LES of coherent structures in a street canyon

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Introduction

- Street canyon experiment in a wind channel measured at the Institute of Thermomechanics o the Czech Academy of Sciences. (Kellnerová et al., EFM 2010; Kellnerová et al., ICWE 2011).
- Analysis using similar methods as used by the authors of the experimental study, i.e. POD, spectra...
- Computed with al 3 velocity components and in full 3D domain.
- Also computed with a free top boundary condition with a higher domain, than the original experimental channel.

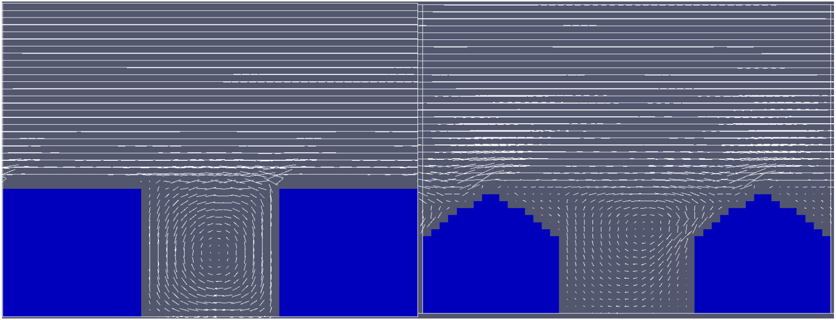
- Lenght of the domain 2 m i.e. 20 canyons.
- Two types of buildings with $H = 5$ cm.
- Cyclic boundary conditions.
- Resolution $640 \times 97 \times 97$, i.e. 15×18 in the canyon.
- Also results with 32×26 in the canyon, but in a shorter domain.
- In the shorter domain run, the results were more detailed, but the flow above canopy was affected by the largest possible wavelength.

Introduction - the model

- The Charles University Large-eddy Microscale Model (CLMM) is a research in-house CFD code for flows in the atmospheric boundary layer
- Large Eddy Simulation (LES) tries to resolve turbulent motions larger than the grid size and model only the subgrid effects.
- CLMM concentrates on contaminant dispersion in complicated geometry.
- CLMM is able to include the buoyancy effects, but now validated only over a flat terrain. Not used in this study.

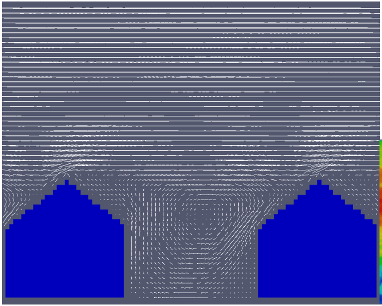
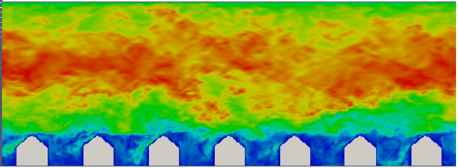
Numerical methods

- Projection (fractional step) method with a 3rd order Runge-Kutta and 2nd order Crank-Nicolson method in time.
- Finite volume spatial discretization on a staggered grid.
- Immersed boundary method for the geometry of the buildings.
- 2nd order central discretization for advective and diffusive fluxes.
- Vreman subgrid model (for LES).



Average flow in the street canyon.

Why the longer domain?

shortvelmag.avi

Animations of the flow - magnitude of velocity.

`shape1velmag.avi`

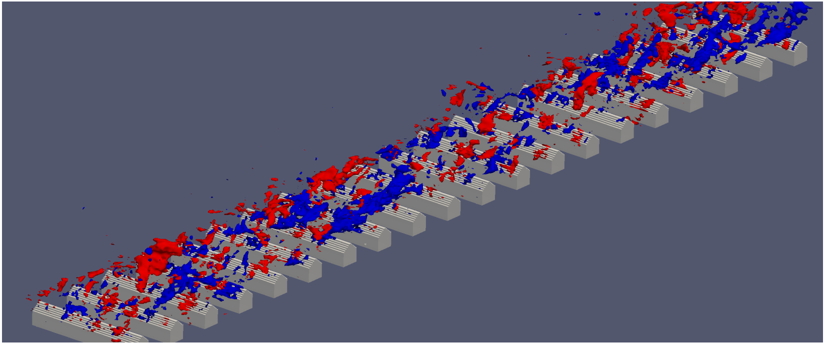
`shape2velmag.avi`

Animation of the flow - detail of the canyon.
`shape2vecsanim.avi`

Animations of the flow - transverse component of velocity (u_y, not measured in the experiment).

`shape1vely.avi`

`shape2vely.avi`



Isocontours of constant v_y.

Proper orthogonal decomposition (POD).

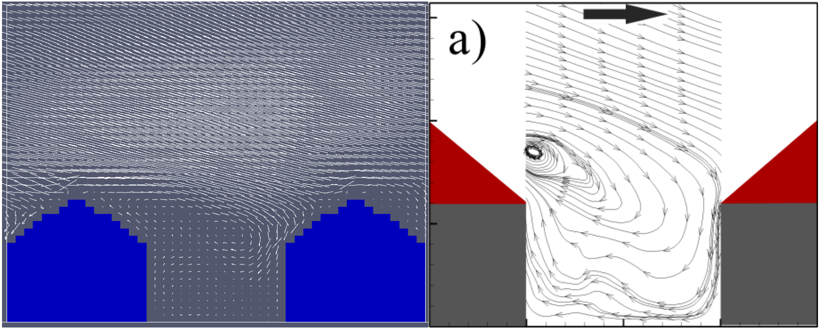
Find a new basis of orthogonal vectors (POD modes) ϕ_k (constant in time), such that the state vectors (flow snapshots) q_j can be expressed as

$$q_j - \bar{q} = \sum_k c_{jk}\phi_k, \qquad \text{such that} < \phi_i, \phi_j >= \delta_{ij}. \tag{1}$$

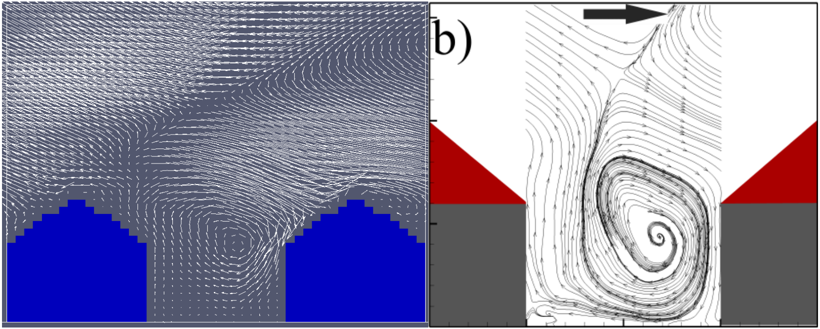
where c_{jk} are the POD coefficients (changing with time) and acting as weights. The new basis is found maximizing the expression

$$\max_{q_1,\dots,q_2} \sum_{i=1}^{l} \sum_{j=1}^{n} \left| < q_j, \phi_i > \right|^2, \qquad \text{(Sirovich, 1987)} \tag{2}$$

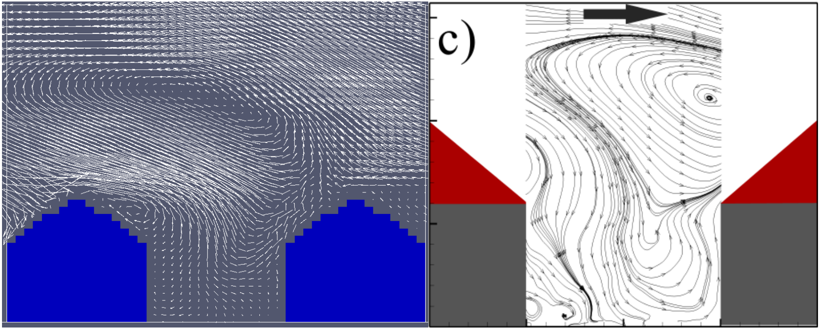
for every consecutive mode. The problem is solved using the singular value decomposition (SVD) by a Fortran program SVD_BASIS (Burkhardt et al.).



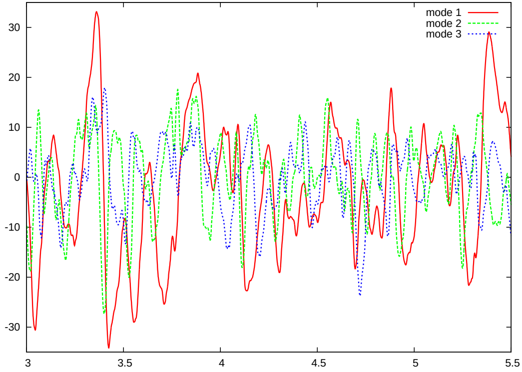
POD mode 1 (left simulation, right experiment from Kellnerová et al. 2011).



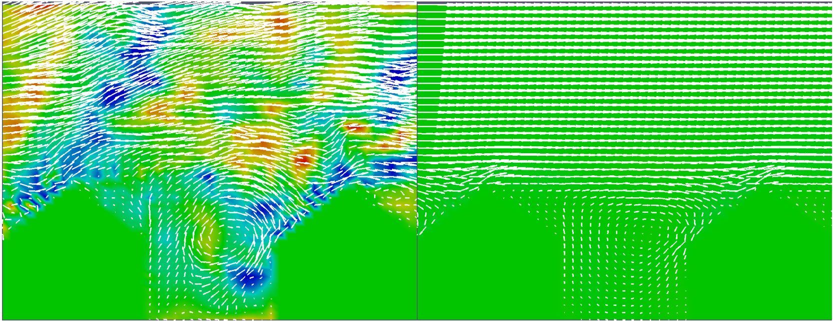
POD mode 2 (left simulation, right experiment from Kellnerová et al. 2011).



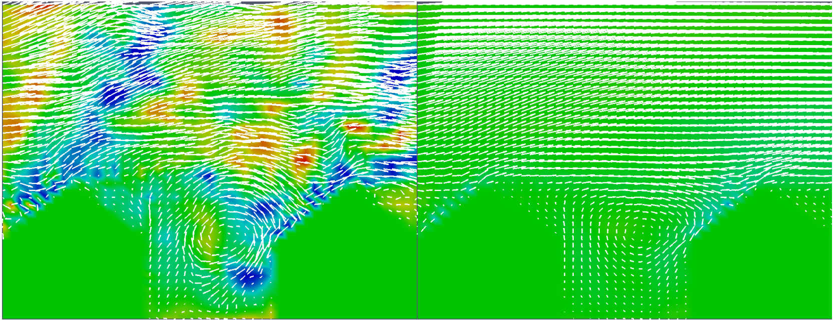
POD mode 3 (left simulation, right experiment from Kellnerová et al. 2011).



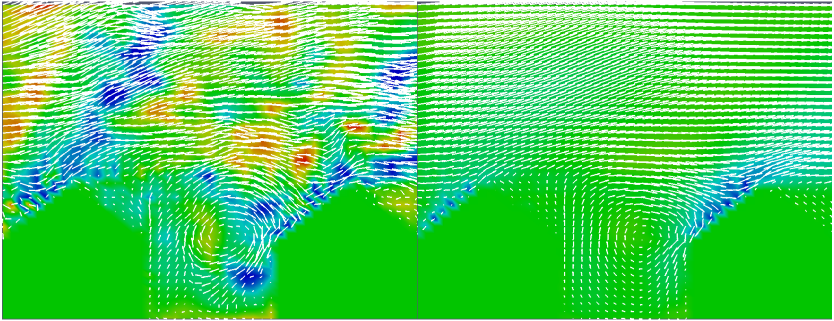
Time coefficients for the first 3 modes (simulation).



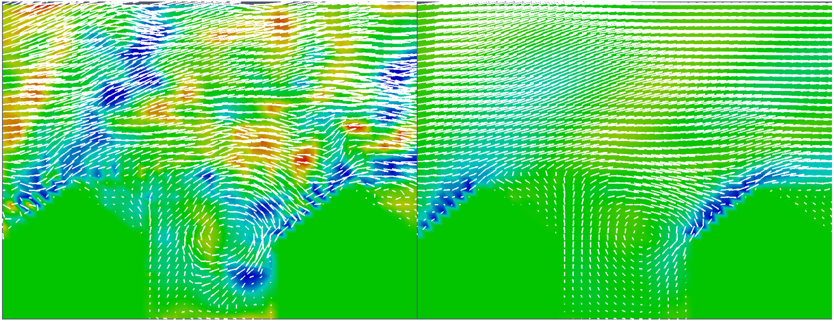
POD reconstruction using the average only (left original snapshot).



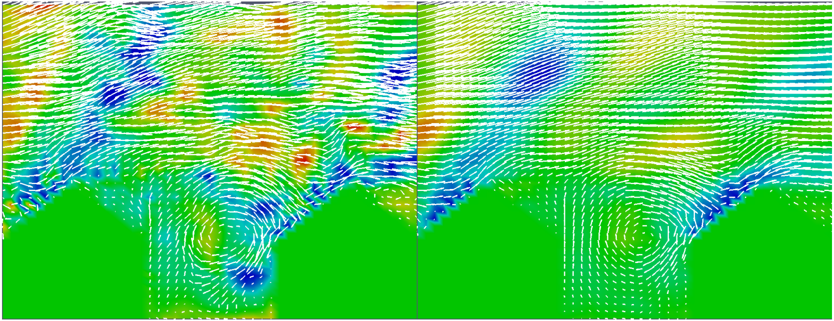
POD reconstruction from 5 modes (left original snapshot).



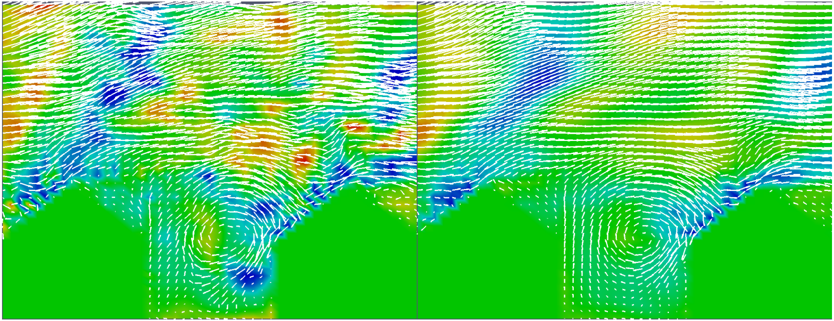
POD reconstruction from 15 modes (left original snapshot).



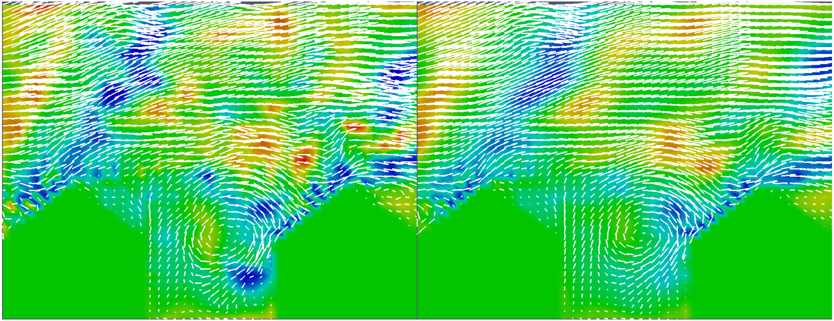
POD reconstruction from 25 modes (left original snapshot).



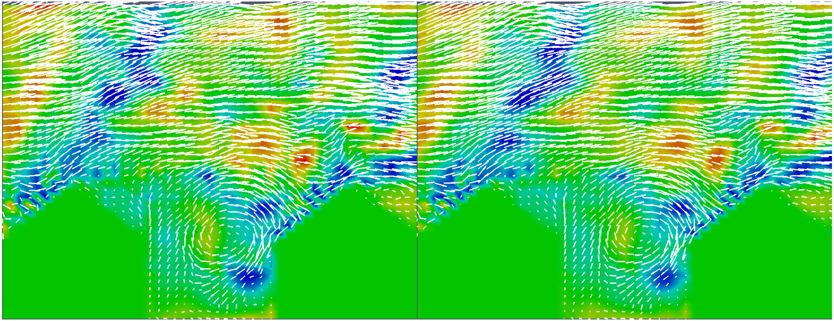
POD reconstruction from 50 modes (left original snapshot).



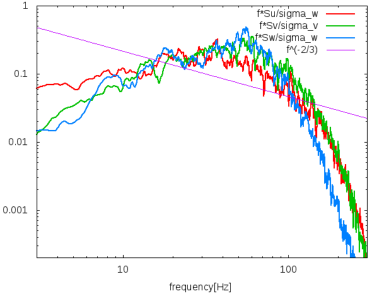
POD reconstruction from 100 modes (left original snapshot).

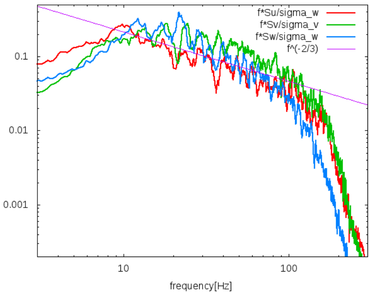


POD reconstruction from 200 modes (left original snapshot).

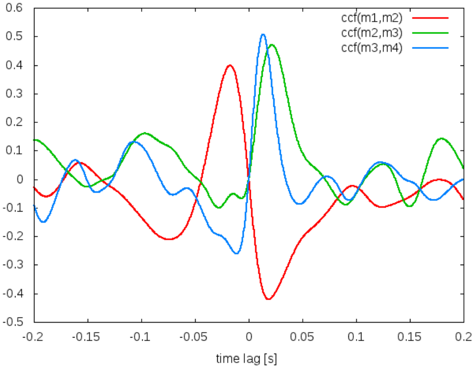


POD reconstruction from 500 modes (left original snapshot).



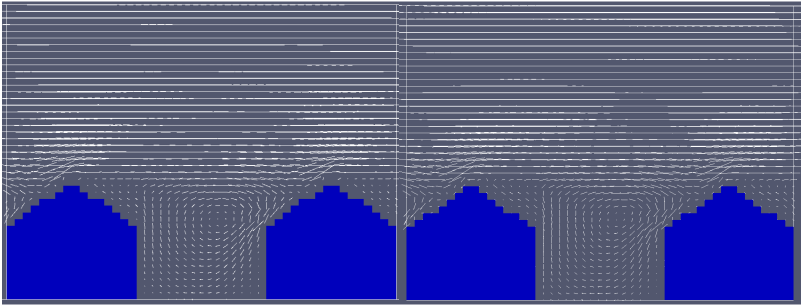


Comparison of velocity spectra for flat roofs and pitched roofs.



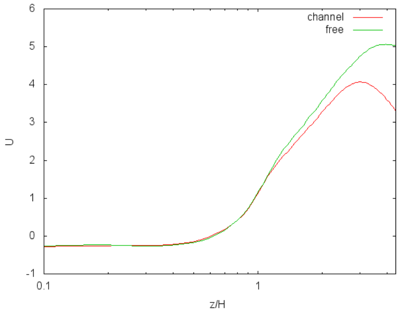
The autocorrelation functions between POD coeficients of the first consecutive modes.

Blockage effect



The difference between the channel configuration and the free top configuration. The average flow vectors.

Blockage effect

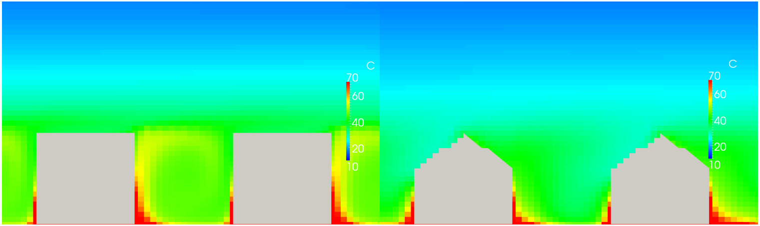


The difference between the channel configuration and the free top configuration (average horizontal velocity in the middle of the canyon).

Scalar dispersion

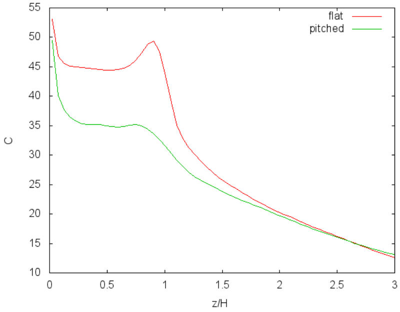
- Continuous uniform source at the bottom of the street canyons.
- Surface flux $Q = 1\,\mathrm{m}^{-2}\mathrm{s}^{-1}$.
- Zero flux at the top.

Scalar dispersion



Concentrations averaged over interval (3 s, 10 s).

Scalar dispersion



Concentration profiles in the middle of the canyon averaged over interval (3 s, 10 s).

Scalar dispersion

Animations of evolution of concentrations.

`shape1tempanim.avi`

`shape2tempanim.avi`

Conclusions

- The model was able to produce results similar to the experiment.
- Still a lot to do:
  - Quantitative comparison with the experiment.
  - Higher resolution.
  - Evaluation of turbulent fluxes.
  - POD of scalar fields, 3D POD, POD on the full domain.
  - Many possibilities for further development of the numerical model (e.g. real parallelization - now only OpenMP).

Thank you for your attention!