Using a Convolutional Neural Network to Super-Resolve Airflow Around a Building

Themistoklis Vargiemezis & Nicholas Bachand

Introduction

Flows around buildings are highly turbulent with a broad range of scales. Accurate numerical predictions from computational fluid dynamics (CFD) codes require solving down to the smallest scales, but these simulations can be prohibitively expensive. In this project we super-resolve the flow filed with deep neural nets designed for natural image processing. Low resolution input images could correspond to an inexpensive and coarse CFD simulation. We focus on the Reynolds normal stresses:

$$k = \frac{1}{2}(\overline{u'u'} + \overline{v'v'} + \overline{w'w'})$$

- **Challenge**: Fluid flows contain structures of various scales that must be super-resolved differently.
- **Prior Work:** Mostly small, custom architectures

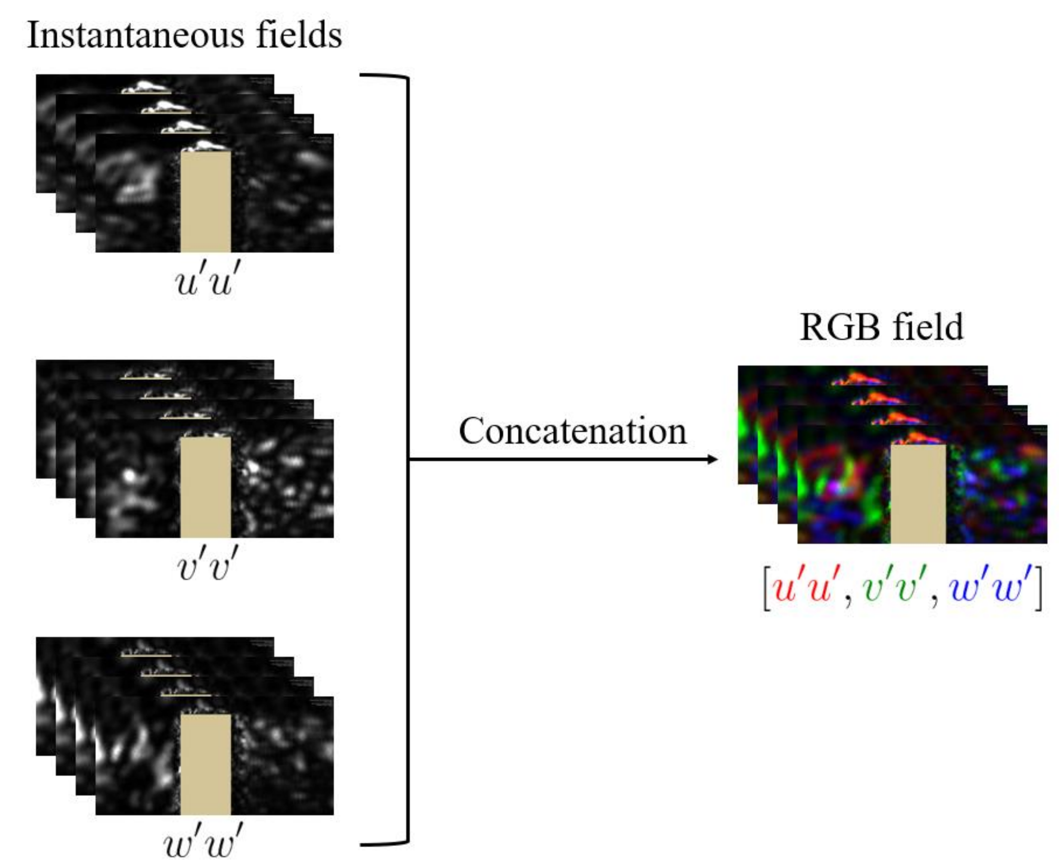
Problem statement

To super-resolve the flow field around a building at 4x.

- **Inputs**: 4x bicubically downsampled
- **Training Labels**: high-resolution
- **Metric:** root mean squared error of the turbulent kinetic energy (RMSE TKE).

Dataset

The images for the dataset are generated from a high-resolution CFD simulation of the flow around a high-rise building. We capture the Reynolds stresses in grey-scale and concatenate then in one RGB image.



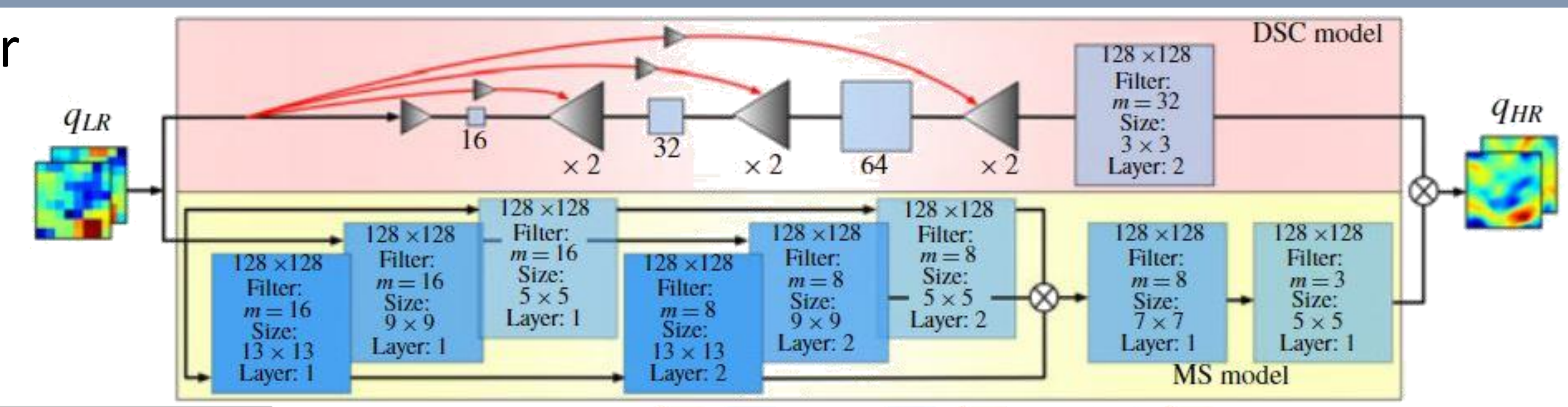
We derive the low-resolution inputs via 4x bicubic downsampling. In total, 2000 images/timesteps are captured and divided into head and tail (1800 + 200).

Experiments

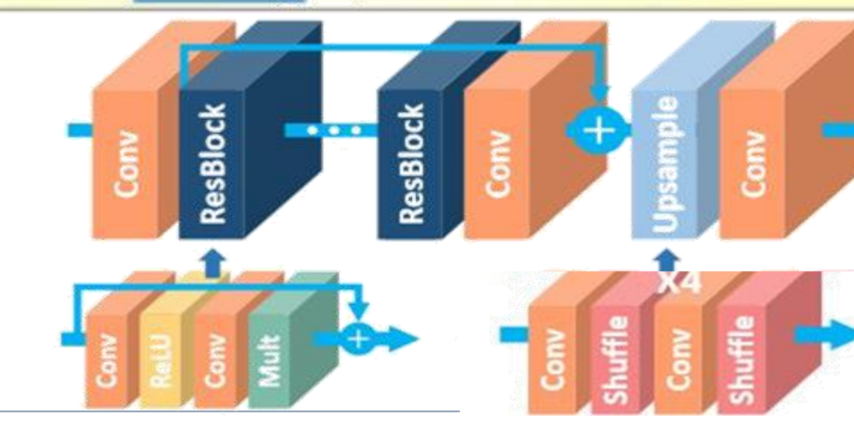
1. From the head we randomly select 200 intermediate steps as the test set, and the remaining 1440+160 as training and validation sets
2. Keep the training model from 1 but add a new tail test with 200 more steps past the original data.

Methods

1. DSC/MS: Designed for Fluid Flows [1]
2. EDSR: Designed for Natural Images [2]



Model	Parameters	ResBlocks	Features
full EDSR	43 mil	32	256
small EDSR	212k	5	35
tiny EDSR	124k	1	35
DSC/MS	216k	NA	≤35

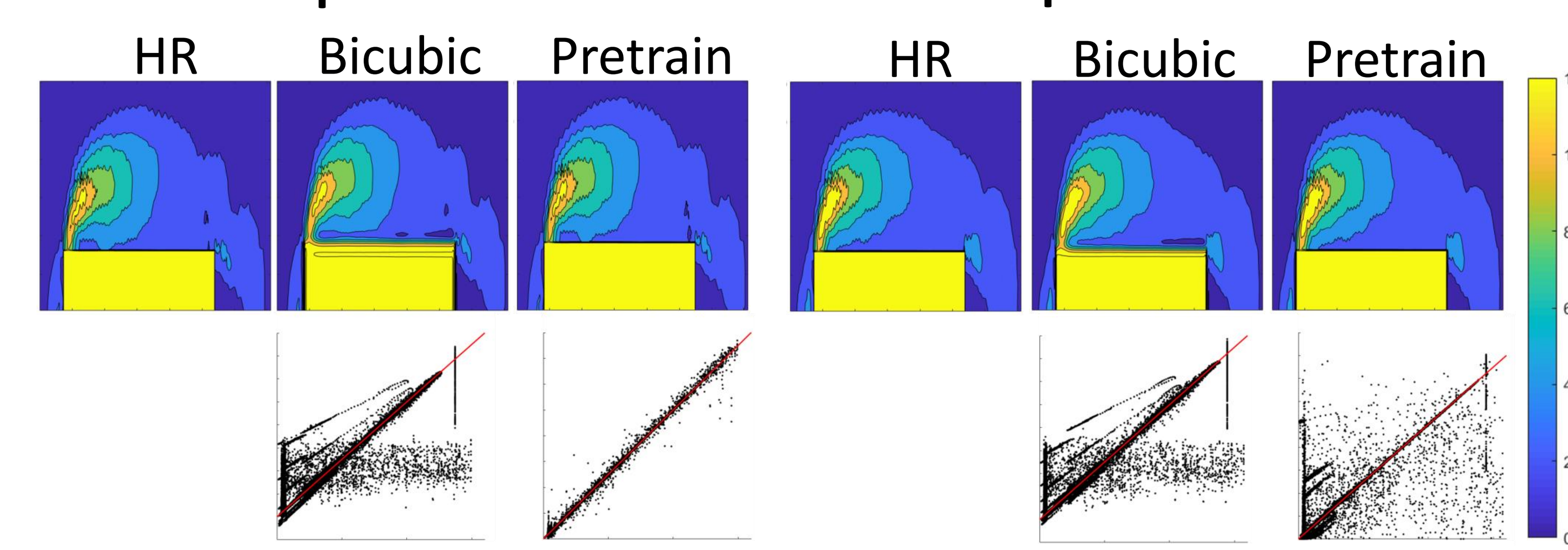


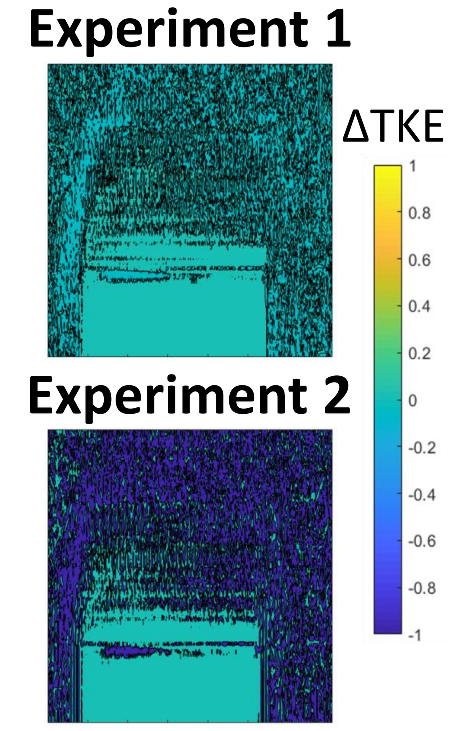
Results

- **Bicubic** method **fails** to reconstruct the flowfield around the edges
- **Pretrained EDSR** shows significant improvement
- **Exp.2** results not as good as **Exp.1**
- Intermediate images are strongly correlated and easy to reconstruct
- Flow structures on the building are reconstructed correctly because they are geometry dependent

RMSE

Model	Exp.1	Exp.2
Bicubic	0.3228	0.3108
DSC/MS	0.3646	0.3829
Tiny	0.1764	0.4346
Small	0.1624	0.3461
Scratch	0.0228	0.3403
Pretrain	0.0151	0.3321





Conclusions

- Natural image techniques apply well
- Prediction struggles as flow evolves
- Benefit of interdisciplinary thinking

Future work

- Transformer networks
- LSTM addition for temporal information
- Explore characteristic timescale impact

1. Kai Fukami, et al. Super-resolution reconstruction of turbulent flows with machine learning. Journal of Fluid Mechanics, 870:106–120, 7 2019.
2. Bee Lim, et al. Enhanced deep residual networks for single image super-resolution. pages 1132–1140, 07 2017.