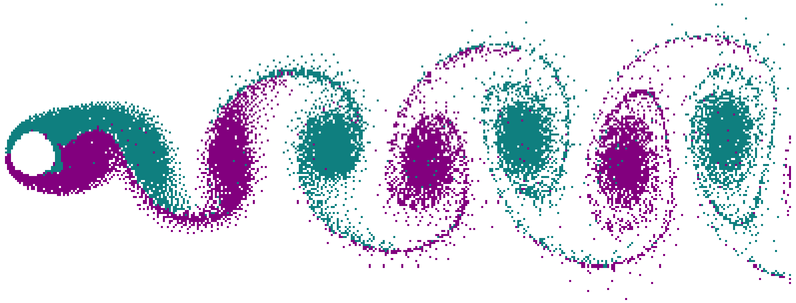
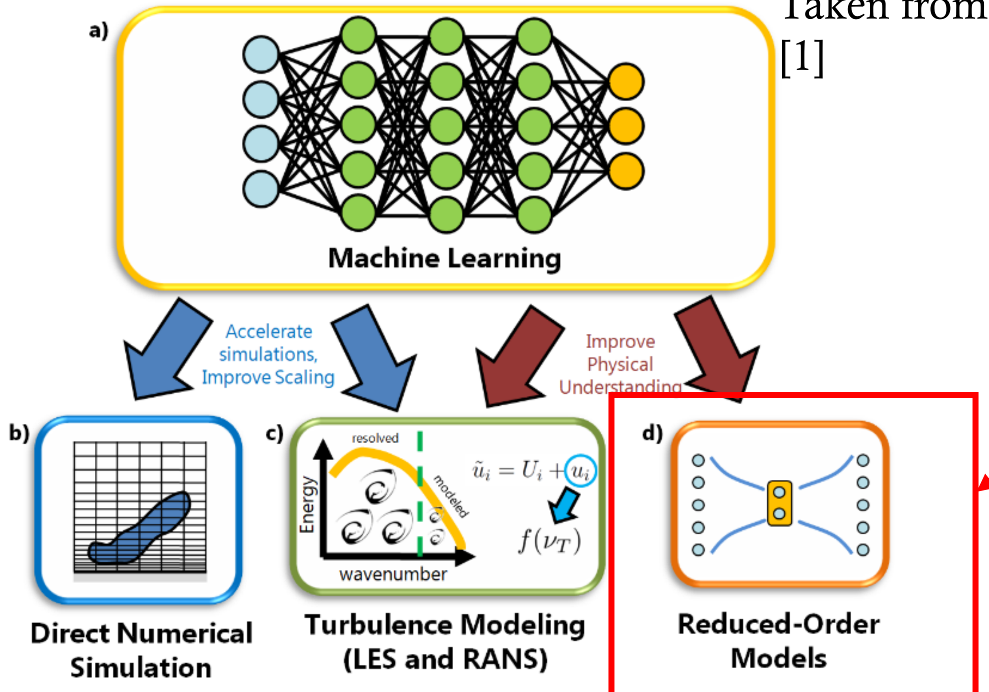
USING MACHINE LEARNING TO PREDICT UNSTEADY FLOW AROUND A CYLINDER

Spencer Schwartz



BACKGROUND

- Accurate CFD Simulations are slow and expensive
- Neural networks have been shown as a good predictor of CFD simulations

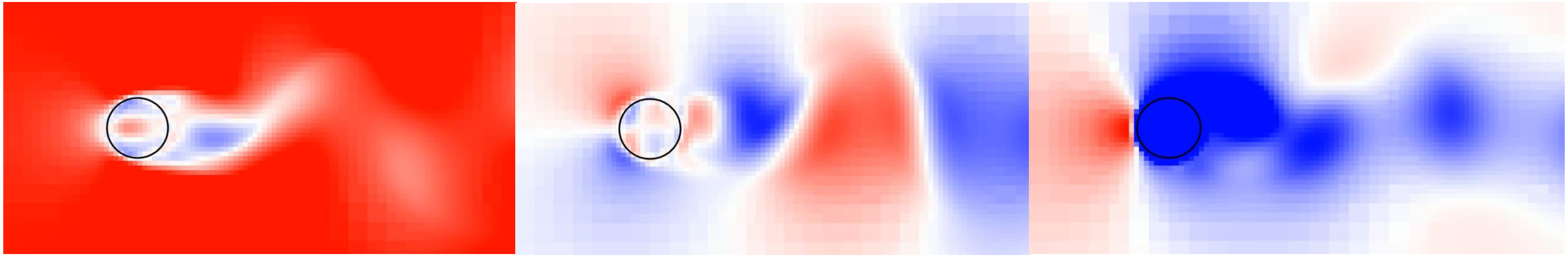


Taken from [1]

This project!

PROJECT PURPOSE

- Use a ROM (Convolutional Autoencoder w/LSTM) to predict flow around a cylinder
  - Trained on: Re = {40, 80, 120, 160, 200}
  - Validated on: Re = {20, 60, 100, 140}



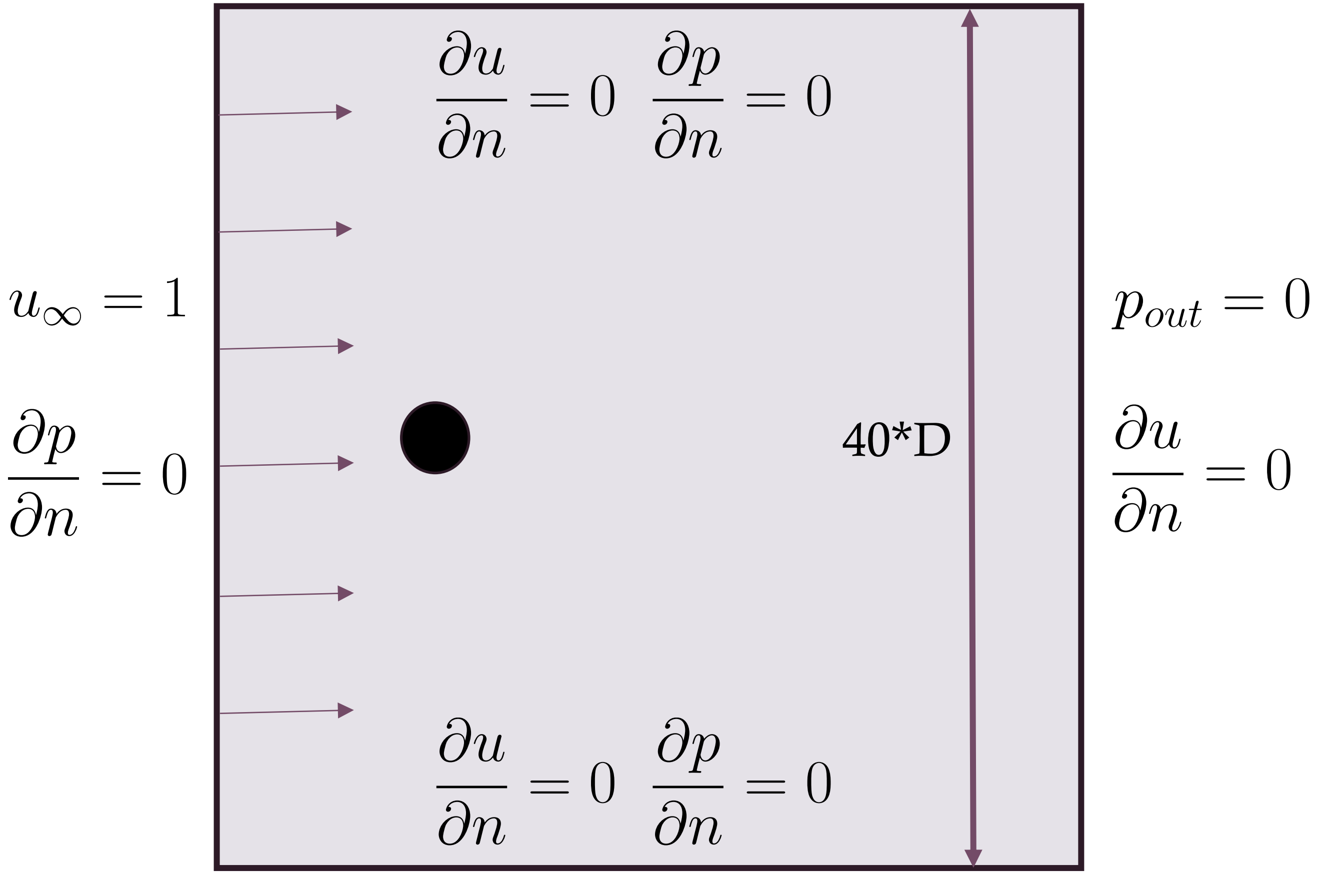
X-velocity Y-velocity Pressure

DNS SETUP

- Solved using *Basilisk* software
- Gov. Eq.

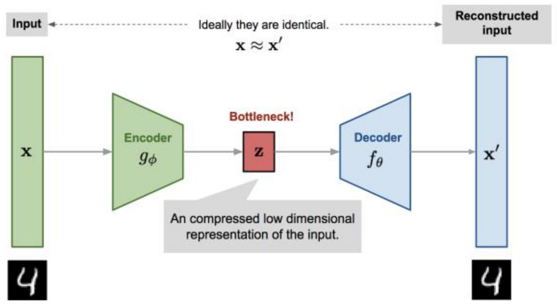
$$\partial_t \mathbf{u} = -\mathbf{u} \cdot \nabla \mathbf{u} - \frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{u} + \mathbf{f}\,,$$

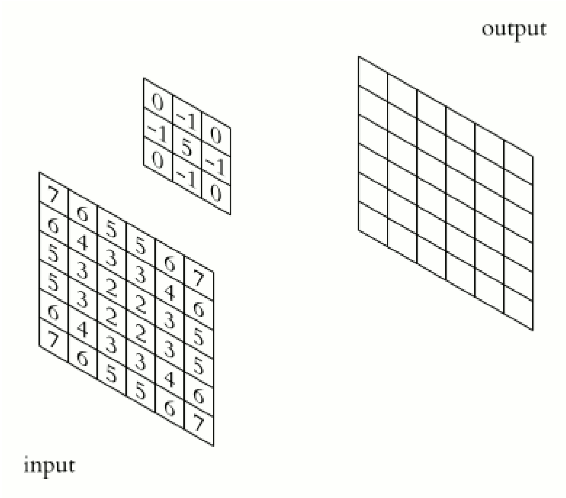
$$\nabla \cdot \mathbf{u} = 0\,,$$



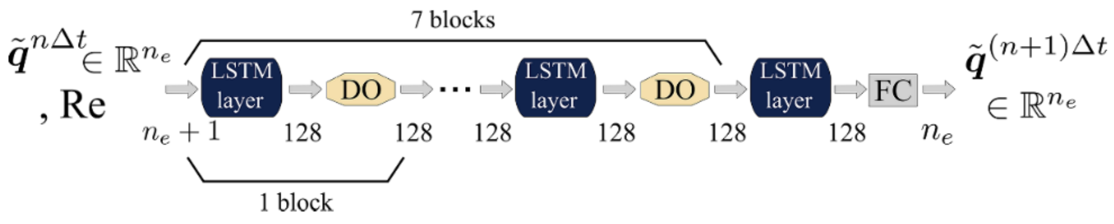
MODEL ARCHITECTURE

- Convolutional Autoencoder (CAE) for image reconstruction

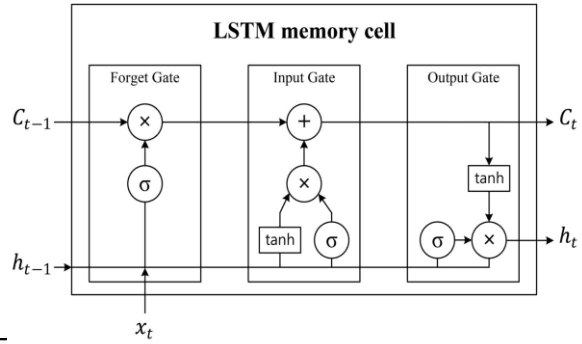




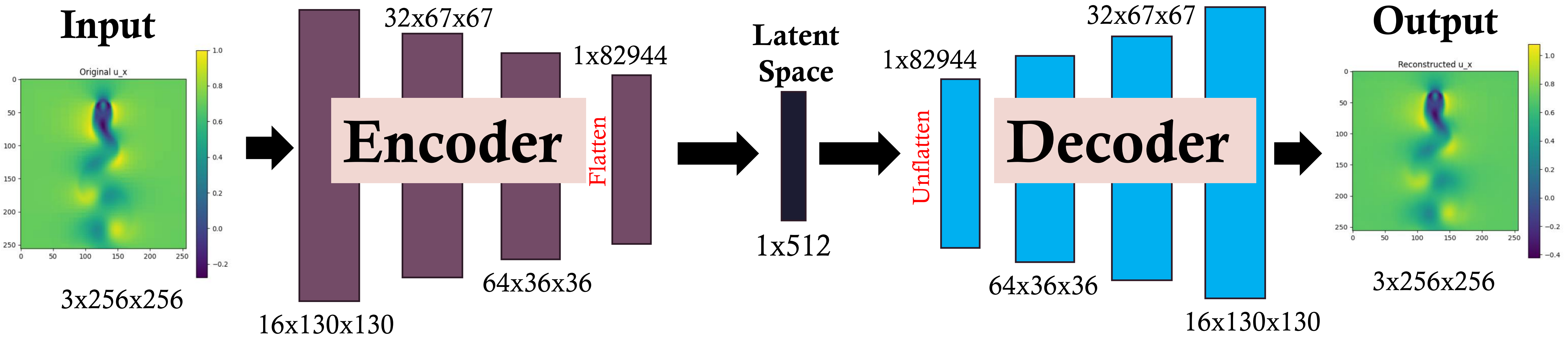
- Long-short term memory (LSTM) for time-series prediction



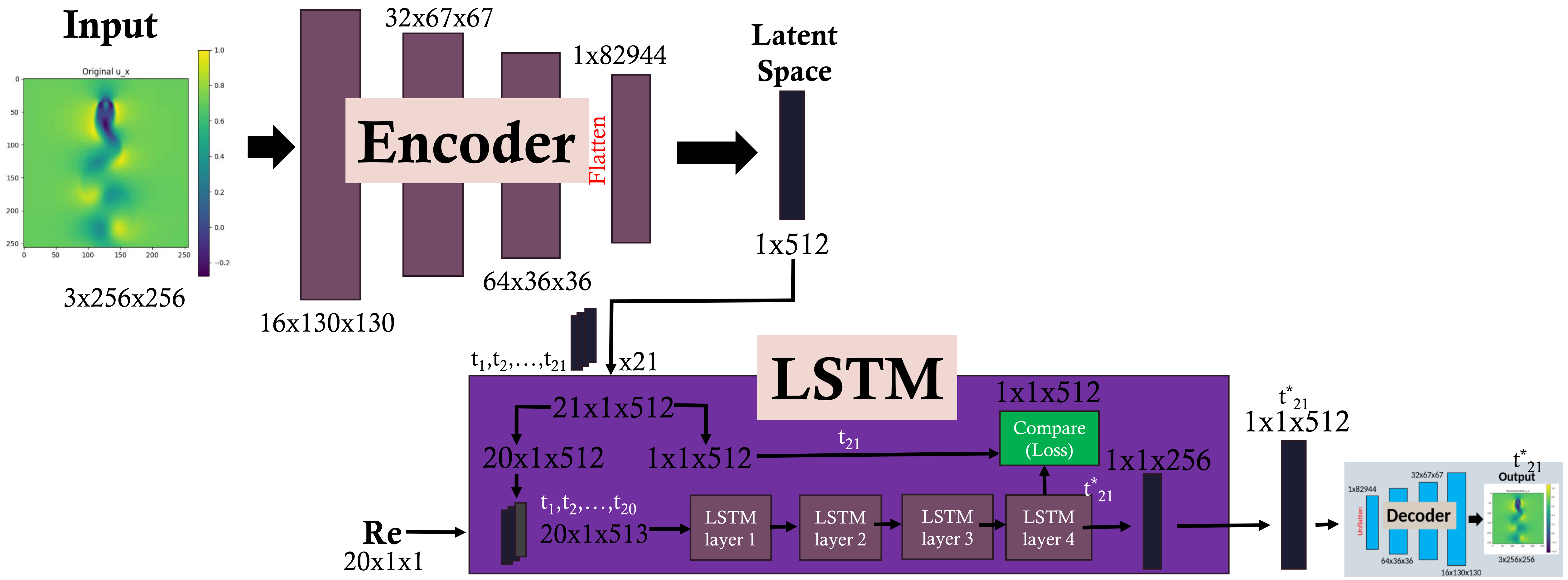
Taken from [2]



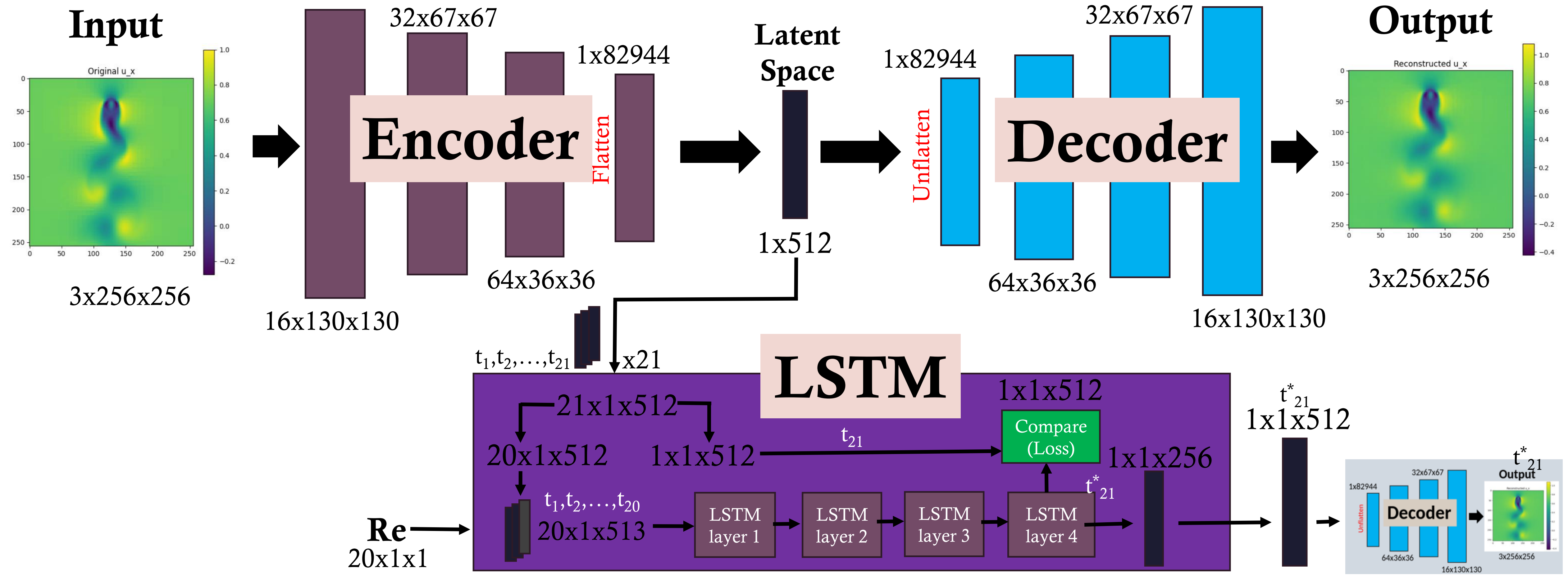
Model Architecture (image reconstruction)



Model Architecture (time-series prediction)

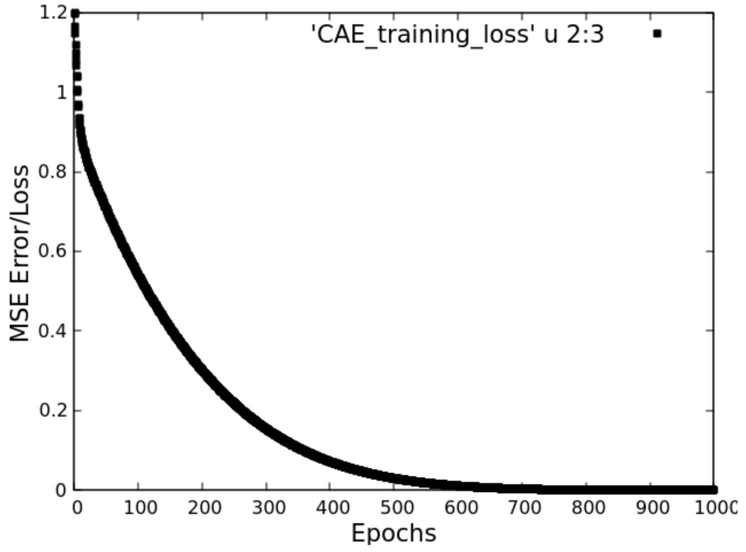


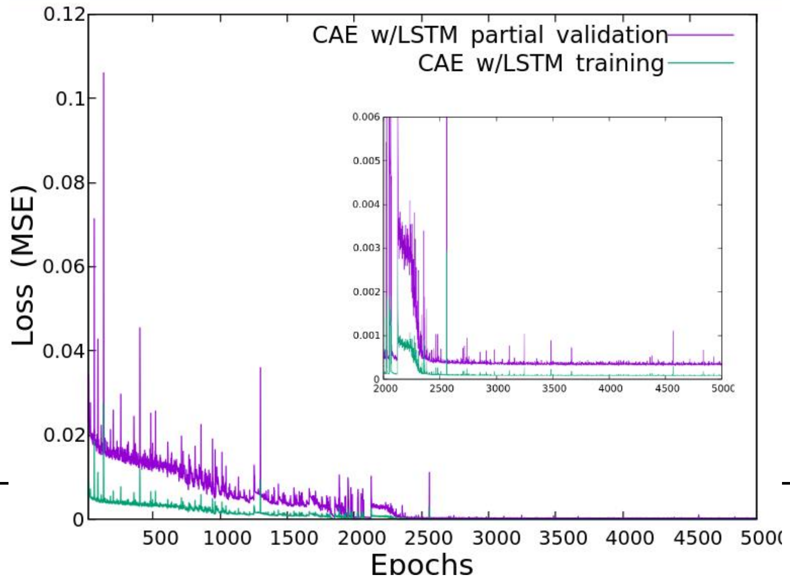
Model Architecture (full model)



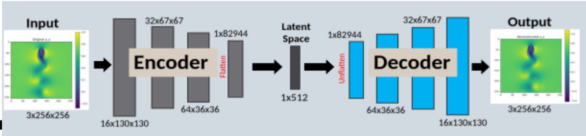
TRAINING SETUP

- Model was made in PyTorch
- Trained on 5 Reynold #s: 40, 80, 120, 160, 200
  - Steady regime: Re <= 40
  - Unsteady Regime: Re > 40
- **CAE** was trained for 1000 epochs
  - Used 1300 input images (260 per Re)
- **LSTM** was trained for 5000 epochs
  - Used 2500 input images (500 per Re) or 2400 sequences
    - 1 sequence = 21 images

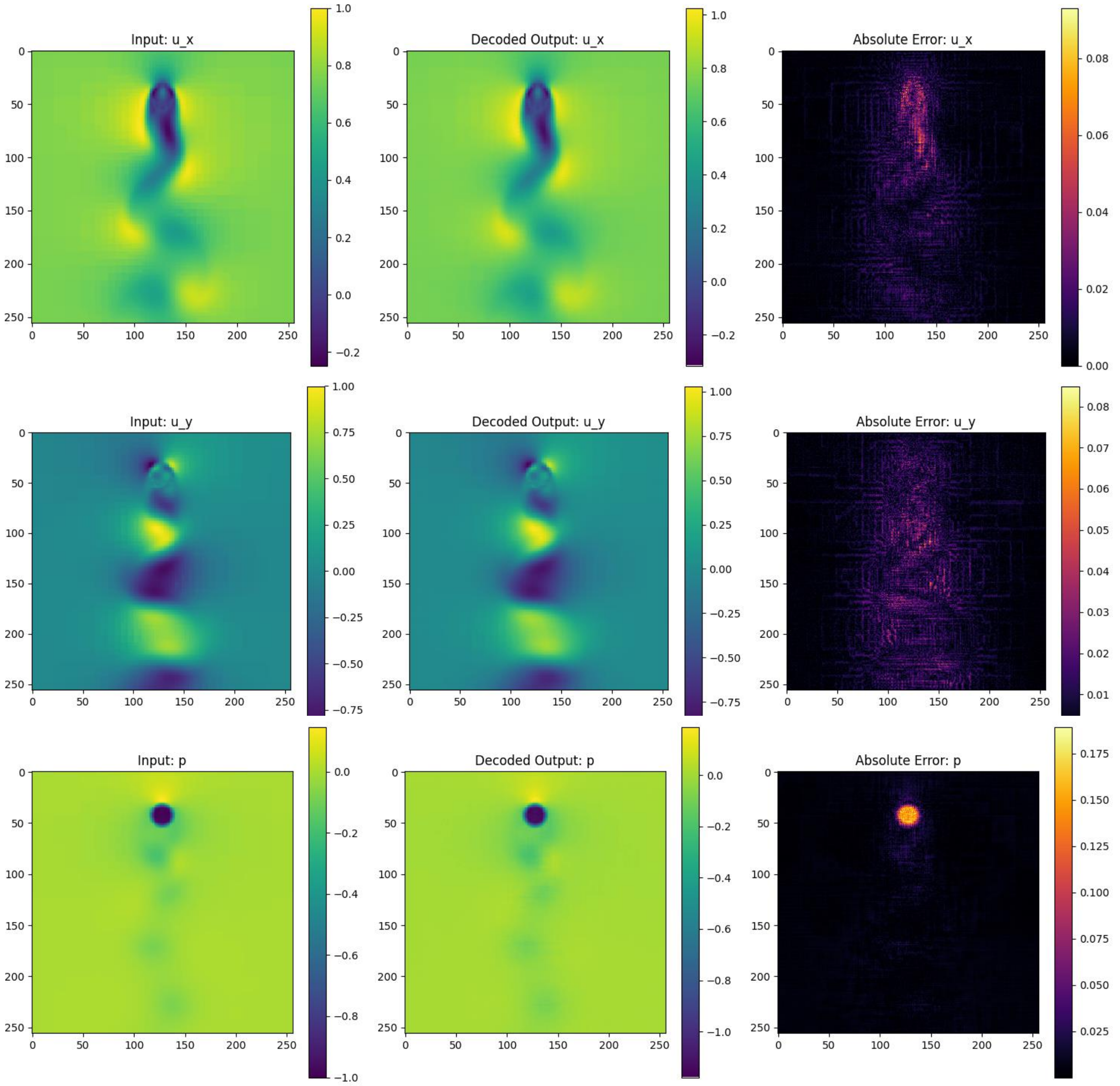




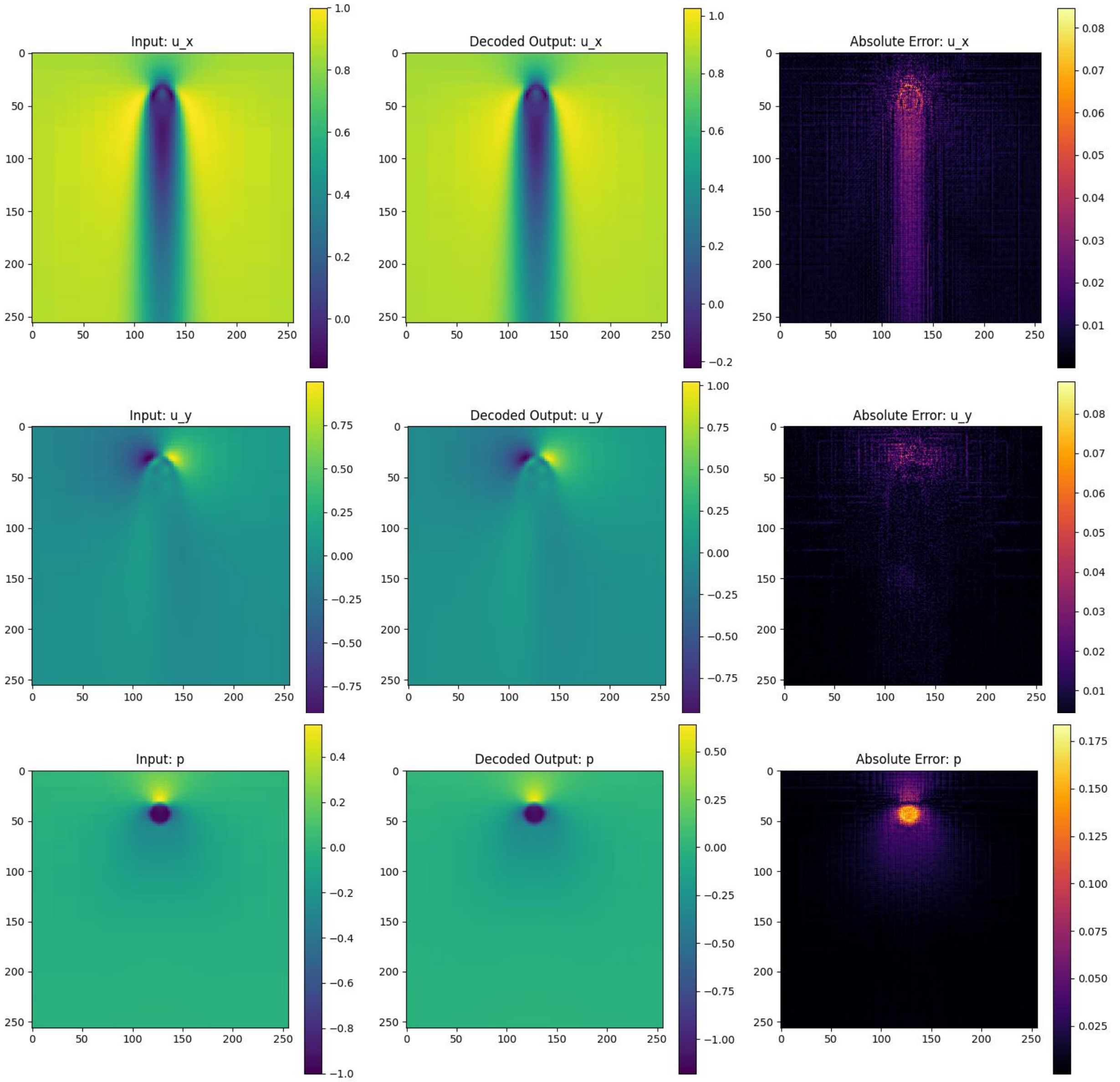
Results (CAE training)



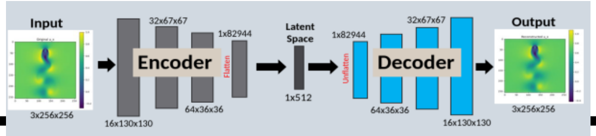
Re = 120



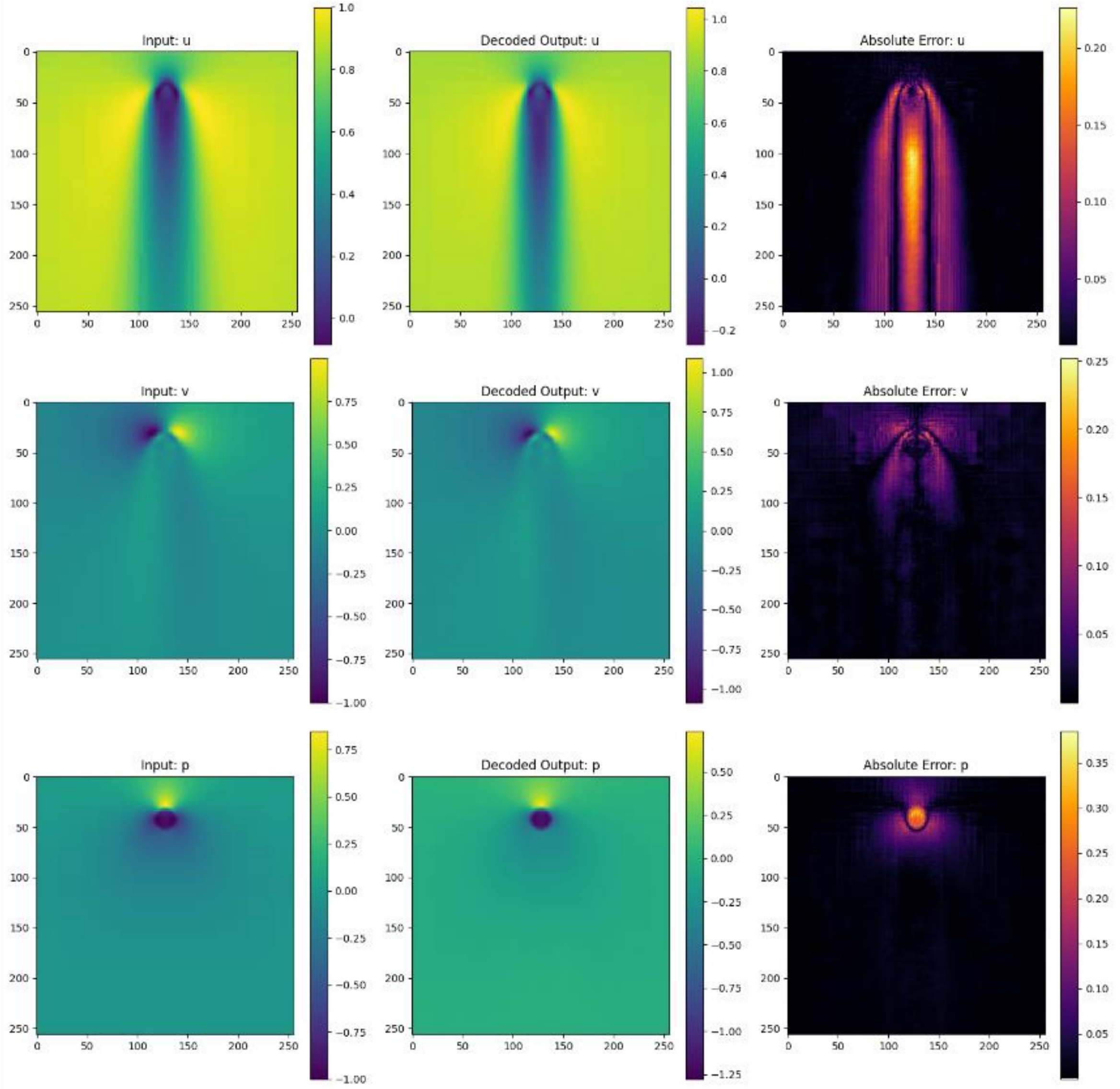
Re = 40



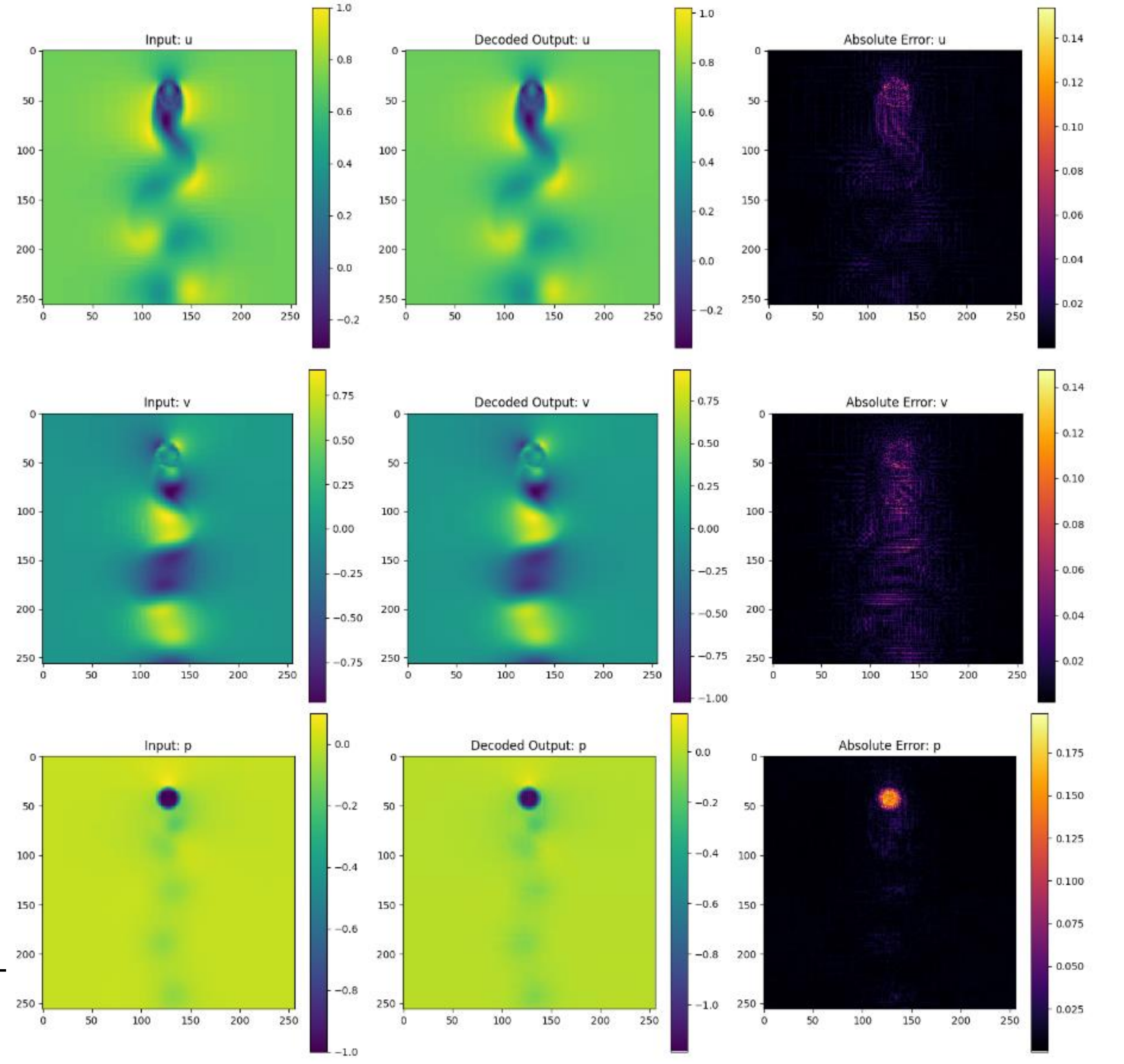
Results (CAE validation)



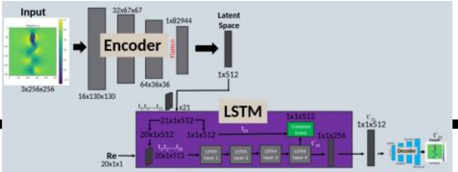
Re = 20



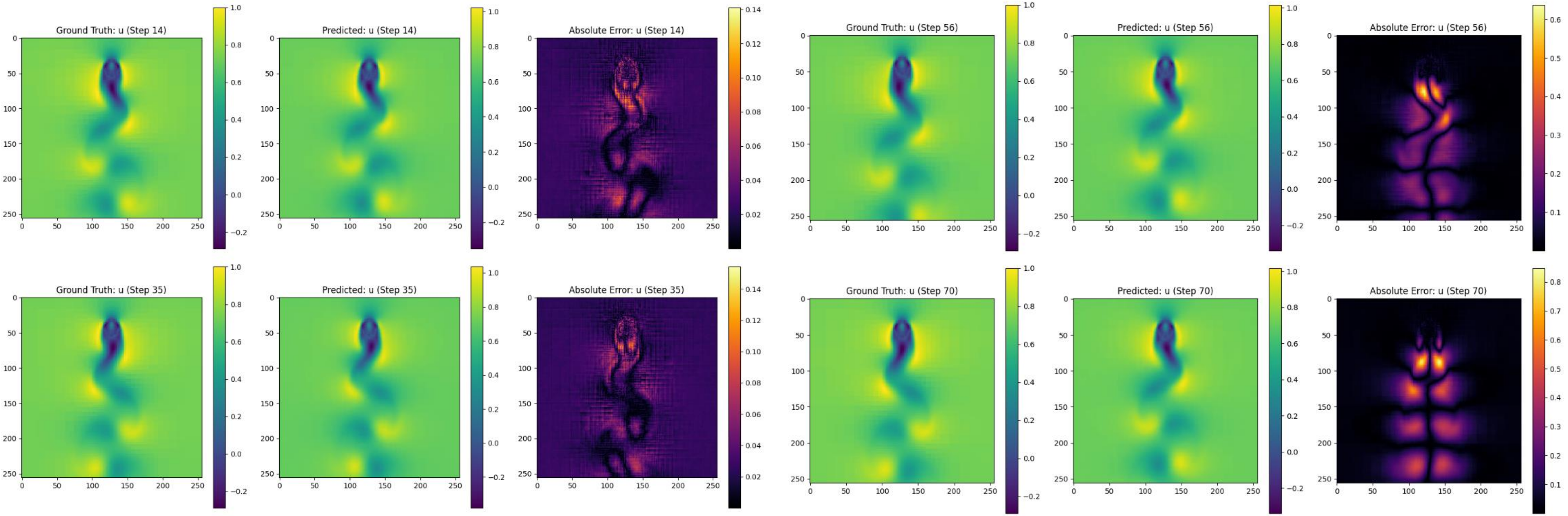
Re = 180



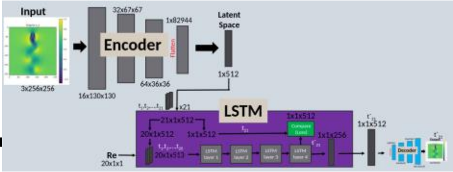
Results (LSTM training)



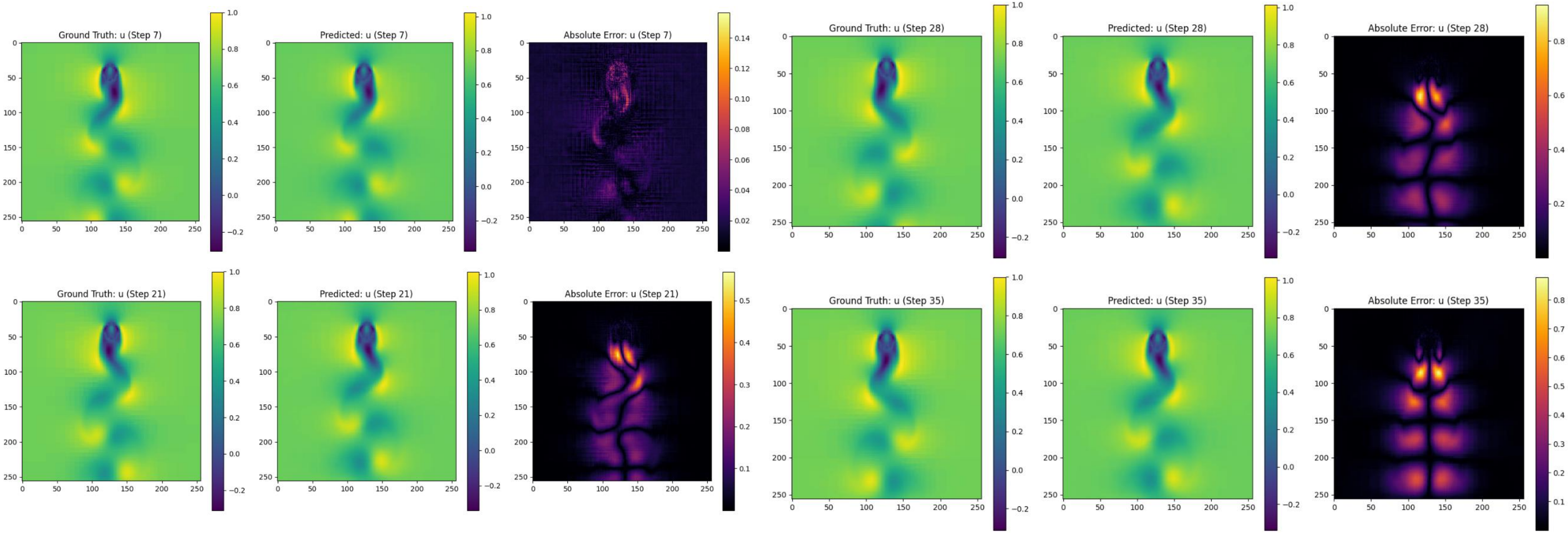
Re = 160



Results (LSTM validation)



Re = 180

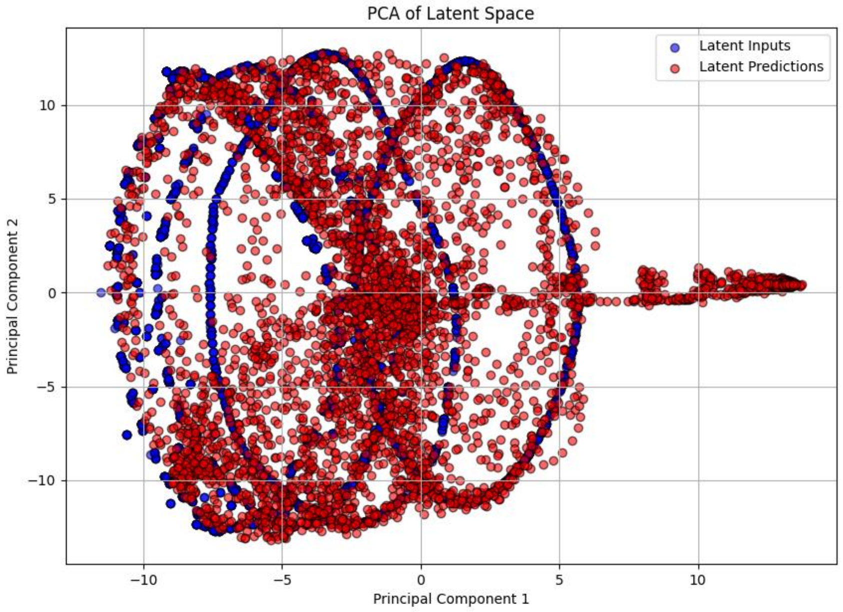


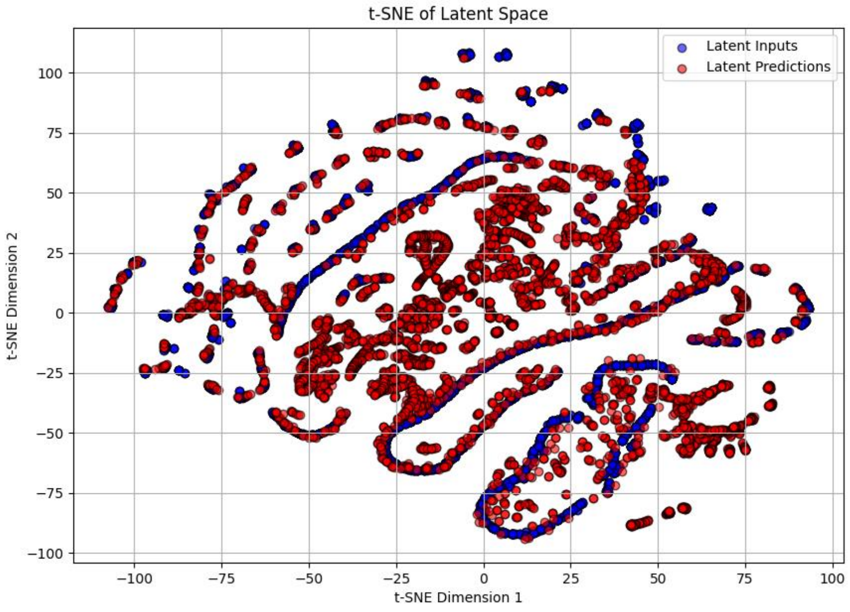
CONCLUSION

- Current model generally does well with image reconstruction
- More work needs to be done to optimize the LSTM's sequence prediction
  - Adjust how LSTM is trained
  - Modify LSTM's model architecture
  - Change encoding and decoding layers to match that of other work

MOVING FORWARD

- Look into how to improve LSTM predictions by anaylsing latent space
- Use PCA and t-SNE to visualize latent space accuracy





REFERENCES

- [1] Vinuesa, R., & Brunton, S. L. (2022). Enhancing Computational Fluid Dynamics with Machine Learning. *Nature Computational Science*, *2*(6), 358–366.
- [2] Hasegawa, K., Fukami, K., Murata, T., & Fukagata, K. (2020). CNN-LSTM based reduced order modeling of two-dimensional unsteady flows around a circular cylinder at different Reynolds numbers. *Fluid Dynamics Research*, *52*(6). https://doi.org/10.1088/1873-7005/abb91d