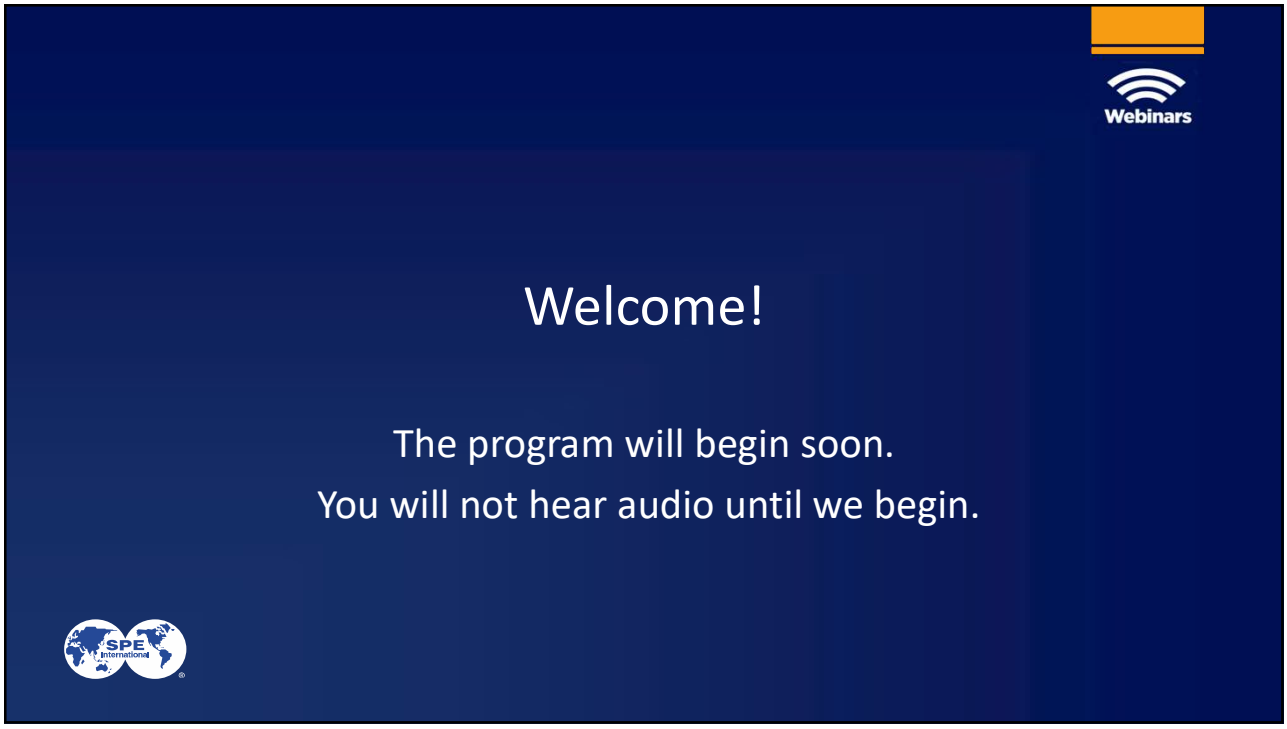
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You will not hear audio until we begin.
SPE International

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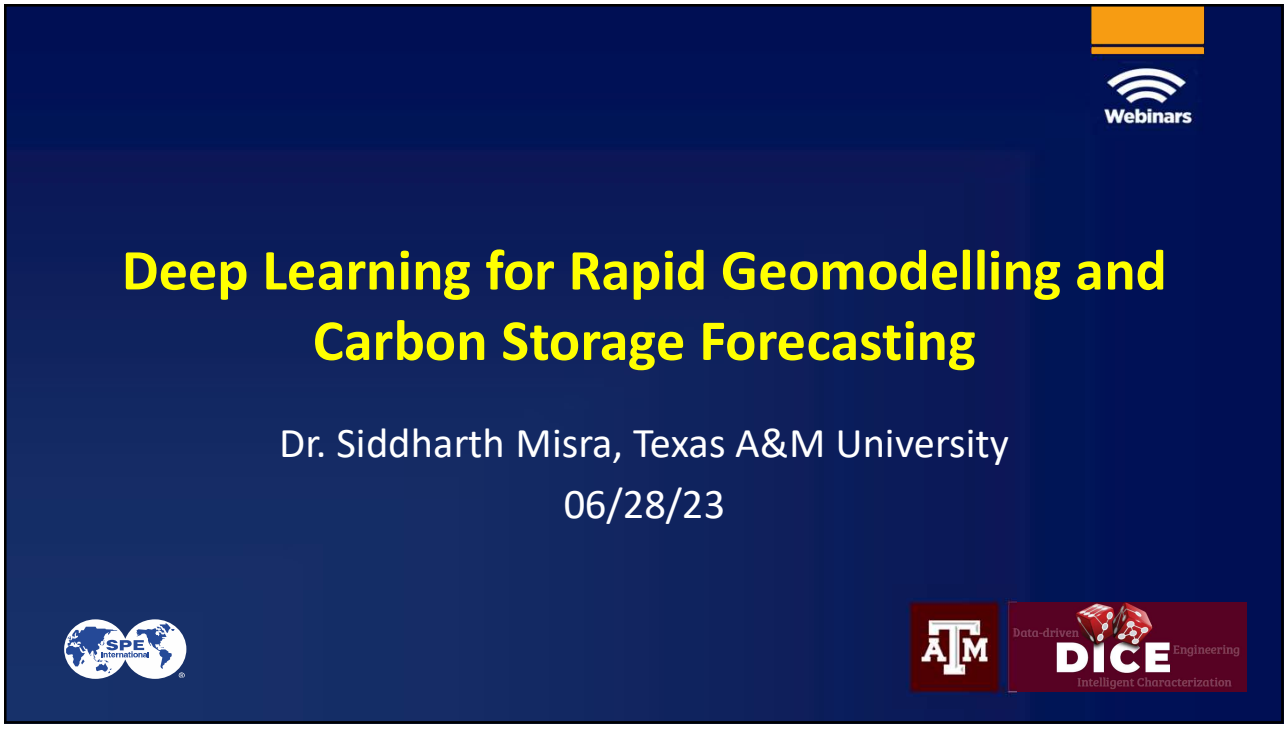
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Deep Learning for Rapid Geomodelling and Carbon Storage Forecasting
Dr. Siddharth Misra, Texas A&M University
06/28/23
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Data-driven
DICE
Engineering
Intelligent Characterization

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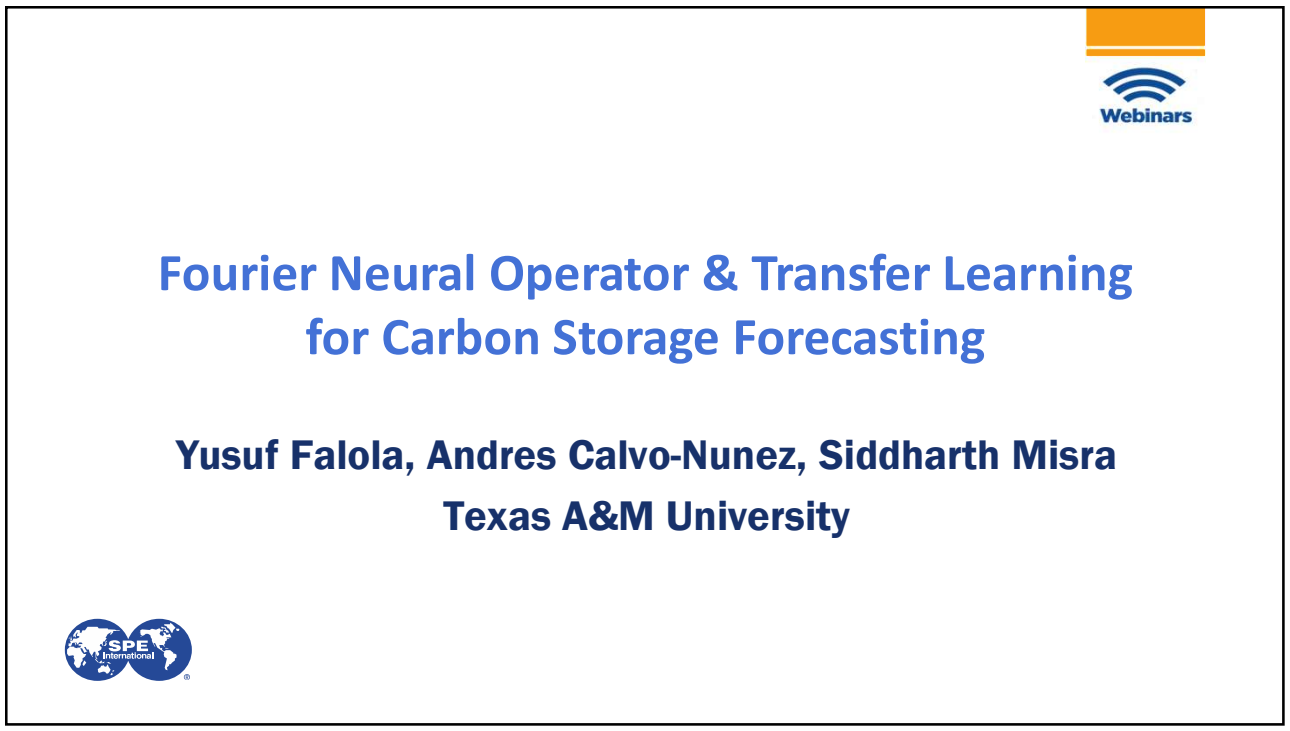
Webinars
Fourier Neural Operator & Transfer Learning for Carbon Storage Forecasting
Yusuf Falola, Andres Calvo-Nunez, Siddharth Misra
Texas A&M University
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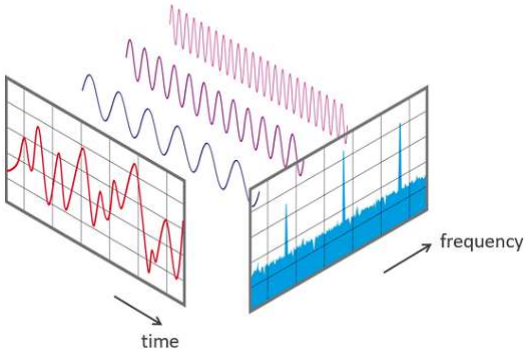
4

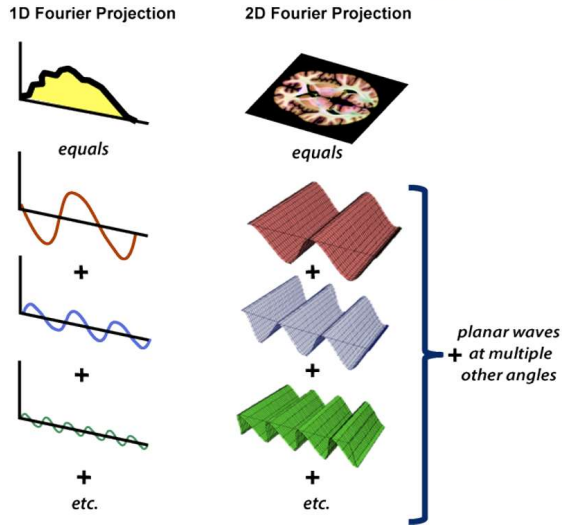
Fourier Neural Operator (FNO)

5

Fourier Transform



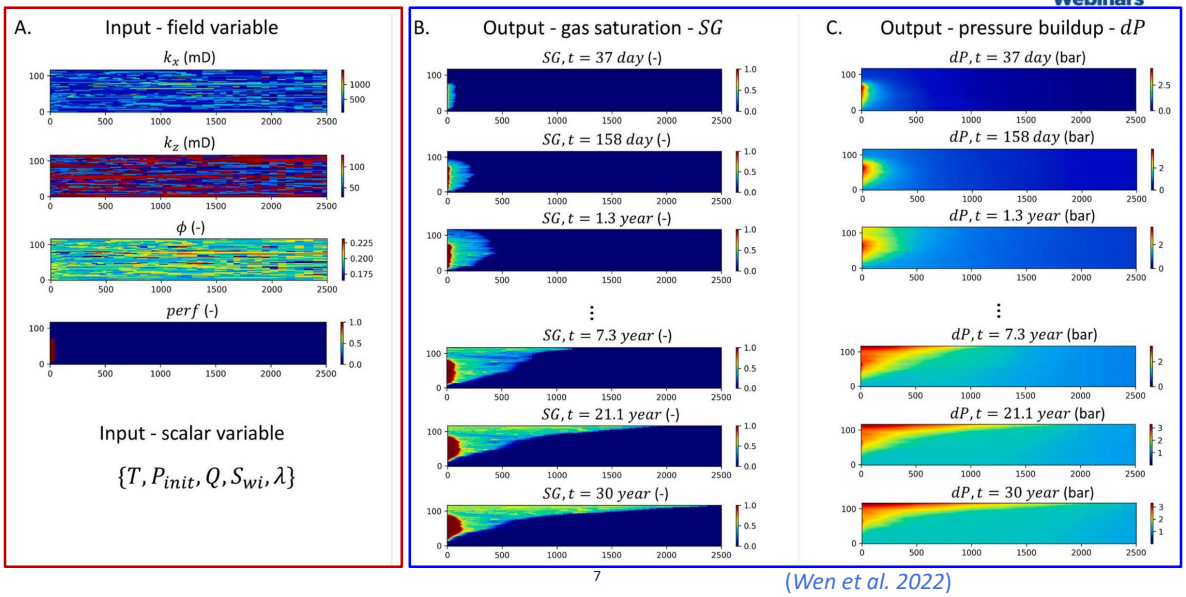
https://makeabilitylab.github.io/physcomp/signals/FrequencyAnalysis/index.html



https://mriquestions.com/what-are-2d---3d-fts.html

6

Mapping



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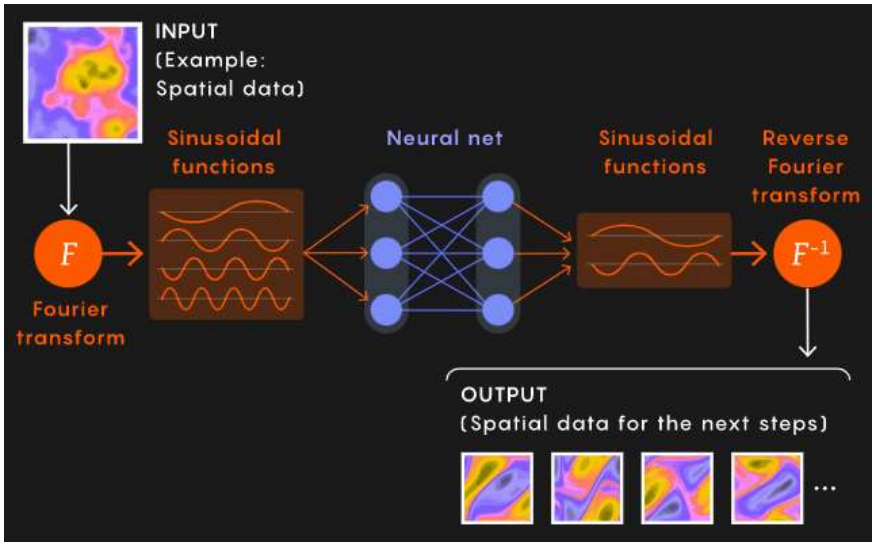
(Wen et al. 2022)

Fourier Layer

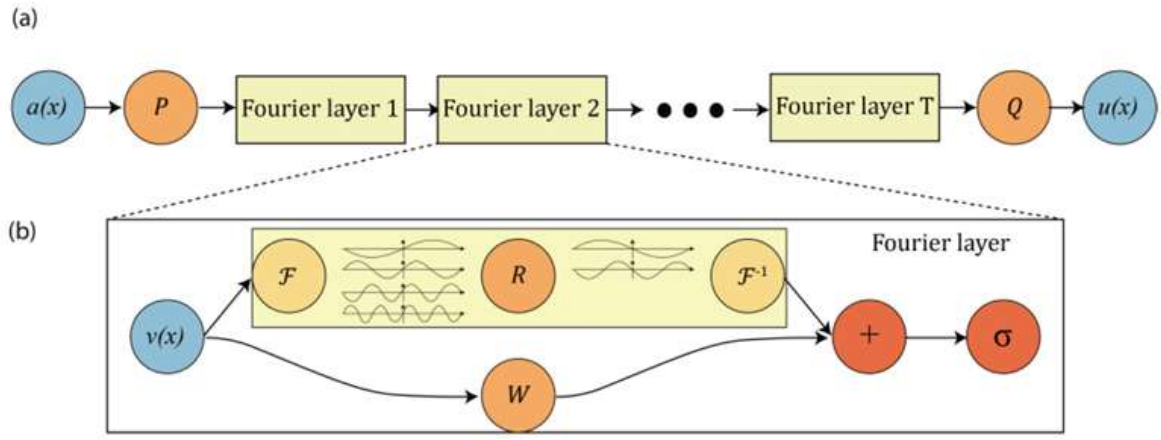


8

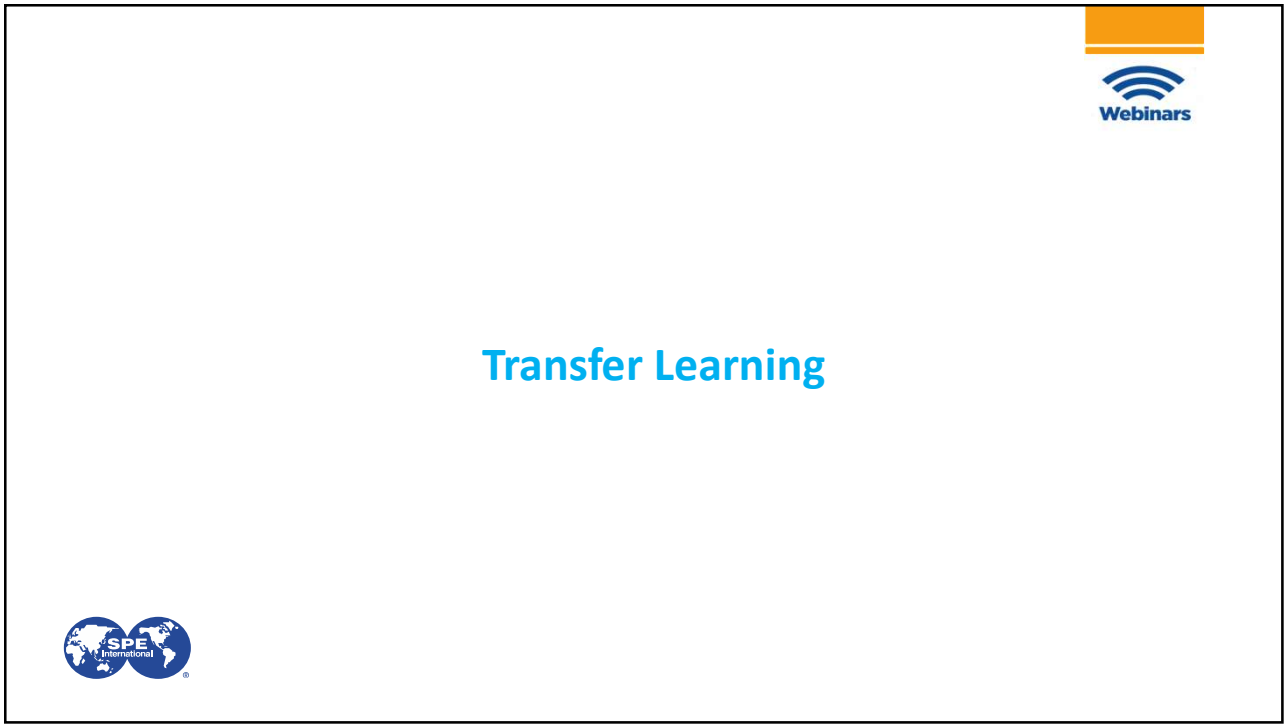
https://www.quantamagazine.org/latest-neural-nets-solve-worlds-hardest-equations-faster-than-ever-before-20210419/

8

Fourier Neural Operator (FNO)



(*Li et al. 2022*)



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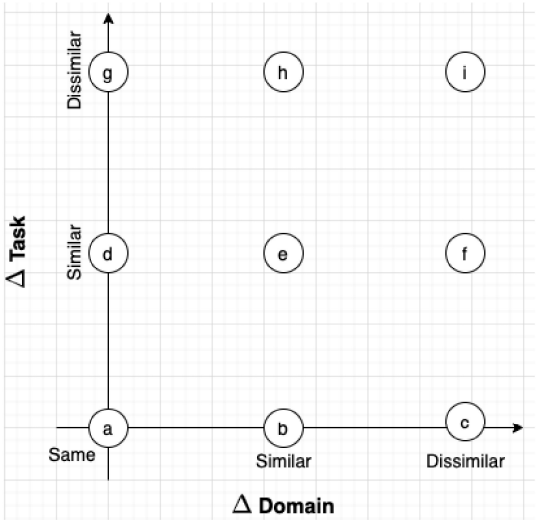
Transfer Learning

- Reusing and repurposing a model trained on a source domain/task for a target domain/task
- Lowers compute, storage and data requirements
- Faster training and better accuracy

Transfer Learning Examples



The knowledge of driving a car in Texas will help you

- **c:** Drive a truck
- **b:** Drive a car in Colorado
- **g:** Bike in a NYC

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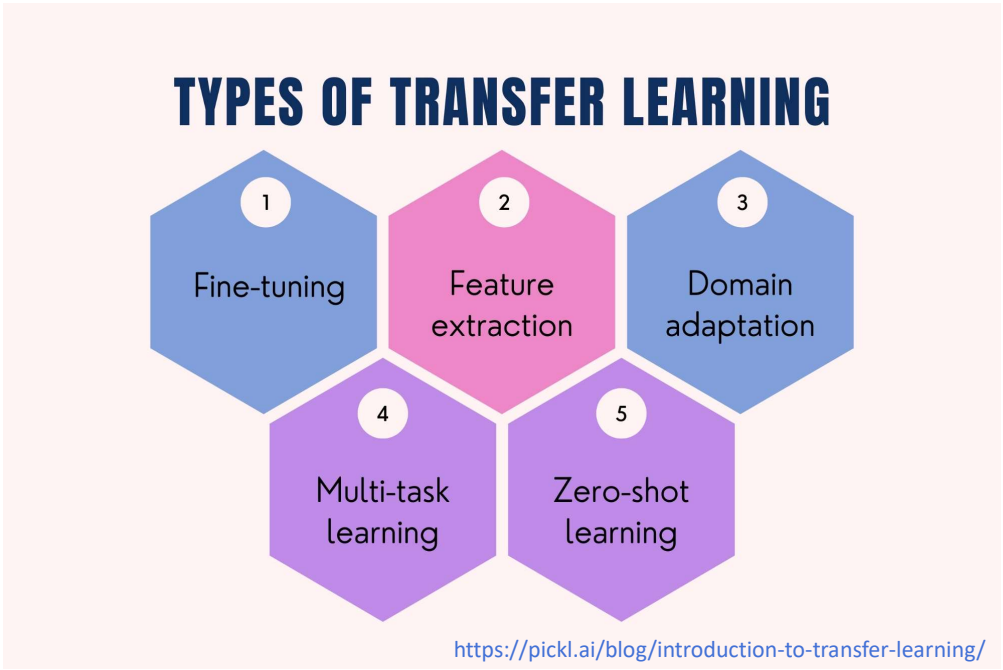
TYPES OF TRANSFER LEARNING
1
Fine-tuning
2
Feature extraction
3
Domain adaptation
4
Multi-task learning
5
Zero-shot learning
https://pickl.ai/blog/introduction-to-transfer-learning/
13

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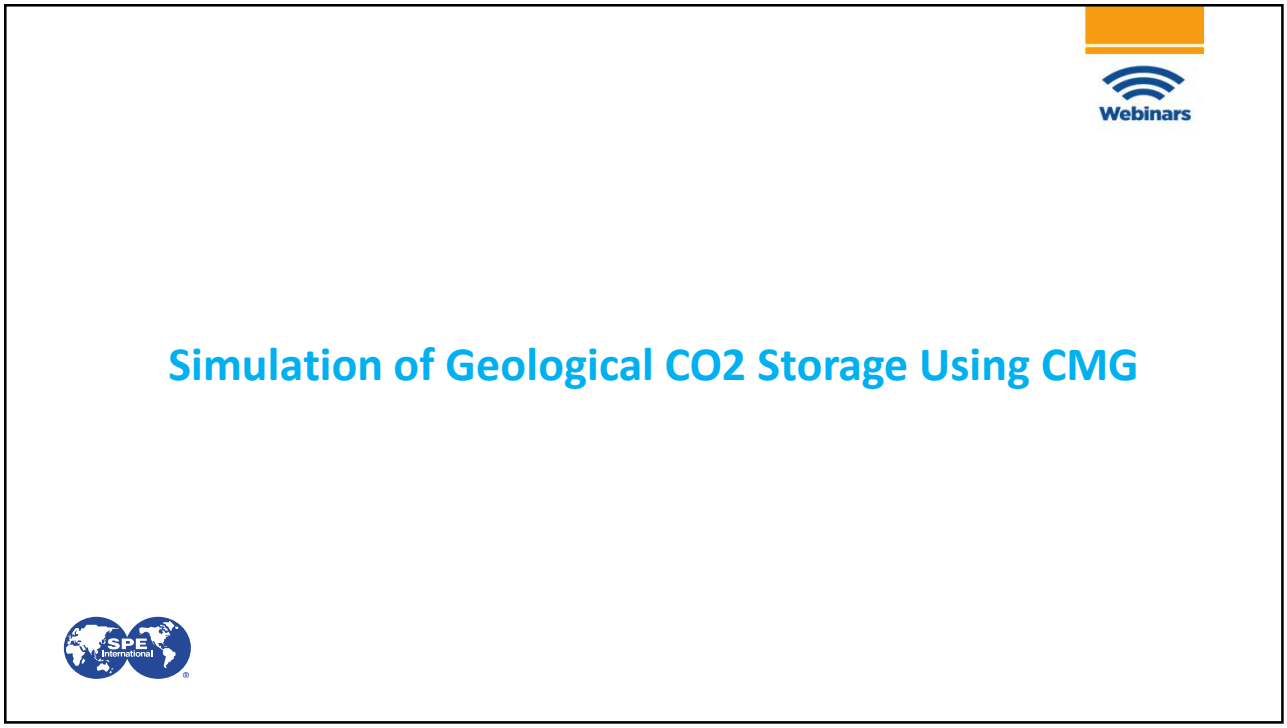
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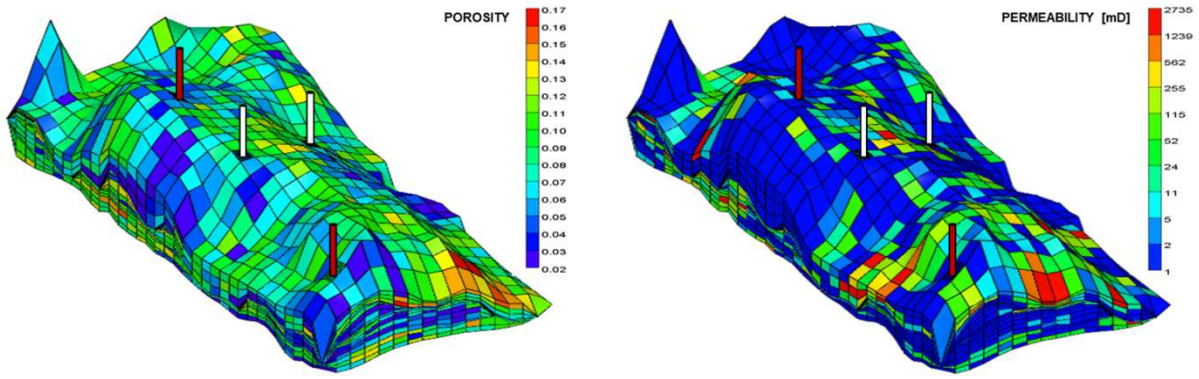
Geostatistical Realization (P30)

SACROC unit is situated in western Texas's Permian basin.



4000 m by 8200 m by 250 m represented using 36x16x25 grid cells

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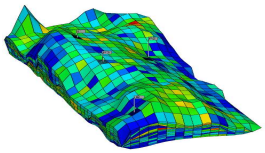
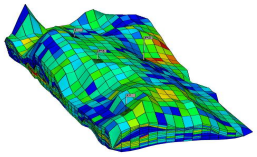
CMG Simulation Parameters

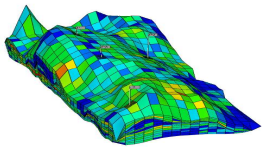
P25



P55



P85



Parameter	Dataset 1 (ML)
Porosity	0.02 – 0.18
Permeability (mD)	1 – 4710
Geomodel	P25, P55, P85
No of Injectors	2 locations (fixed)
No of Producers	2 locations (fixed)
Producers Constraint (kPa)	16200, 15600
Total mass of CO2 injected (MT)	5 (5.6, 9.8, 14. 0, 18.2, 22.4)
Injection Split	50:50, 10:90, 90:10, 70:30, 30:70

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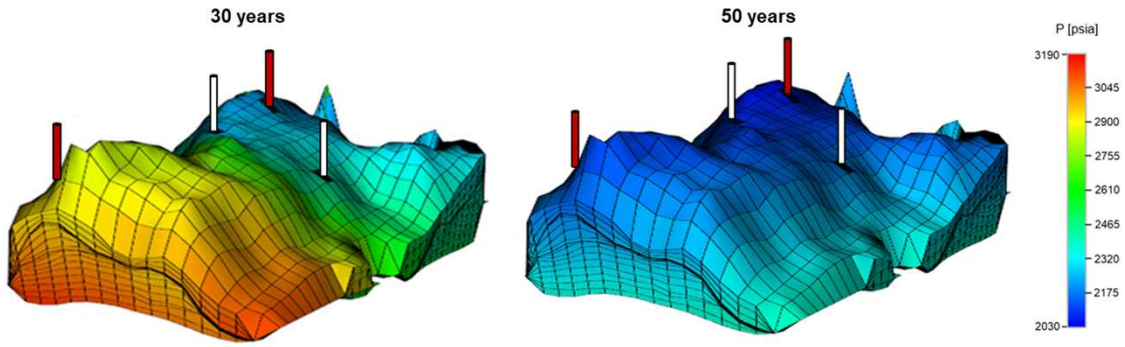
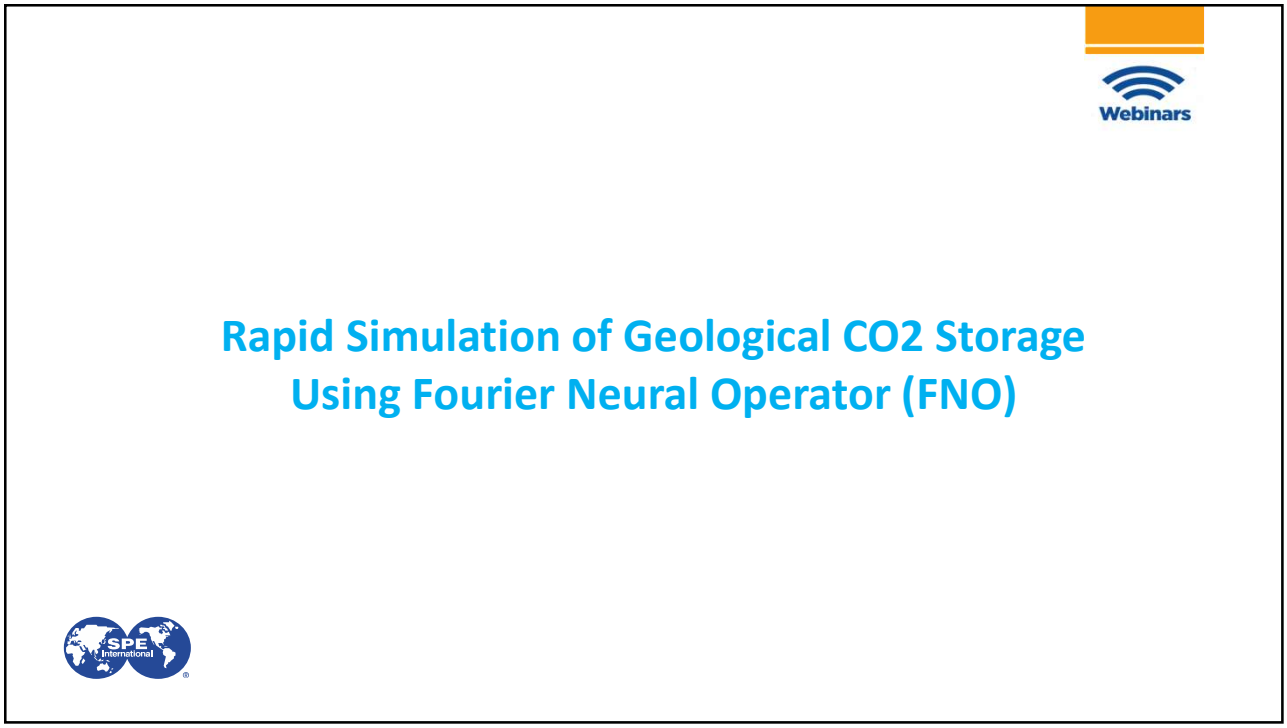
CMG Simulated Pressure Distribution

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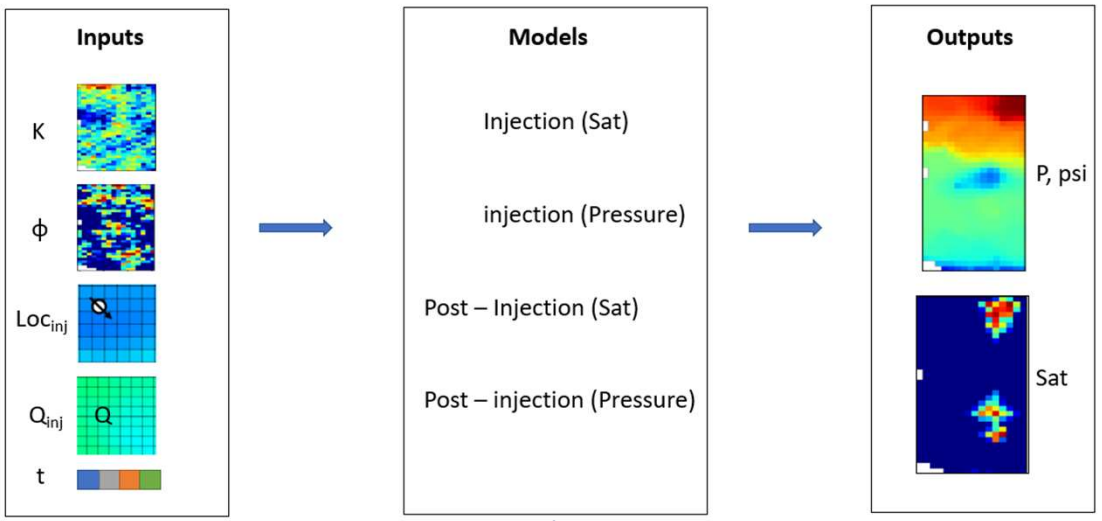
Fourier Neural Operator for CO2 Forecasting



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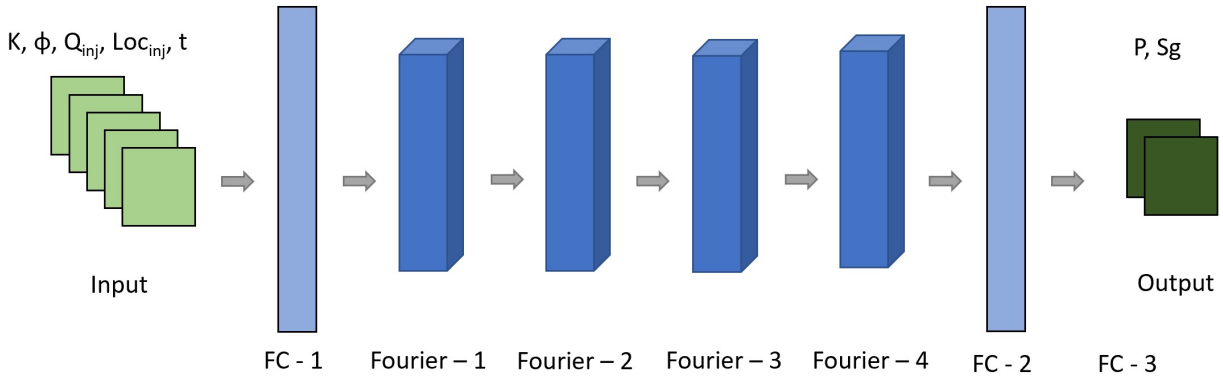
Training Fourier Neural Operator



4,736,130 model parameters

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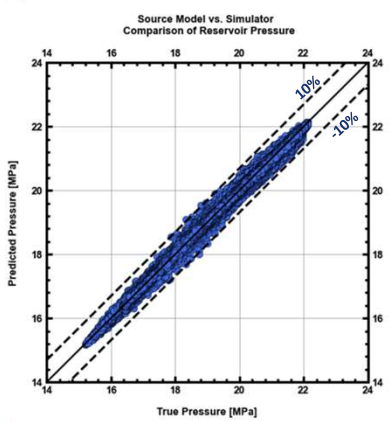
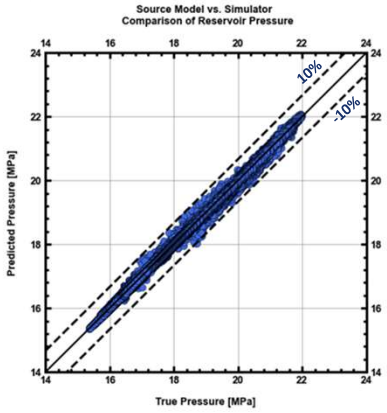
Pressure Forecasting

Injection



Post-Injection



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Saturation Forecasting

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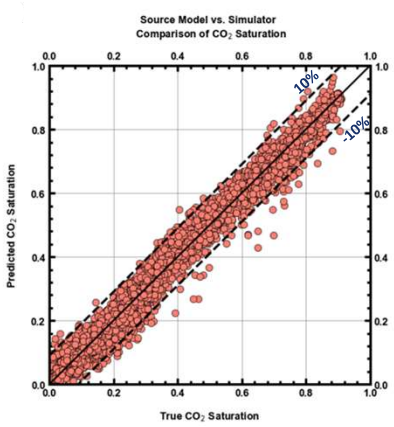
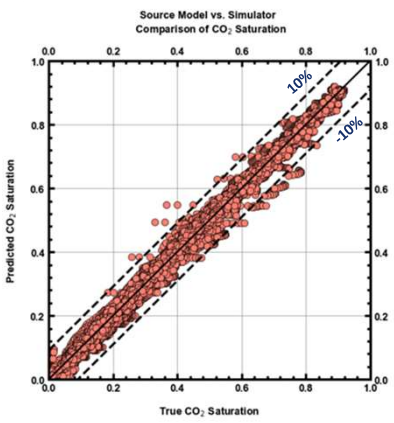
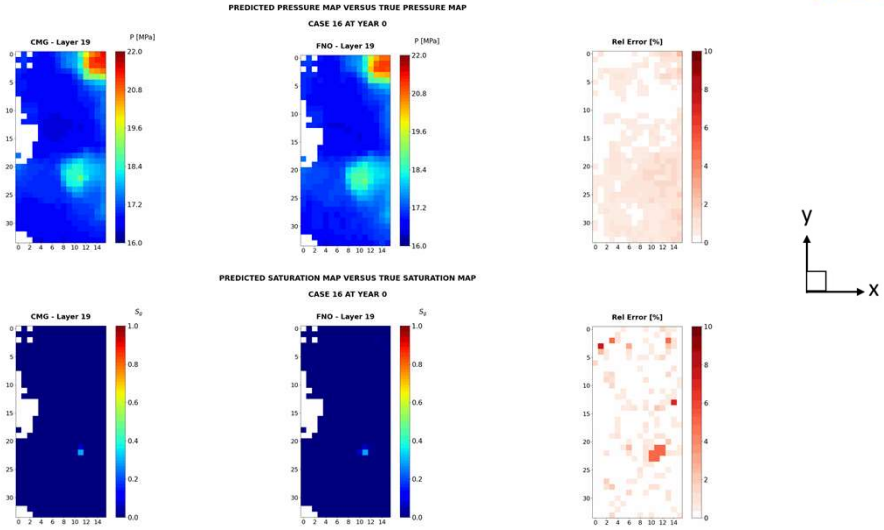
Injection



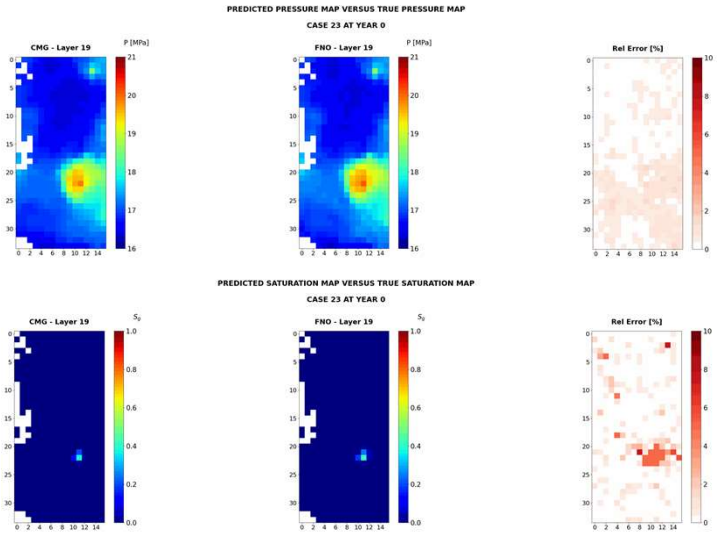
Post-Injection



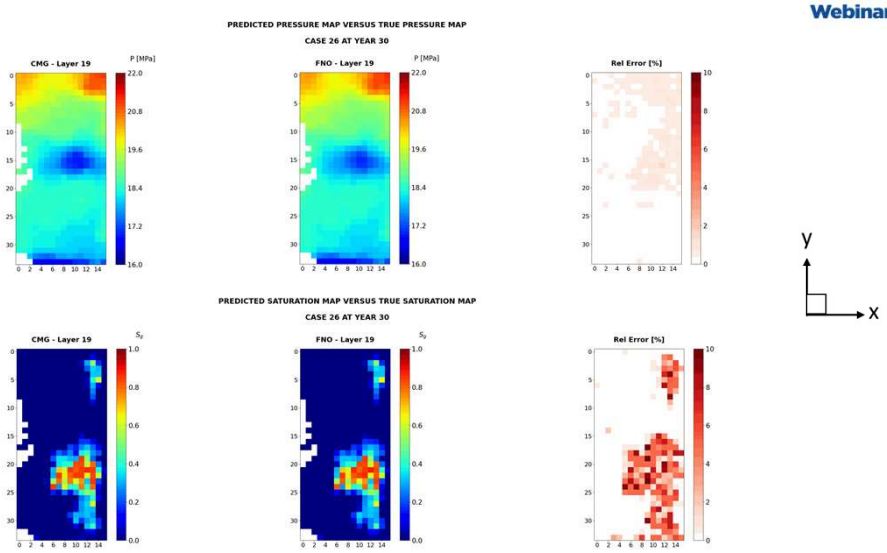
FNO MODEL: INJECTION PERIOD



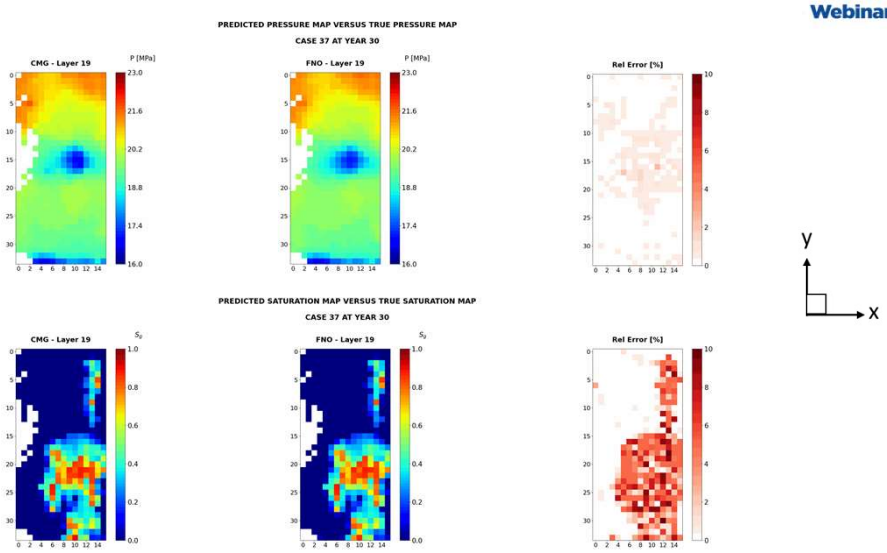
FNO MODEL: INJECTION PERIOD

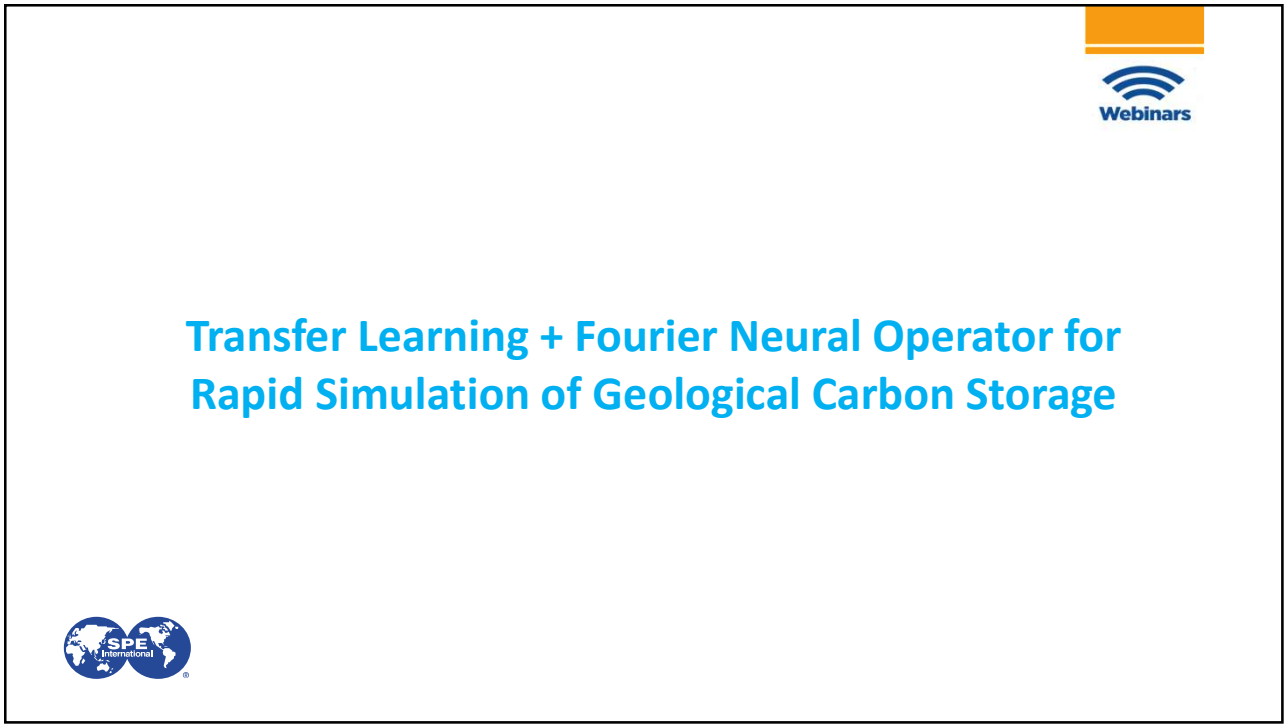


FNO MODEL: POST-INJECTION PERIOD



FNO MODEL: POST-INJECTION PERIOD

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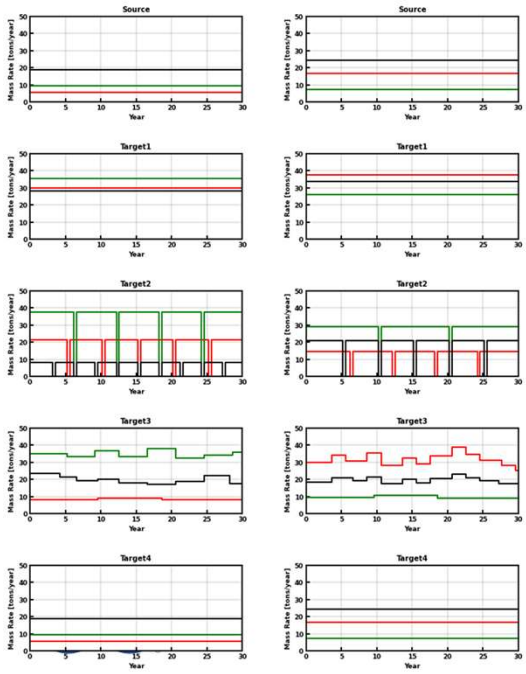
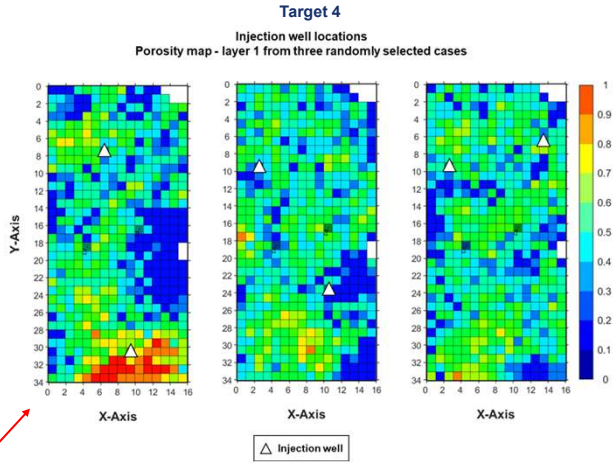
TARGETS





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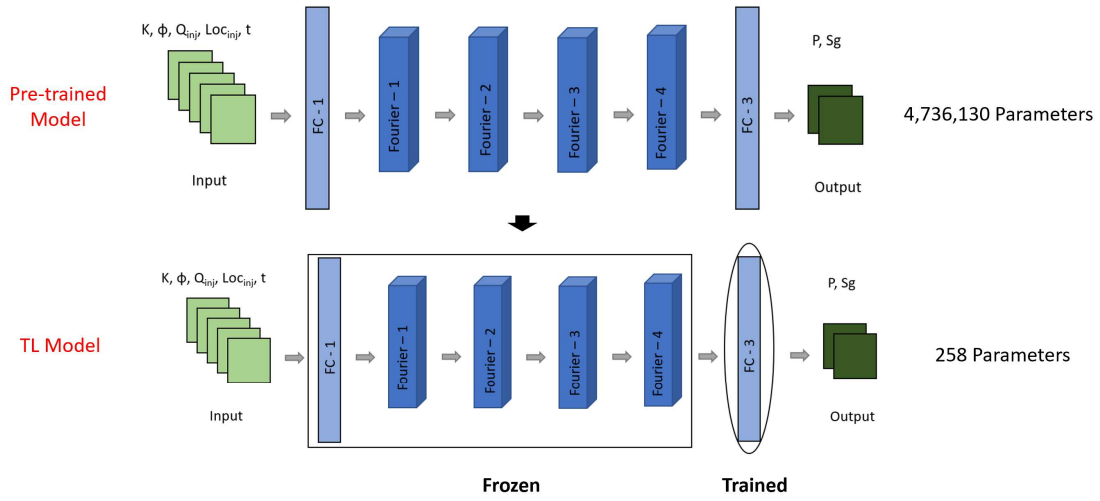
Transfer Learning: Feature Extraction



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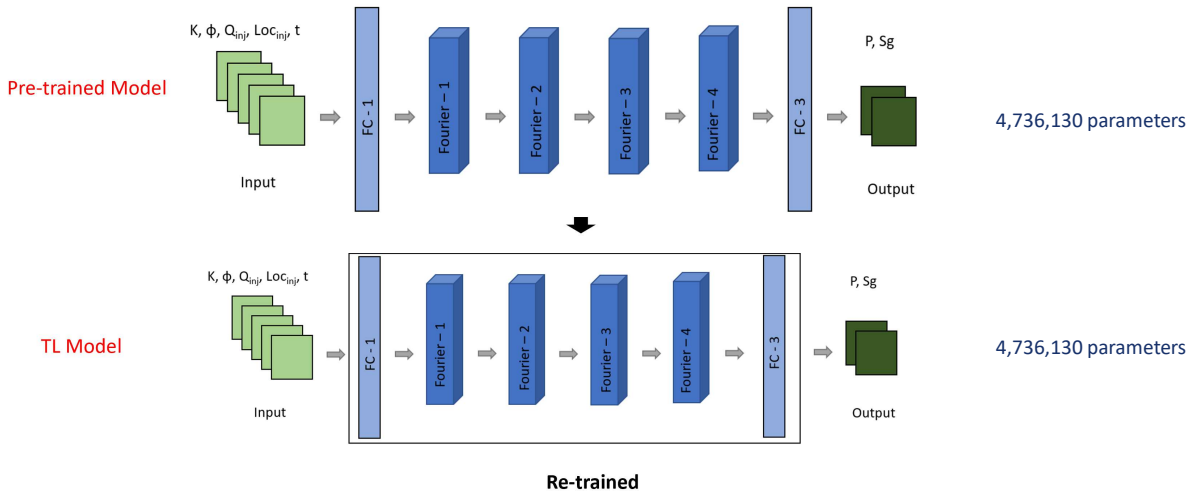
Transfer Learning: Fine Tuning



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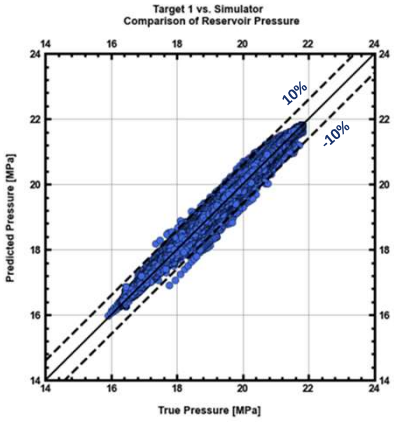
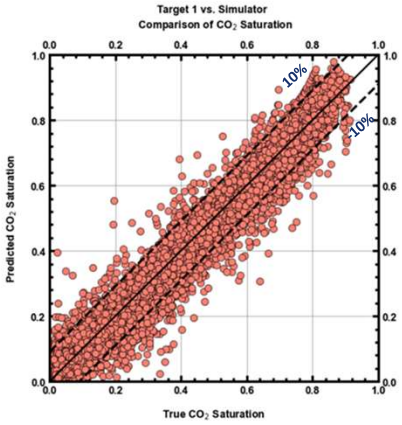
TARGET 1: VALIDATION

- **Feature extraction**





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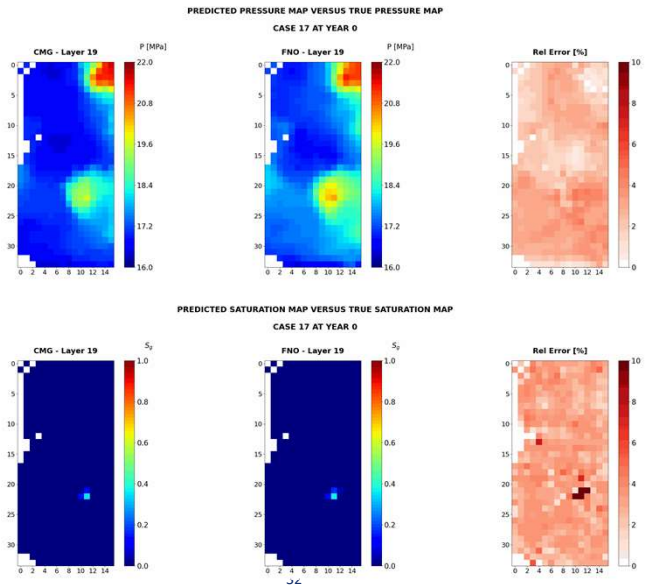
TARGET 1: FEATURE EXTRACTION



TARGETS COMPARISON

Parameter	Source	Target 1	Target 2	Target 3	Target 4
Methodology	FNO	Feature Ext.	Fine-tuning	Feature Ext.	Fine-tuning
Total Simulation time [hrs]	175	66.5	66.5	66.5	66.5
Total training time [hr]	5.76	0.43	0.41	0.42	0.42
Forecast Time per scenario [min]	42	0.95	0.95	0.95	0.95
Data Storage [GB]	243	91.1	92.3	95.5	93.4
Model Storage [GB]	2	0.005715	0.005715	0.005715	0.005715
Pressure Mean Relative Error [%]	0.28	**0.46**	**2.04**	**2.16**	**2.12**
Saturation Mean Relative Error [%]	0.10	**0.33**	0.49	**0.83**	**0.95**

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Massive Geomodel Compression and Rapid Generation Using Advanced Autoencoders

Sid Misra, Jungang Chen, Yusuf Falola & Polina Churilova, Texas A&M
Chung-Kan Huang & Jose Delgado, ConocoPhillips

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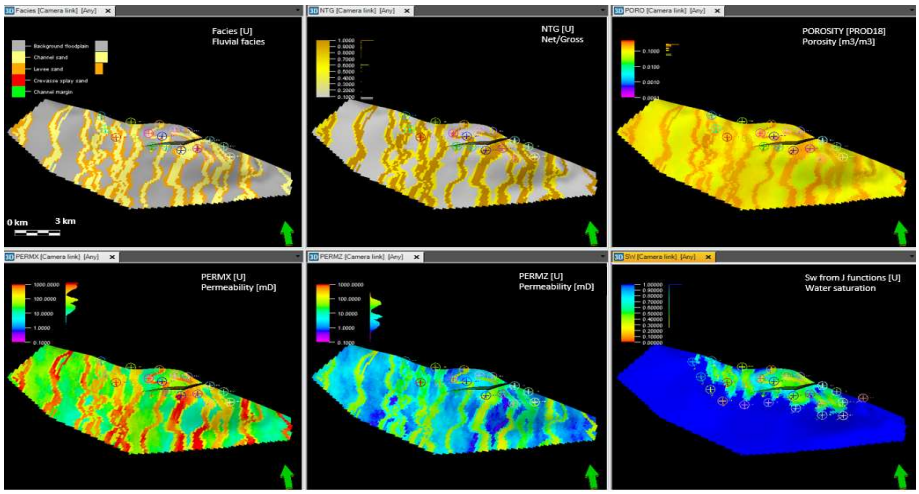
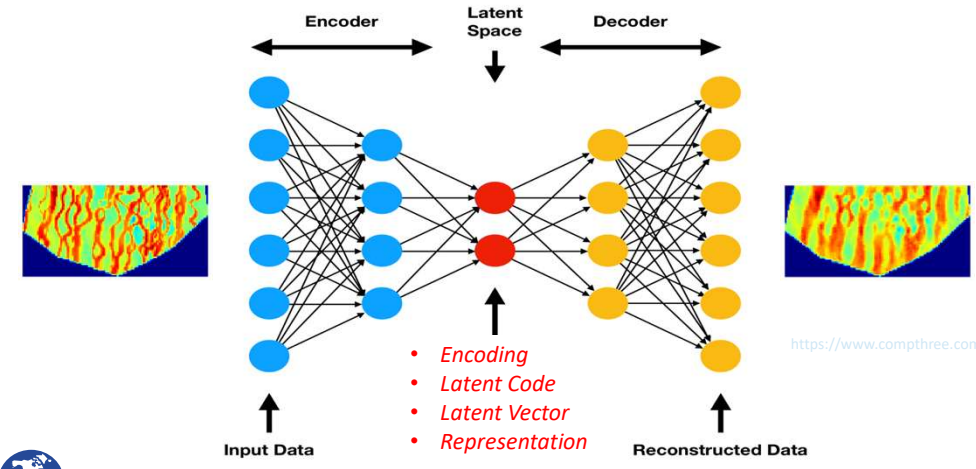
Geomodels



2000 realizations of 15km×5km reservoir; Each geomodel contains 60K cells

Autoencoder



- *Encoding*
- *Latent Code*
- *Latent Vector*
- *Representation*

https://www.compthree.com/blog/autoencoder/

Minimize the reconstruction error

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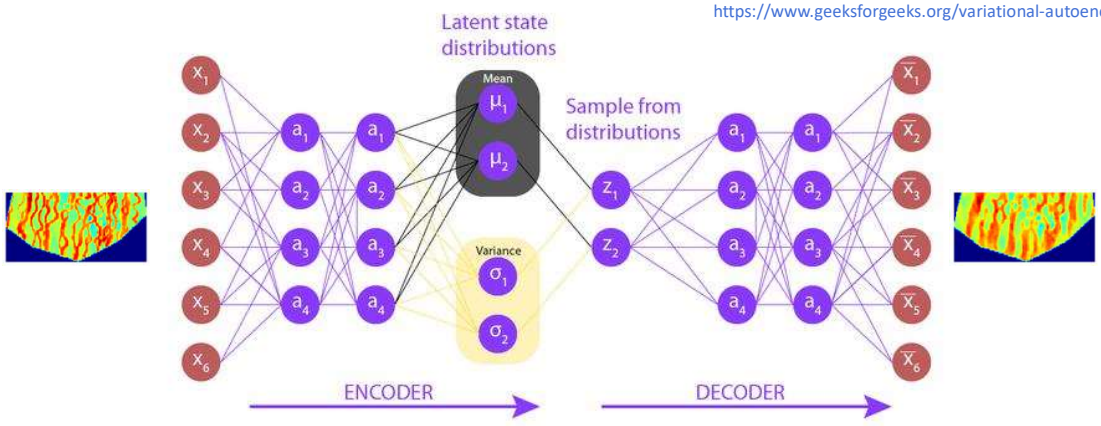
Variational Autoencoder (VAE)

https://www.geeksforgeeks.org/variational-autoencoders/



Map input to a multivariate latent distribution while ensuring quasi-continuity

Minimize the reconstruction error + Regularize the latent representation

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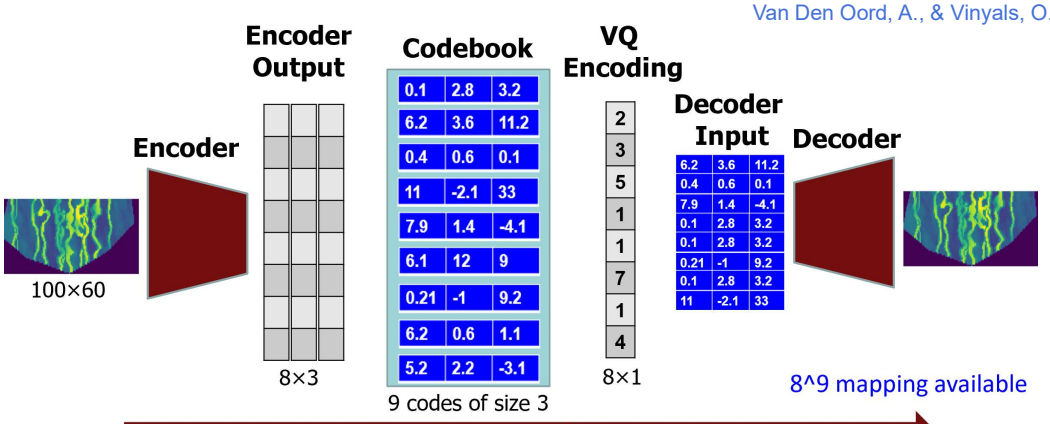
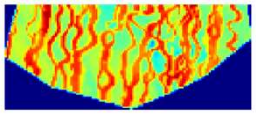
Vector-Quantized VAE

Van Den Oord, A., & Vinyals, O. (2017)



Minimize (Reconstruction + Codebook + Commitment) Loss

Vector Quantization



- *Information-rich encoding*
- *Building blocks*
- *Sparse data*
- *Faster optimization*
- *Sequential decisions*
- *No interpolation*

	Codewords or Embedding Vector		
# Channels	0.1	2.8	3.2
Parallel Channels	6.2	3.6	11.2
Channel Orientation	0.4	0.6	0.1
Background Perm at Edges	11	-2.1	33
Background Perm in Mid	7.9	1.4	-4.1
Thin or Thick Channels	6.1	12	9
Straight or Tortuous Channels	0.21	-1	9.2
Channels on edges vs. mid	6.2	0.6	1.1

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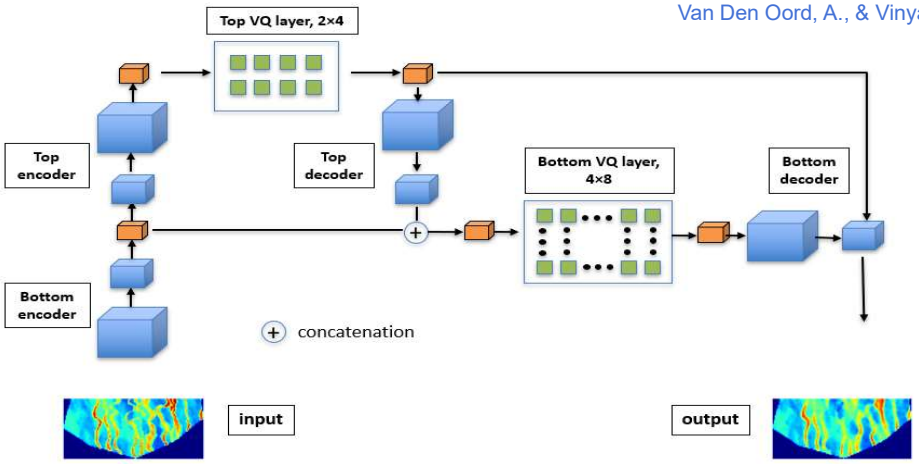
VQ-VAE-2

Van Den Oord, A., & Vinyals, O. (2017)



Global info (shape; geometry) at Top vs. Local info (texture) at Bottom

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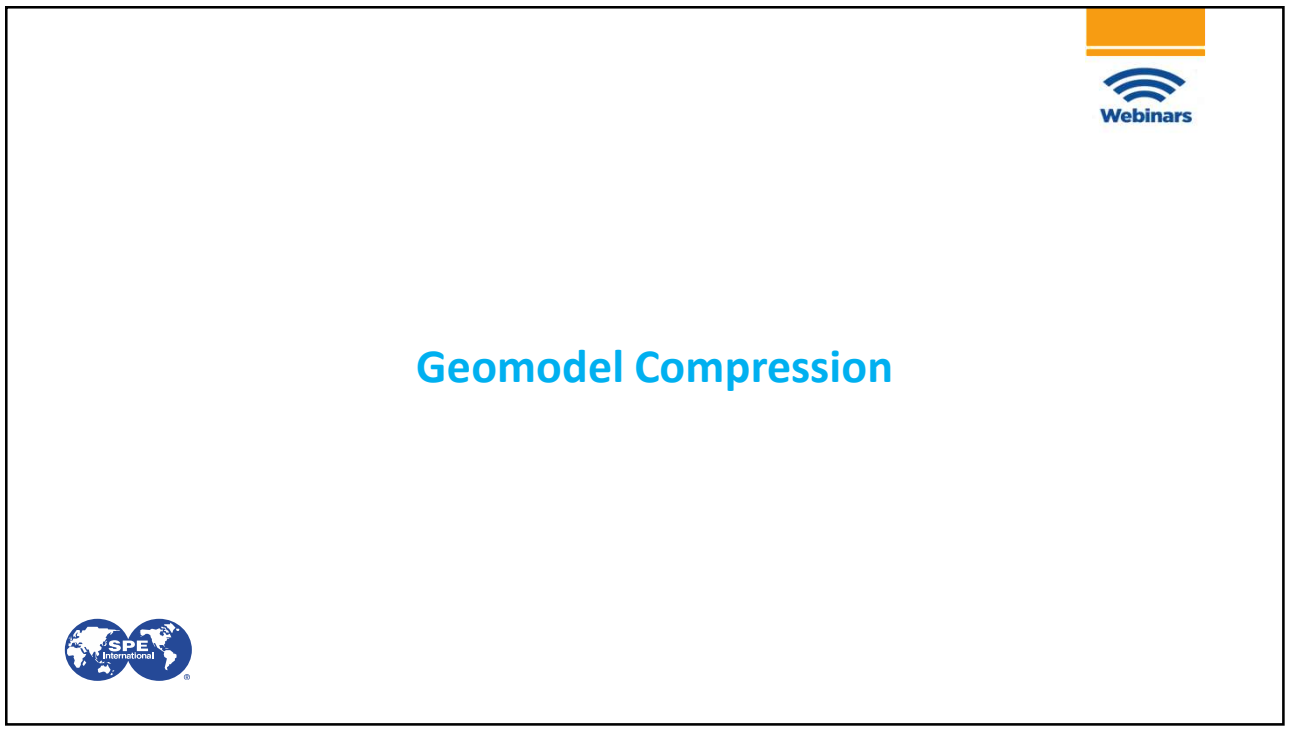
40



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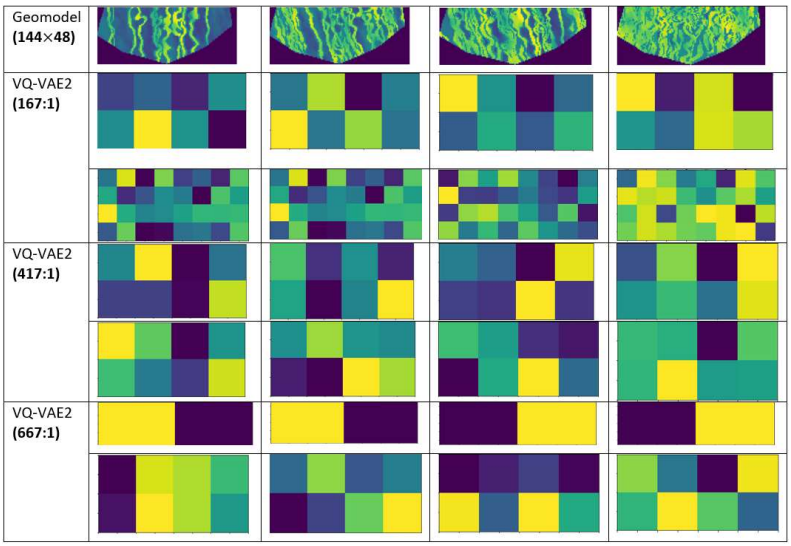
Latent Codes



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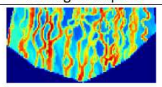
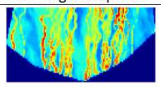
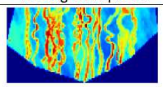
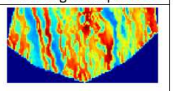
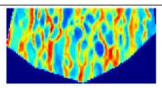
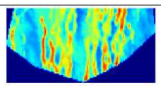
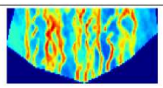
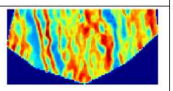
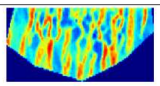
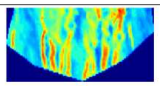
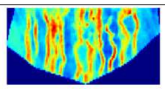
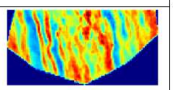
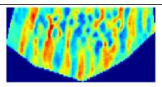
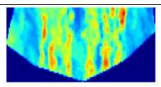
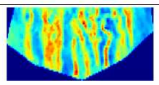
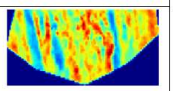
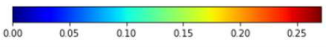
Porosity Reconstruction

CR	Mean Test SSIM	Porosity			
		Testing example 1	Testing example 16	Testing example 12	Testing example 21
Original	1.00				
167	0.95				
417	0.92				
834	0.87				
Colorbar					

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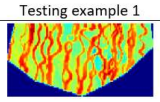
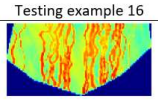
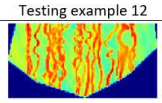
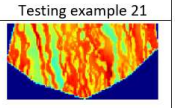
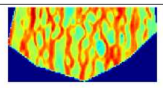
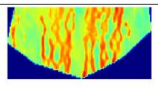
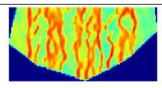
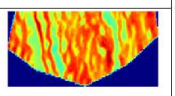
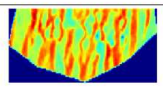
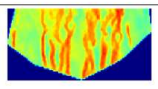
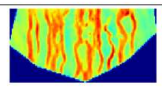
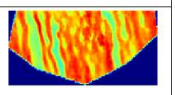
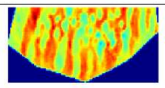
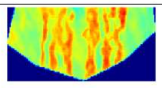
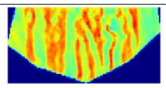
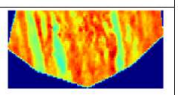
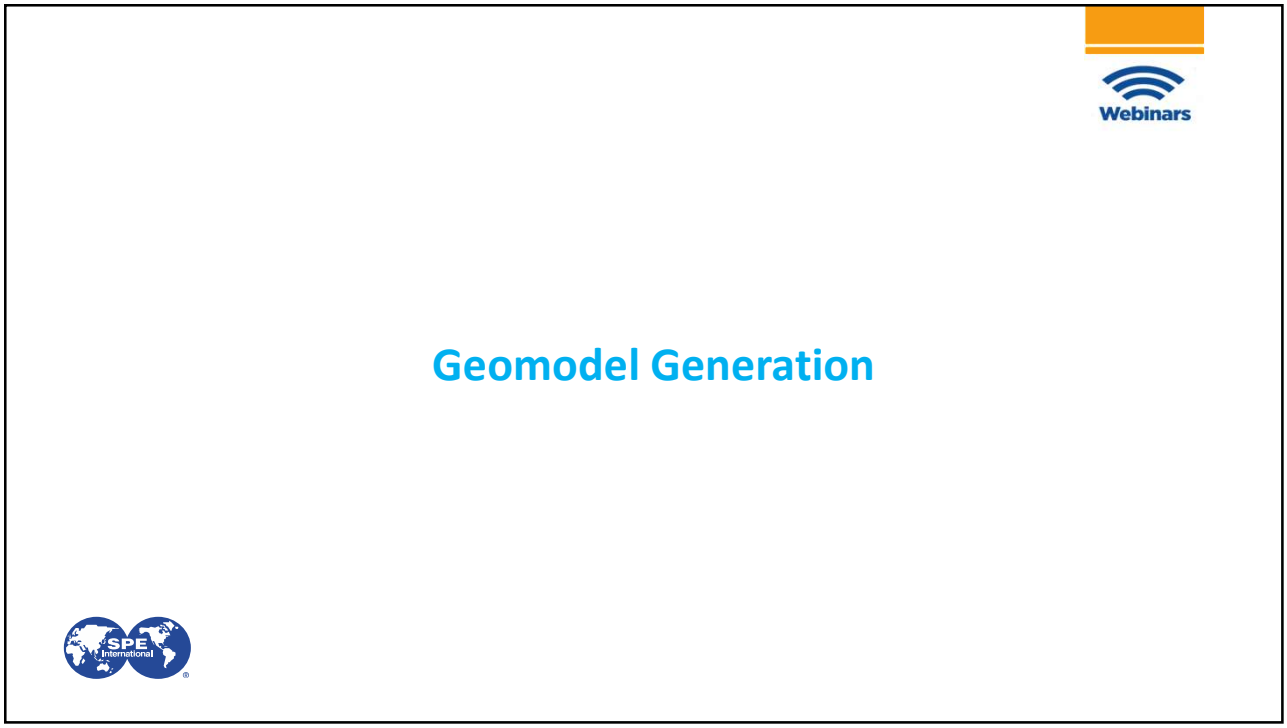
Permeability Reconstruction

CR	Mean Test SSIM	Log(Permeability)			
		Testing example 1	Testing example 16	Testing example 12	Testing example 21
Original	1.00				
167	0.93				
417	0.86				
834	0.82				
Colorbar					



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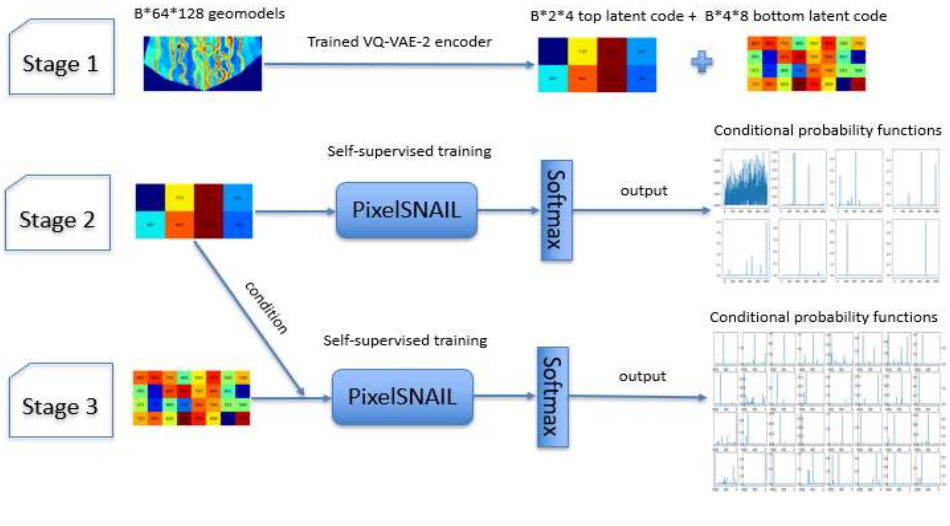
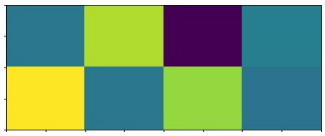
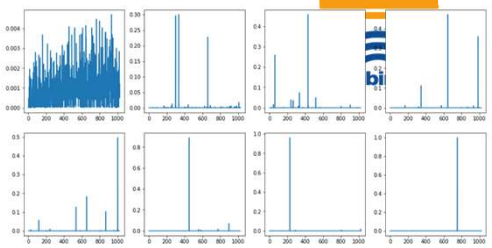
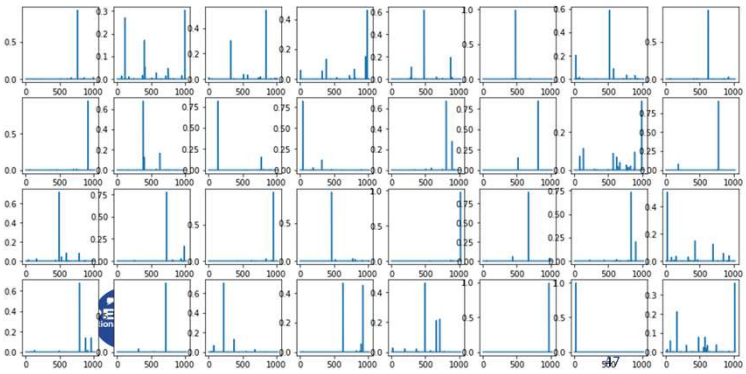
Sampling New Latent Code



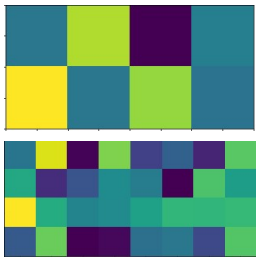
New Code







New Geomodel Generation

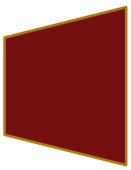


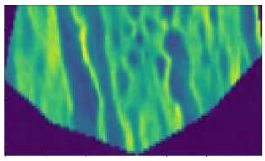
0.1	2.8	3.2
6.2	3.6	11.2
0.4	0.6	0.1
11	-2.1	33
7.9	1.4	-4.1
6.1	12	9
0.21	-1	9.2
6.2	0.6	1.1
5.2	2.2	-3.1

Decoder Input

6.2	3.6	11.2
0.4	0.6	0.1
7.9	1.4	-4.1
0.1	2.8	3.2
0.1	2.8	3.2
0.21	-1	9.2
0.1	2.8	3.2
11	-2.1	33

Decoder





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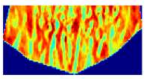
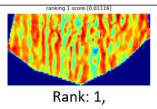
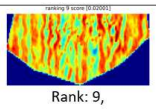
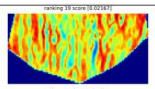
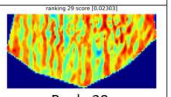
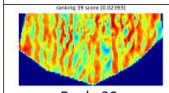
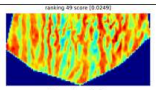
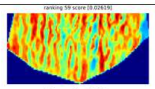
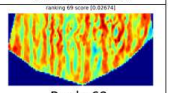
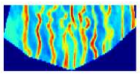
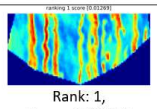
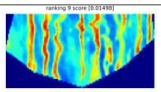
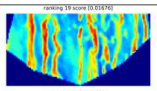
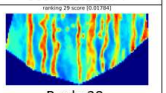
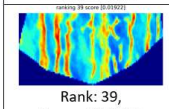
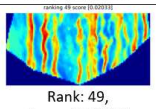
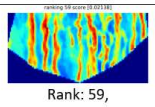
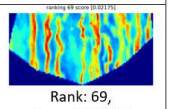
Conditional Geomodel Generation

Source Geomodel	Generated Geomodels conditioned on Source Geomodel			
	 Rank: 1, Score: 0.01116	 Rank: 9, Score: 0.02001	 Rank: 19, Score: 0.02167	 Rank: 29, Score: 0.02303
	 Rank: 39, Score: 0.02393	 Rank: 49, Score: 0.02490	 Rank: 59, Score: 0.02619	 Rank: 69, Score: 0.02674
	 Rank: 1, Score: 0.01269	 Rank: 9, Score: 0.01498	 Rank: 19, Score: 0.01676	 Rank: 29, Score: 0.01784
	 Rank: 39, Score: 0.01922	 Rank: 49, Score: 0.02033	 Rank: 59, Score: 0.02138	 Rank: 69, Score: 0.02175

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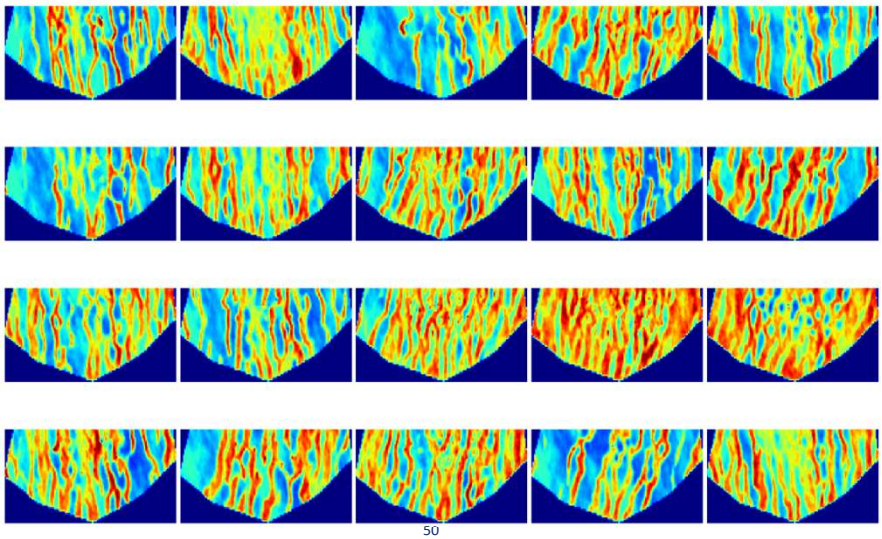
Unconditional Geomodel Generation



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