Enhanced Carbon Storage Forecasting via Cross-Geology Transfer Learning

Sid Misra, Texas A&M University
Yusuf Falola, Texas A&M University

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Disclaimer

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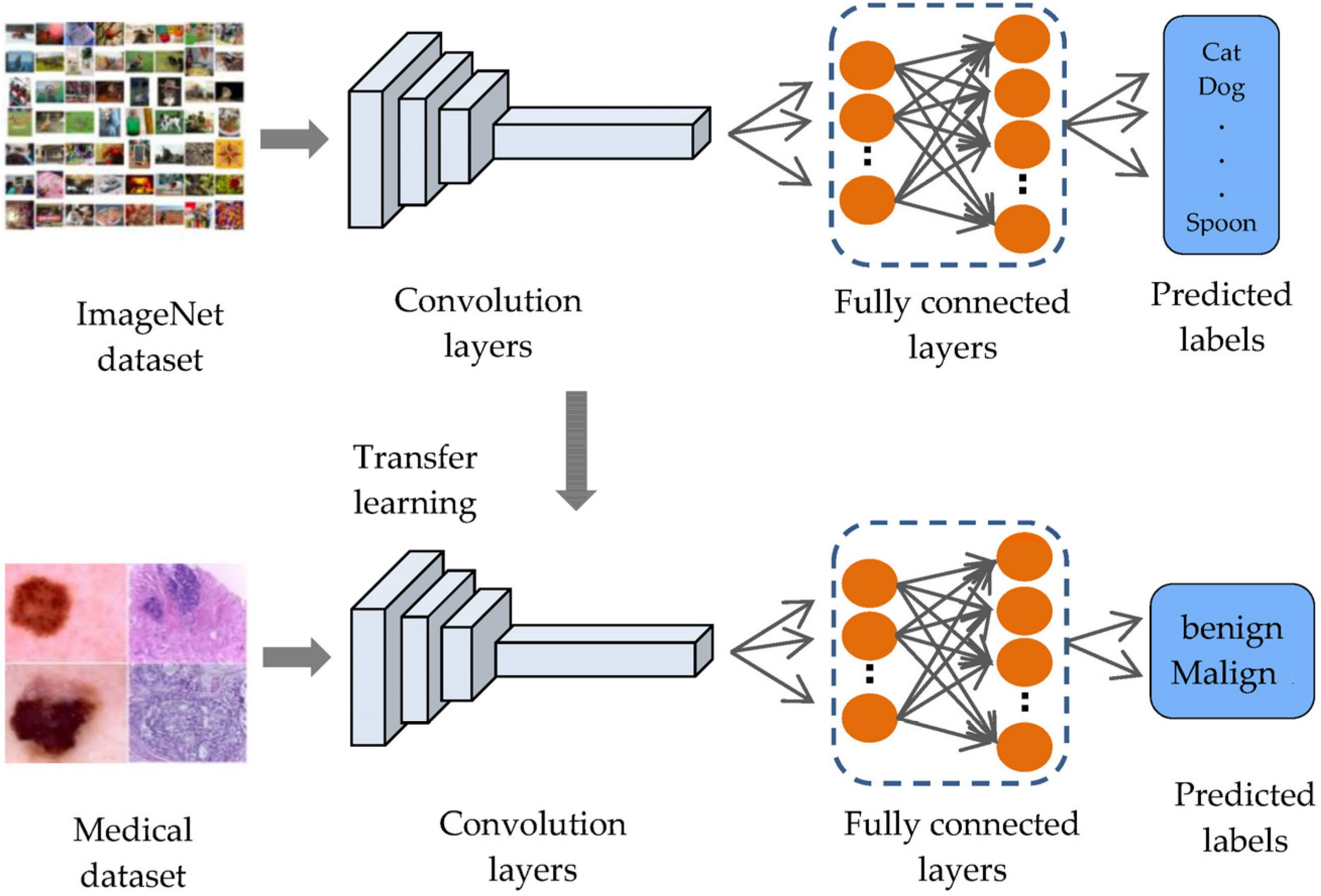
TRANSFER LEARNING

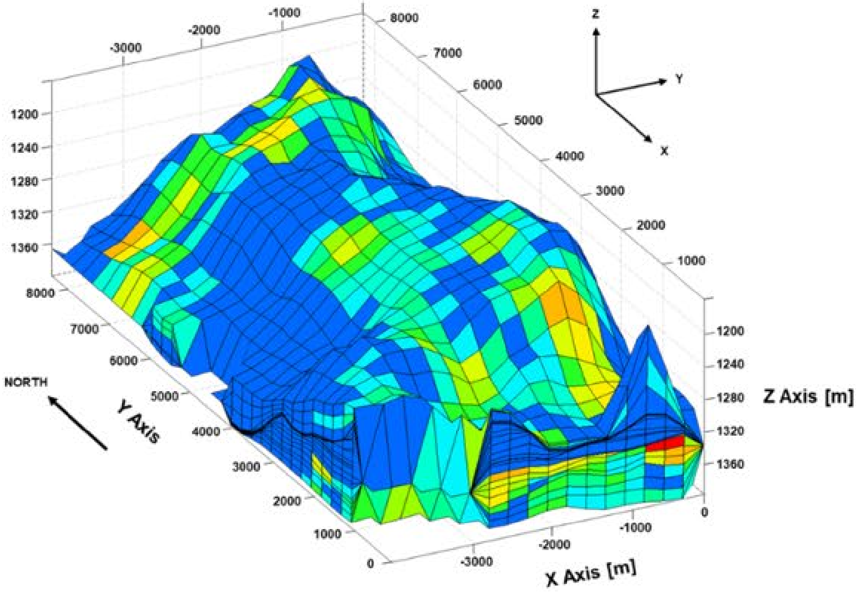


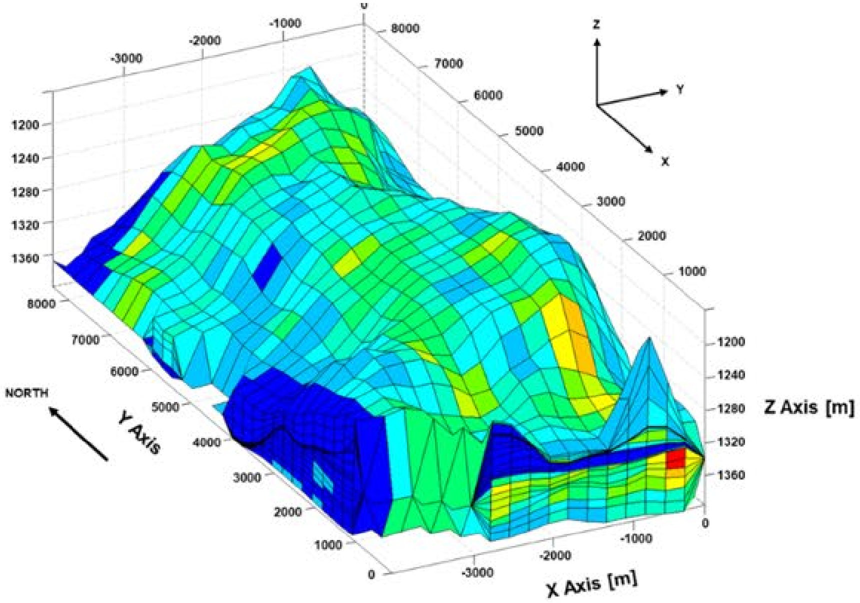
TRANSFER LEARNING

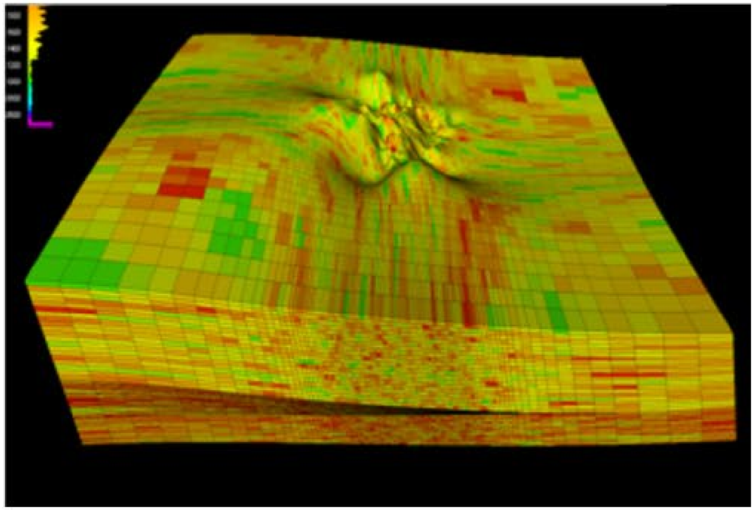
SOURCE (SACROC)

Phase 2
*From one **field** to the other*

TARGET (IBDP)







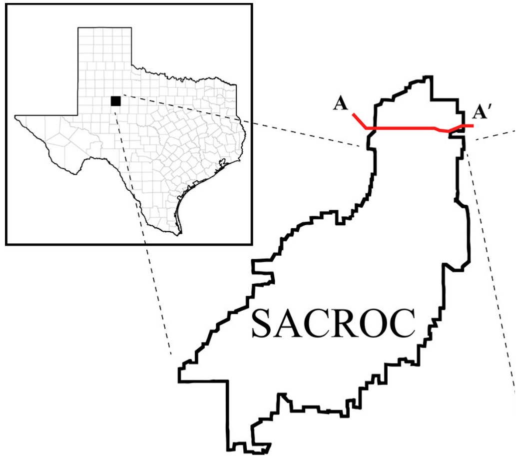
TARGET (SACROC P10)

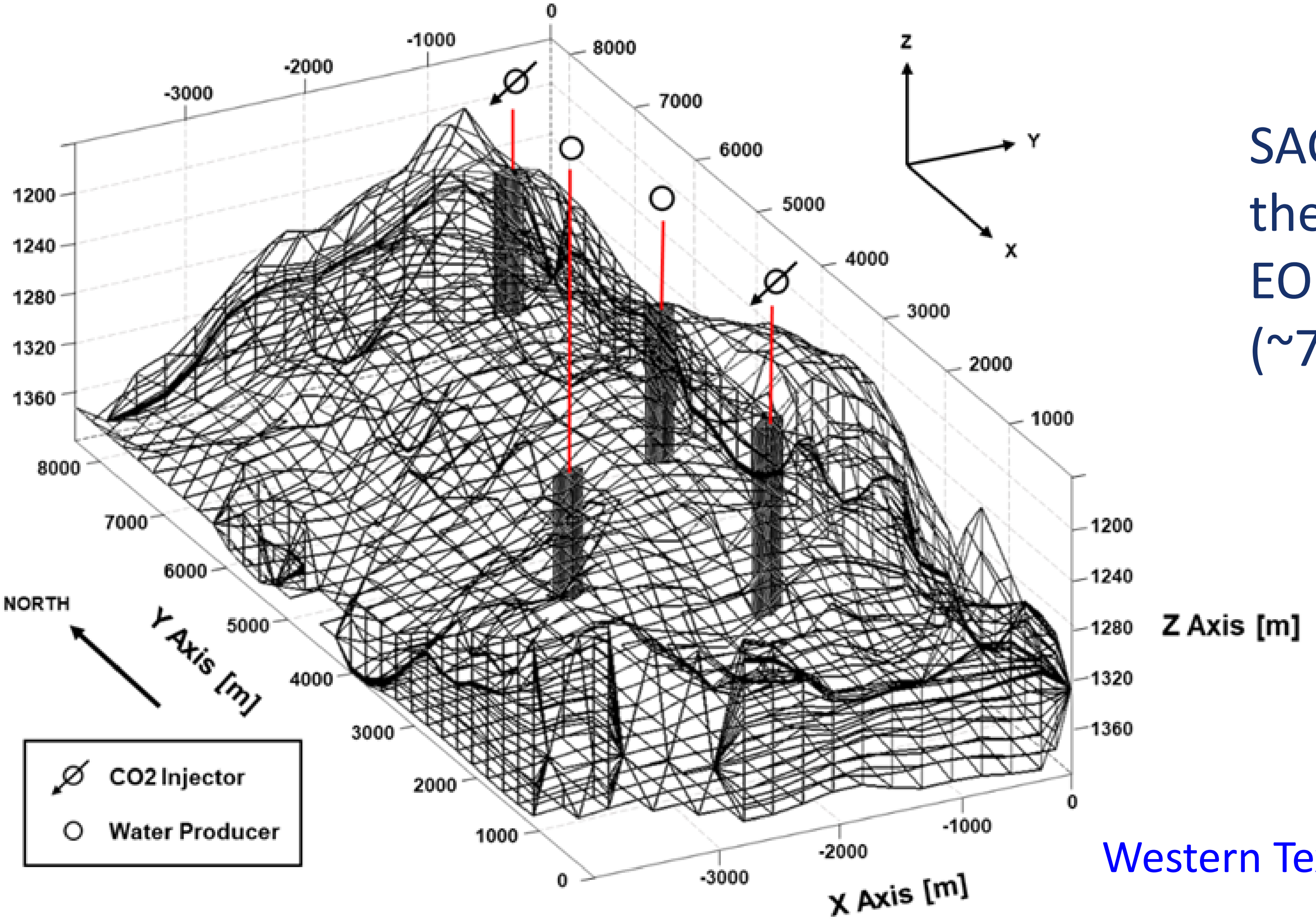
Phase 1
*From one **realization** to the other*

SOURCE (SACROC P90)

SOURCE SITE: SACROC

SACROC GEOMODEL

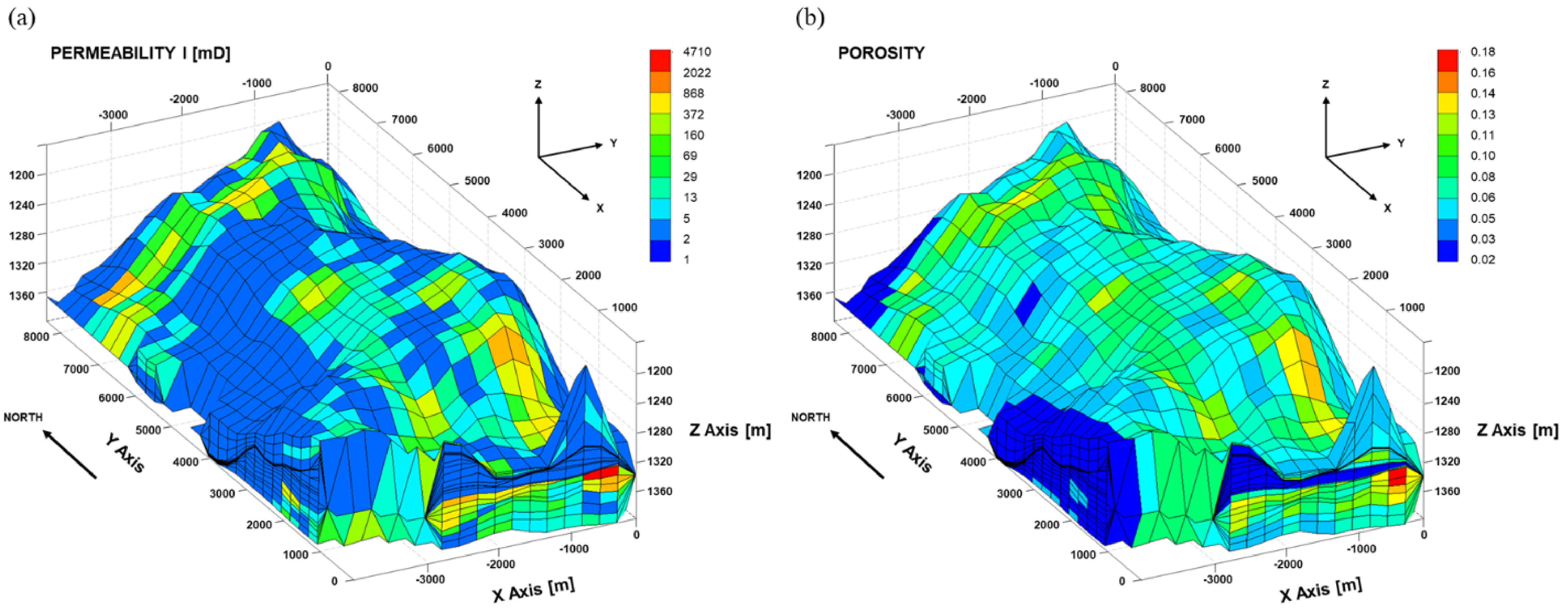




SACROC unit is the oldest CO_2-EOR site in the US (~75 years).

Western Texas Permian Basin

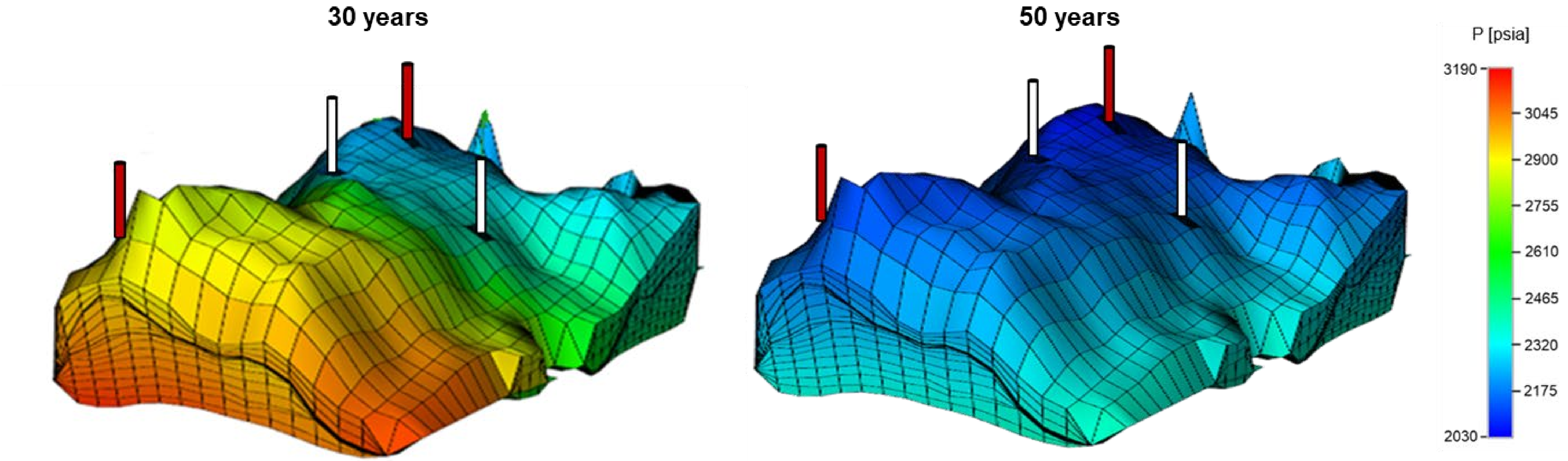
POROSITY AND PERMEABILITY



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

TRAINING DATASET

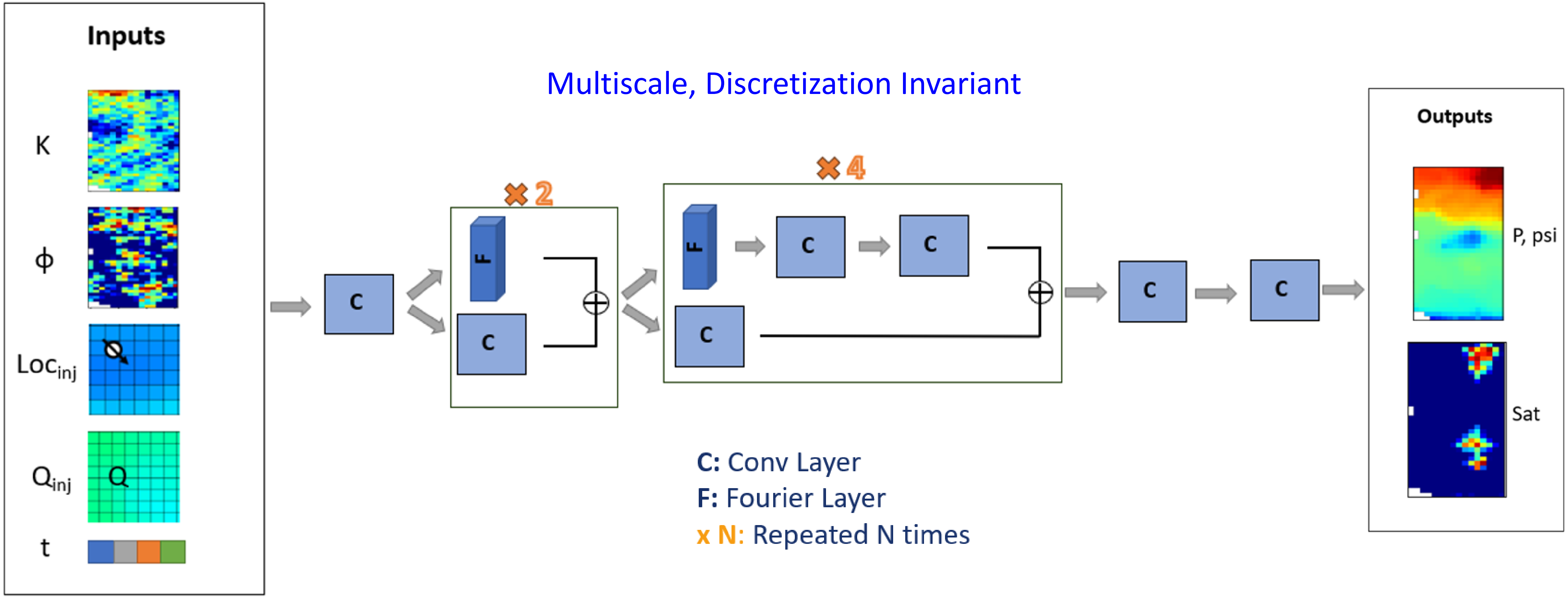
4000 m by 8200 m by 250 m represented using 36x16x25 grid cells



Miscible & Immiscible Displacement; Oil Swelling; Viscosity Reduction; IFT reduction; Carbonic Acid; Pressure Maintenance; Sweep

RAPID FORECASTING USING NEURAL OPERATOR

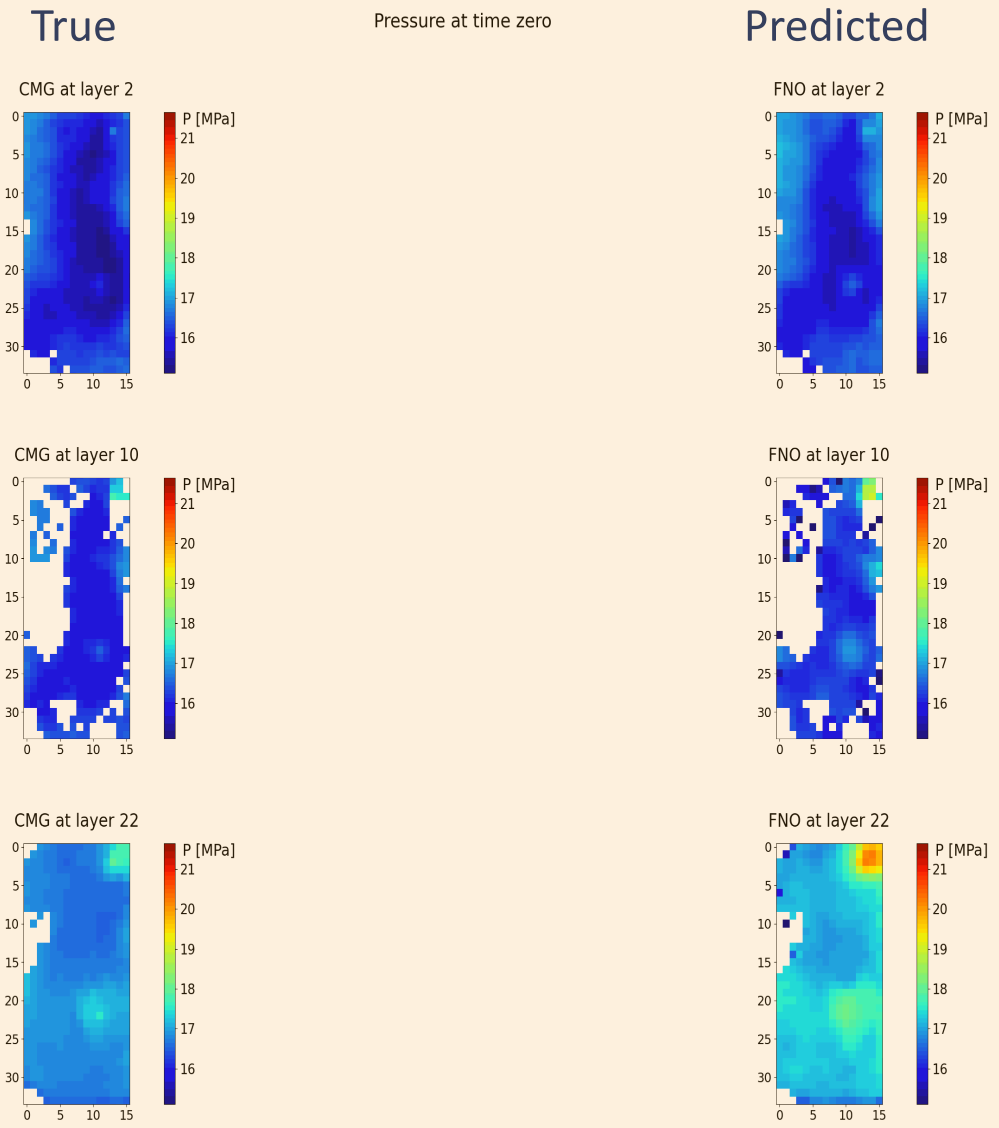
Multiscale, Discretization Invariant



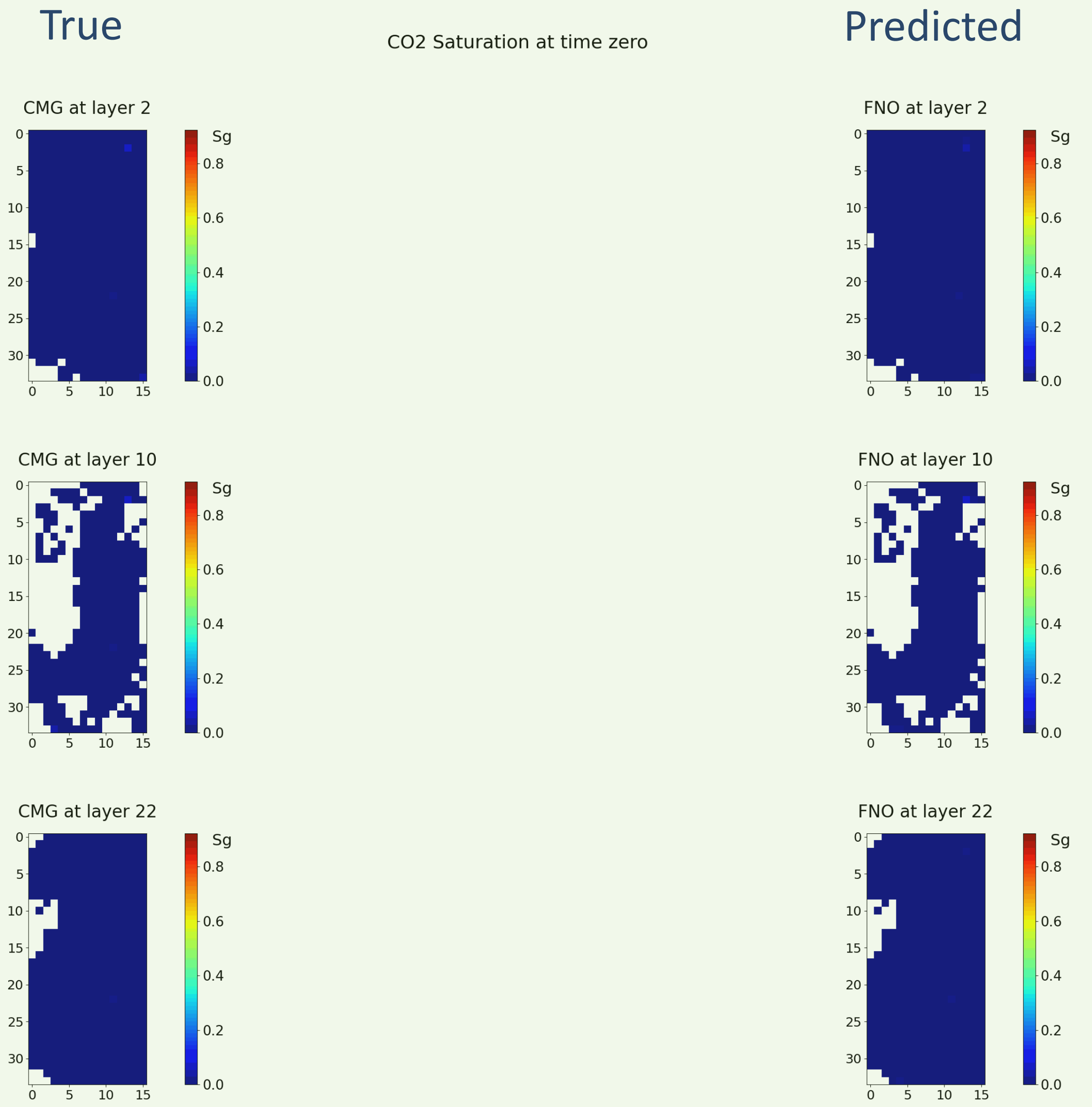
C: Conv Layer
F: Fourier Layer
x N: Repeated N times

Mapping the spatial distribution of transport/engineering parameters to spatiotemporal pressure & saturation

Pressure Forecast

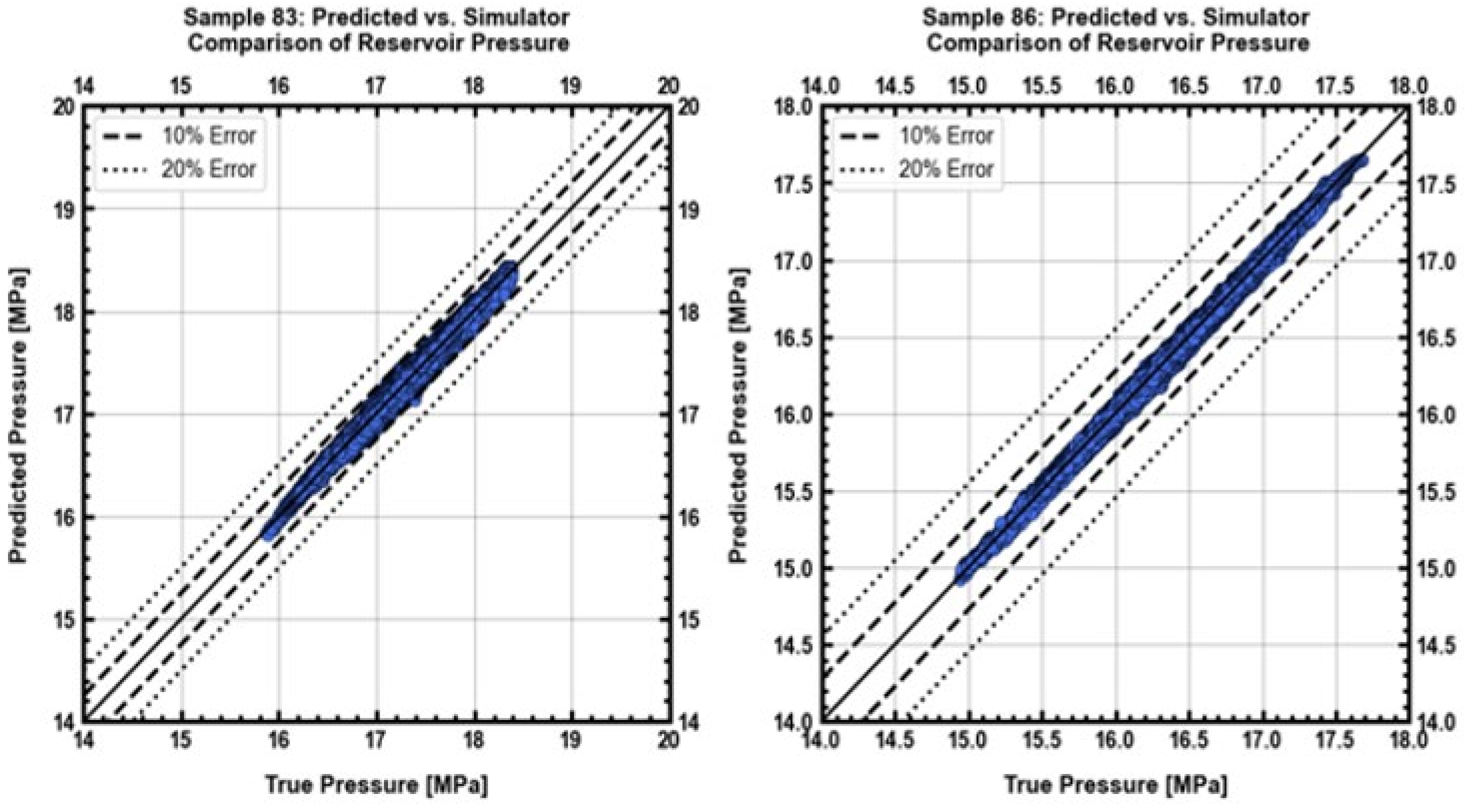


Saturation Forecast



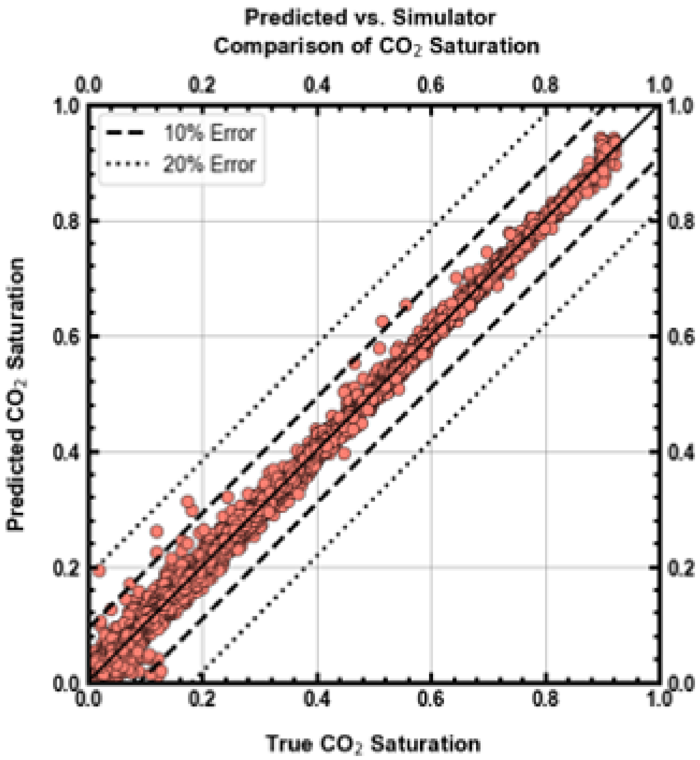
FNO-I Performance for Pressure

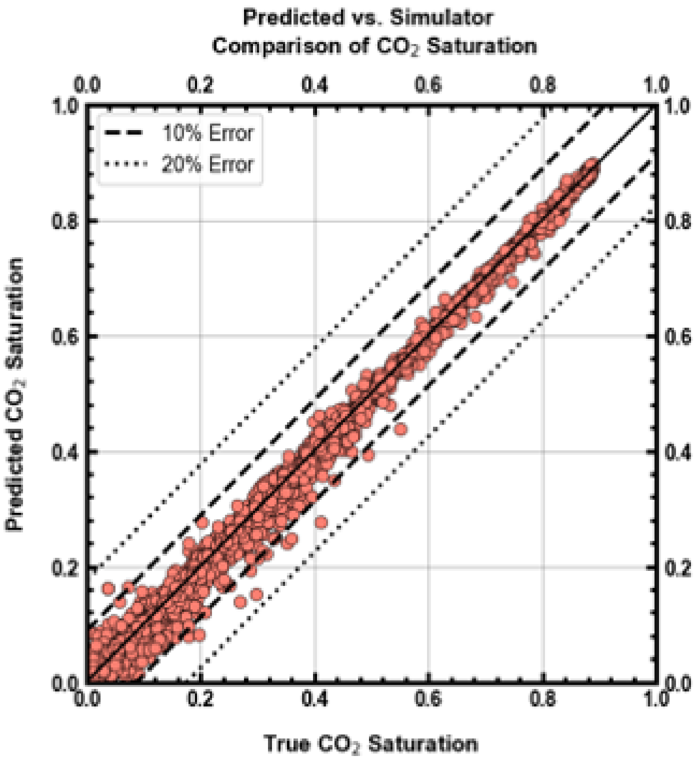
Improved FNO-I



FNO-II Performance for Saturation

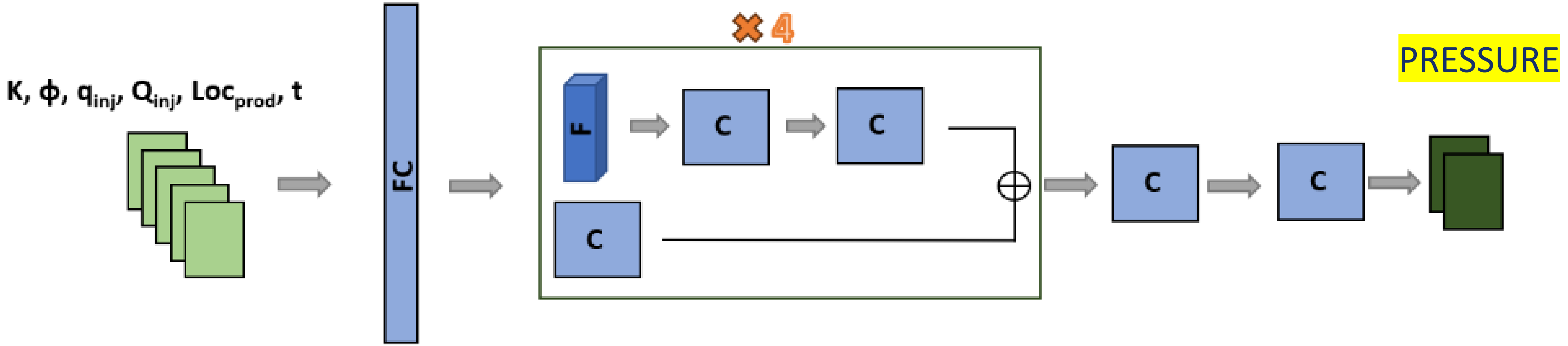
Improved FNO-II



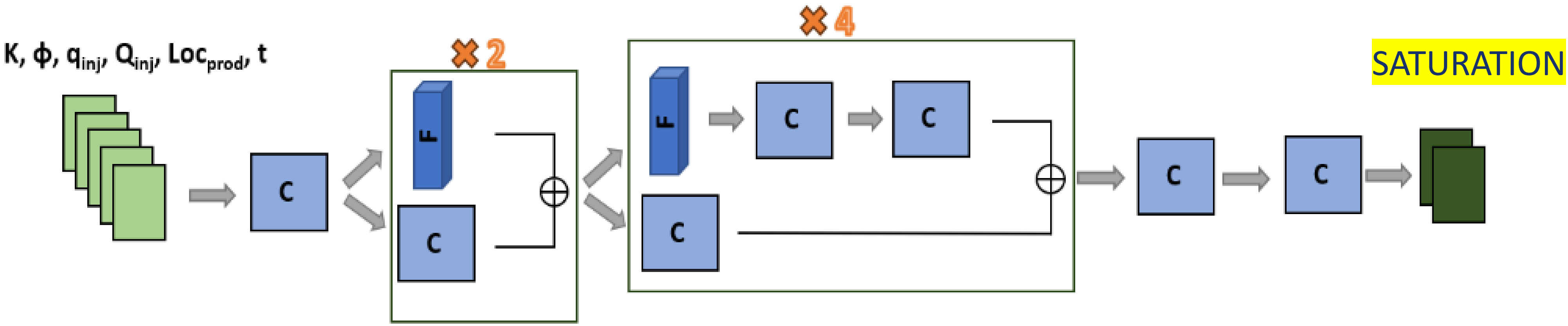


Model Architecture

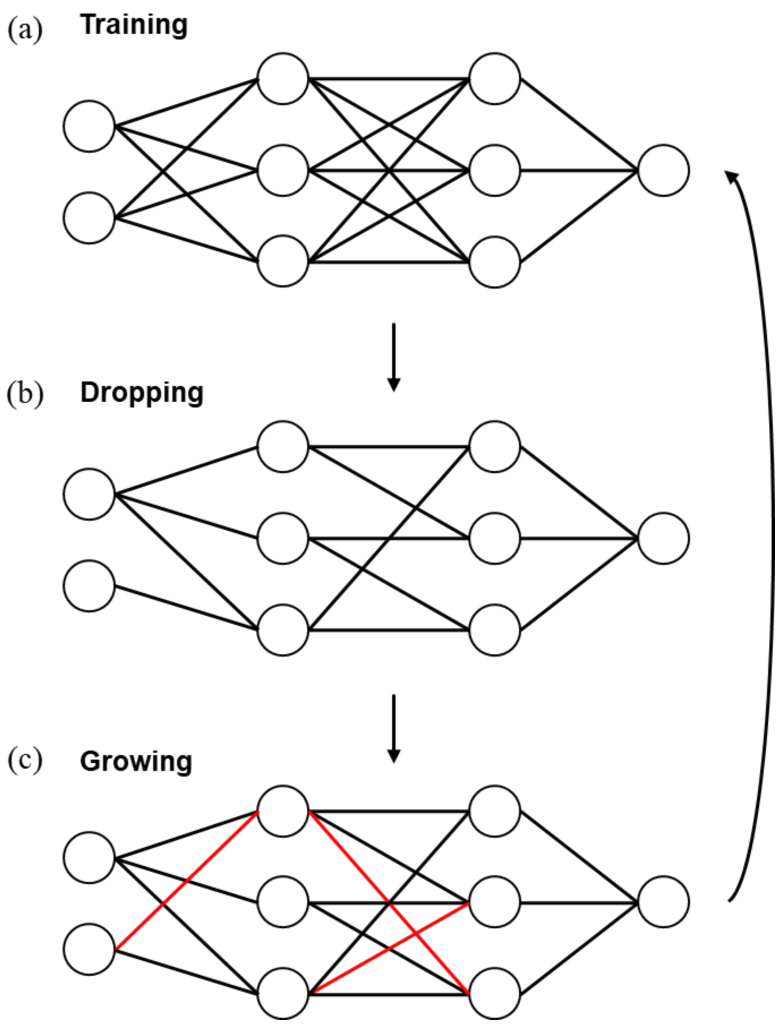
0.5 million parameters



0.8 million parameters



SPARSE REPRESENTATION

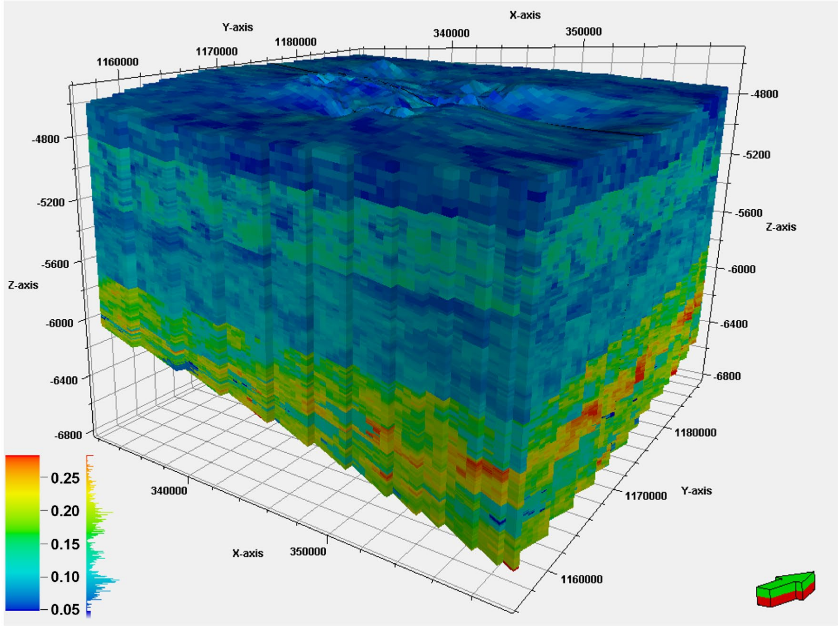


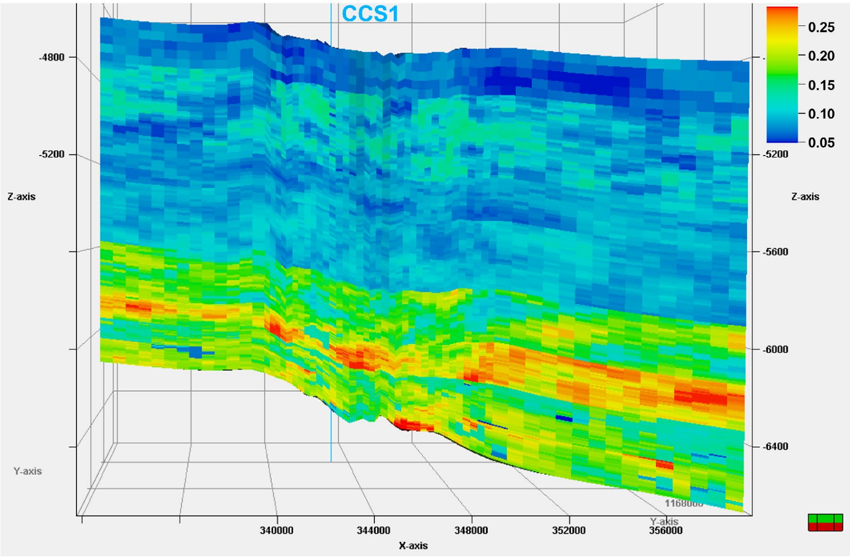
- Inference speed-up is possible using sparse neural network developed using RigL Library
- At regularly spaced intervals, remove a fraction of connections and then activate new.
- First layer is kept dense.
- Update is based on ΔT, Fraction, Decay, T_{end}
- GeLU within, Modified ReLU for final

TARGET SITE: IBDP

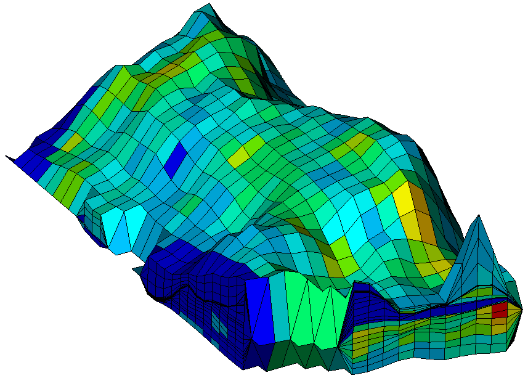
IBDP Site

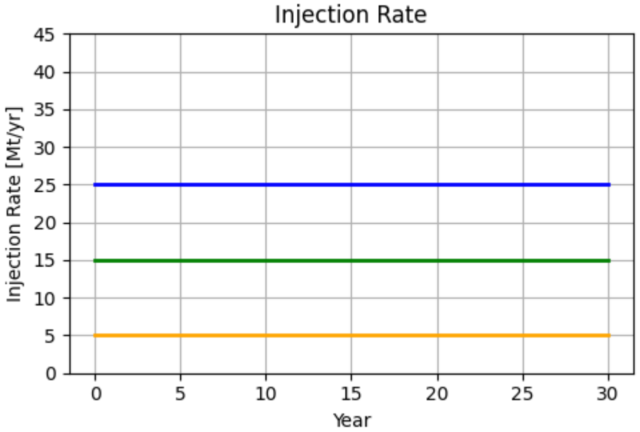
- U.S. DOE carbon storage project located in Illinois Basin
- 15.6km x 15km x 2.14km (126x125x110)
- Heterogeneous Sandstone (layered)

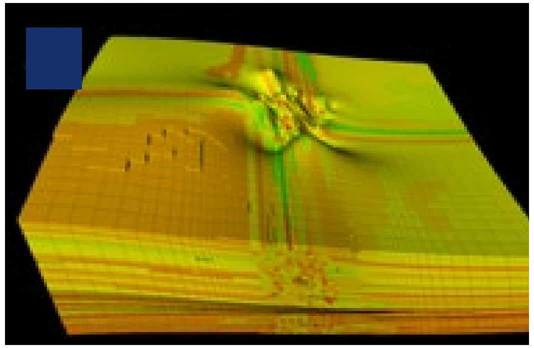


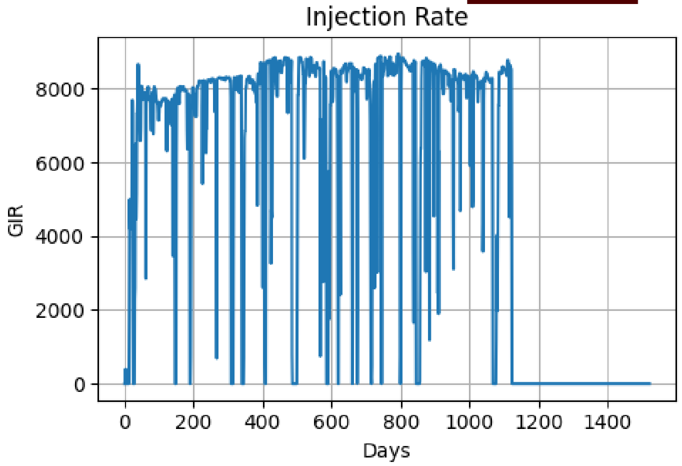


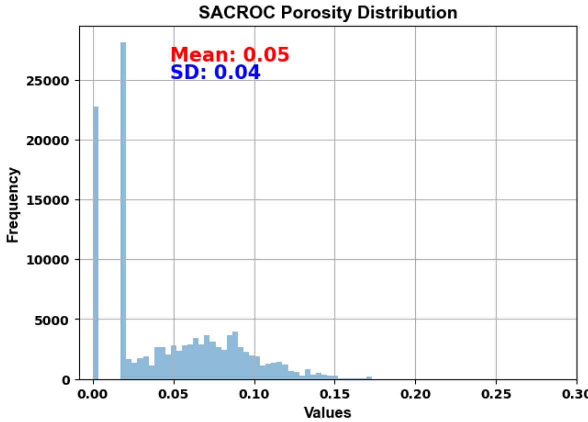
Transfer Learning from SACROC to IBDP

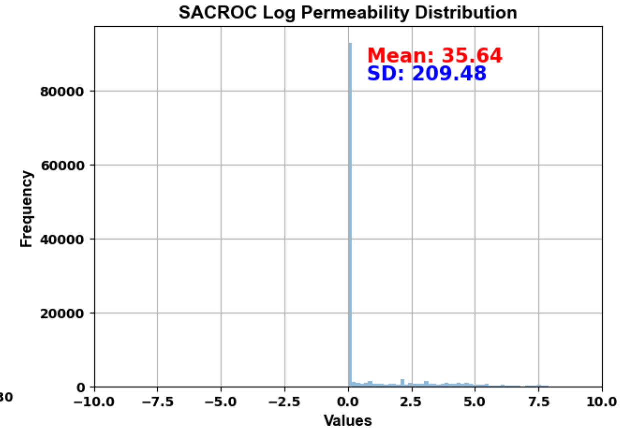


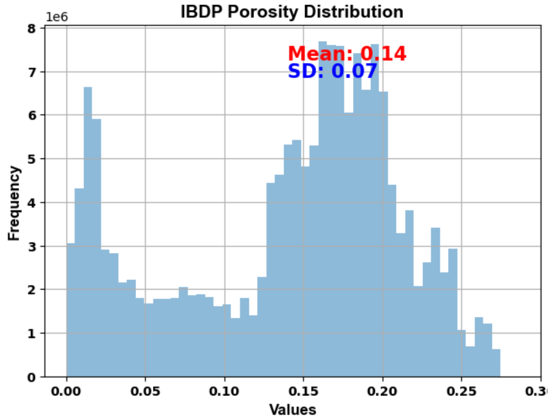


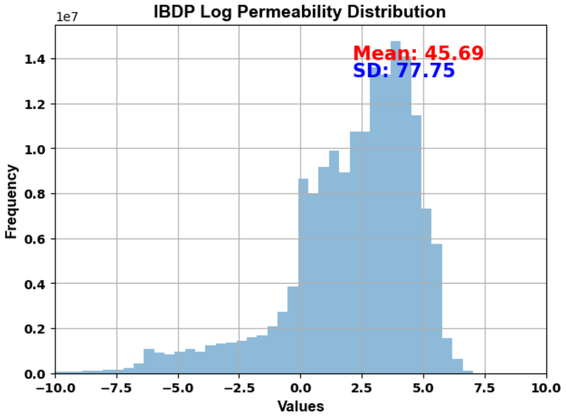












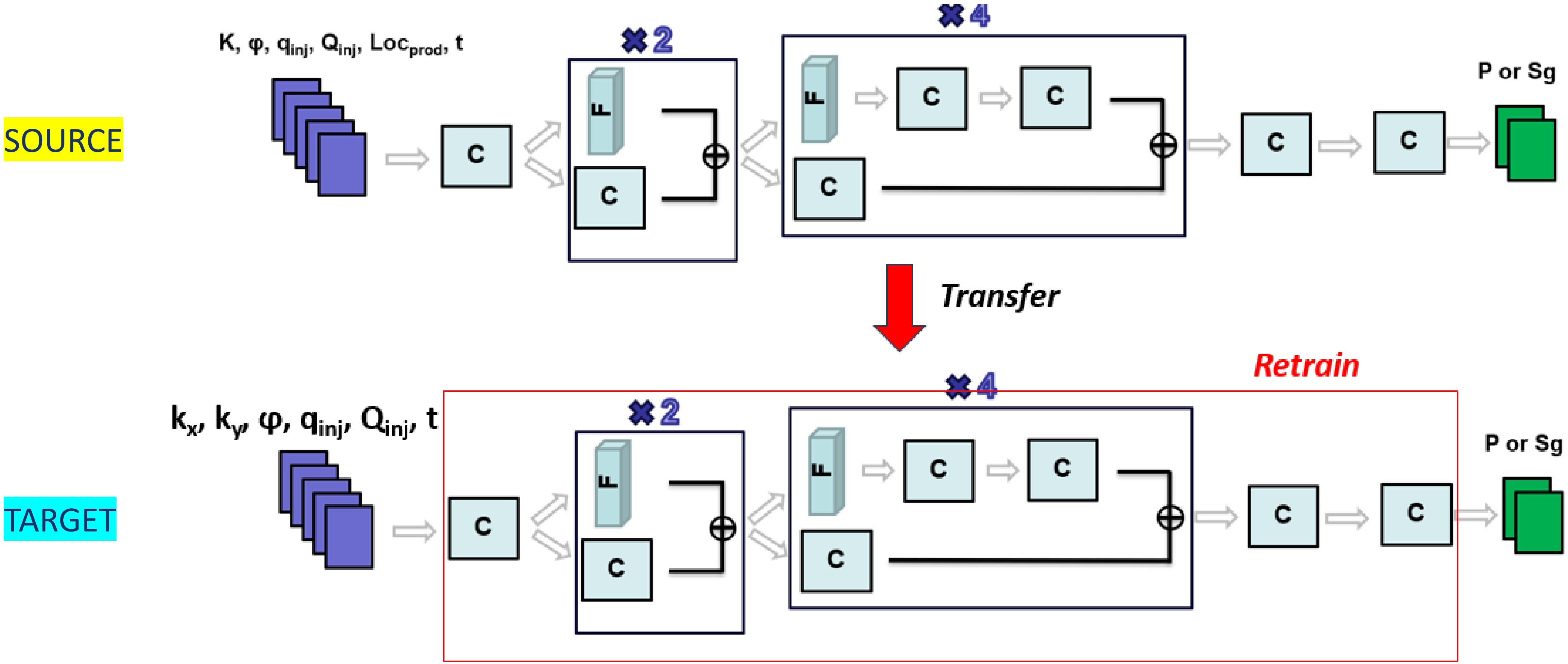
- SACROC Geomodel (SOURCE)
- 4km x 8.2km x 0.2km (36 x 14 x 25)

- IBDP Geomodel (TARGET)
- 15.6km x 15km x 2.14km (126 x 125 x 110)

Differences between SACROC and IBDP

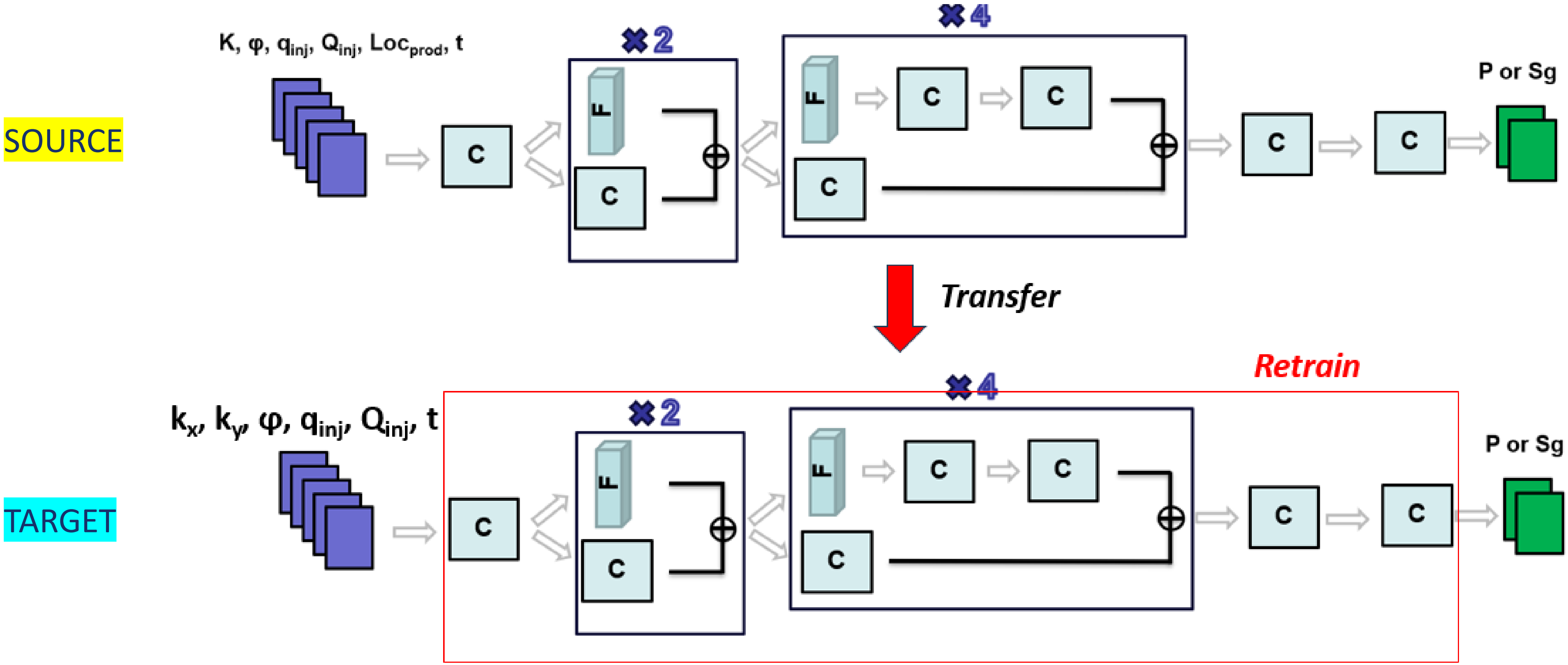
Parameter	SACROC (Source)	IBDP (Target)
Input Variables	q, Q, Kx, poro, t, prod locs	q, Q, Kx, Kz, poro, t
Injection Period (years)	30 (monthly and yearly)	3 & 1 (monthly)
Relative Perm	Tight Rock: Carbonate/Dolomite	Sandstone
Distinct Geomodels	5 (regular grid)	100 (tartan grid)
No of Injection Wells	2	1
No of Producer Wells	2	0
Injection Type	Constant	Variable/Intermittent
Injection Rates Range (MT/yr)	5.6 – 40.8	0.5 – 1.5
Perforation zones	All through z-axis	3 non-continuous zones
Train – Val – Test Split	133 – 20 – 20	10 – 10 – 80 (or 20 – 10 – 70)

Base Transfer Learning with Fine-Tuning



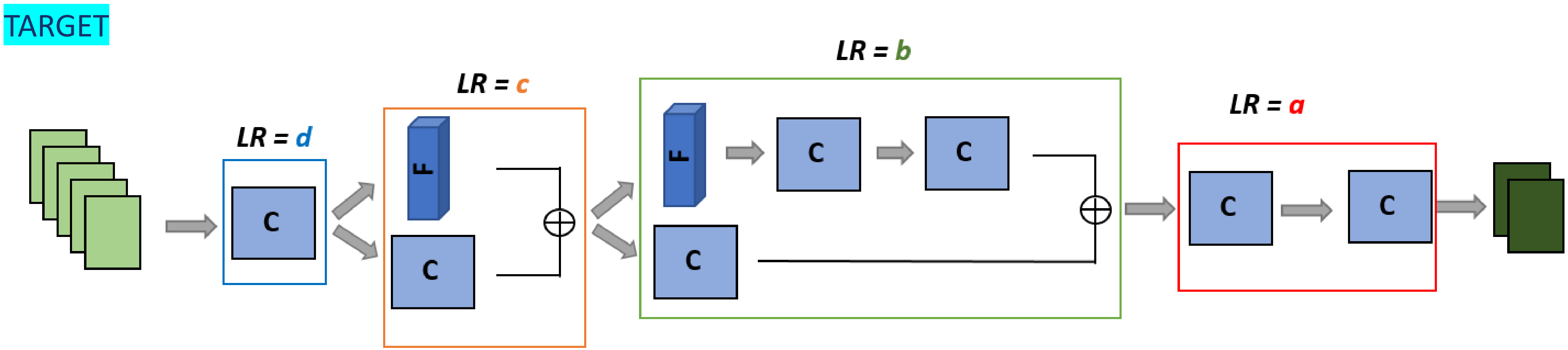
- Fine-tuning with constant learning rate (LR) all through training epochs

Transfer Learning with Adaptive Fine-Tuning



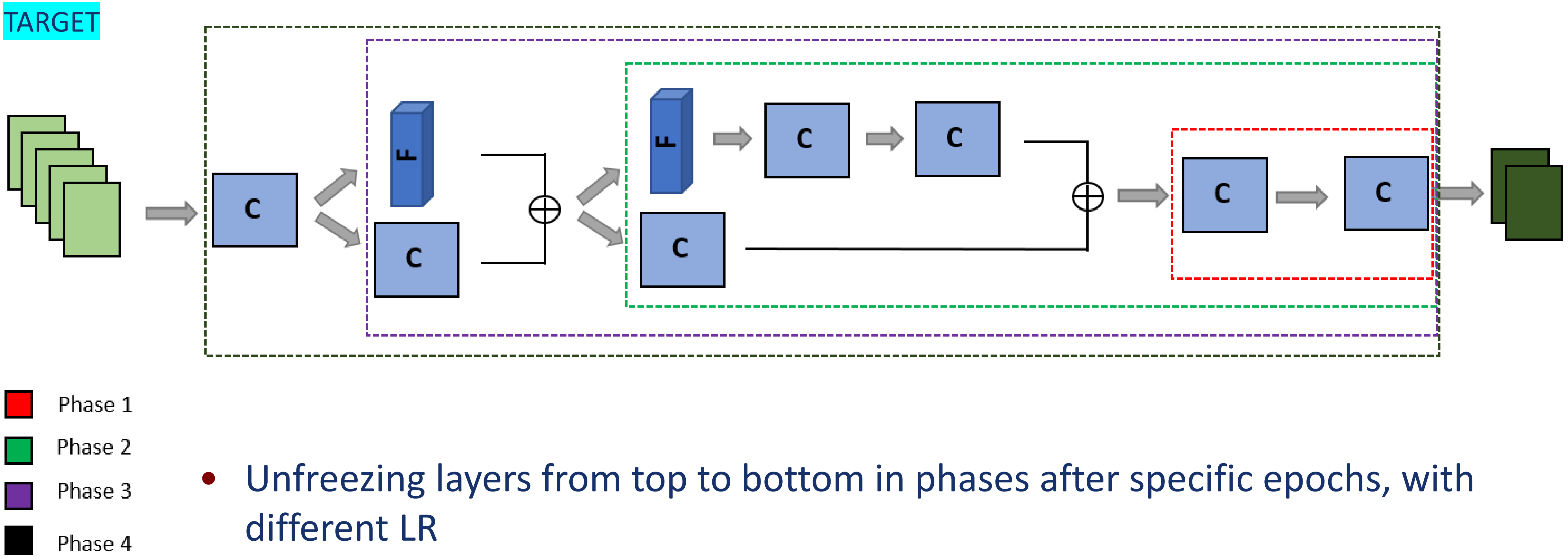
- Fine-tuning with learning rate (LR) that adapts all through training epochs

Transfer Learning with Variable Learning Rates



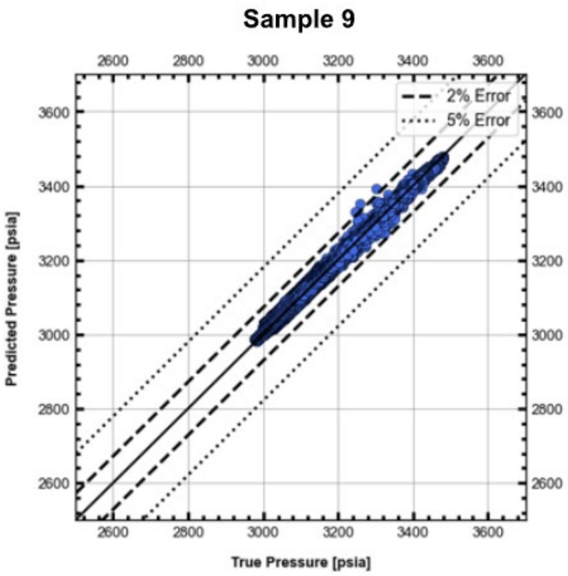
- Fine-tuning by training blocks of layers with specific LR all through training epochs

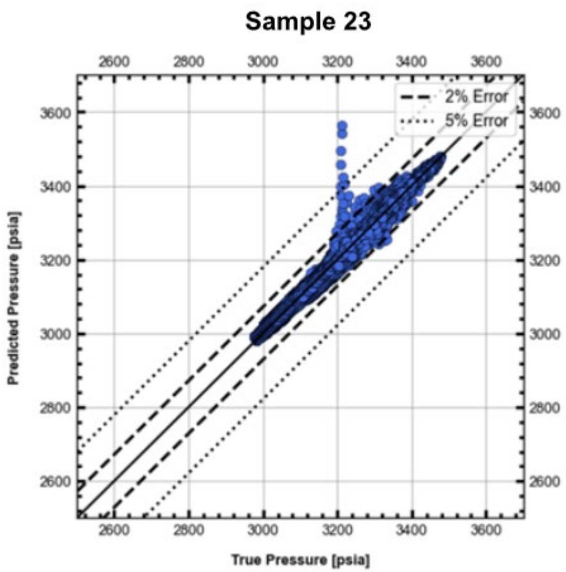
Transfer Learning with Multi-Phase Fine-tuning

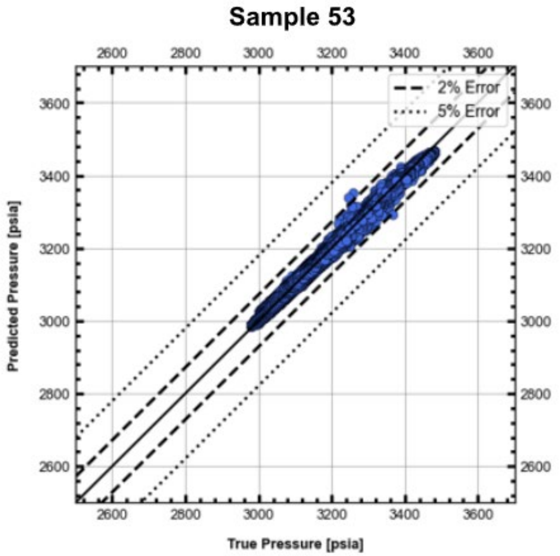


- Unfreezing layers from top to bottom in phases after specific epochs, with different LR

Pressure Forecast with 10 Train Samples

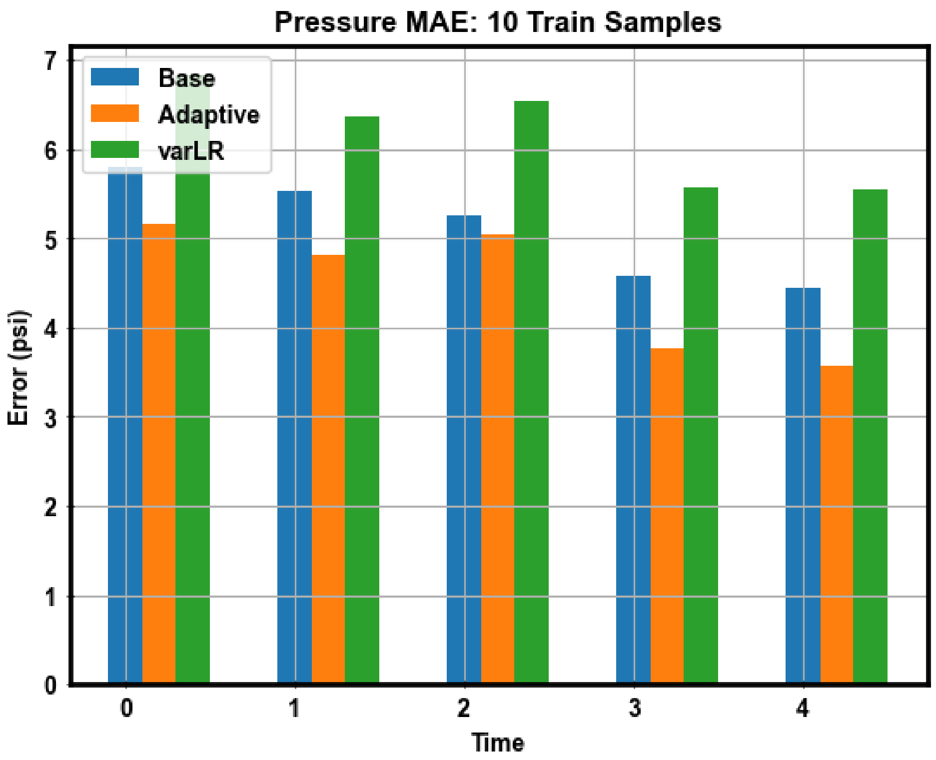


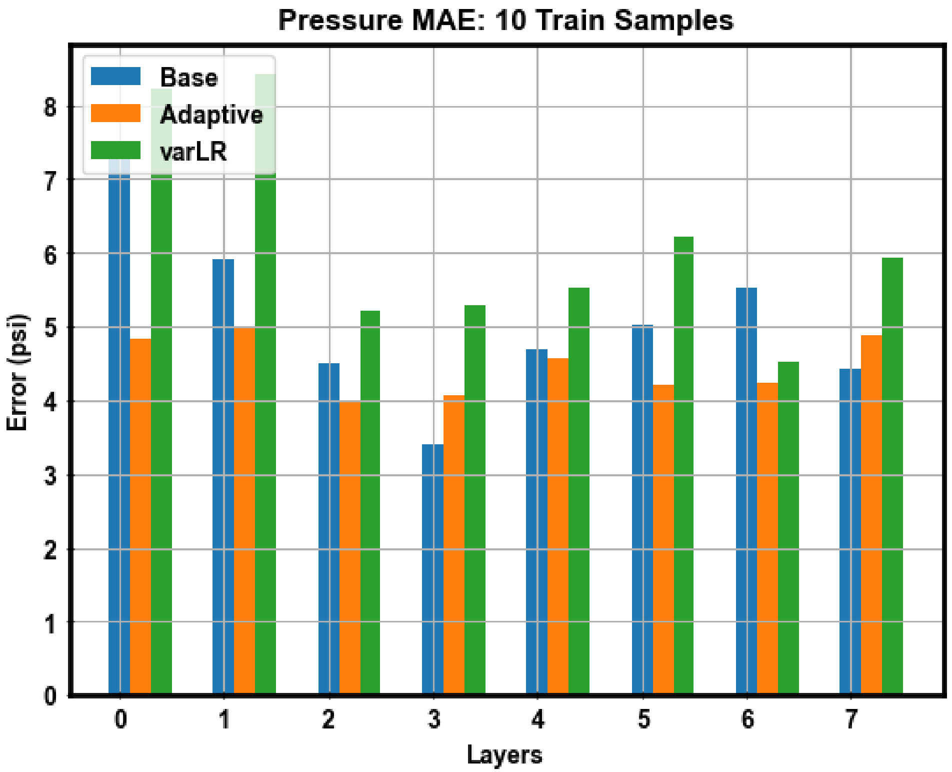




- Cross plots for test samples over all time-steps and layers
- Plots majorly within the 2% error range
- Training+Validation set: 20, Test set: 80

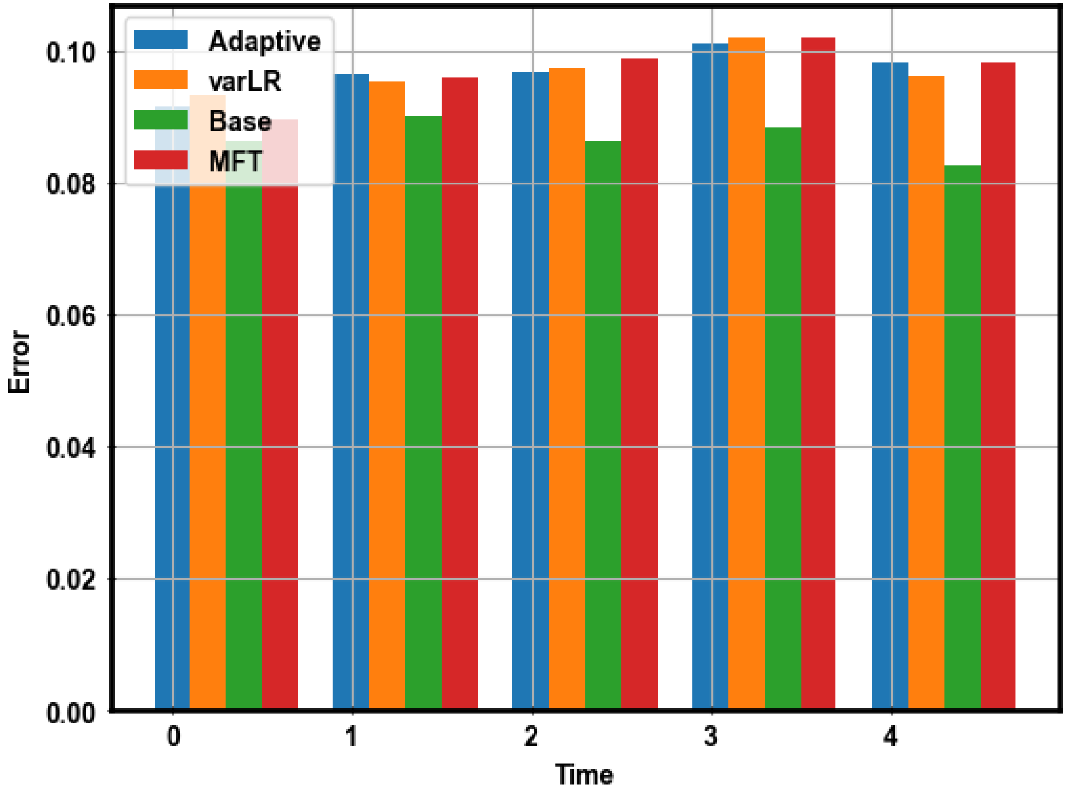
Error plots for Pressure Forecast





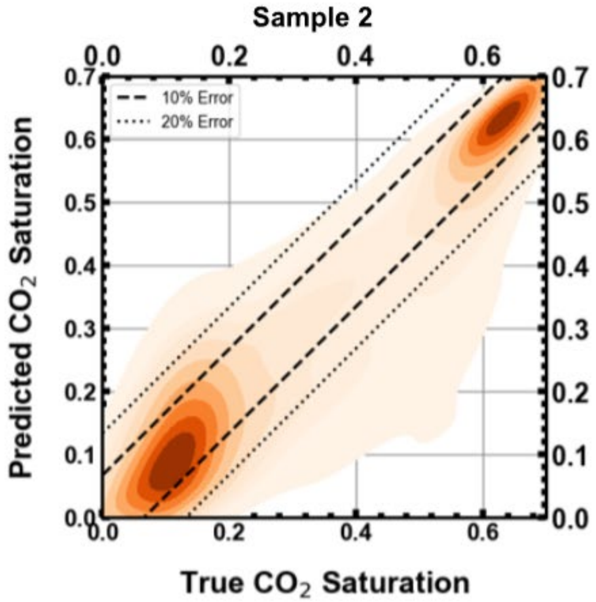
- Adaptive LR gave the best results of the TL techniques
- Overall MAE: 4.47psia for all samples, time-steps and layers
- 87% data reduction (7 times)

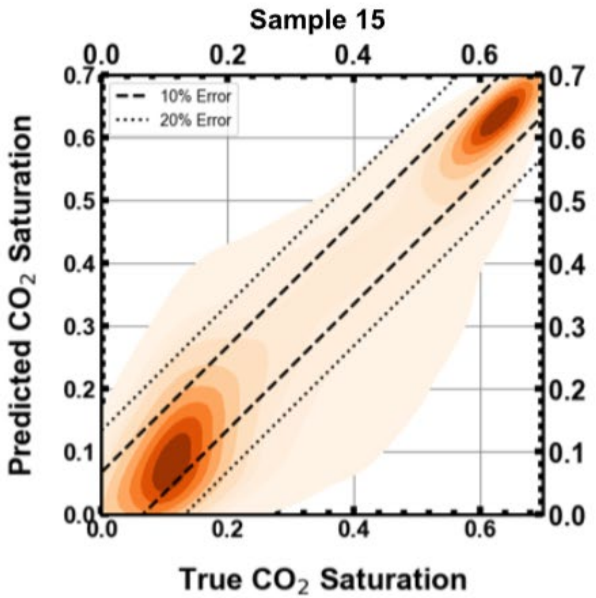
Error plots for Saturation Forecast

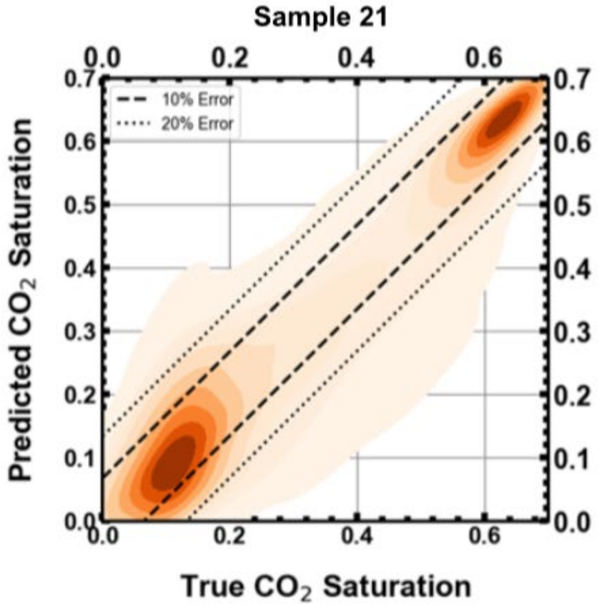


- Base fine-tuning gave the best results of the TL techniques
- Overall MAE: 0.086 for all samples, time-steps and layers
- 80% data reduction (5 times)

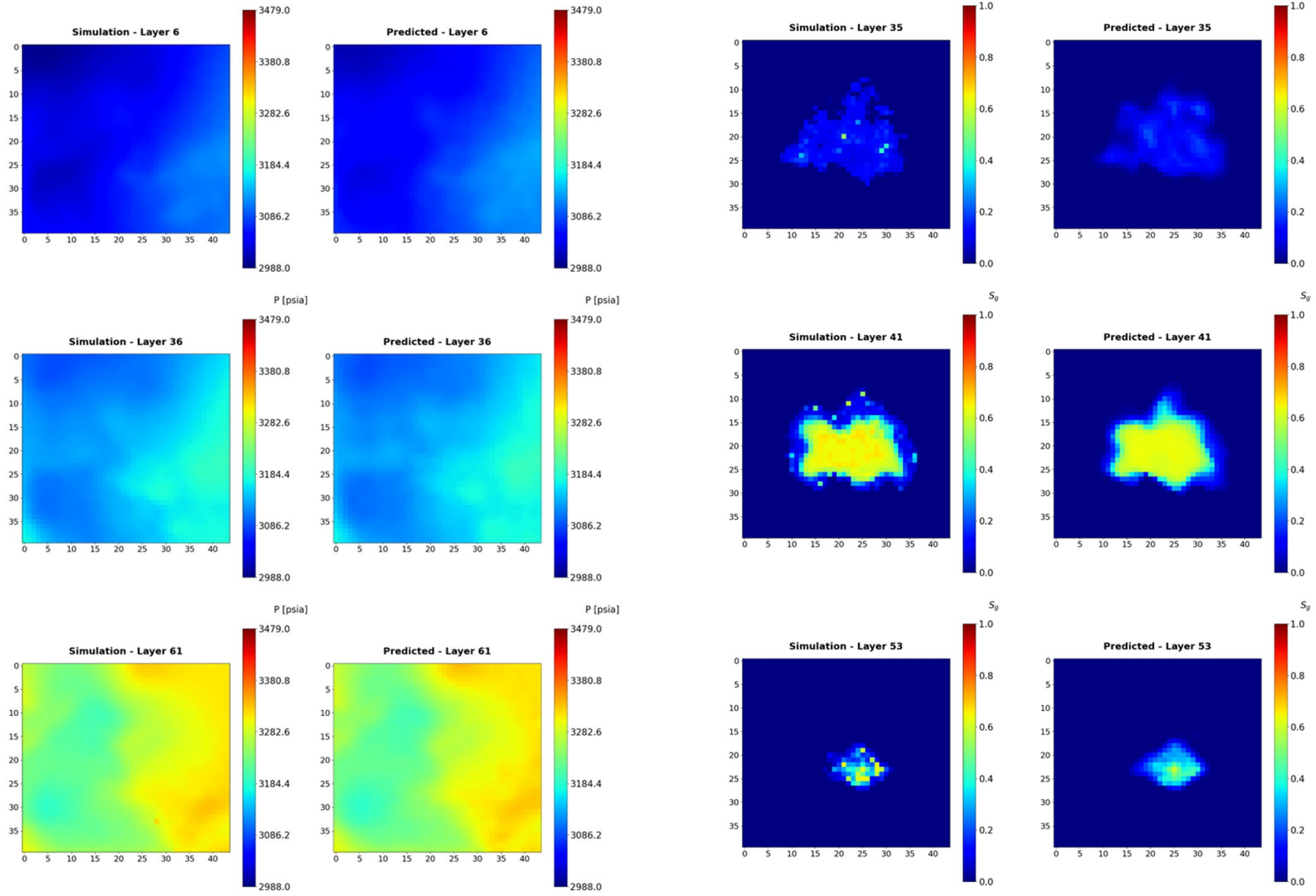
Saturation Forecast with 20 Train Samples





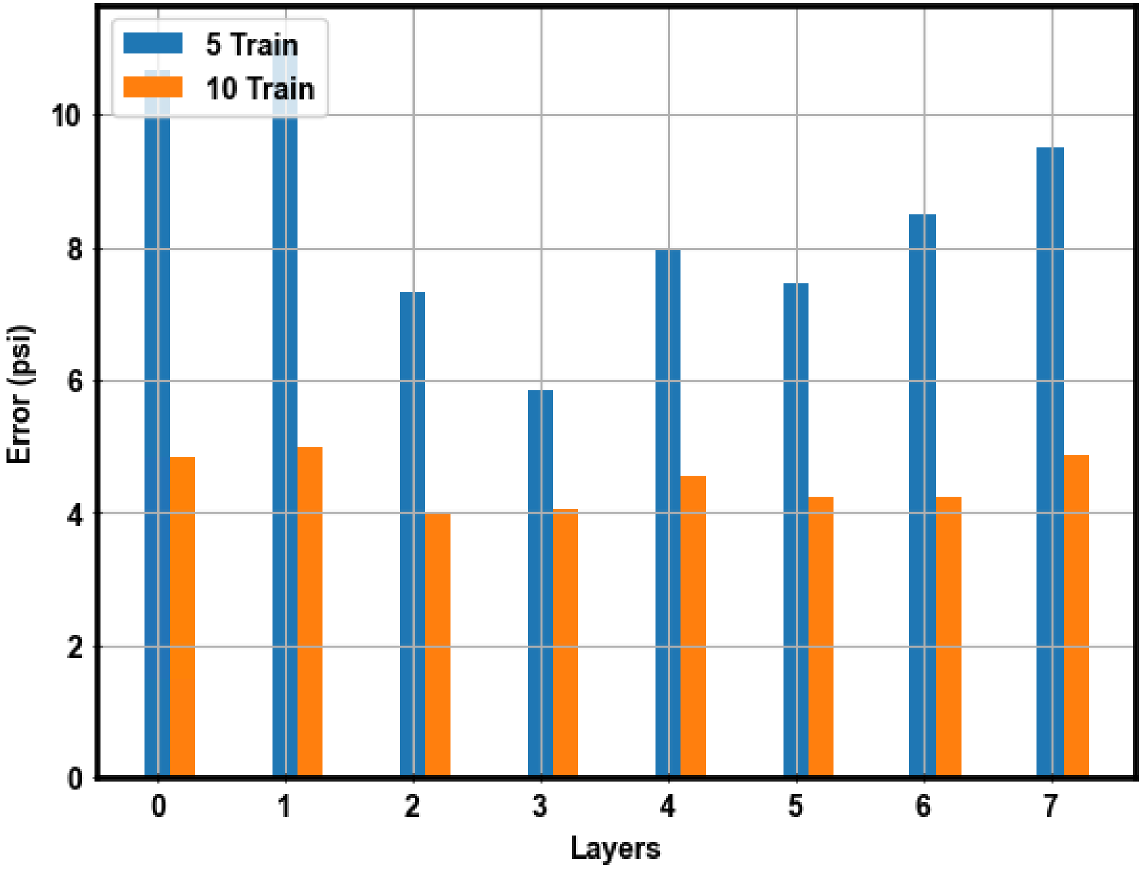


- Cross plots for test samples over all time-steps and layers
- Plots majorly within the 10% error range
- Training-Validation set: 30, Test set: 70

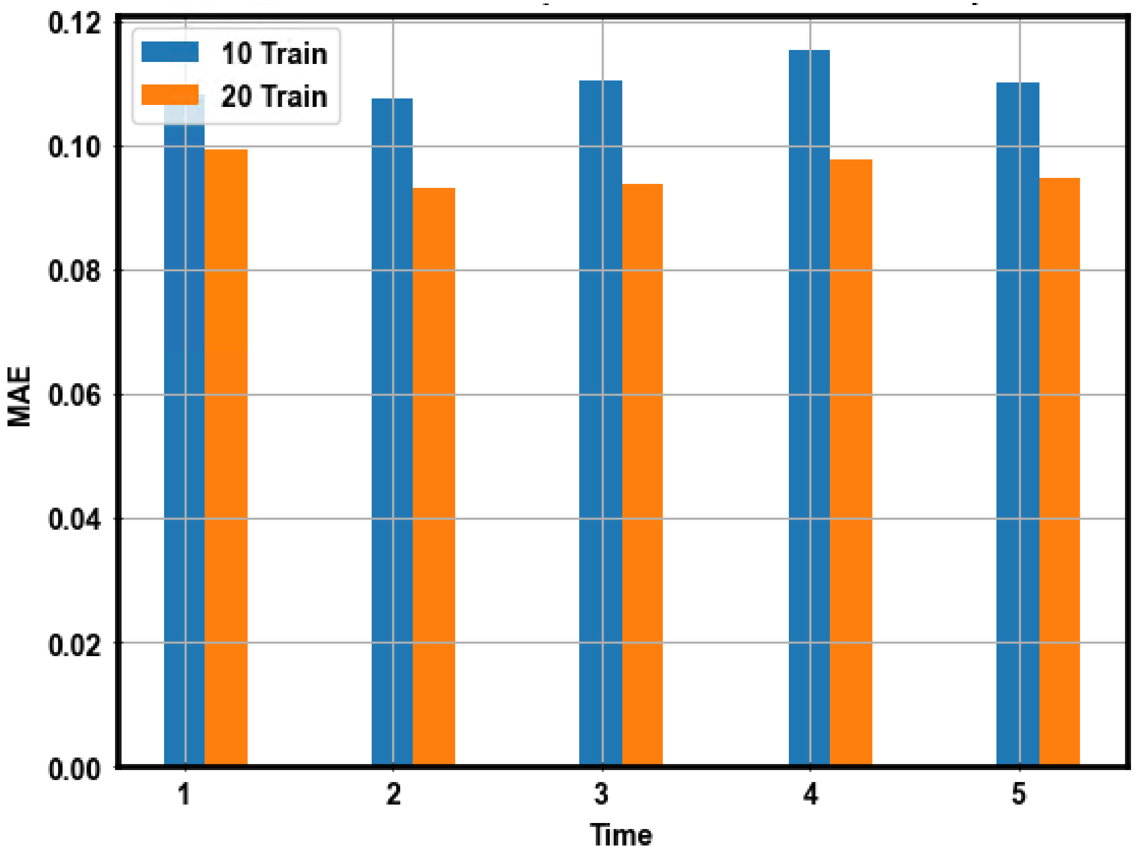

Simulation - Layer 6
Predicted - Layer 6
Simulation - Layer 35
Predicted - Layer 35
Simulation - Layer 36
Predicted - Layer 36
Simulation - Layer 41
Predicted - Layer 41
Simulation - Layer 61
Predicted - Layer 61
Simulation - Layer 53
Predicted - Layer 53
P [psia]
S_g
3479.0
3380.8
3282.6
3184.4
3086.2
2988.0
1.0
0.8
0.6
0.4
0.2
0.0

Reducing Training Datasize

PRESSURE



SATURATION



Key Takeaway

- *Transfer Learning was implemented on the SACROC-based Neural Operator that was trained on only 20 simulation runs for IBDP Site*
- *SACROC and IBDP Sites have several significant differences in geology and engineering parameters.*
- *Pressure forecast has less than 9 psi error*
- *Saturation forecast has less than 8% error*
- *Traditional simulator takes 1 hour for a single scenario, while neural operator takes less than 1 minute to forecast.*

Transfer Learning Benefits

Model	Train	Validation	Test
Source Pressure & Saturation	133	20	20
Target Pressure	10	10	80
Target Saturation	20	10	70

	Source	Target
Pressure (MAE) [2K to 4K psi]	2.4 psia	8.7 psia
Saturation (MAE) [0 to 1]	0.05	0.08
Average Training Time (hrs)	4	1.5
Training Data Storage (GB)	28	2.8
RAM Required (GB)	200	64

Thanks for your Attention !!

More Info on Google Scholar (Sid Misra)

Email: misra@tamu.edu