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Introduction and validation of a simplistic method to represent vehicle-induced turbulence in high-resolution large-eddy simulations

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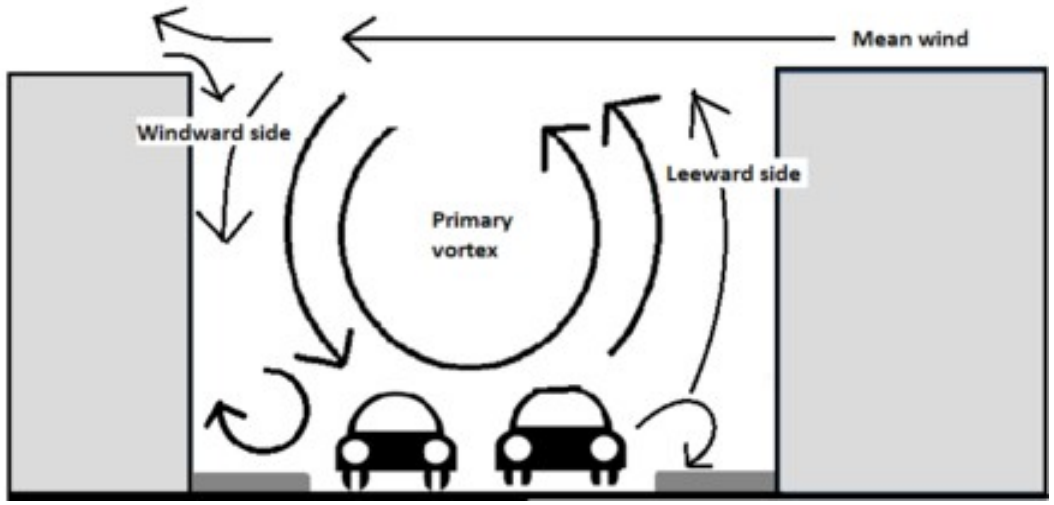
Motivation and Aim



Skimming flow regime with mean wind direction perpendicular to street canyon (after Oke, 1988)
(https://en.wikipedia.org/wiki/Street_canyon)

- Flow and pollutant dispersion within street canyons influenced by many processes like aspect ratio (AR), roof shape and thermodynamics
- Additional critical factor: **vehicle-induced turbulence** (**VIT**)
- Research so far mainly based on wind tunnel experiments and CFD studies using RANS (Reynolds-Averaged-Navier-Stokes) models
- Our aim: account for VIT in Large-Eddy Simulation (LES) Model PALM[1]

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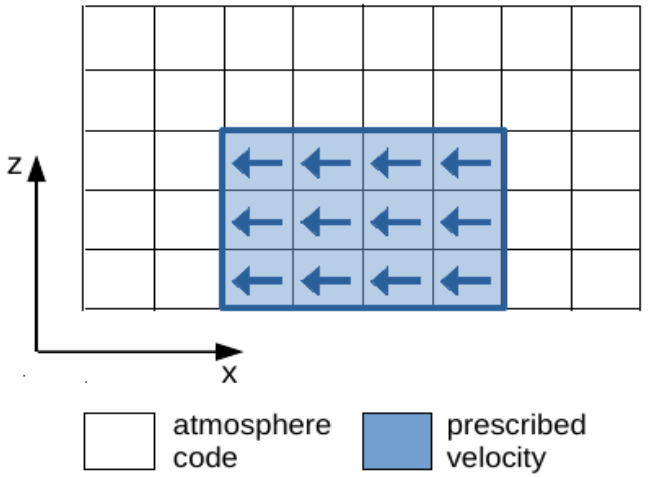
Technical realization

Air block method (newly developed):



- Fixed velocity prescribed to objects (vehicles) grid volumes that equals the driving speed
- Assumption: frictional drag << form drag → neglectable
- Due to advection scheme: additional numerical viscious drag

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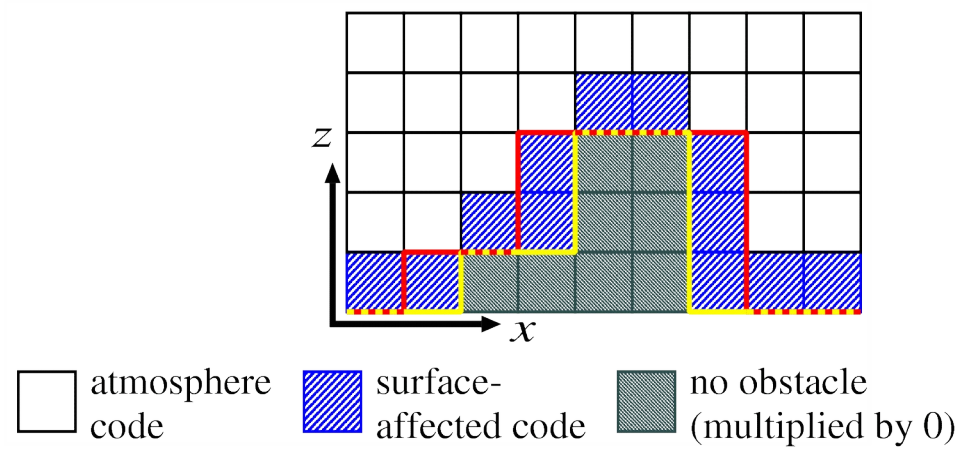
Technical realization

Solid block method (already implemented):



Sketch of the topography implementation using the mask method (here for w)
(https://palm.muk.uni-hannover.de/trac/wiki/doc/tec/bc#Topography)

- Model domain is separated into three subdomains
- Frictional drag is taken into account by surfaces
- Advection scheme is successively degraded at respective grid volumes adjacent to obstacles

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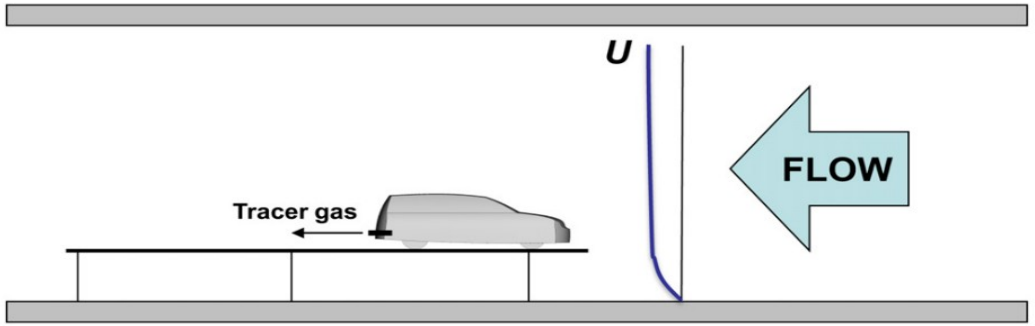
Validation study

- Experimental setup according to wind tunnel experiments of Carpentieri et al. (2012)[2]



Schematic representation of experimental setup in wind tunnel
(Carpentieri, Matteo et al. “Wind tunnel measurements for dispersion modelling of vehicle wakes.” (2012))

- To remove unrealistic effects of a boundary layer → Model (2004 Vauxhall AstraVan) was placed near the edge of a raised floor
- Exposed to free wind stream of 2.5 m/s (1:5 scale)
- Tracer gas released from tailpipe with 0.33 m/s
- Dimensionless coordinates: X=x/h, Y=y/h, Z=z/h
- Velocity parameters normalized by reference velocity u_{ref}

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Validation study

- Simulation setup:
  - Turbulence-resolving LES model PALM[1] used
  - Sensitivity study: necessary grid spacing of 0.05 m (according to findings of Letzel et al. (2008)[3])
  - No raised floor but small roughness length of $1*10^{-4}$ m
  - Scaled to reality (1:1) → reference speed of 12.5 ms^{-1}
  - No coriolis force
  - Neutral stratification
  - Averaging time based on requirement SEM < 0.006 ms^{-1} = 600s
  - Use of same geometry (2004 Vauxhall AstraVan) as in wind tunnel experiments

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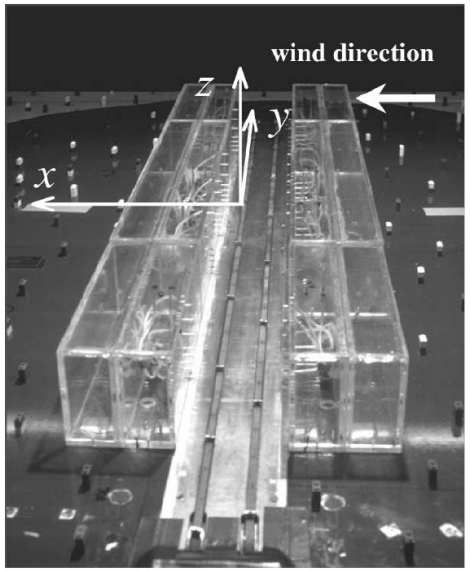
Validation study

- Upcoming validation study according to wind tunnel experiments of Kastner-Klein et al. (2001)[4]



- Street canyon with aspect ratio (AR) of 1, wind flow perpendicular to canyon
- Plates mounted on moving belts were used to account for VIT
- Reproduction of one-way and two-way traffic

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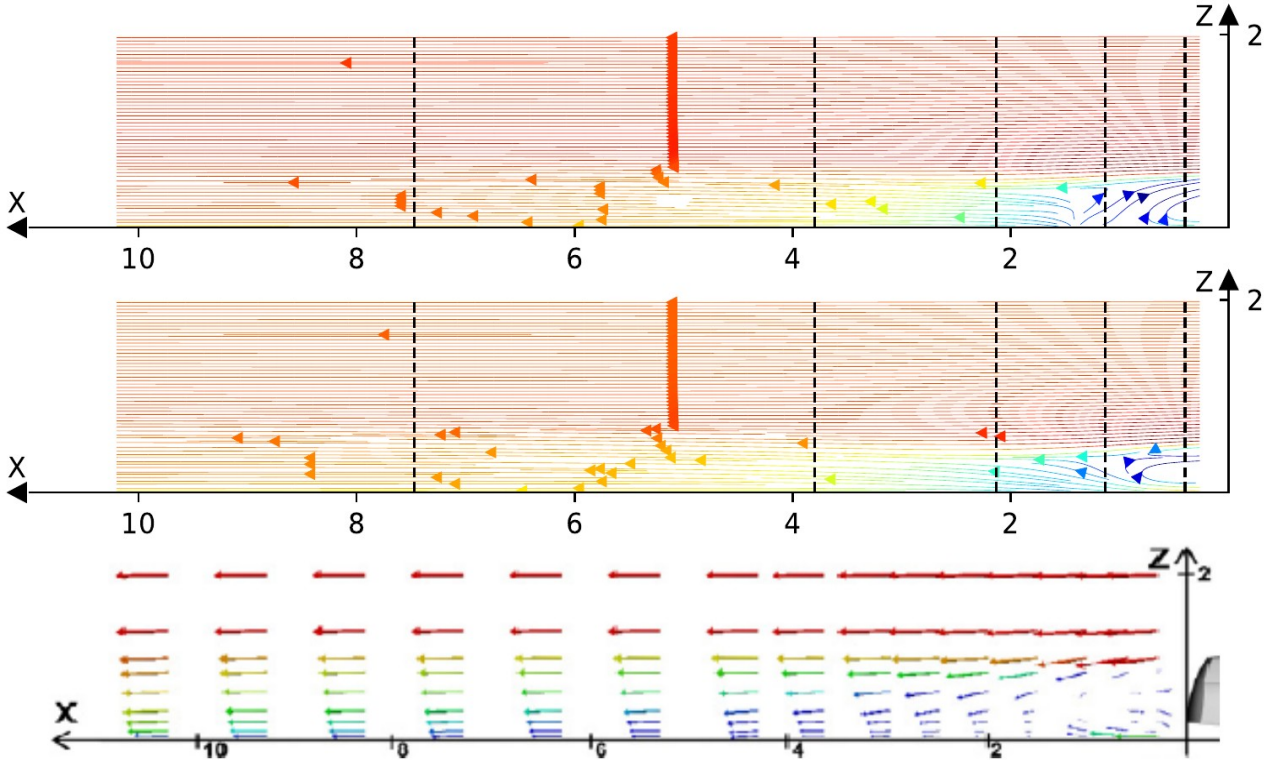
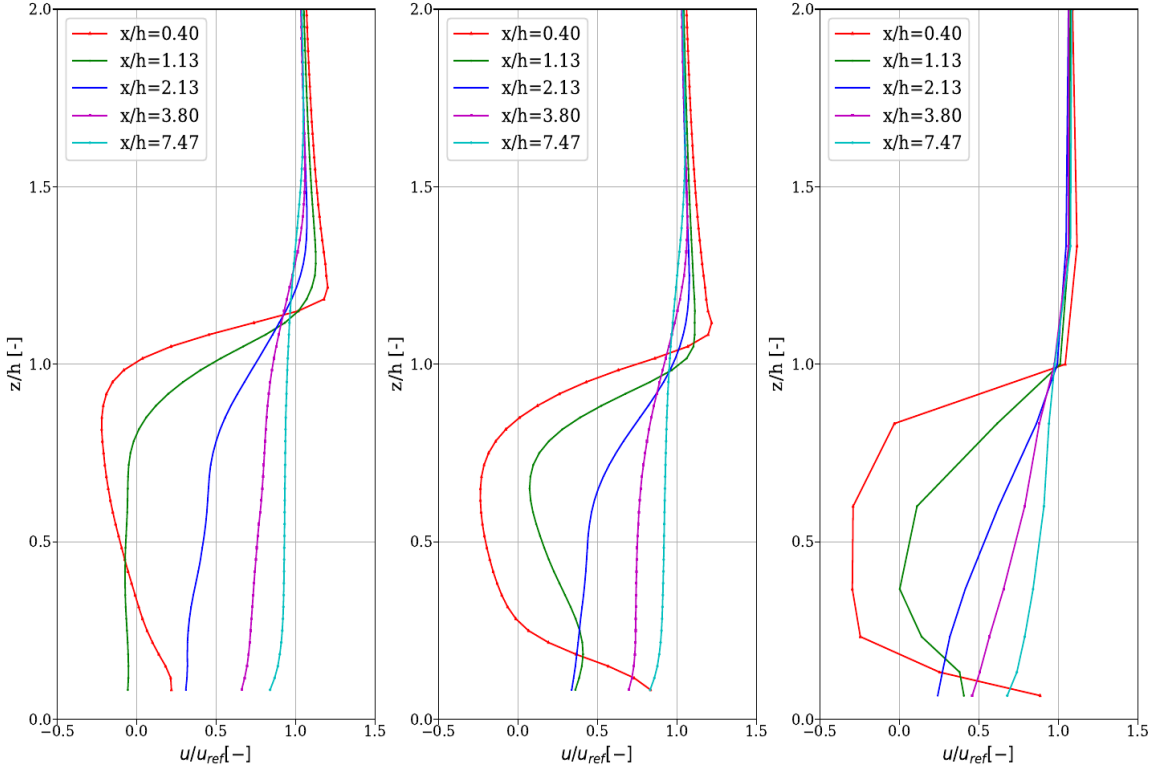
Left: u/u_{ref} – w/u_{ref} vector plot at Y=0 (upper = air block method, middle = solid block method, lower = experimental data)

Right: Vertical profiles of longitudinal dimensionless mean speed (u/u_{ref}) (left = air block method, middle = solid block method, right = experimental data)





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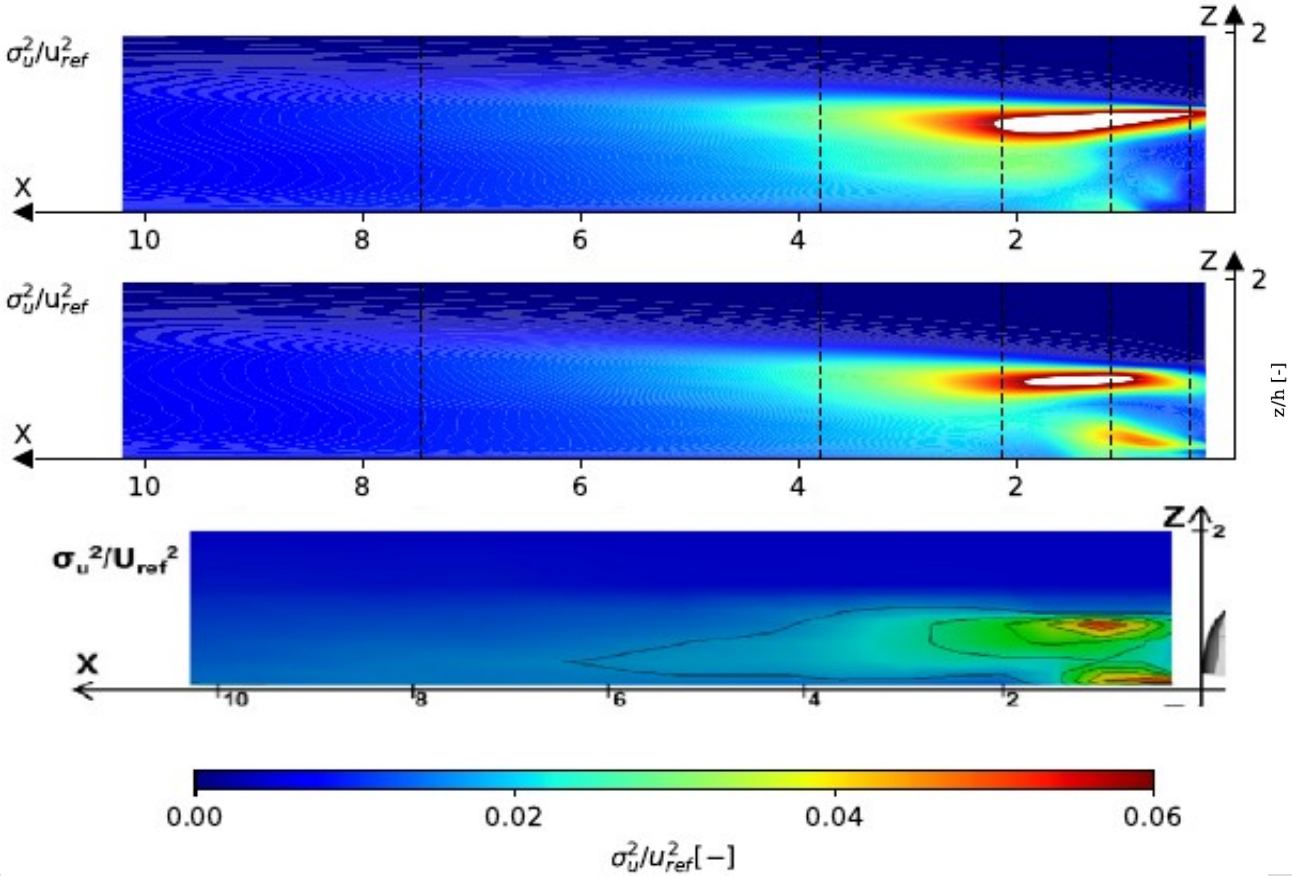
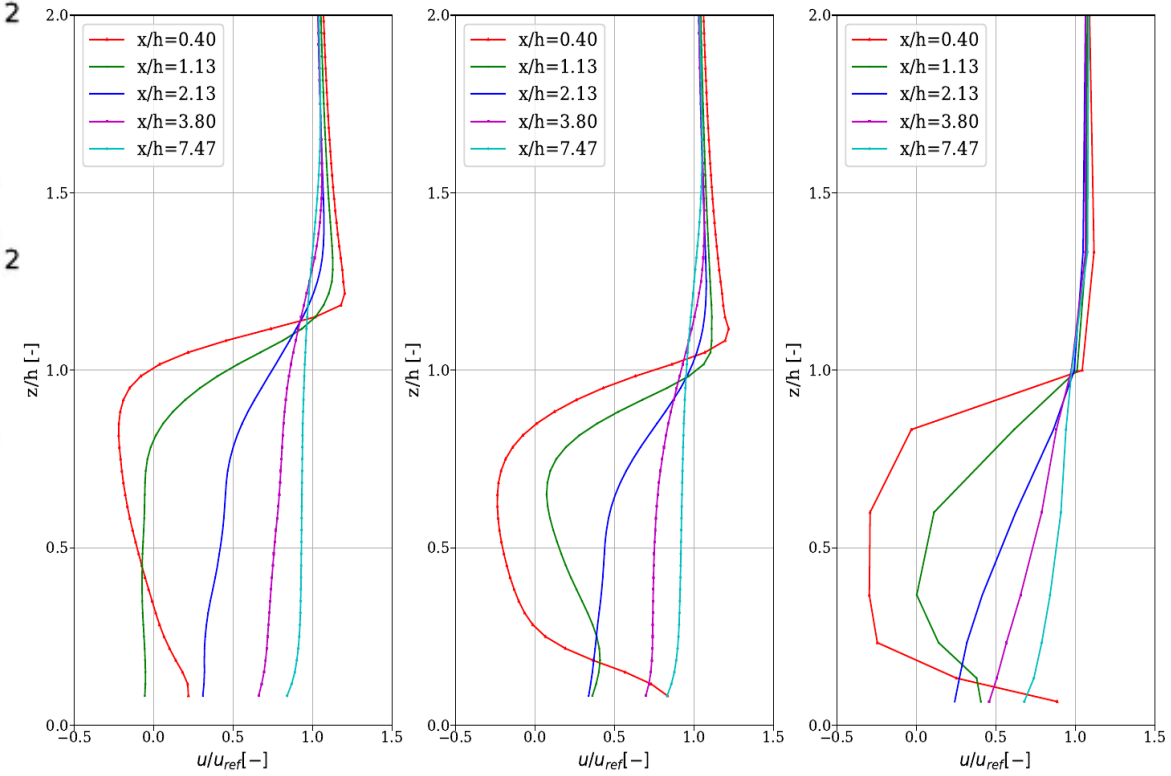
Left: σ_u^2/u_{ref}^2 velocity variance contour plot at Y=0 (upper = air block method, middle = solid block method, lower = experimental data)

Right: Vertical profiles of longitudinal dimensionless mean speed (u/u_{ref}) (left = air block method, middle = solid block method, right = experimental data)





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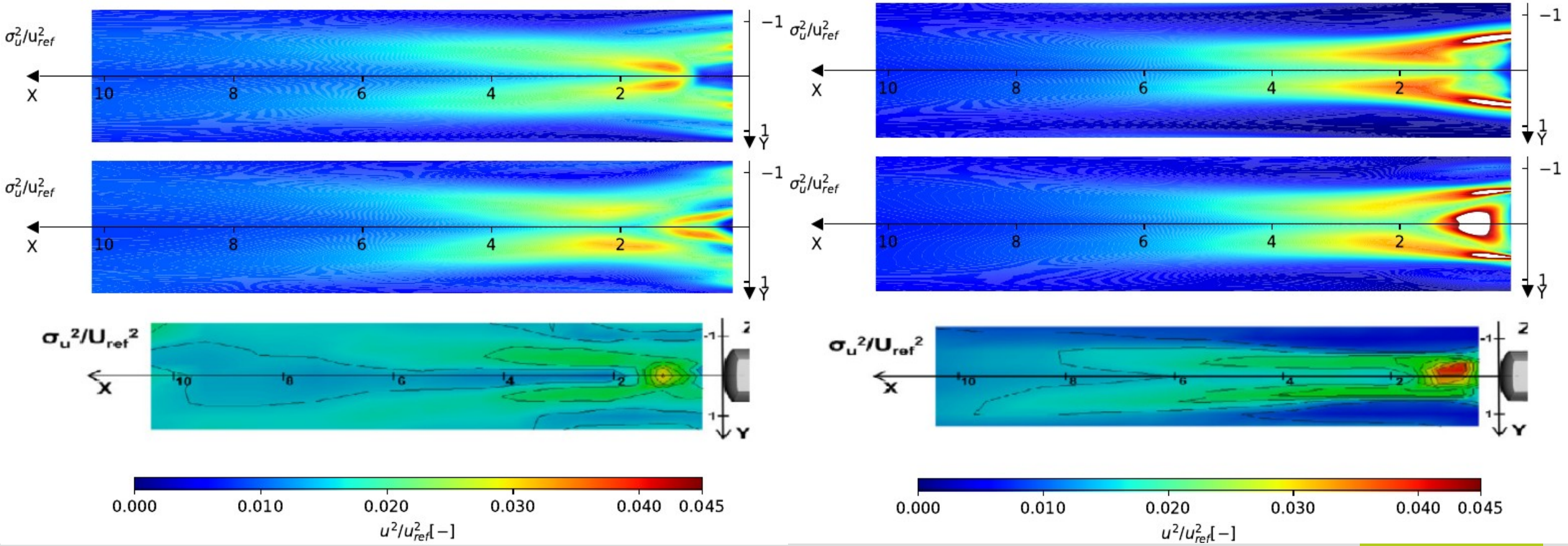
Left: σ_u^2/u_{ref}^2 velocity variance contour plot at Z=0.07 (upper = air block method, middle = solid block method, lower = experimental data)
Right: σ_u^2/u_{ref}^2 velocity variance contour plot at Z=0.23 (upper = air block method, middle = solid block method, lower = experimental data)



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Thank you for your attention!