Application of Modified Meshgraphnets for Subsurface Prediction during CO_2 Sequestration

Chung Shih, Ph.D.

AIChE 2024

October 29, 2024

Disclaimer

Study Contributors

***Paul Holcomb*[1, 2], *Alex Sun*[2, 3], *Chung Yan Shih*[3], *Gavin Liu*[3], *Hema Siriwardane*[3]**

[1] *National Energy Technology Laboratory, 3610 Collins Ferry Road, Morgantown, WV 26505*

[2] *National Energy Technology Laboratory Support Contractor*

[3] *National Energy Technology Laboratory, 626 Cochrans Mill Road, Pittsburgh, PA 15236-0940, USA*

National Climate Task Force Goals

Established by President Joe Biden to reduce emissions, increase resilience, advance environmental justice, and achieve true energy security

50-52%

U.S. GREENHOUSE GAS EMISSIONS REDUCTION BELOW 2005 LEVELS IN 2030

100%

CARBON POLLUTION-FREE ELECTRICITY BY 2035

NET-ZERO

EMISSIONS ECONOMY BY 2050

40%

OF THE BENEFITS FROM FEDERAL CLIMATE AND CLEAN ENERGY INVESTMENTS TO DISADVANTAGED COMMUNITIES

The White House. (2021). President Biden's historic climate agenda. https://www.whitehouse.gov/climate/

The Science-informed Machine Learning for Accelerating Real-Time Decisions in Subsurface Applications (SMART) Initiative

- Ten-year, multi-organizational effort
- Transforming interactions within the subsurface and significantly improving efficiency and effectiveness of field-scale carbon storage operations.

Rapid Prediction
Virtual Learning

Real-Time Visualization
"CT" for the Subsurface

Real-Time Forecasting
"Advanced Control Room"

Modulus Graph Neural Network (MeshGraphNets) provides a flexible and generalizable AI/ML approach to address unique needs

BE ABLE TO HANDLE STRUCTURE AND UNSTRUCTURED DATA

LEARNING FROM LIMITED DATA

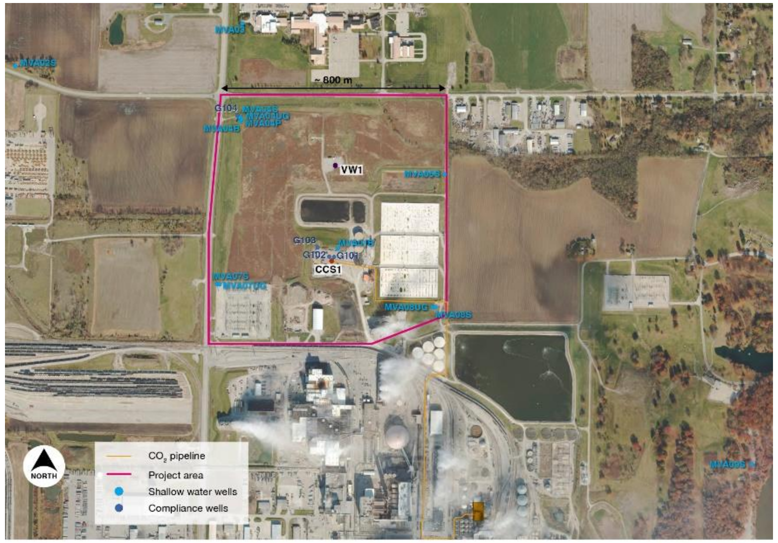
CAPTURE GLOBAL PROPERTIES FROM LOCAL NEIGHBORHOODS VIA MESSAGE PASSING AND NODES/EDGES

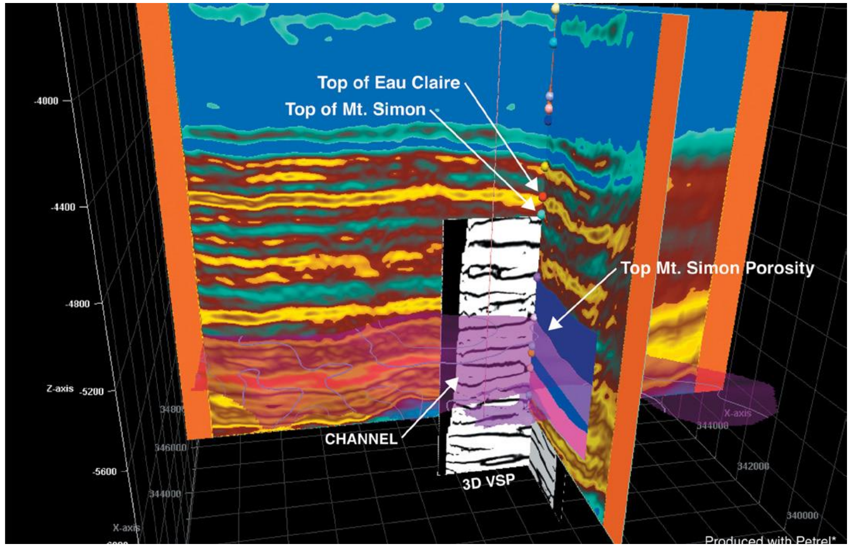
SCALING AND TRANSFER FROM ONE SITE TO ANOTHER FIELD

The Illinois Basin Decatur Project (IBDP)

Demonstrated the feasibility of Carbon Capture and Storage as a Critical Path

- The goal was to safely and effectively demonstrate the full carbon capture, utilization, and storage (CCUS) value chain in a saline reservoir
- The project stored CO2 from ADM's ethanol fermentation plant. Operations consist of a compression/dehydration facility, a delivery pipeline, one injection well, one deep observation/verification well, and a geophysical test well, all developed on the ADM-owned site.
- The IBDP developed and implemented a rigorous and extensive monitoring, verification, and accounting (MVA) program
- 1 million metric tons of CO2 have been injected into an extensive reservoir with no difficulties.
- One of the first EPA Underground Injection Control Class VI permits (CO2 storage well).





https://www.netl.doe.gov/sites/default/files/2018-11/Illinois-Basin-Decatur-Project.pdf

IBDP Dataset for Training

Name	IBDP Model
Inputs	Porosity, permeability, fault transmissivity modifiers, horizons (or formation indexes) @ 1M tons / 30-year rate
Outputs	Pressure, Saturation
Injection Wells	1
Grid Size	9.7 mile x 9.3 mile
Timestep	3 years injection, 1 year post-injection
Realization	100

IBDP GRID (X-Y)

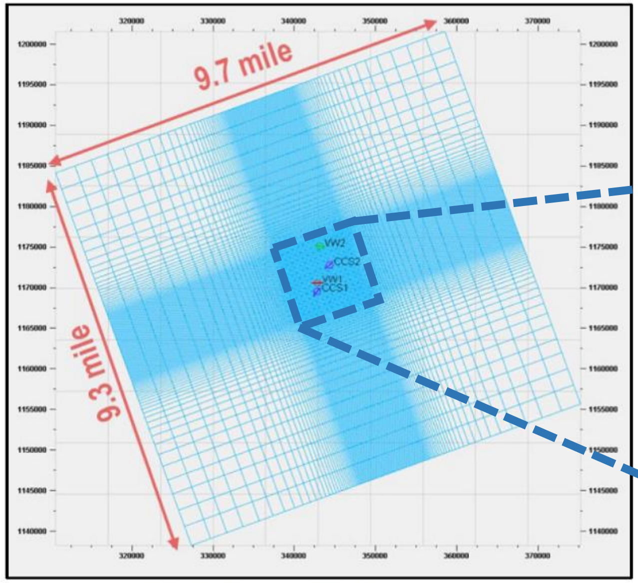
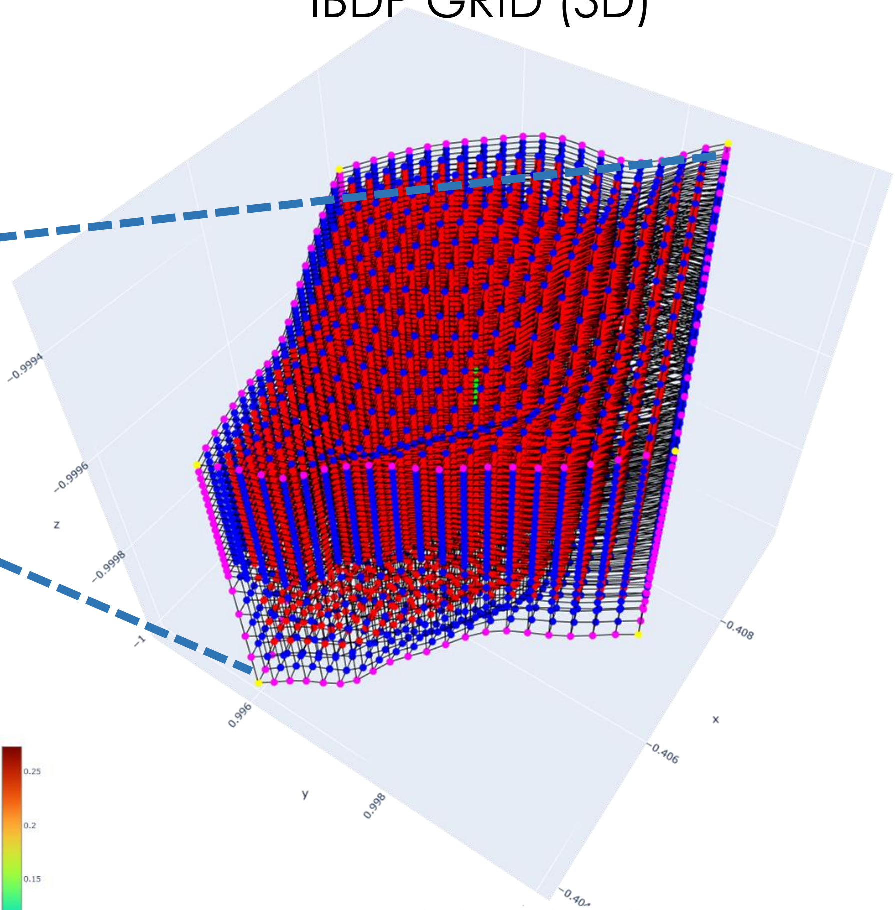
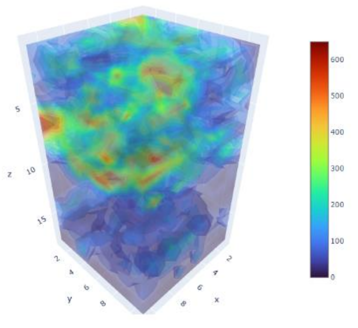


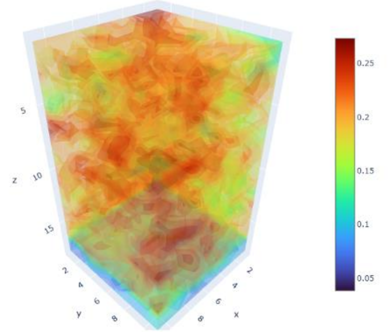
Figure 67. Dynamic model domain and tartan grid.

IBDP GRID (3D)

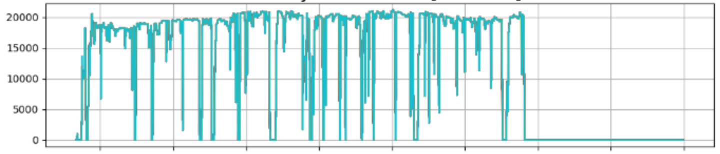




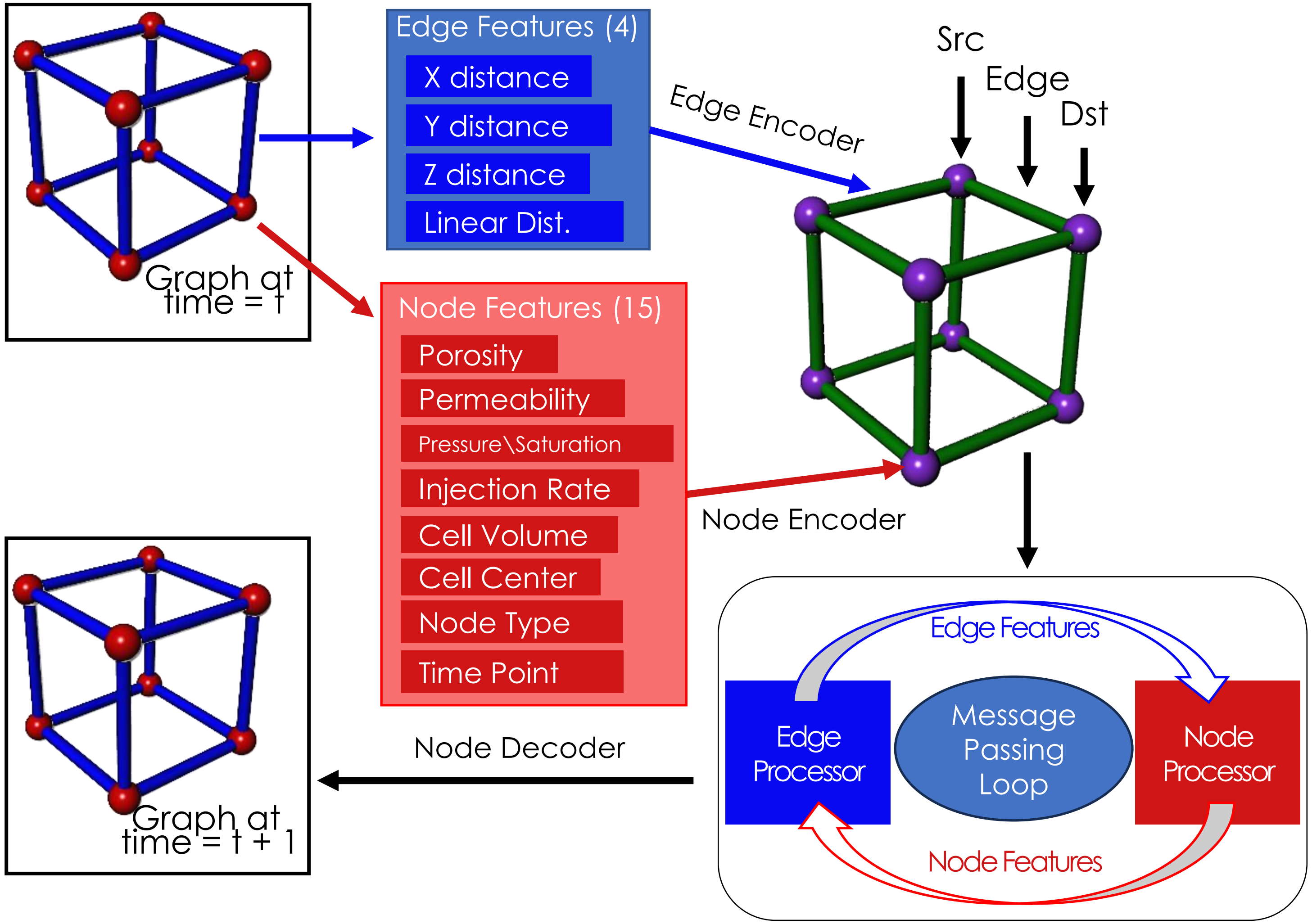
Avg. Permeability



Avg. Porosity

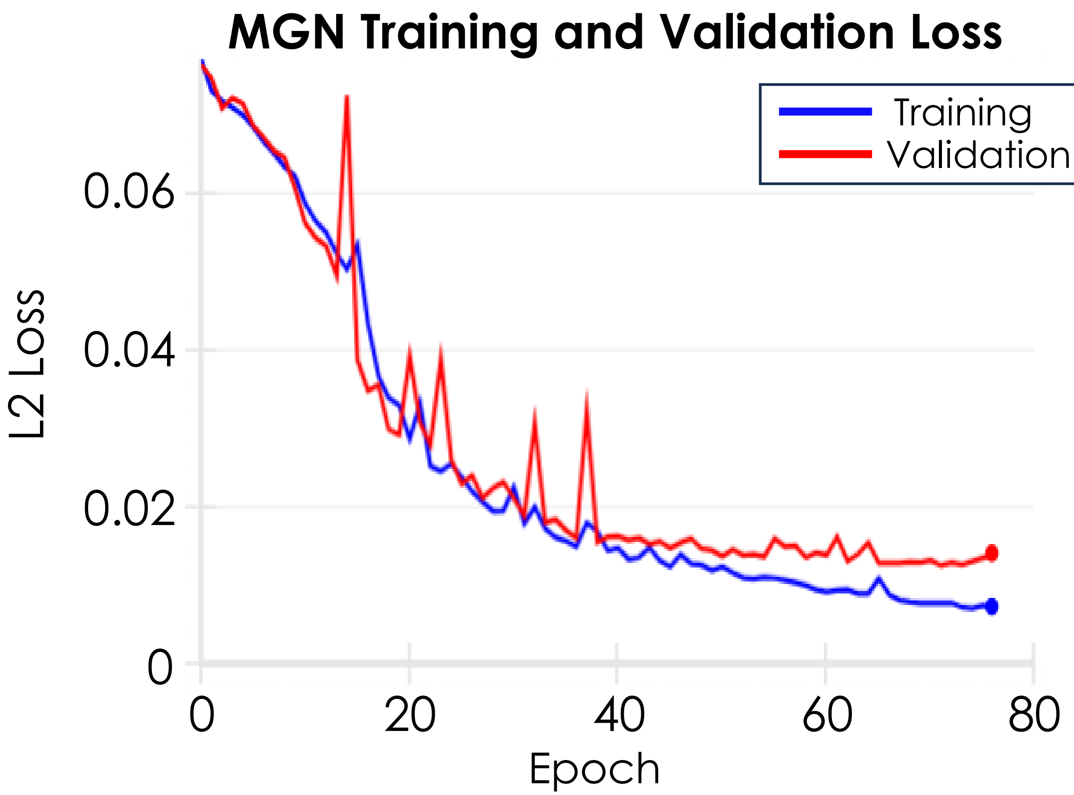


MeshGraphNets (MGN)

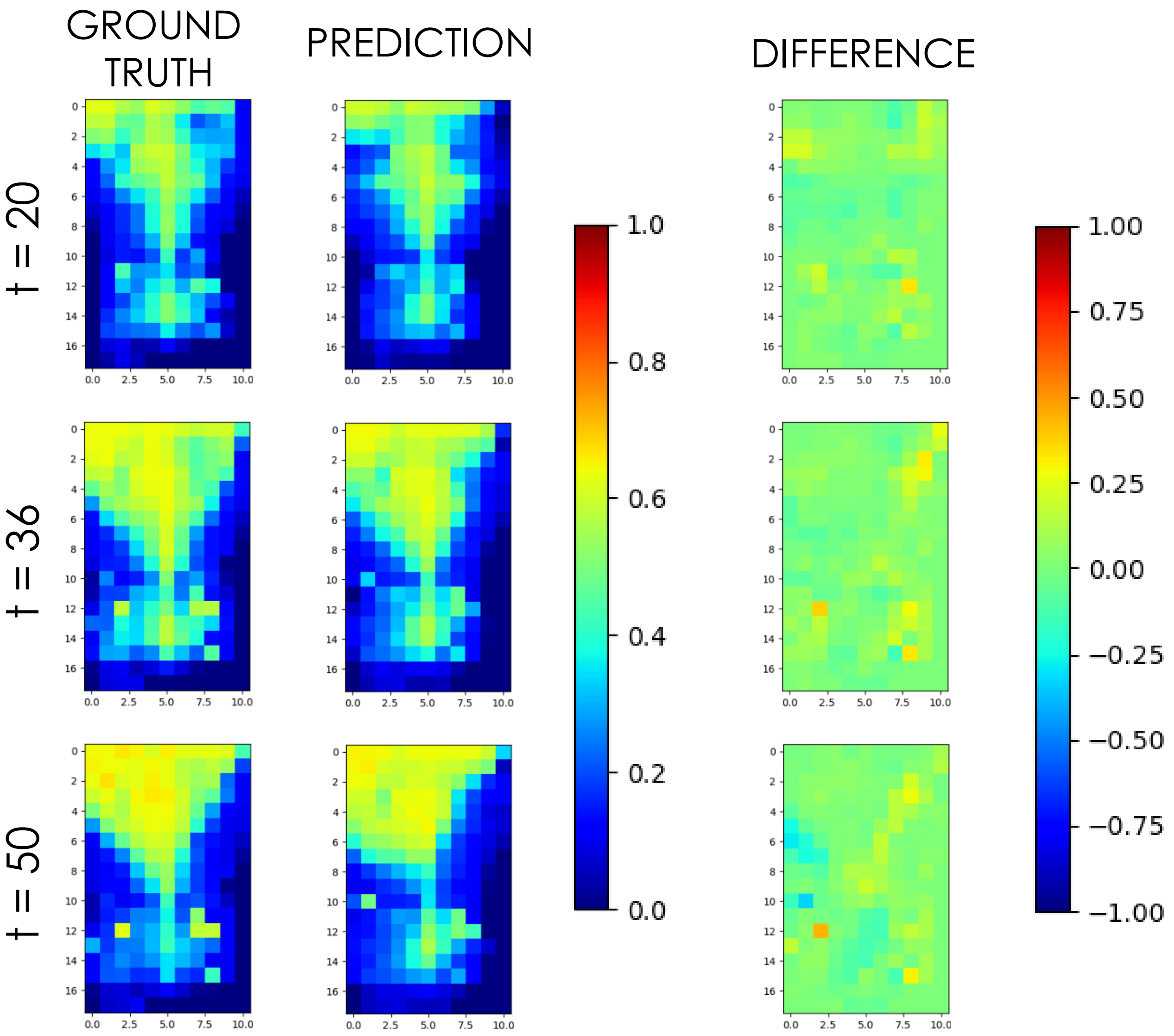


- Nodes contain cell-specific data
- Edges contain information on how information flows
- Message passing (MP) allows nodes to "see" neighbors by passing information through edges
- The distance a node can "see" is determined by the number of MP loops – "hops"

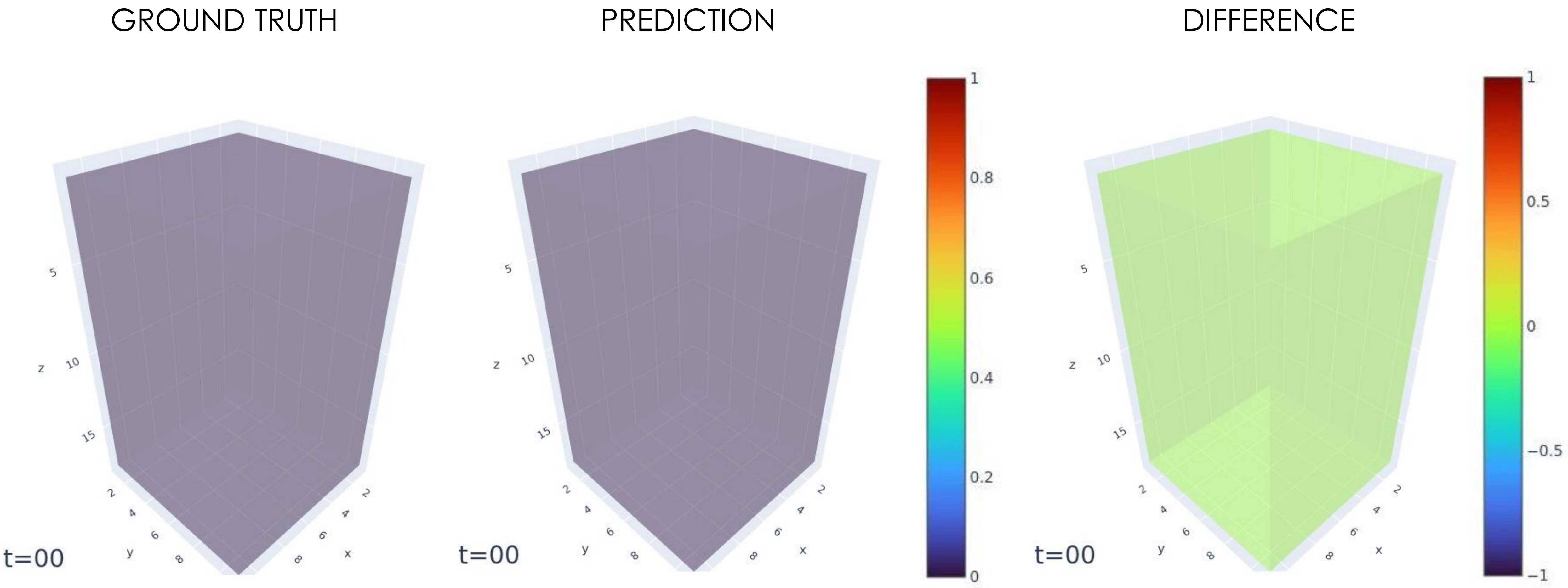
Saturation Prediction (MGN) – 50 Time Points



Root Mean-Squared Error (RMSE): 0.0735
Only Zeros RMSE: 0.0169
Nonzero RMSE: 0.0914

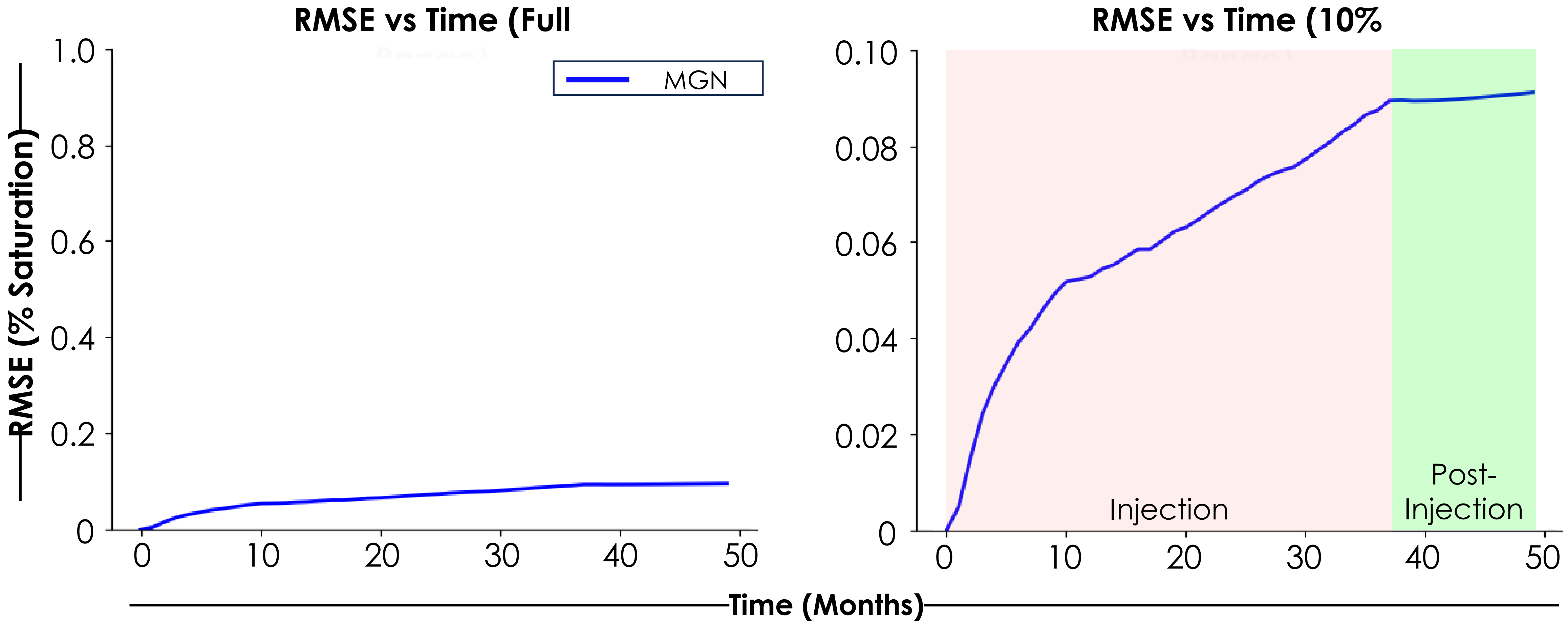


Saturation Prediction (MGN)

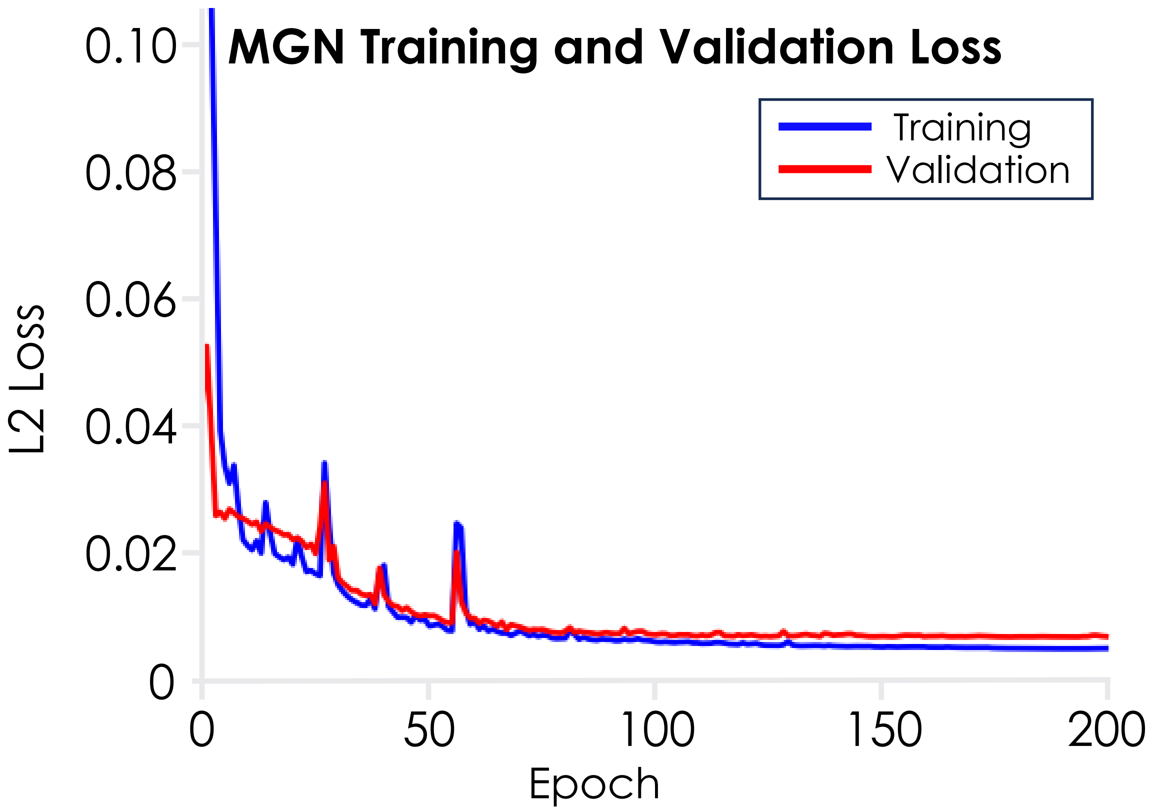


Saturation Results (MGN)

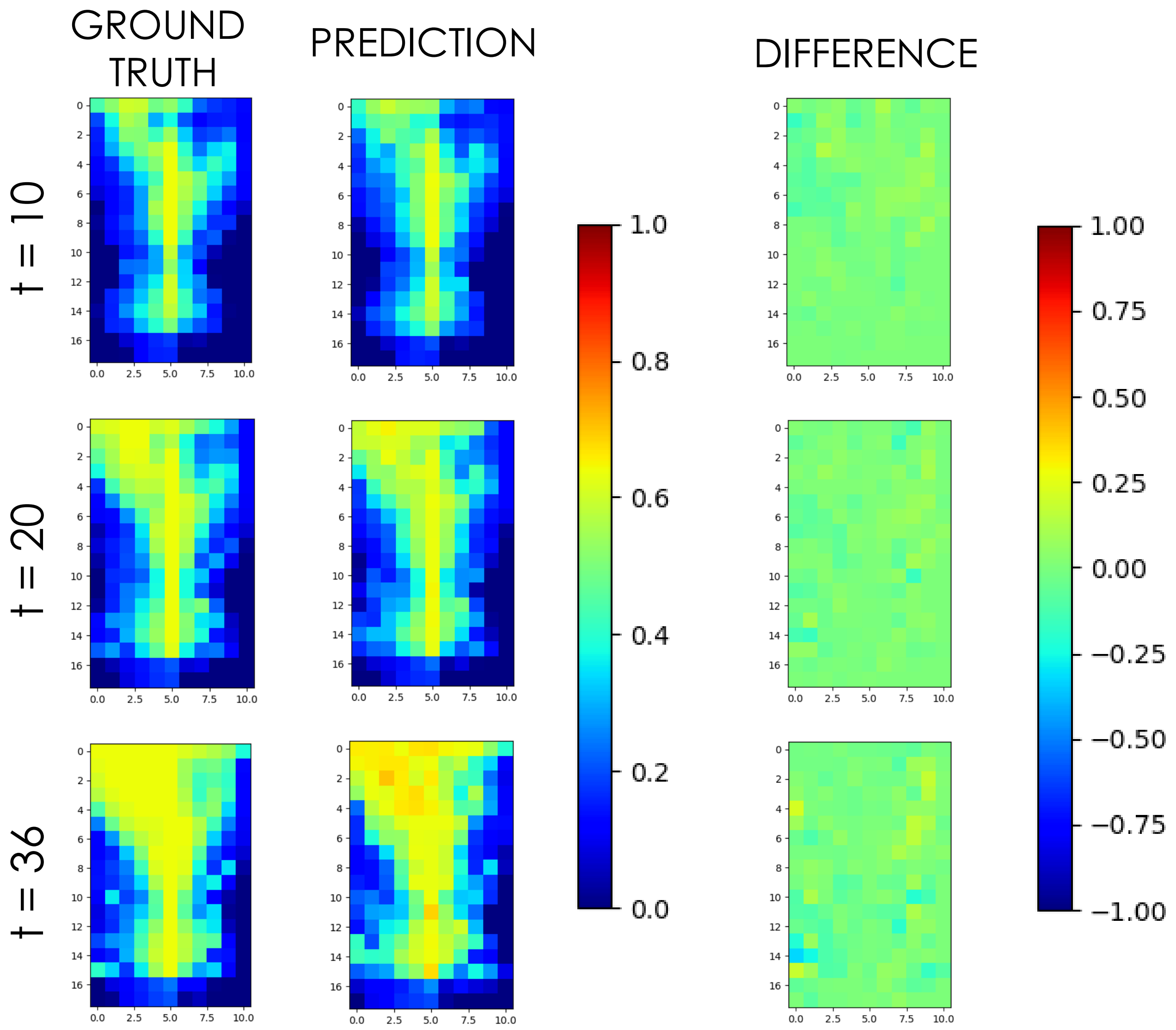
Autoregression and Temporal Instability



Saturation Prediction (MGN) – 36 Time Points

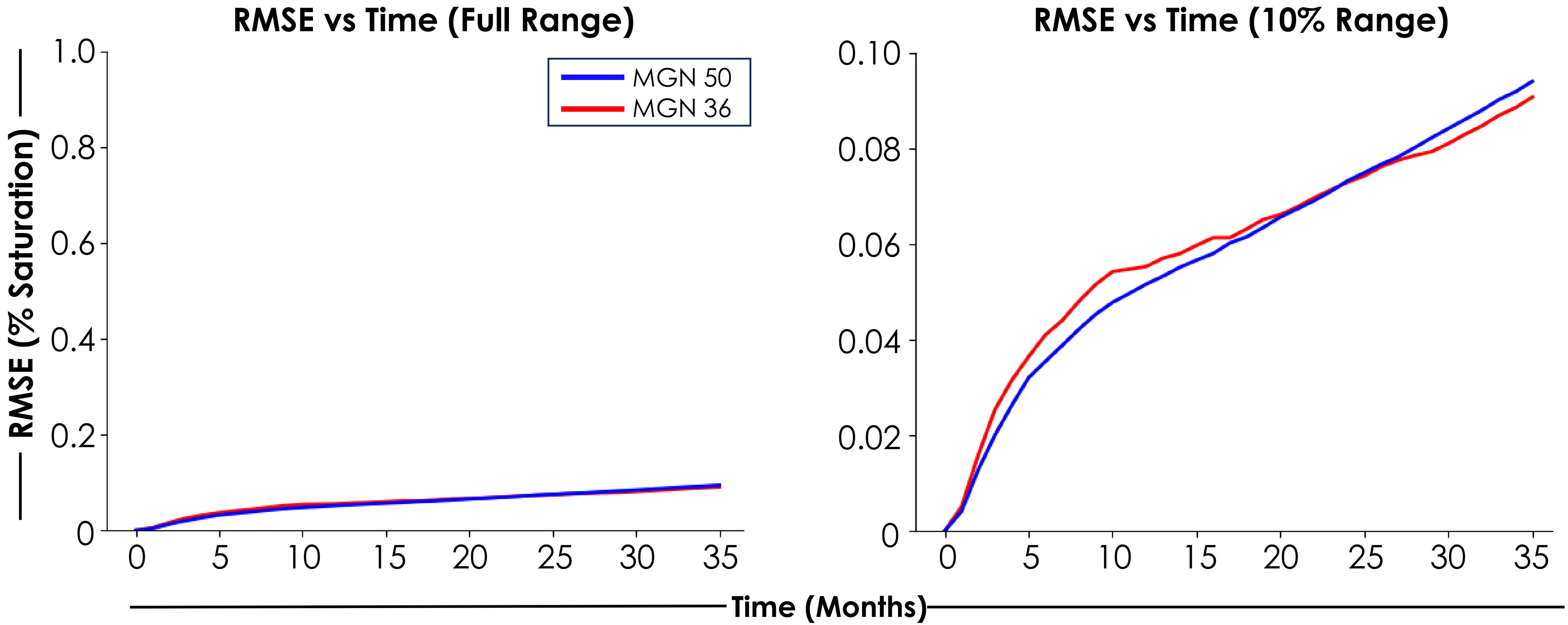


Root Mean-Squared Error (RMSE): 0.0630
Only Zeros RMSE: 0.0290
Nonzero RMSE: 0.0787



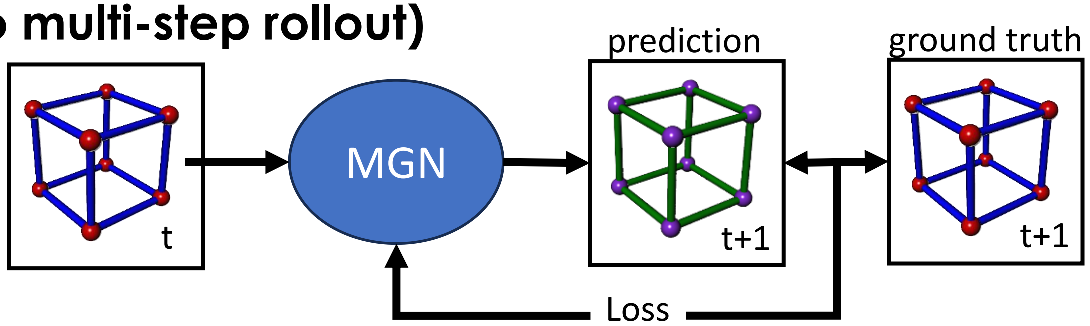
Saturation Results (MGN t=50 vs MGN t=36)

Autoregression and Temporal Instability

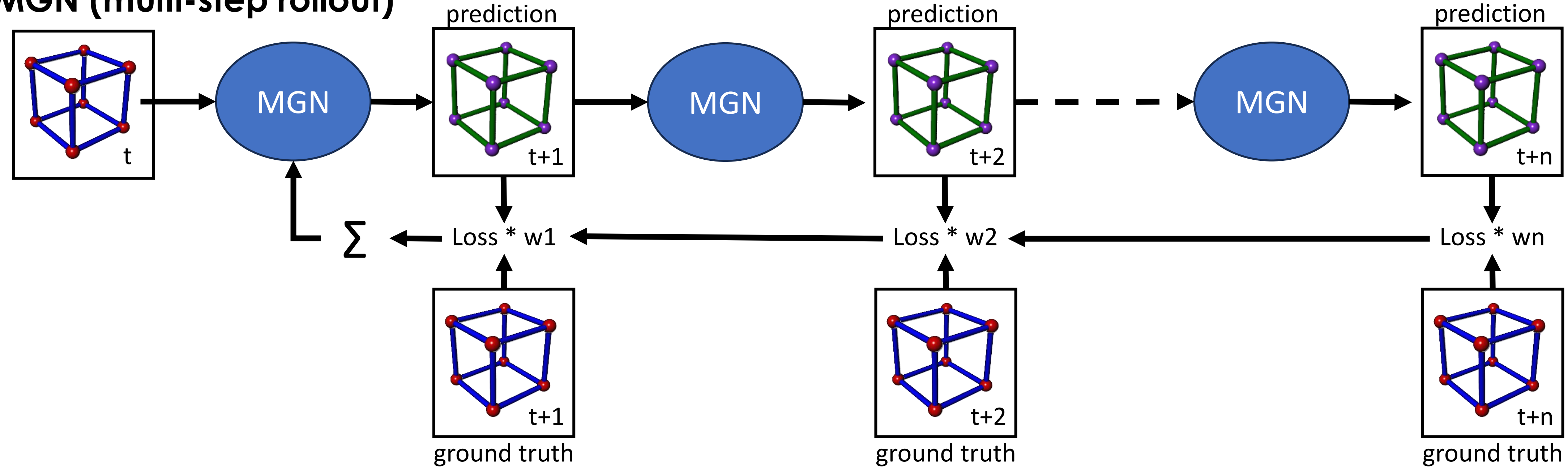


MeshGraphNets with Multi-step Rollout (MGN-MR)

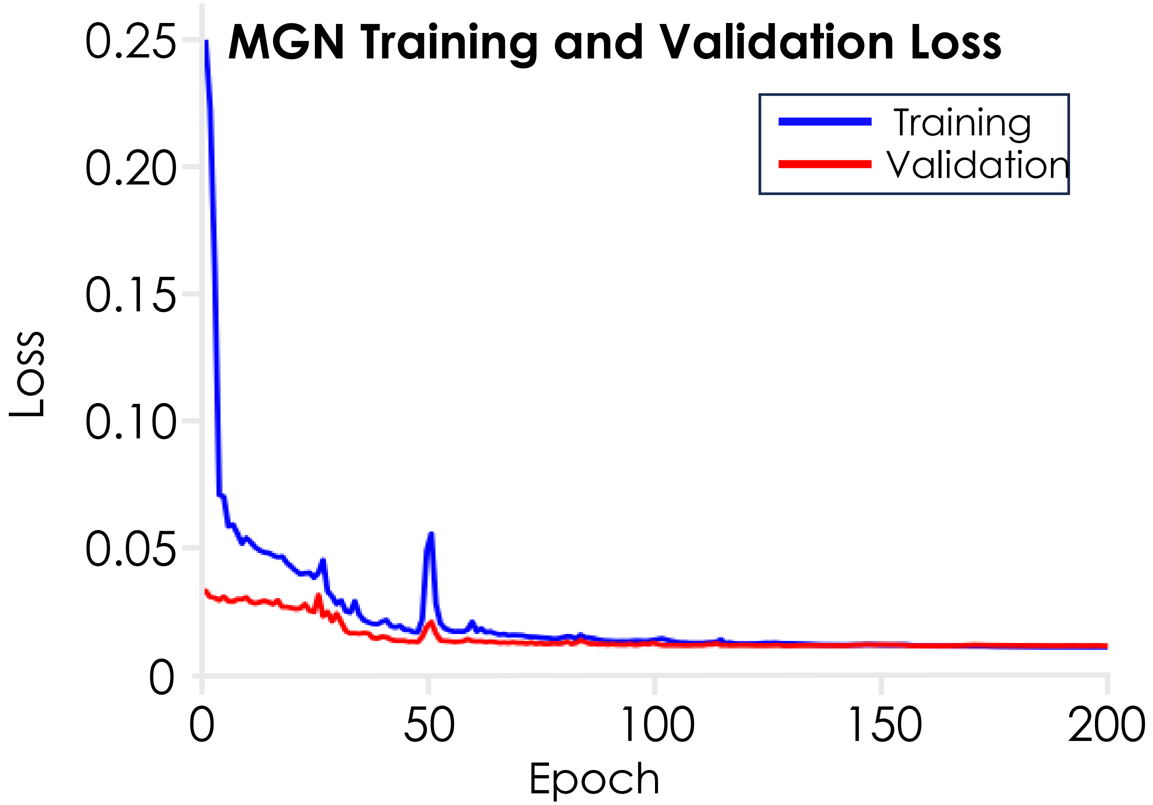
MGN (no multi-step rollout)



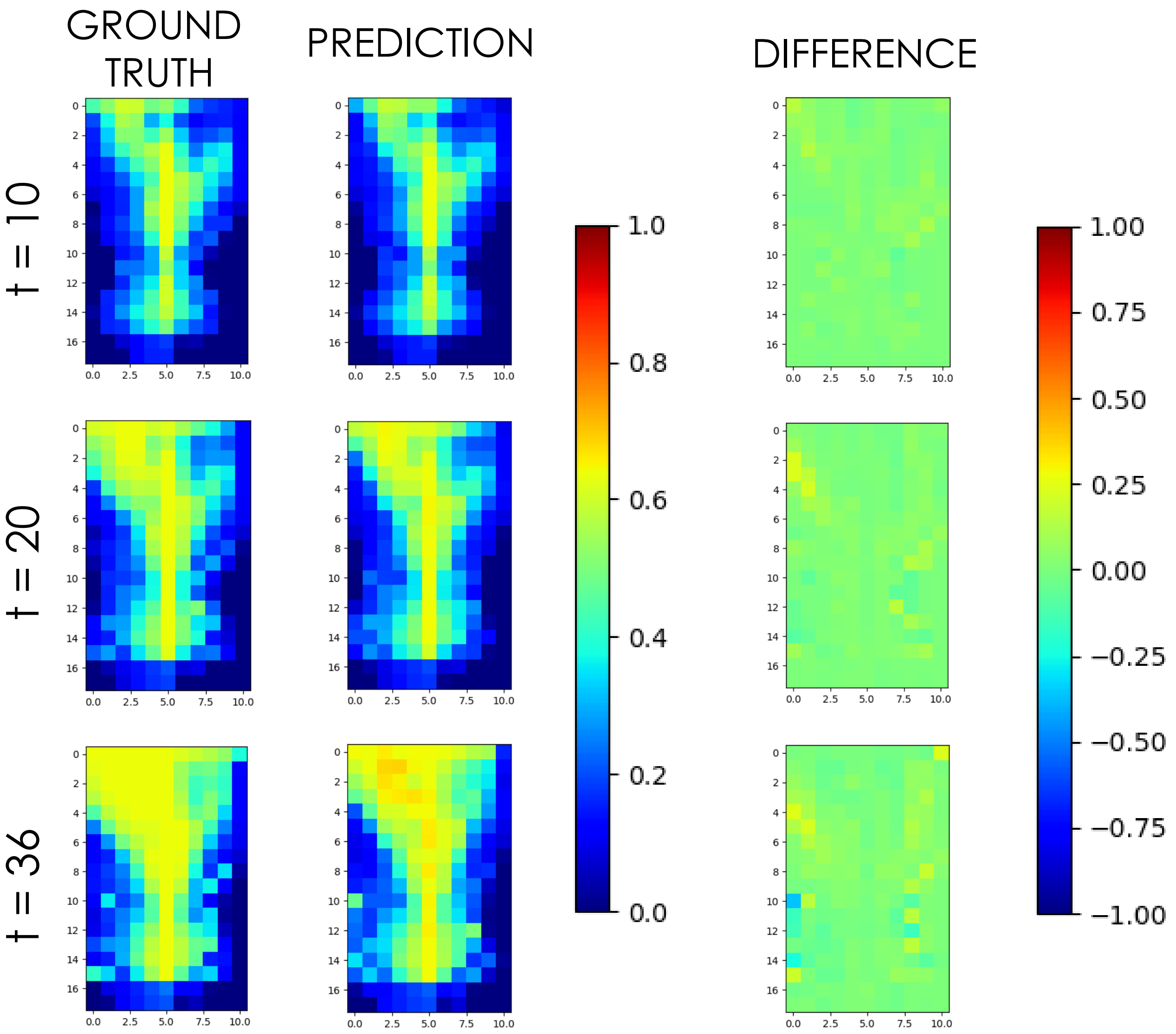
MGN (multi-step rollout)



Saturation Prediction (MGN-MR)

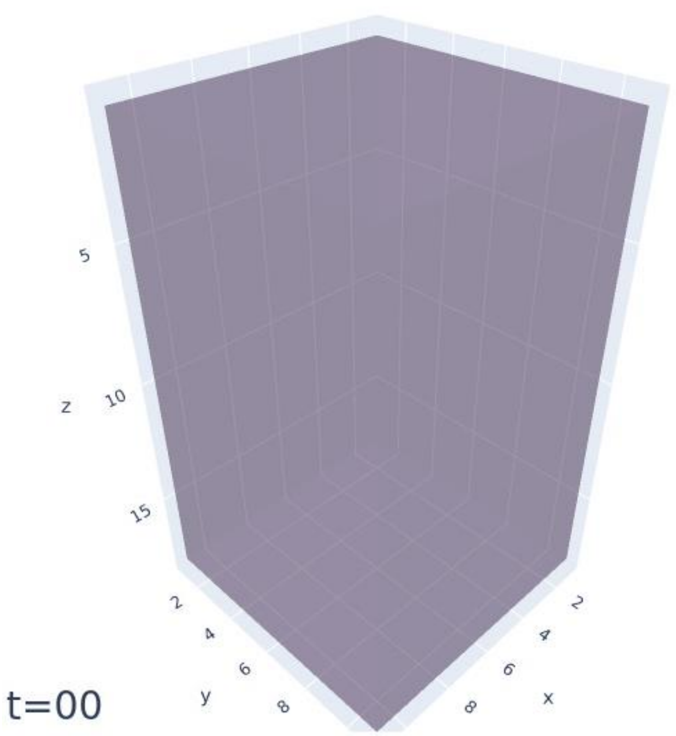


Root Mean-Squared Error (RMSE): 0.0527
Only Zeros RMSE: 0.0114
Nonzero RMSE: 0.0683

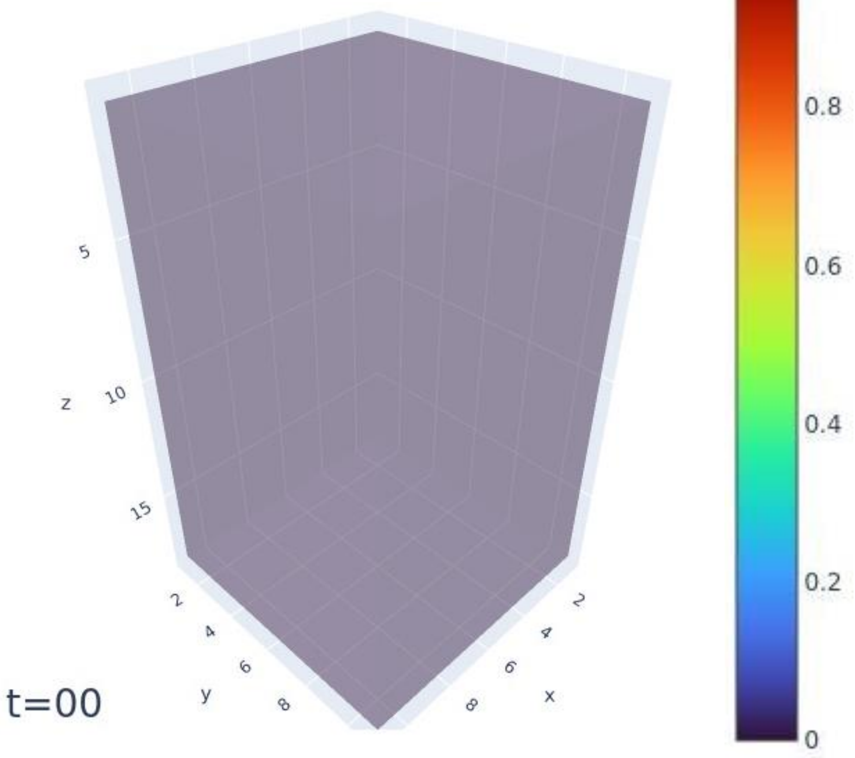


Saturation Prediction (MGN-MR)

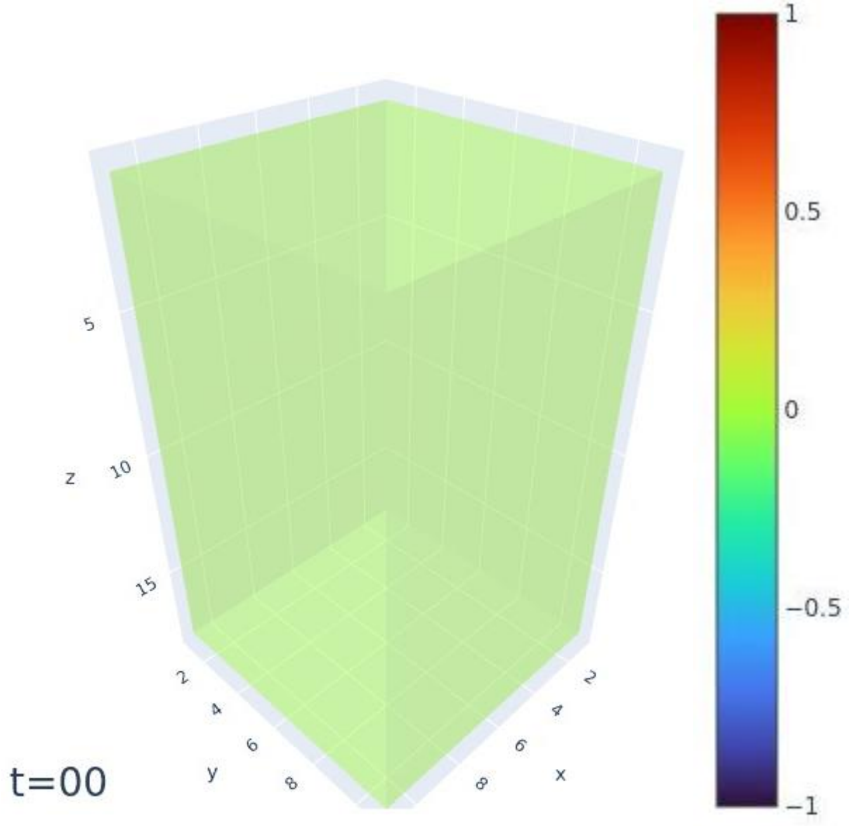
GROUND TRUTH



PREDICTION

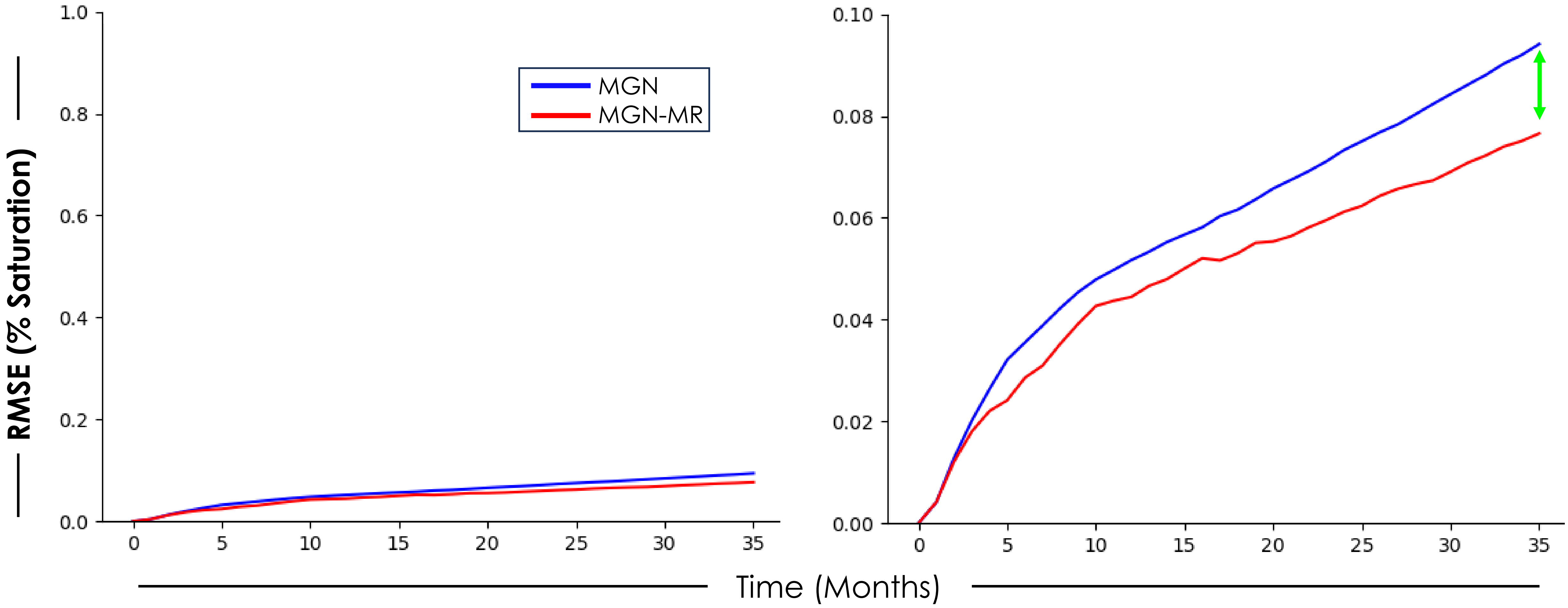


DIFFERENCE



Saturation Results (MGN VS MGN-MR)

Autoregression and Temporal Instability



Conclusion and Future Directions

- We established a 3D spatiotemporal MeshGraphNets with heterogenous geological properties
- The initial results showed that GNN is capable of capturing patterns with a relatively small datasets (80 simulations)
- Temporal “drift” was found to be an issue using autoregression, but only in the injection regime
- Application of multi-step rollout improves stability when doing forward prediction

Thank you

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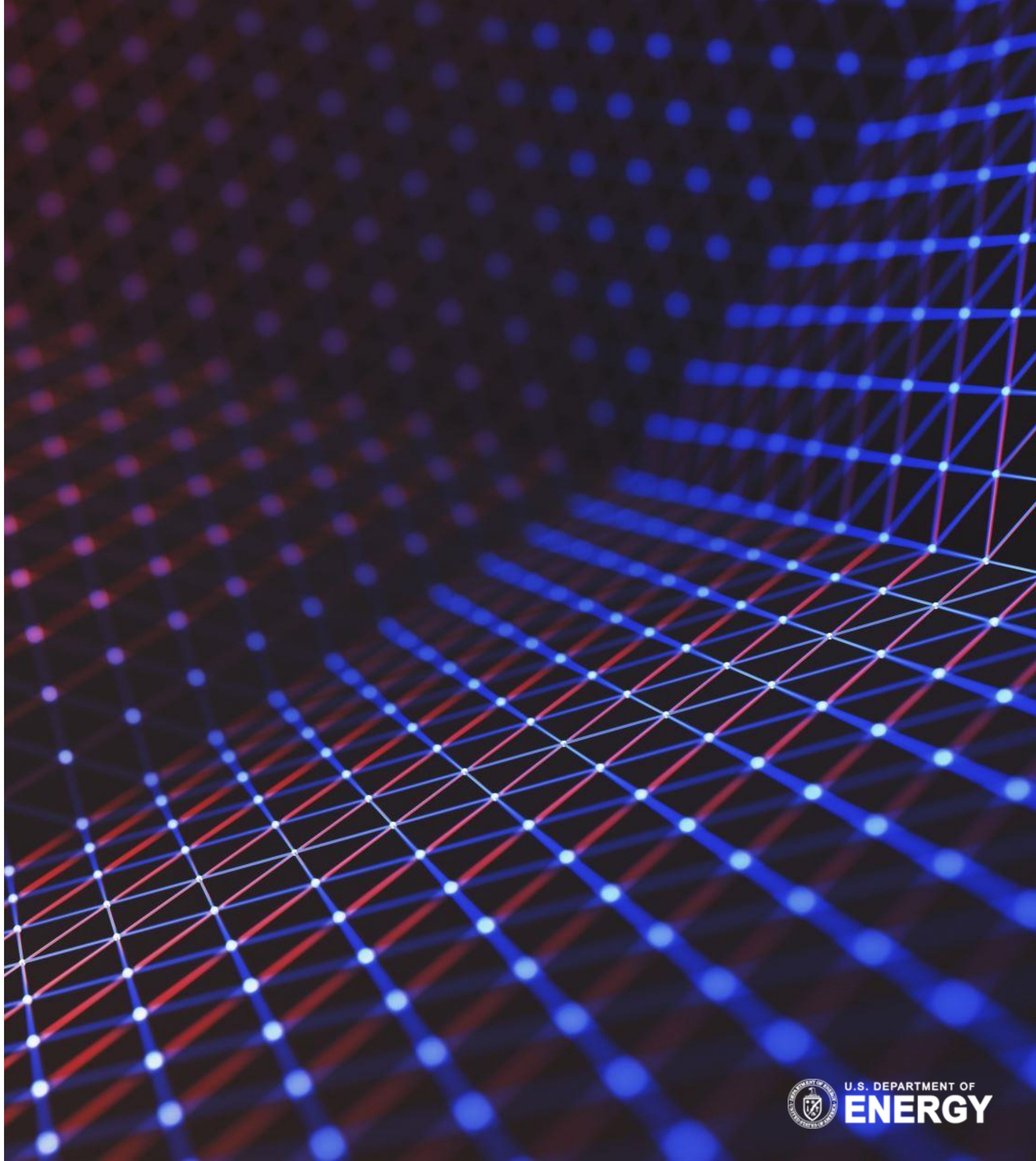
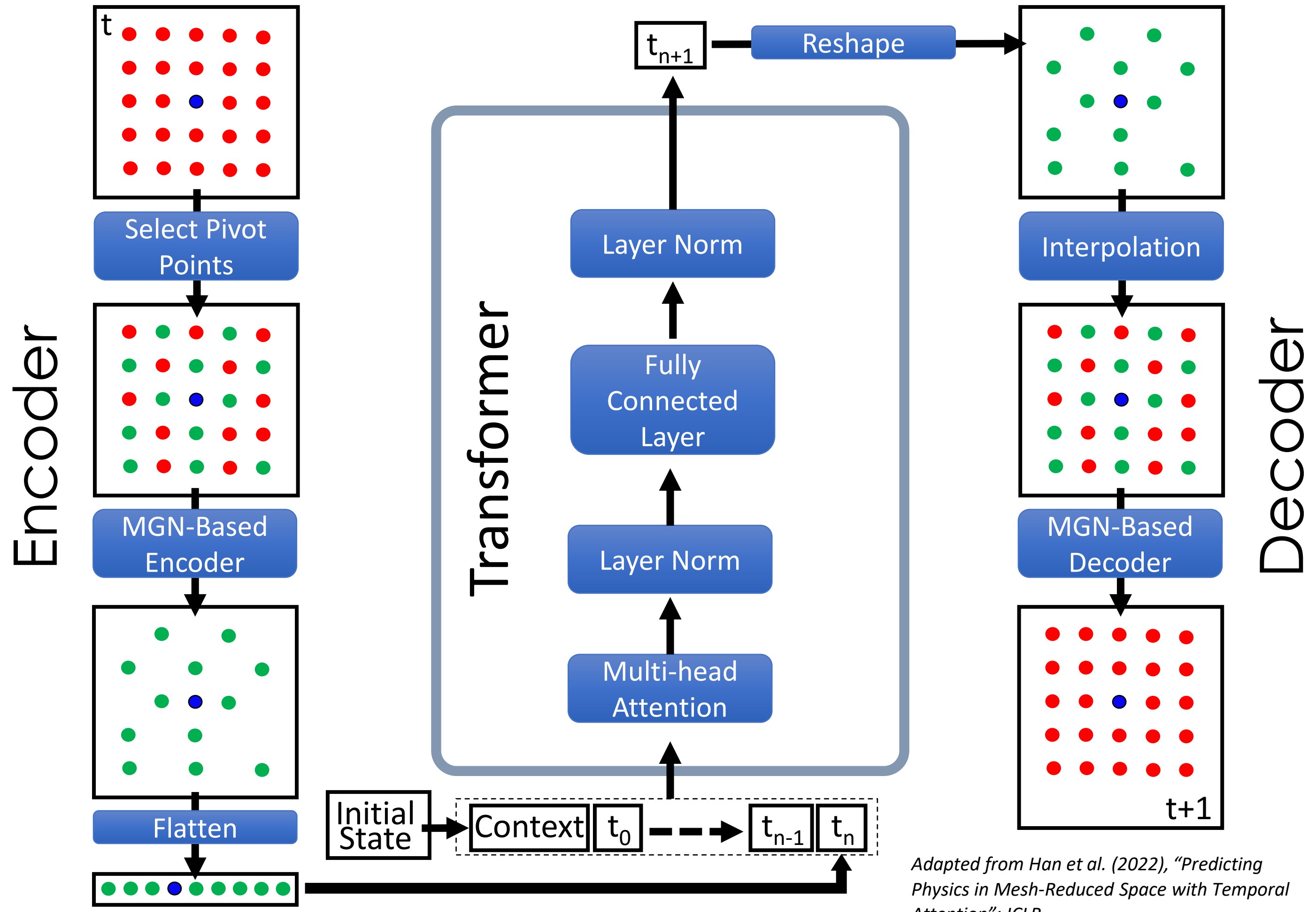
CONTACT:
Chung Shih
Chungyan.Shih@netl.doe.gov



MeshGraphNets with Transformer (MGN-T)



Adapted from Han et al. (2022), "Predicting Physics in Mesh-Reduced Space with Temporal Attention"; ICLR

- Encoder/Decoder use MP to compress data into latent space
- Transformer uses each time point as a "token" to learn context – similar to LLM
- Model can "see" all previous time points

Saturation Prediction (MGN-T)

Saturation Prediction (MGN-T)

GROUND TRUTH

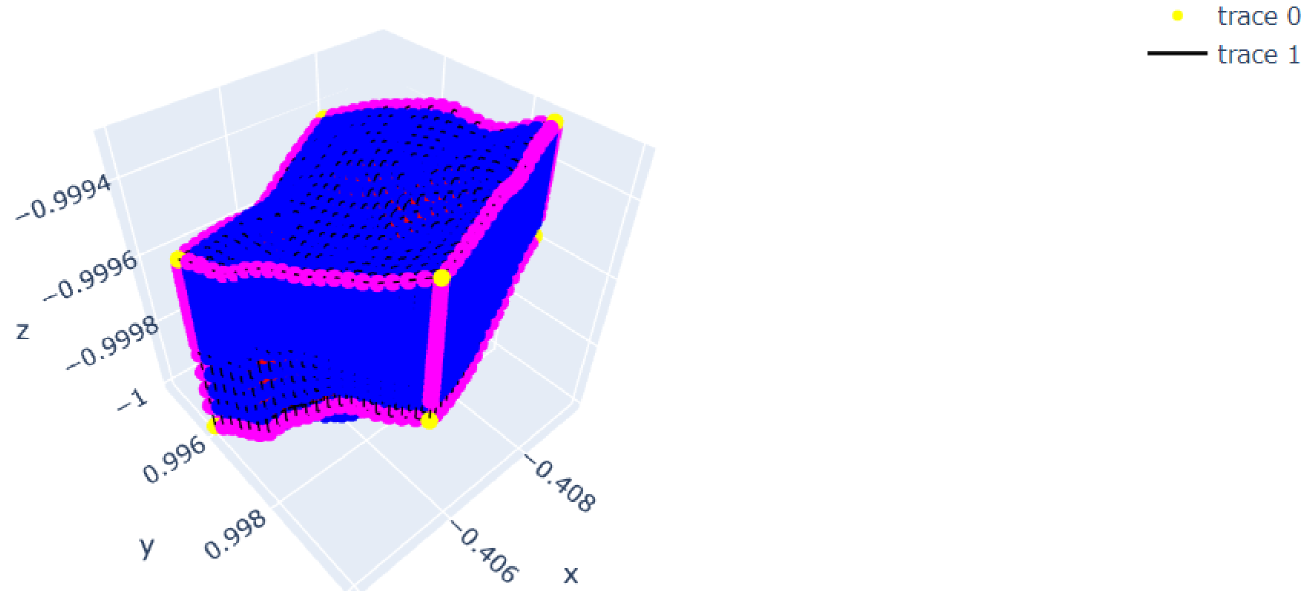
PREDICTION

DIFFERENCE

Saturation Results (MGN-T)

Autoregression and Temporal Instability

IBDP Graph (11 x 11 x 18)



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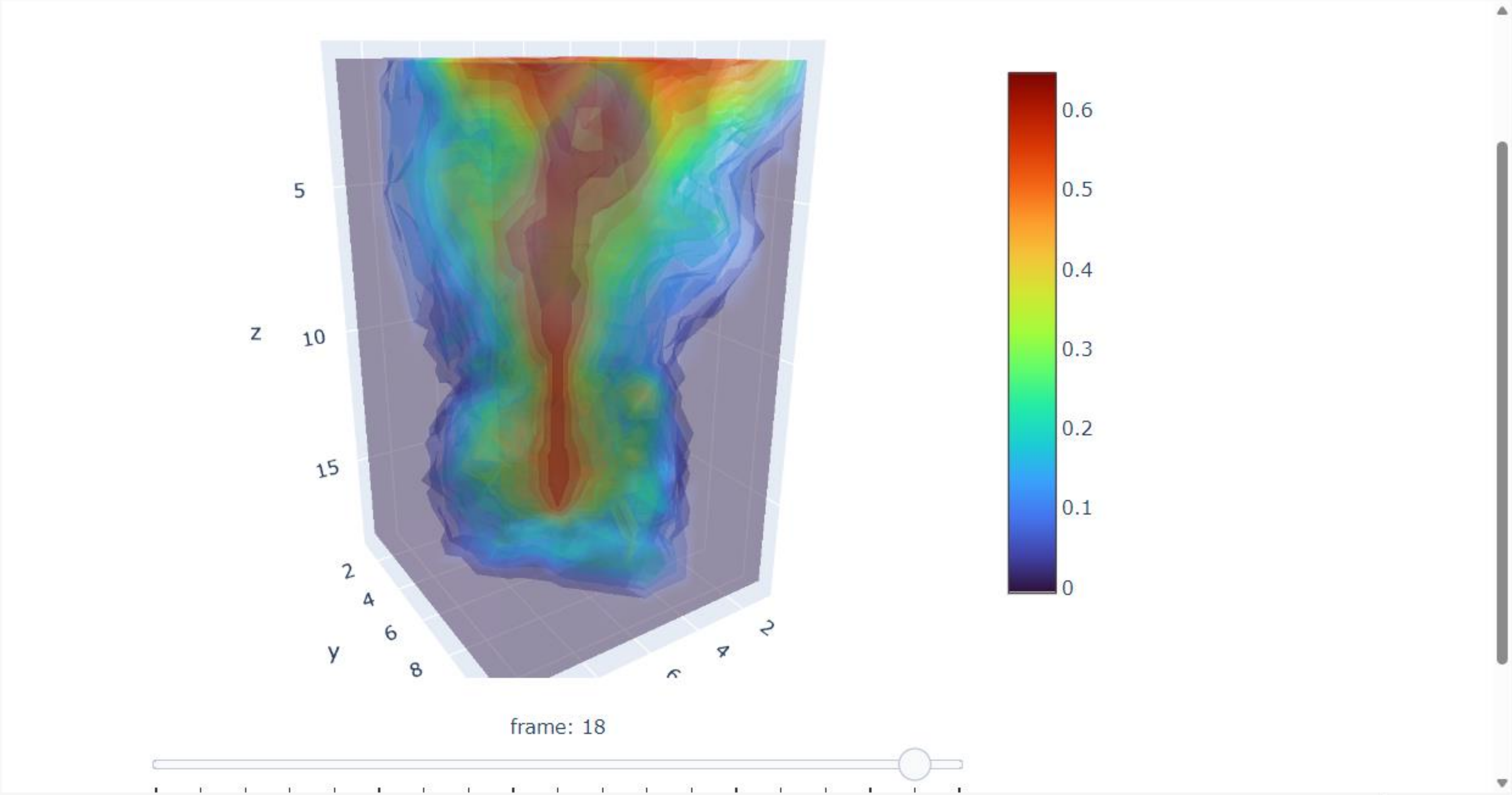
IBDP Saturation (Ground Truth)



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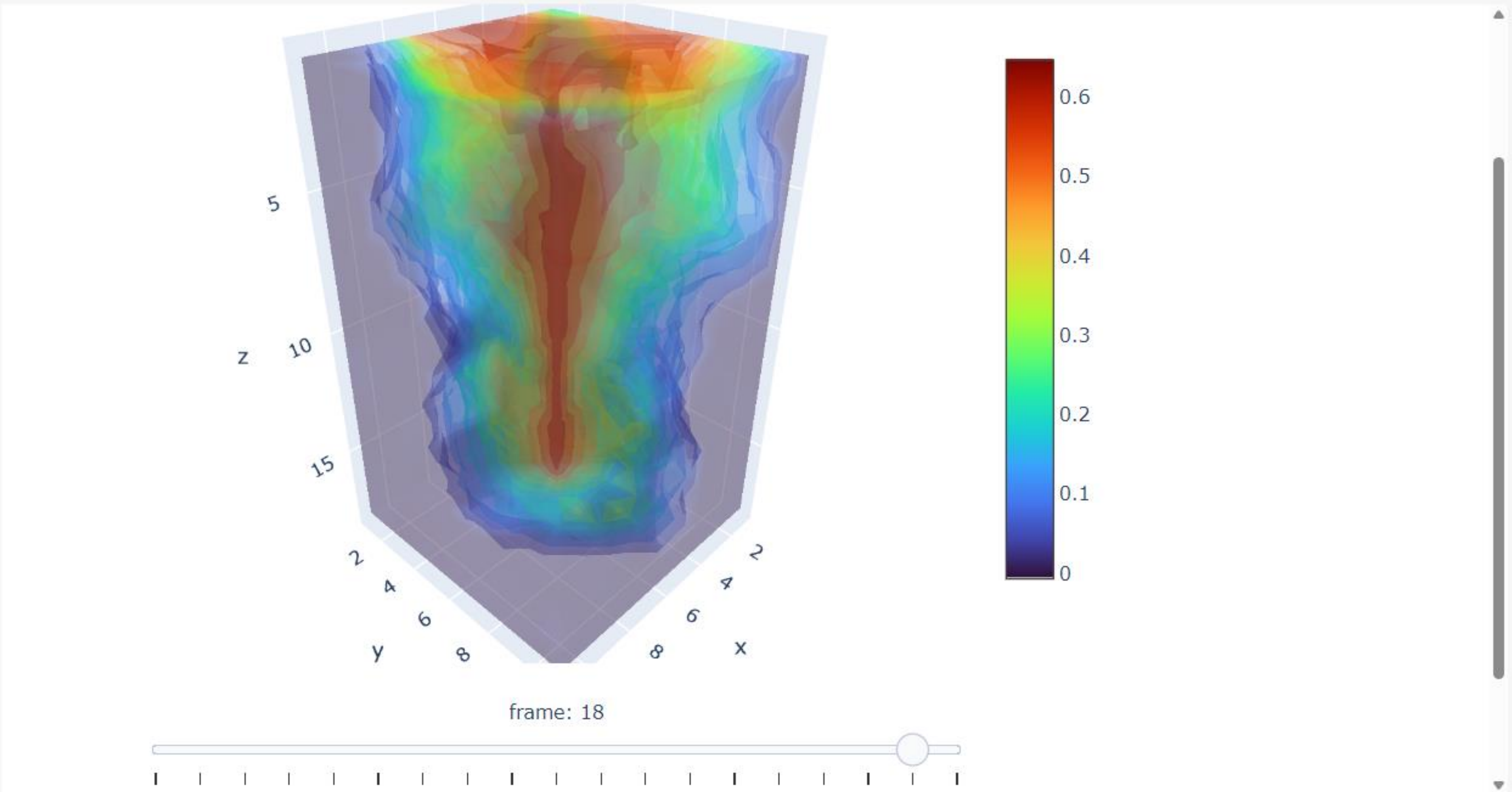
IBDP Saturation (Ground Truth)



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IBDP Saturation (Ground Truth)

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https:// raw.githack.com/paulholcomb/GNN_IBDP/main/diff_denorm.html

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