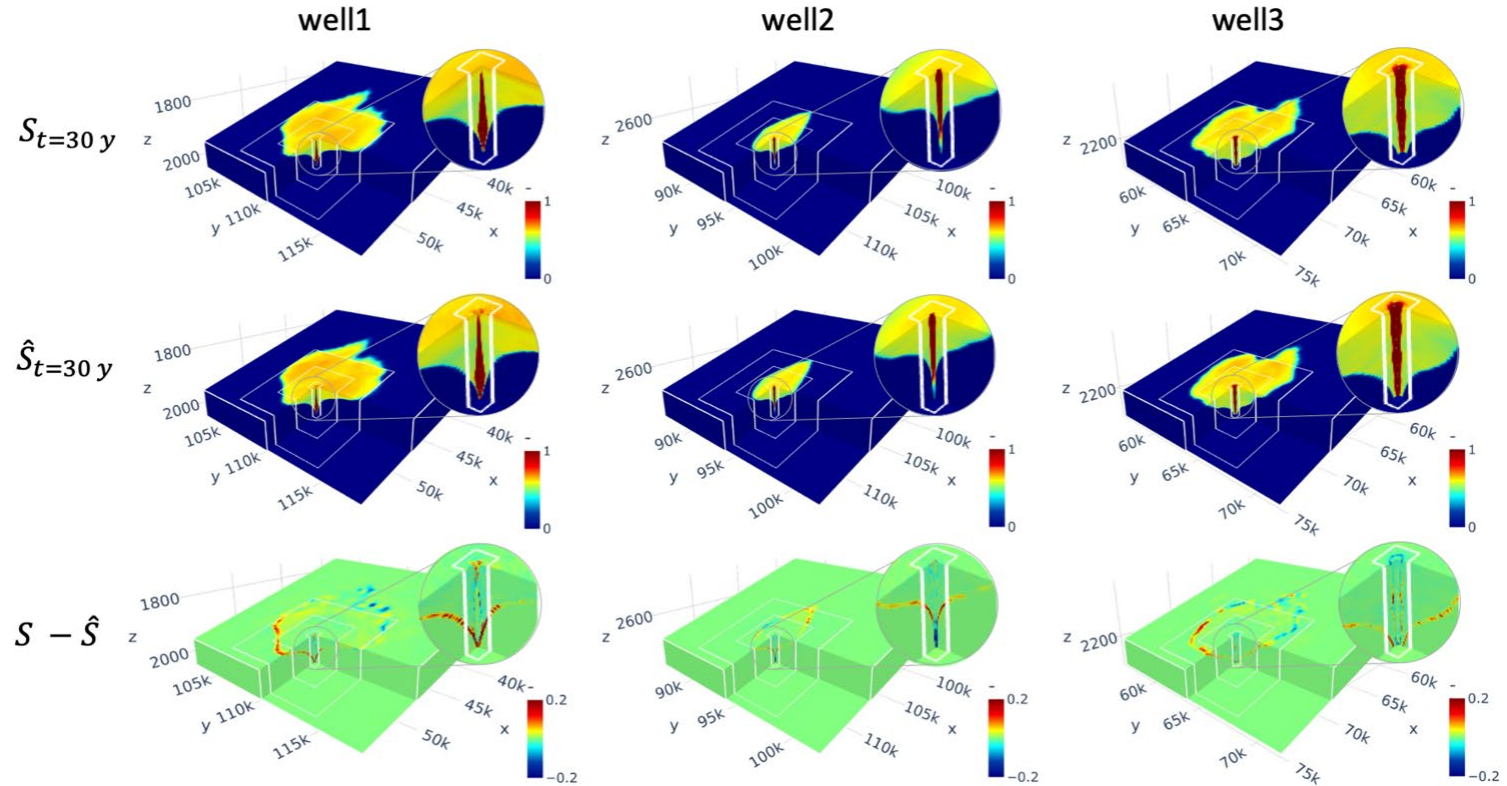
# CCSNet.ai: Basin-scale 3D Reservoir with Multiple Injection Well Dataset using Local Grid Refinement Technique



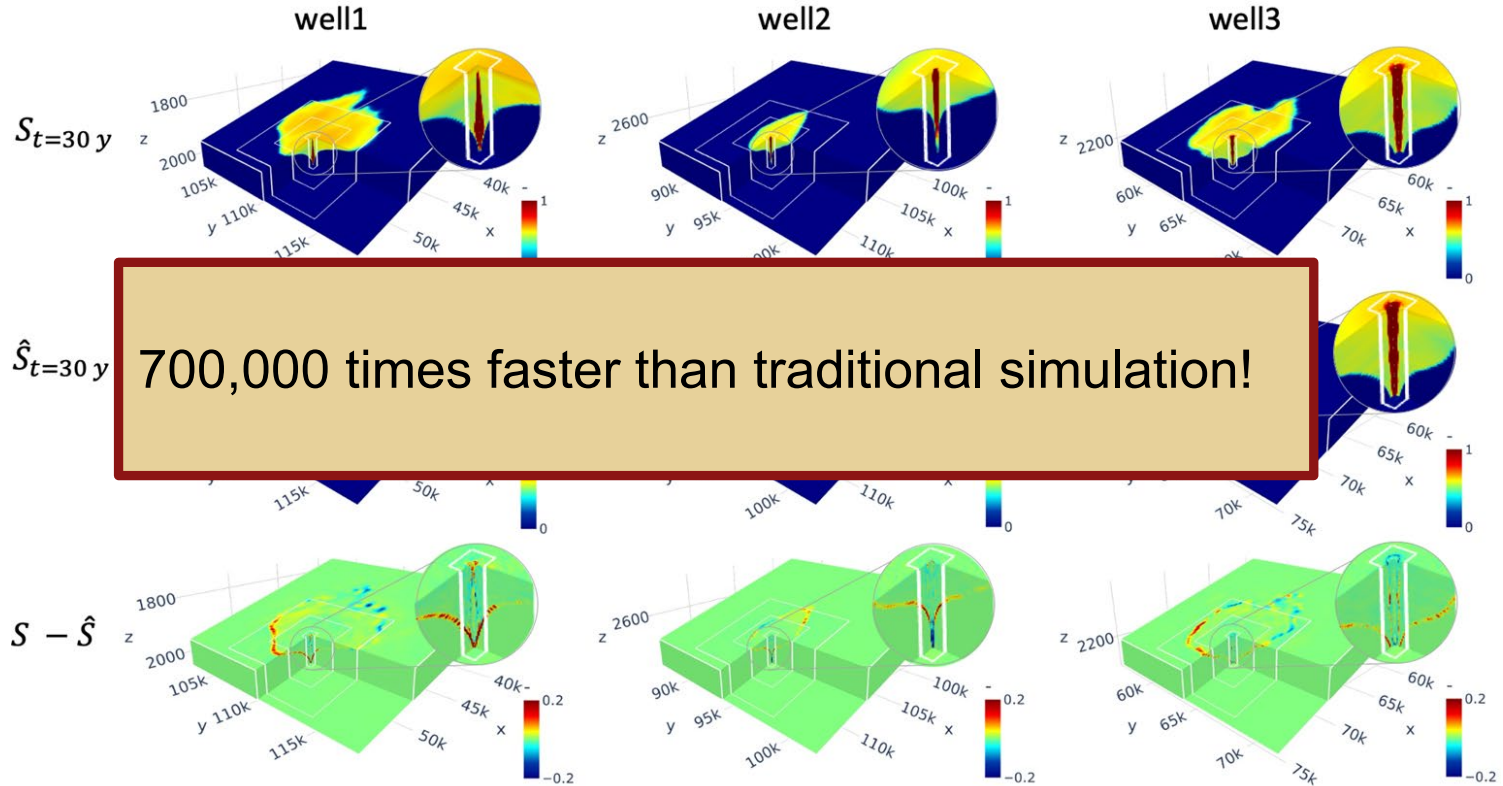
Wen, Gege, et al. "Real-time high-resolution CO<sub>2</sub> geological storage prediction using nested Fourier neural operators." *Energy & Environmental Science* 16.4 (2023): 1732-1741.

To try it out, go to <https://ccsnet.ai/>

# Gas Saturation Prediction with 1.8% relative plume error

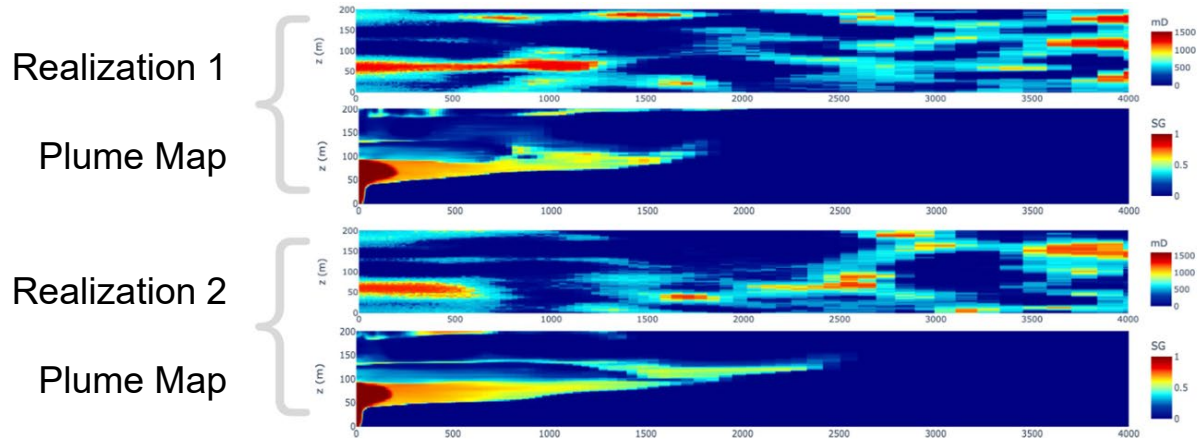


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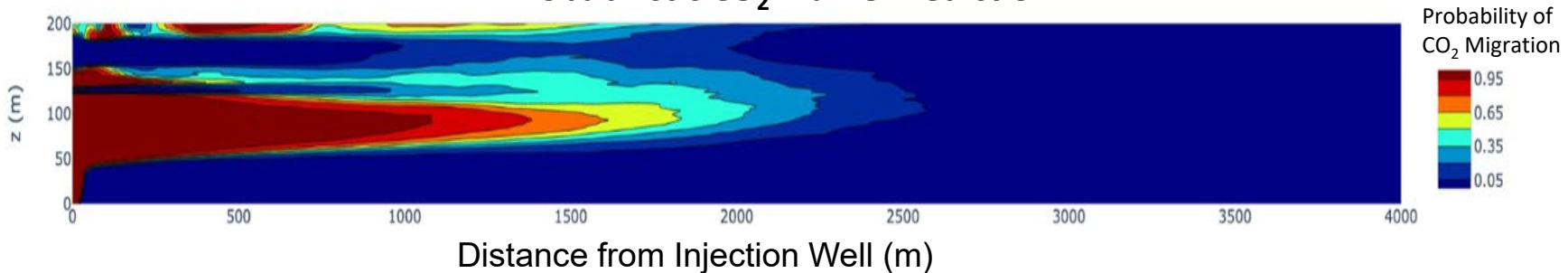


# Example of Probabilistic Plume Prediction

One well log  
500 realizations  
2.5 seconds



## Probabilistic CO<sub>2</sub> Plume Prediction



To try it out, go to <https://ccsnet.ai/>

# 2020's: Laying The Foundation for 2050

## 2020's

NETL, 2024

STATOIL

Confidence Building

## 2030's

- About 5 Gt/year CCS needed by 2050
- 100 x scale-up
- 2 x growth rate compared to the past decade
- Modern IT and knowledge systems needed for data, modeling, decision support, monitoring, compliance...

Global Scale-Up

## 2050's

total net CO<sub>2</sub> emissions  
in Gt/yr

IPCC, 2018

Four illustrative model pathways

In pathways limiting global warming to 1.5°C with **no or limited overshoot** as well as in pathways with a higher overshoot, CO<sub>2</sub> emissions are reduced to net zero globally around 2050.

Massive Deployment