Predicting Turbulence with Artificial Intelligence

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Today’s plan

- Subject context:
  - Meiji University & Fluid Mechanic Laboratory
  - Interest of turbulence
  - Problem to solve
  - Scientific context
- My approach: The different methods I used to improve predictions
  - Discriminator Influence
  - Scale Filtering
- Results & Conclusion

Meiji University & Fluid Mechanic Laboratory

30,000 students

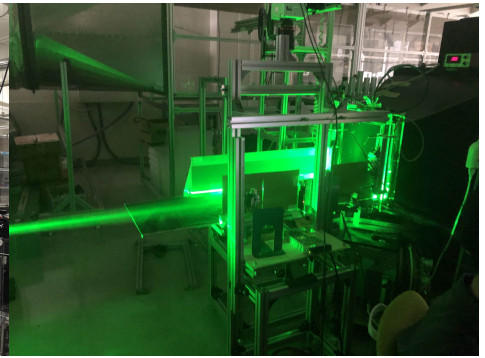
4 campuses

26 different schools

Directed by Prof. Naka Yoshitsugu

14 members

3 wind tunnels



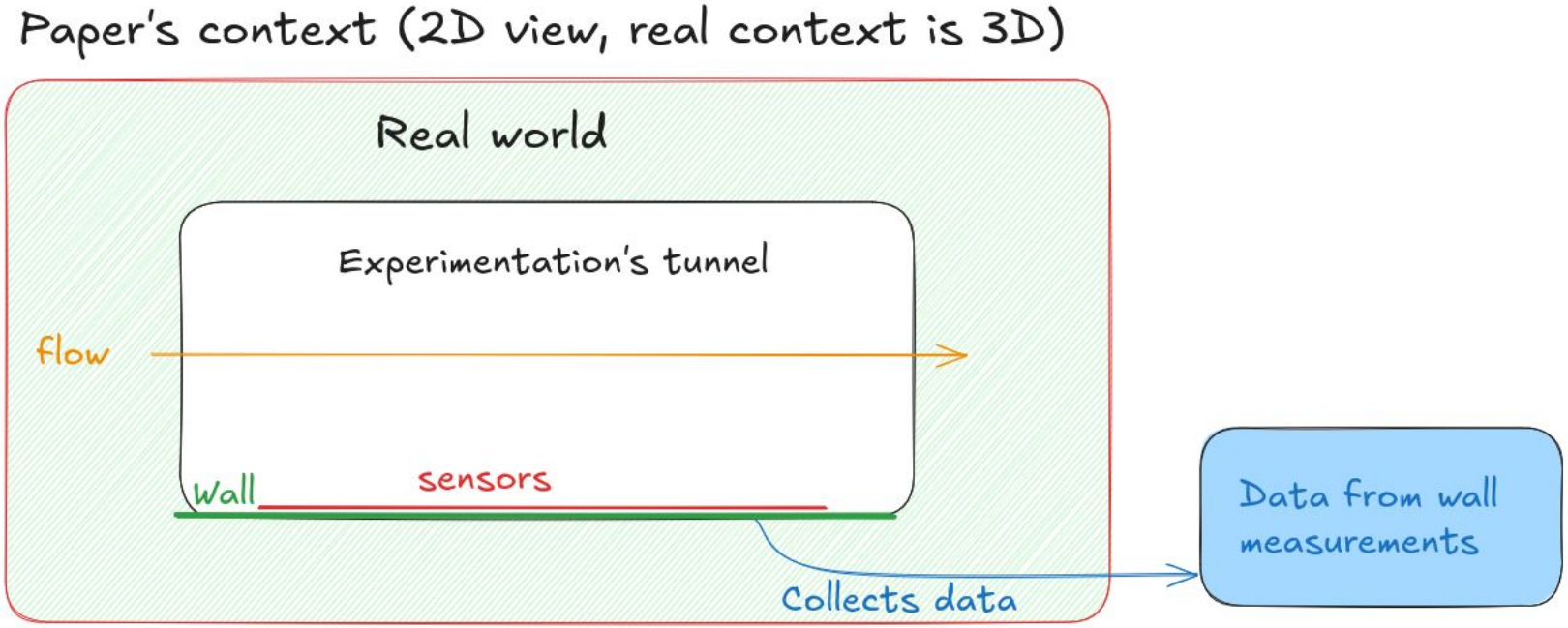
The interest of turbulence

Turbulence is everywhere

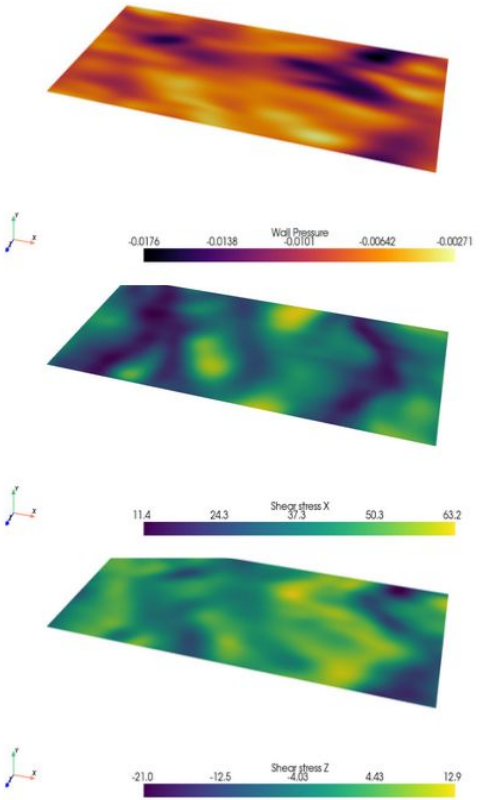
Drag reduction is very important

Understanding & predicting turbulence improves efficiency of transport & energy generation

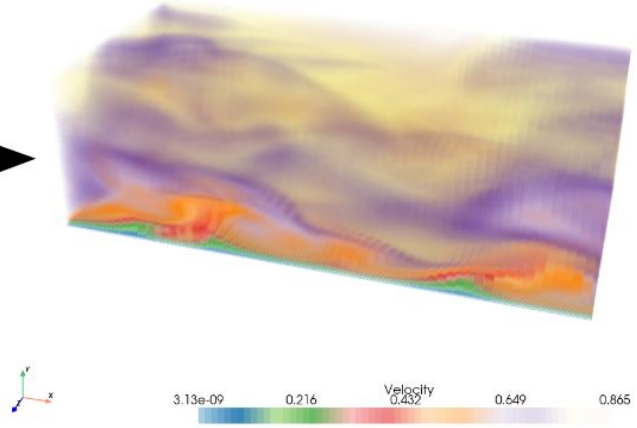
Predicting channel turbulence with wall information



Predicting channel turbulence with wall information



Wall pressure
Wall Shear-Stress X & Z



Channel Velocities

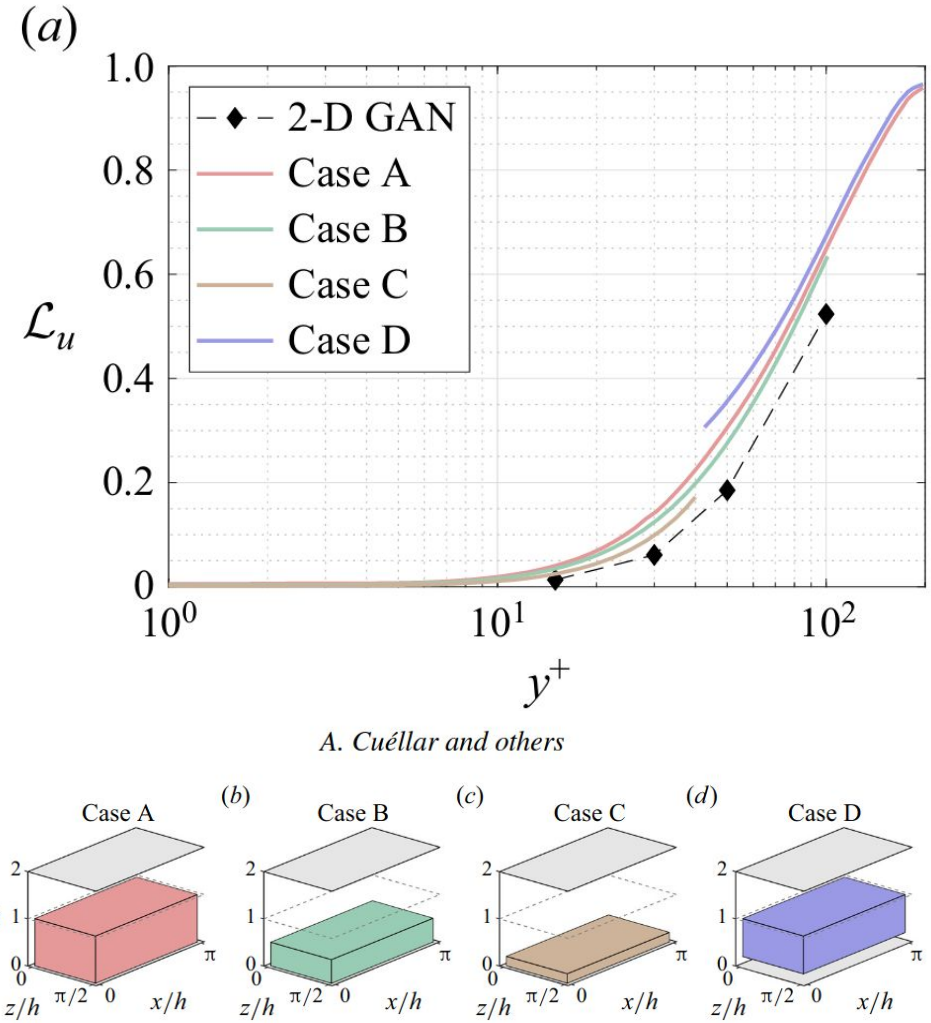
Scientific Context

Three-dimensional generative adversarial networks for turbulent flow estimation from wall measurements

A. Cuéllar and others

arXiv:2409.06548

Submitted on 10 Sep 2024



My objectives

- Replicate results from the reference paper
- Improve predictions

- I established a complete research environment to ease data related processes
- I created a reference generator
- I explored different ways to improve predictions

First step: Understanding the subject and its difficulties

Computer science

- Data generation
- Data storage
- Data manipulation
- Data visualization

My strength

Mechanical engineering

- Data interpretation
- Data validation

My weakness

First step: Understanding the subject and its difficulties
Levers of action

What is improvement?
- Reduce computation
- Reduce imprecisions

Where do we improve?
- Near wall
- Far wall
- Loss
- Realism

By doing what can we improve?
- Tune architecture
- Change inputs
- Replace architecture
- Change dataset
- Change training
- Change prediction area

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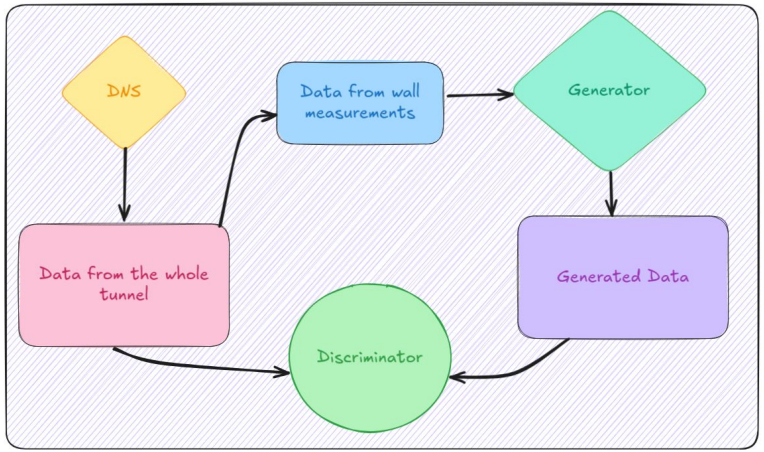
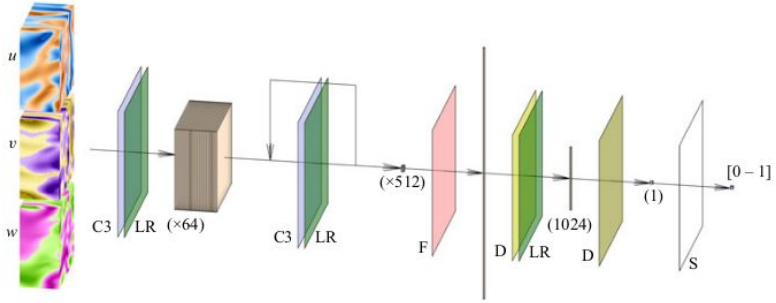
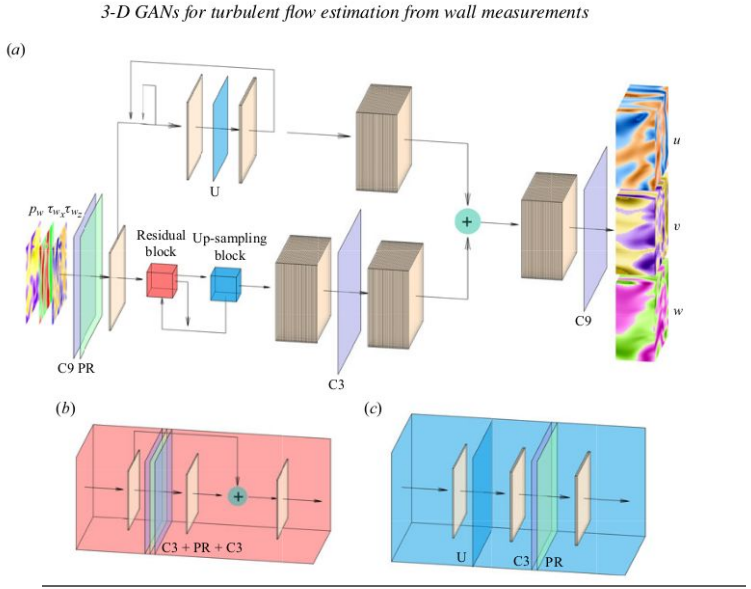
First improvement: Discriminator Influence







Case	Residual block up-sampling scheme	Trainable parameters G	Trainable parameters D
A	0-6-12-18-24-30	9.0×10^6	18.2×10^6
B	0-5-10-15-20	8.0×10^6	18.2×10^6
C	6-12-18-24-30	8.0×10^6	23.8×10^6
D	0-7-14-21-28	8.0×10^6	23.8×10^6
2-D GAN	—	7.3×10^5	8.0×10^7

Graphs taken from reference paper arXiv:2409.06548, A. Cuéllar and others

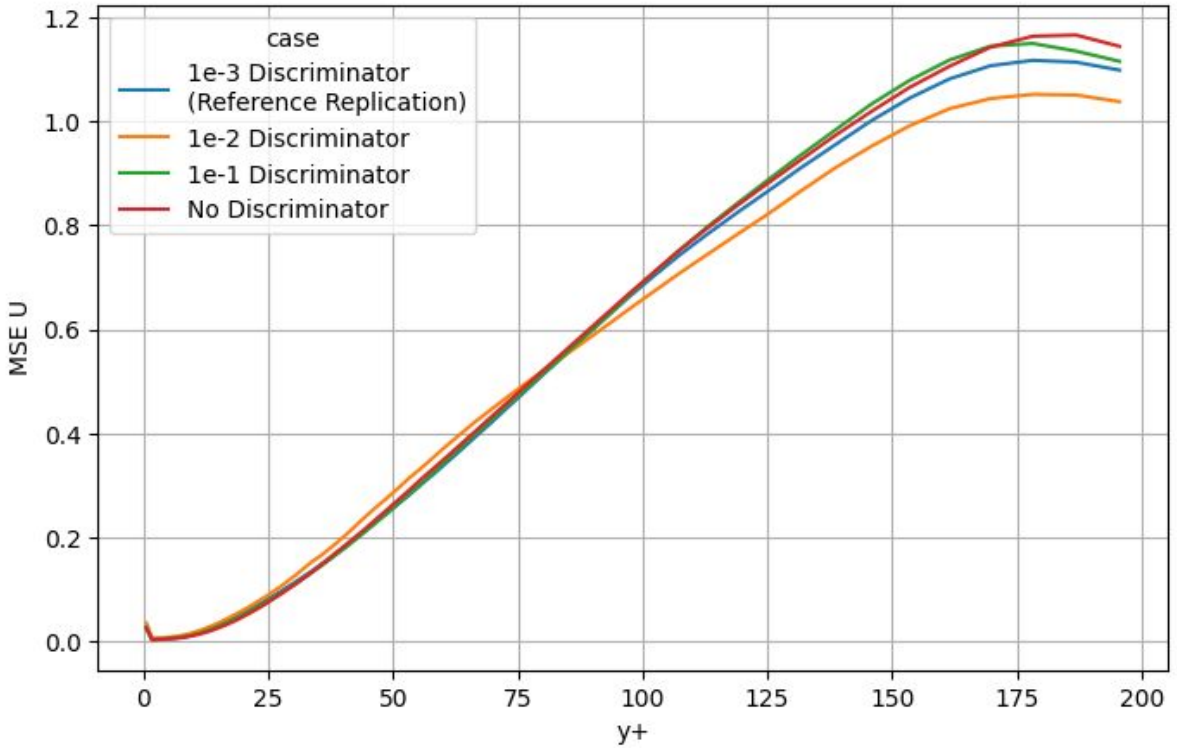
First improvement: Discriminator Influence

4 cases

paper discriminator influence: 0.001

no discriminator is better for near-wall

0.01 influence best for far-wall

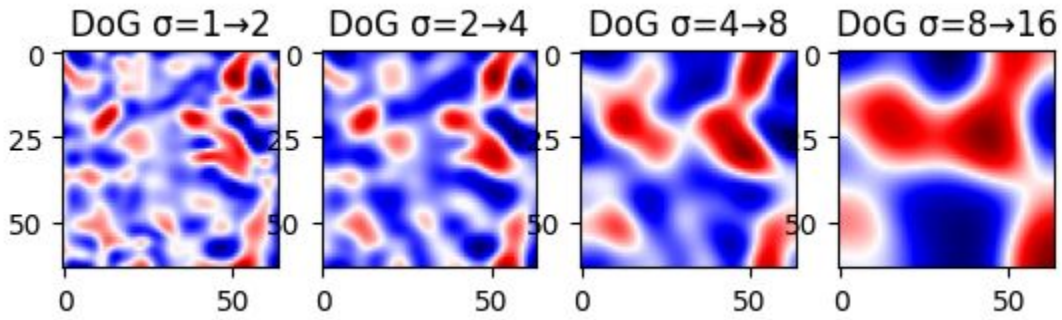


Second improvement: Scale filtering

Flow contains many scales of patterns

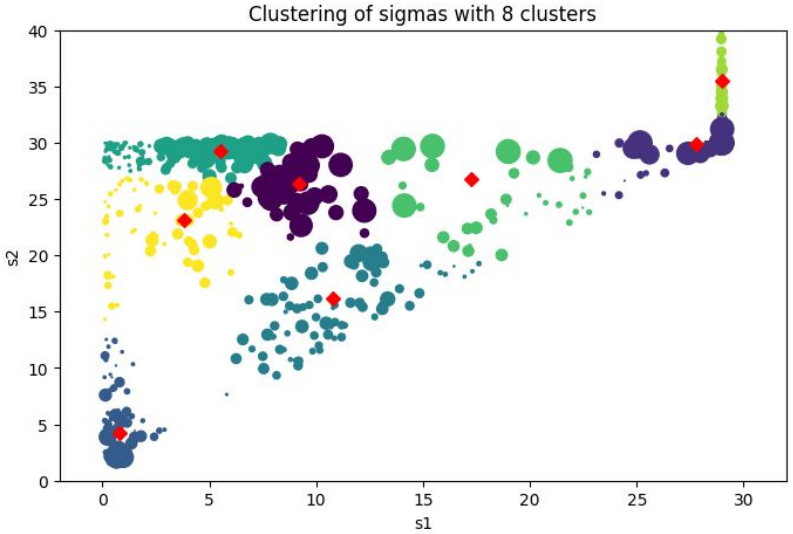
The further from the wall, the bigger the patterns

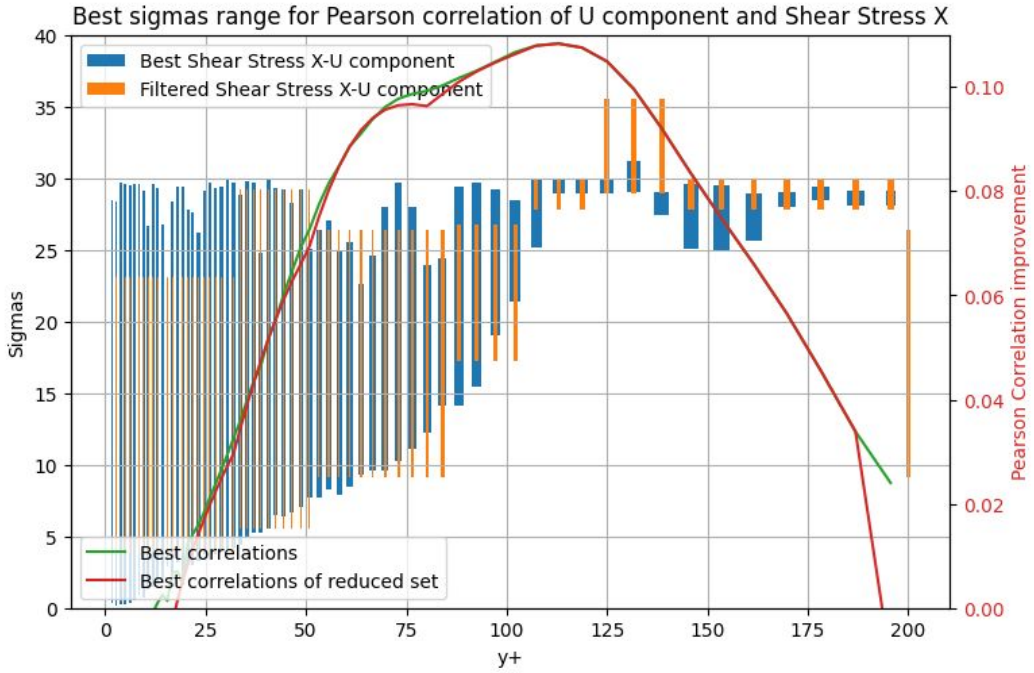
Idea: Highlight the bigger patterns to improve predictions in the far-wall area



Second improvement: Scale filtering

Each layer for each input component is associated to a filter from a reduced set of the best filters





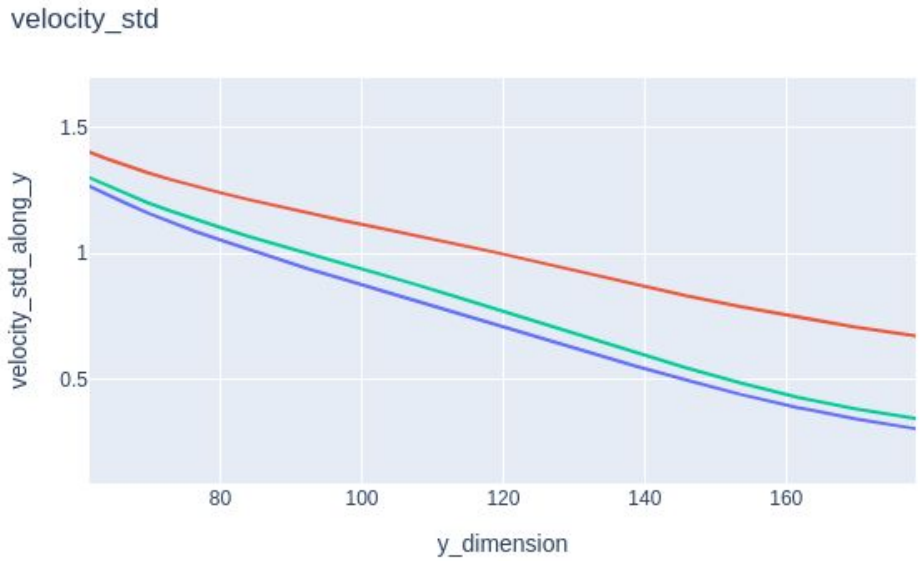
filters from bayesian optimization with correlation

Second improvement: Scale filtering

First test with raw filtered inputs

No accuracy improvement

Better standard deviation



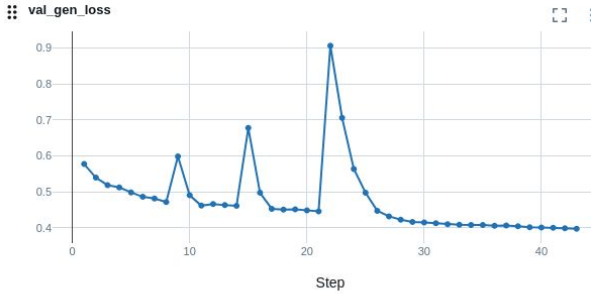
ground truth

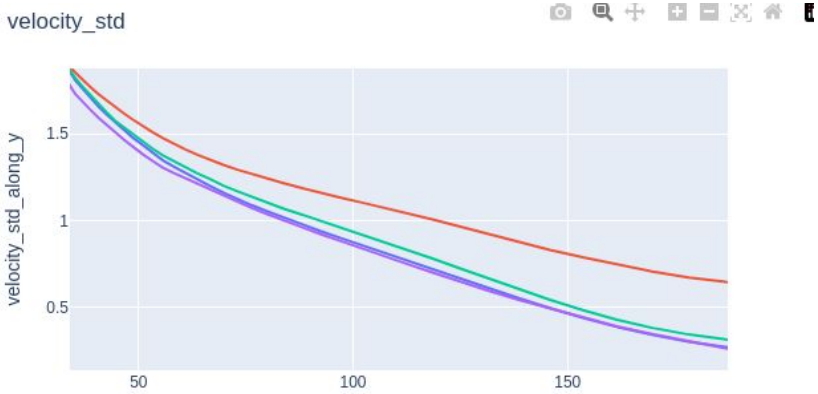
my reference

scale filtering 1

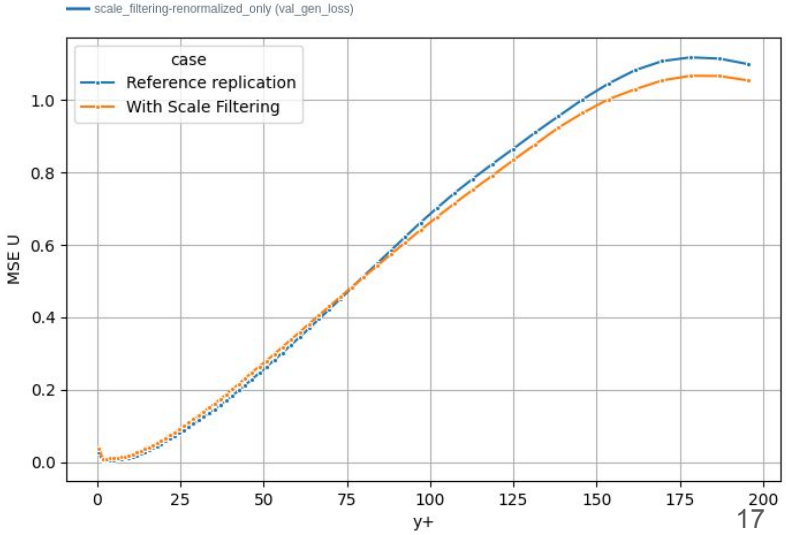
Second improvement: Scale filtering renormalized

Second test with renormalized filtered inputs
Chaotic training
Lower standard deviation
Better prediction



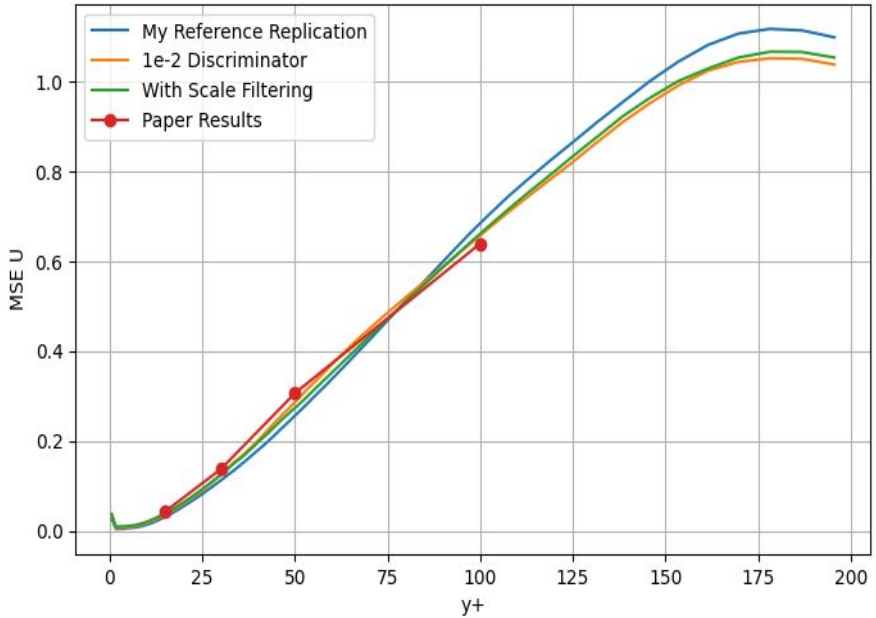


ground truth
scale filtering 1
my reference
scale filtering 2

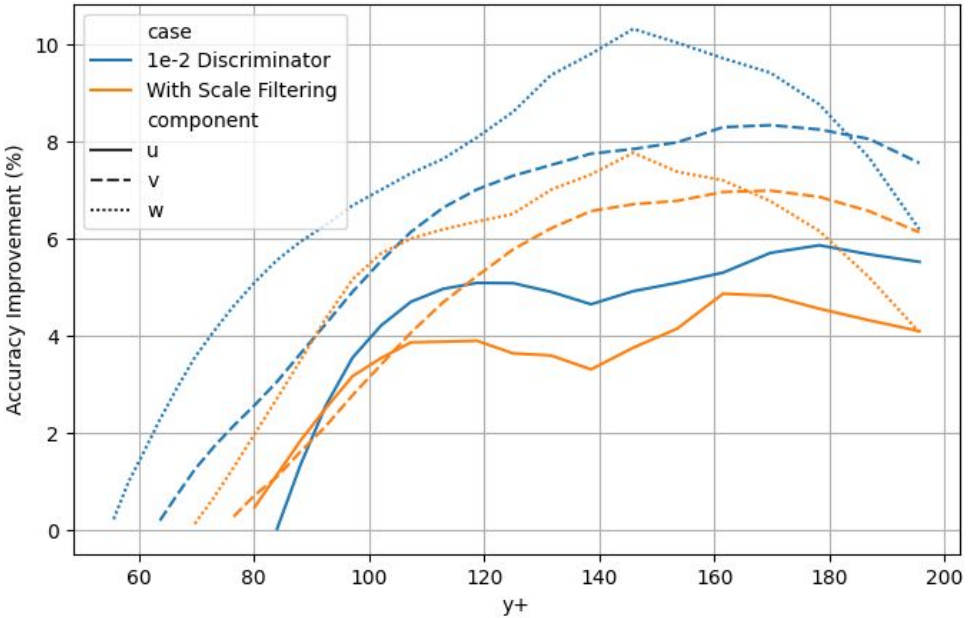


My improvements

Generators comparison



Improvement over replication



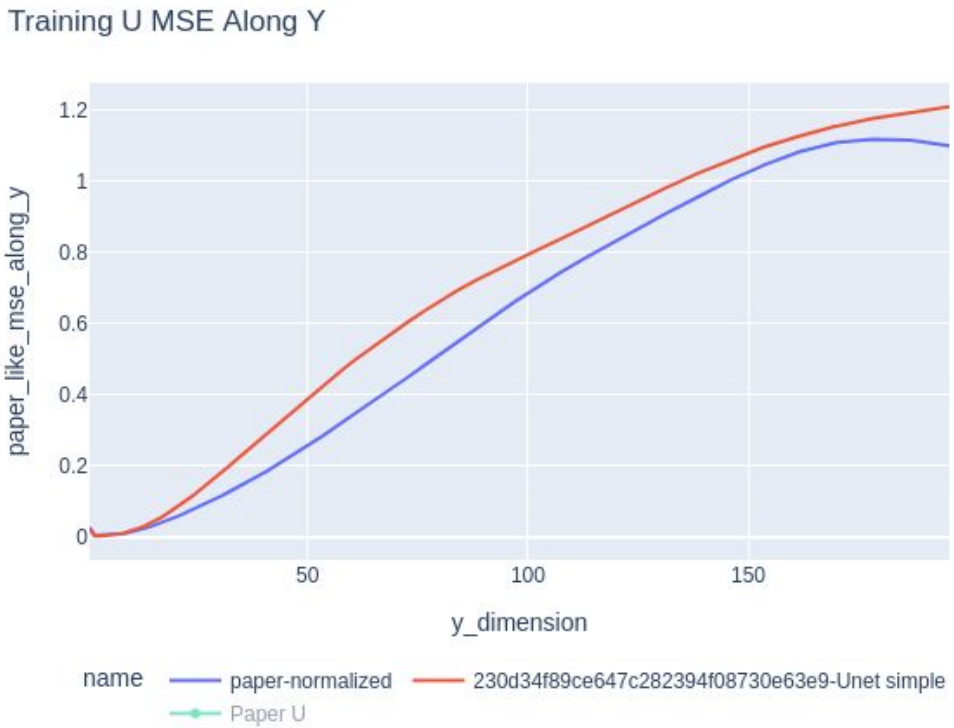
Conclusion

I achieved improvement of up to 10% in the far-wall part

Further improvements might require complete architectural changes (UNet / diffusion)

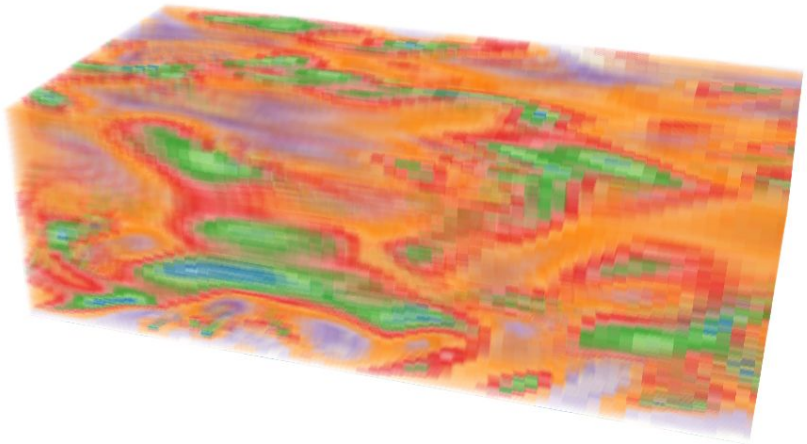
Reducing problem size could allow for faster iteration

UNet perf

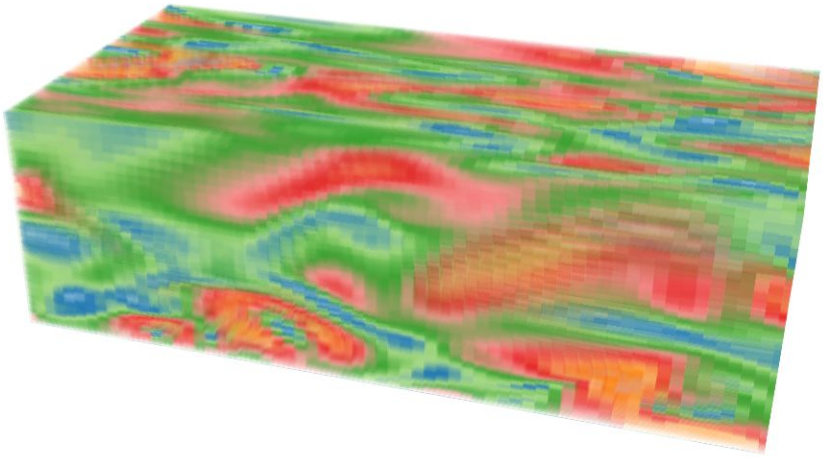

Training U MSE Along Y
paper_like_mse_along_y
1.2
1
0.8
0.6
0.4
0.2
0
50
100
150
y_dimension
name
paper-normalized
230d34f89ce647c282394f08730e63e9-Unet simple
Paper U

Diffusion

prediction



target



Clustering comparison