Challenges of modelling wind engineering problems

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Case Study 1: **DIPLOS**

- DIPLOS: Dispersion of Localised Releases in a Street Network – for **emergency response scenarios**
- LES by University of Southampton
- Experiments by University of Surrey
- DNS and simple street network model parametrisations using the LES and DNS data by University of Reading

DIPLOS

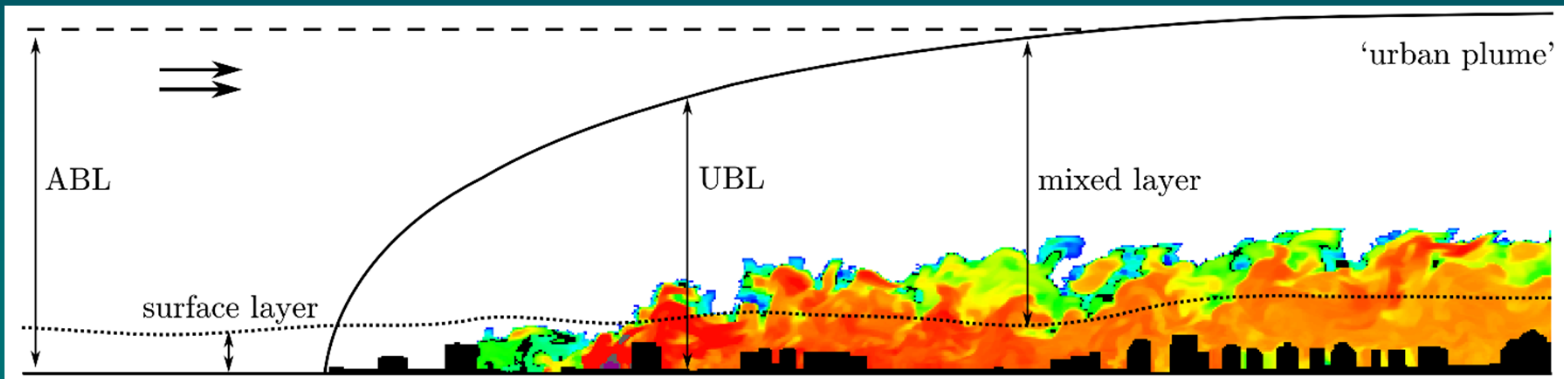
Improve the capability to model accidental or deliberate releases of harmful airborne materials in cities

Effects of source location etc on urban pollutant plumes

How do initial advection and detrainment characteristics of pollutants depend on the source position in relation to the surrounding buildings?

Prediction of concentration fluctuations and model uncertainty

Can accurate fluctuation levels be estimated from simple models?



DIPLOS

- Produce and analyse *laboratory measurements* and high-resolution *numerical simulations* of flow and dispersion in urban environments
- Develop and validate *parametrisations* for dispersion processes
- Implement parametrisations in an *emergency response* model

Wind tunnel (WT) measurements

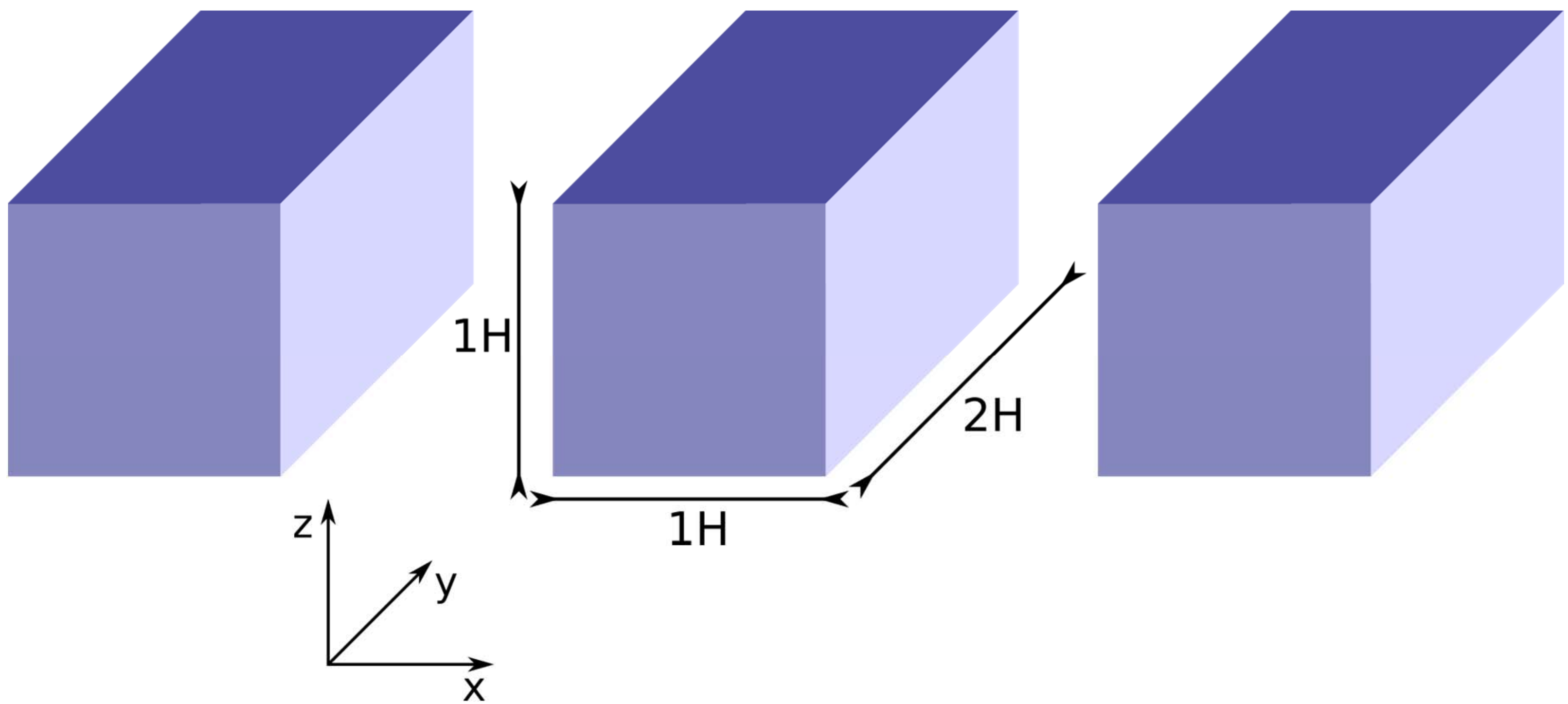
Large eddy simulations (LES)

Direct numerical simulations (DNS)

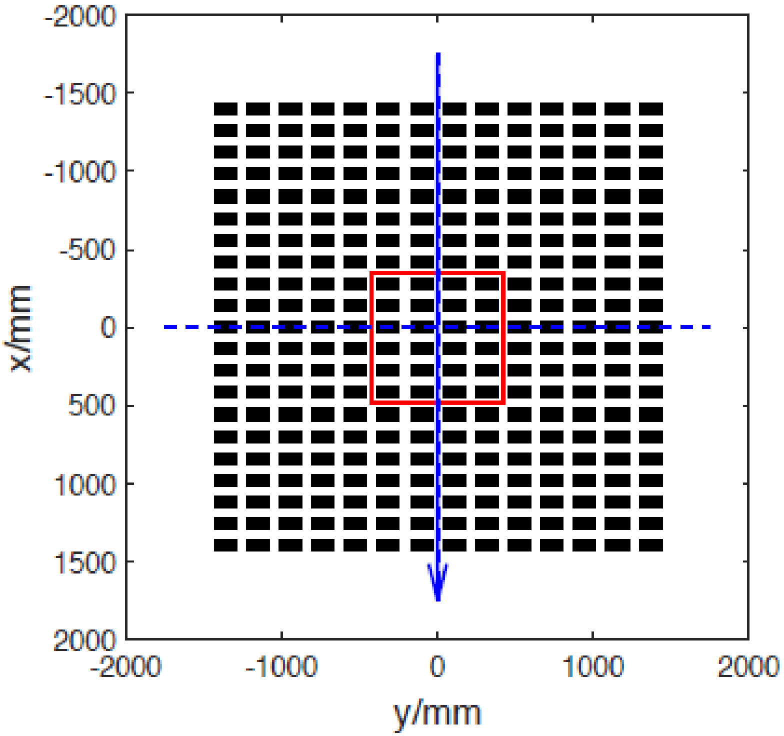
Street-network modelling (SNM)

Buildings

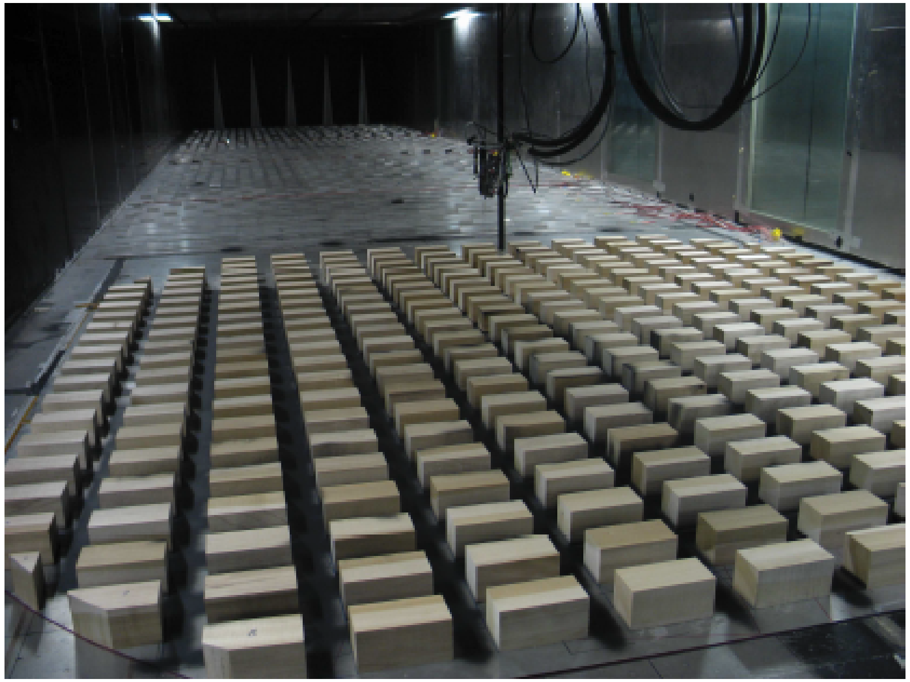
- Building dimensions 1H × 2H × 1H
- H = 70 mm as in the wind tunnel, Re ~ 16 000
- All streets 1H wide



Wind Tunnel model in Surrey (EnFlo)



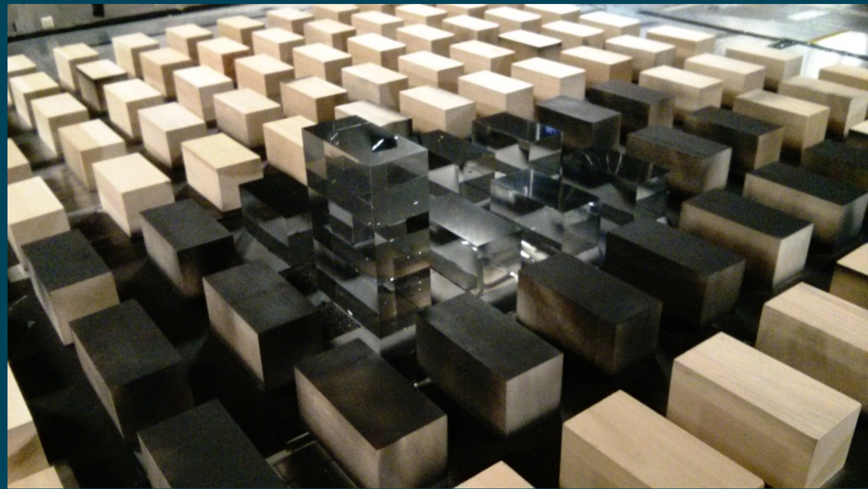
(a)

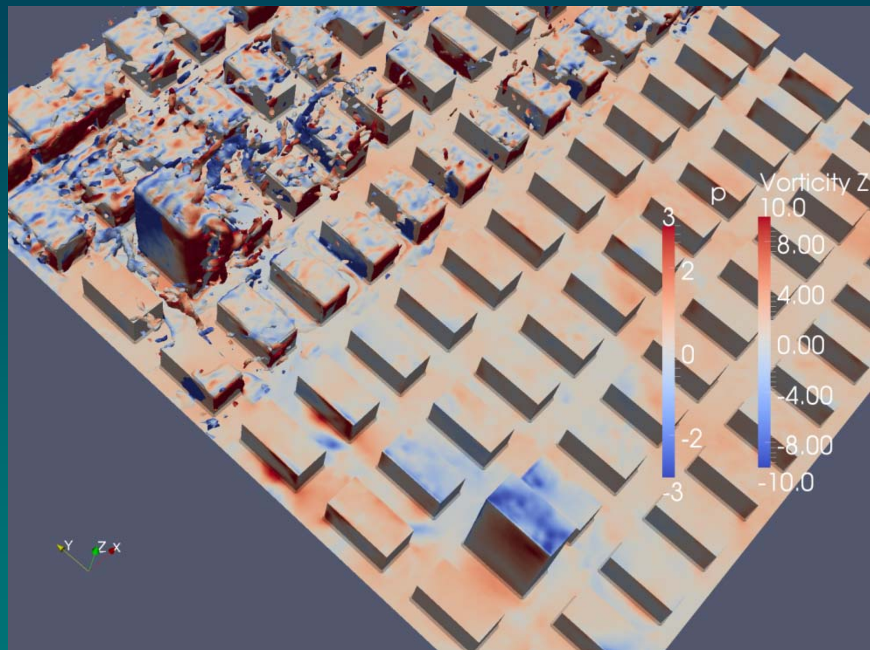


(b)

DIPLOS (with one tall building)

- Isolated tall building in regular array (LES & WT)





Large eddy simulations (Southampton)

- Simulations of dispersion from small sources in street networks
- Regular arrays of rectangular buildings
- Continuous point source of passive scalar on the ground
- Several wind directions
- Tall building effects

Two LES models

OpenFOAM v. 2.1

- cell centered grid
- mixed time scale subgrid model (Inagaki et al., 2005)

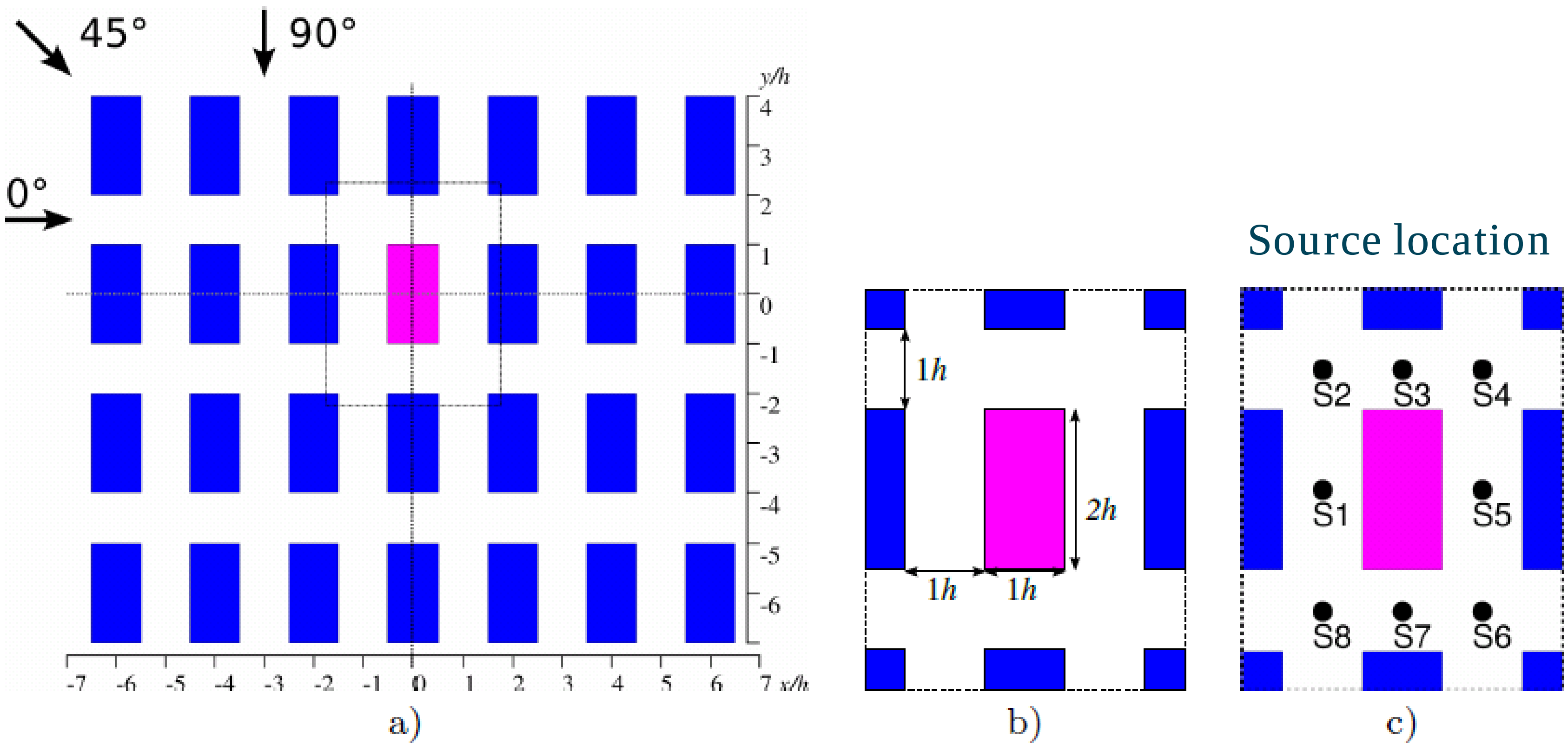
CLMM

- in-house code
- immersed boundary method, staggered uniform grid

Both

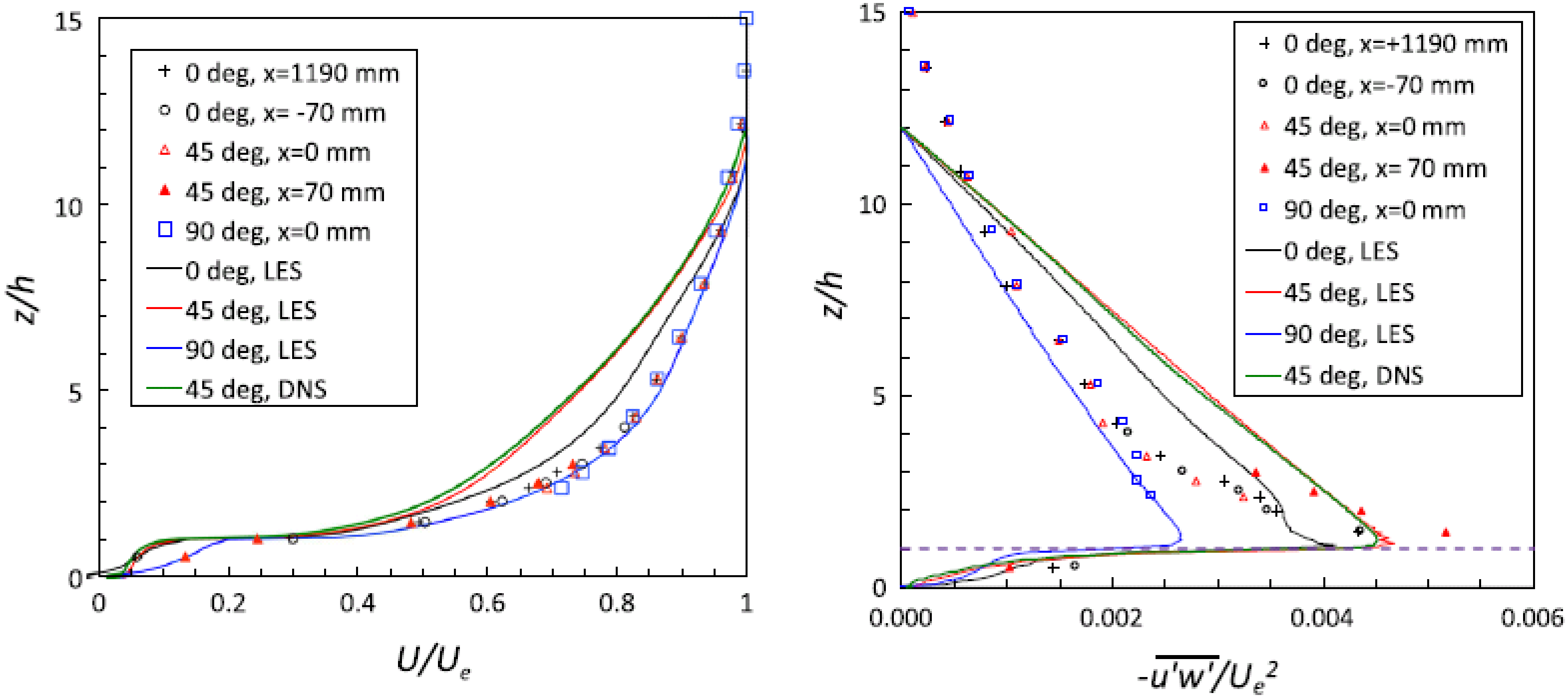
- second order central differences
- domain 12 H x 12 H x 12 H, and 24 H x 24 H x 12 H
- resolution 16 cells for 1 H
- Periodic in-outlet BCs for turbulence

Building array and source position



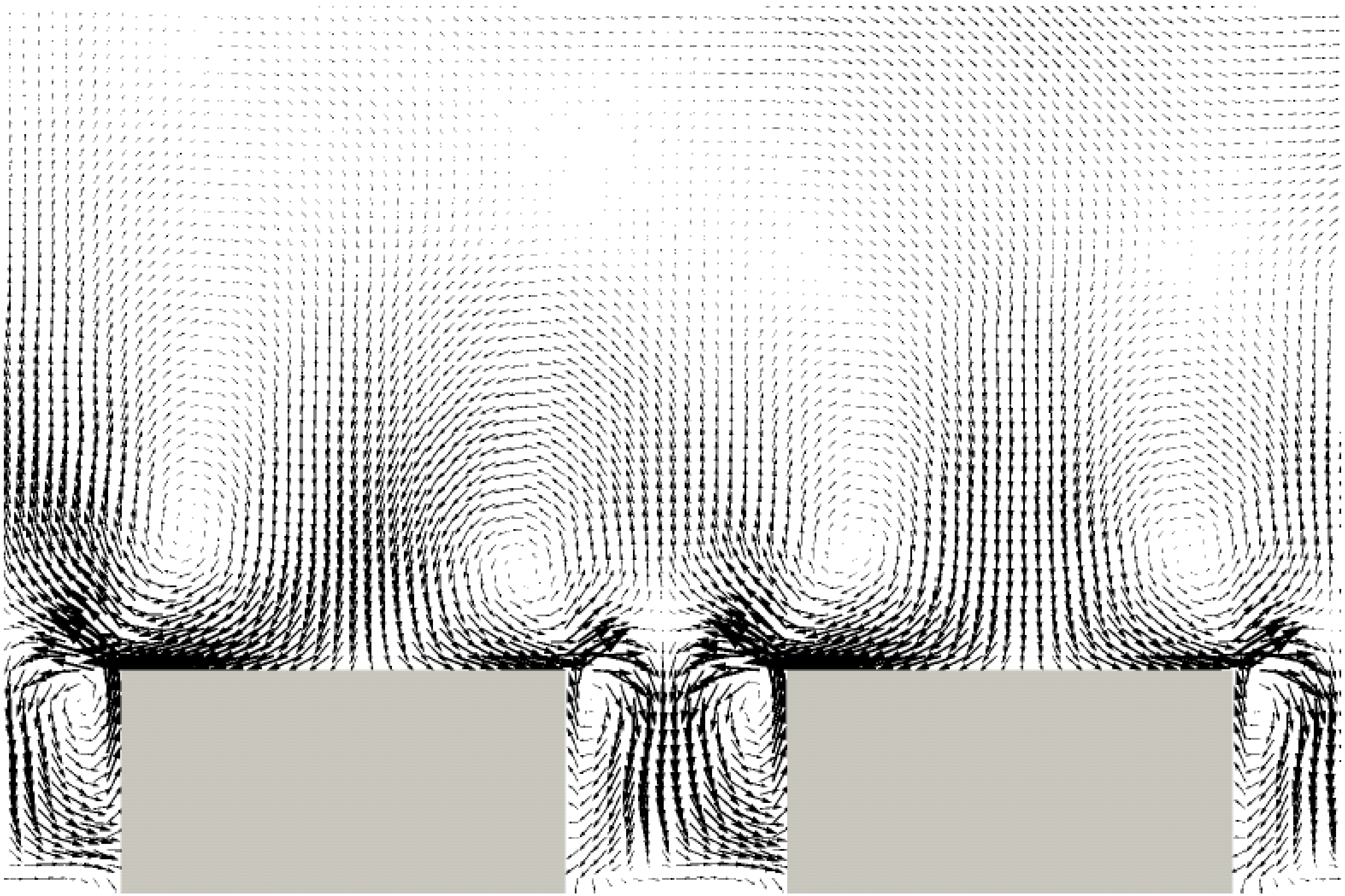
Only a subset of the experimental array. The magenta building is replaced by the tall building (3h) in the tall building scenario.

Simulated and wind tunnel boundary layer

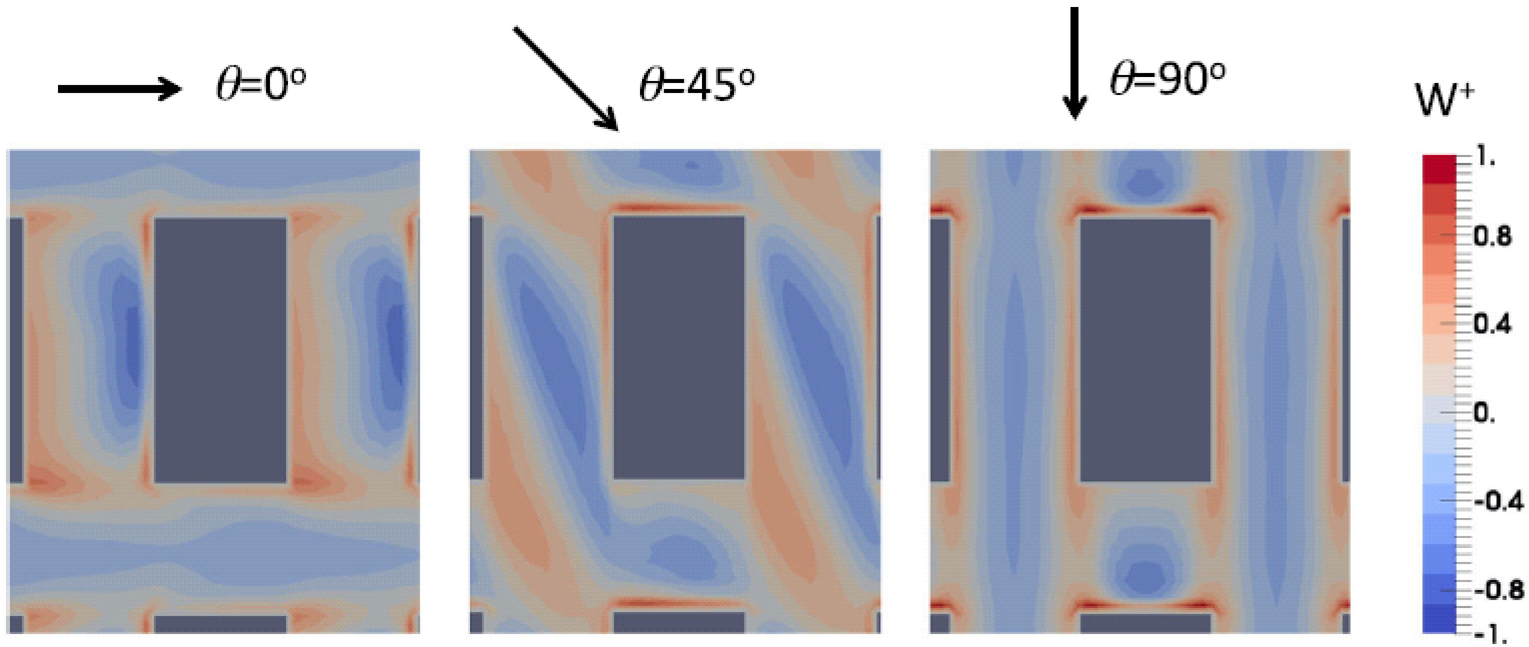


(a) (b)

Mean velocity profiles (a) and shear-stress profiles (b) for the three urban array orientations. Note the location of the top of the canopy, shown as a dashed line at z/h = 1 in (b)

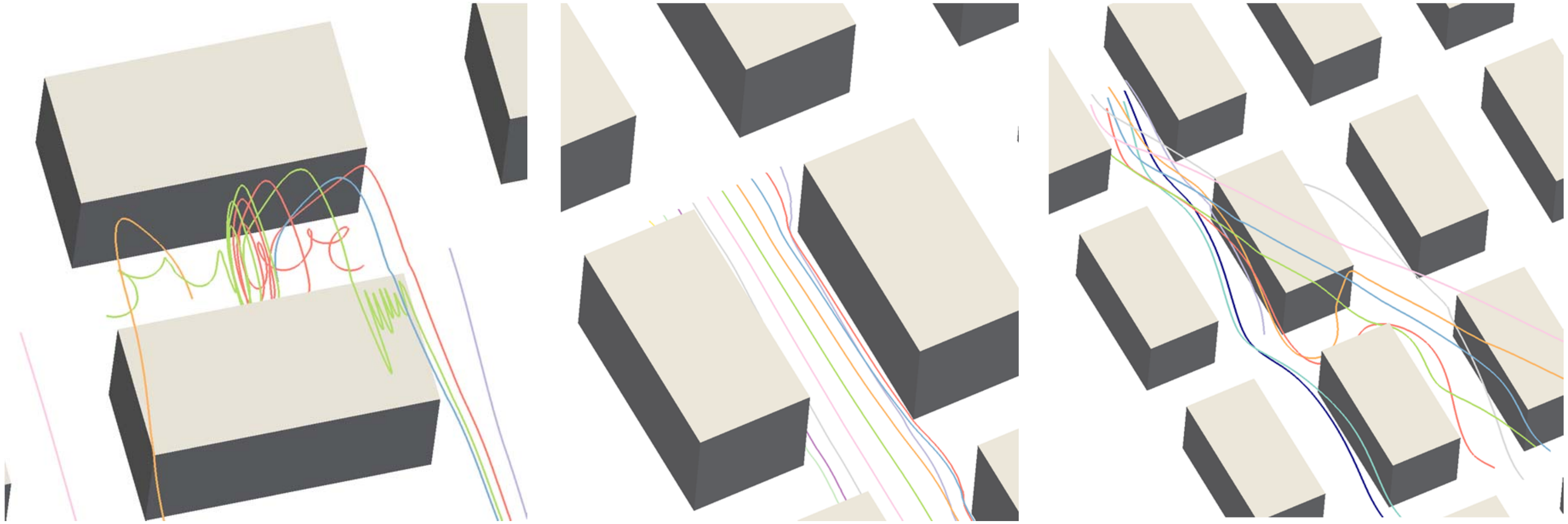


Mean flow vectors in the array of regular buildings at wind direction 0° ,
at a yz plane (cross-wind) at x = 0 (centre plane)



Contour plots of the normalized mean vertical velocity, W+, at z/h = 1

Flow pattern



0° 90° 45°

0° – source is in a street canyon, recirculation and 2nd sources

90° – source is in a channel, recirculation in the short streets

45° – flow along the streets with a recirculating component

Results of scalar dispersion

3D fields of

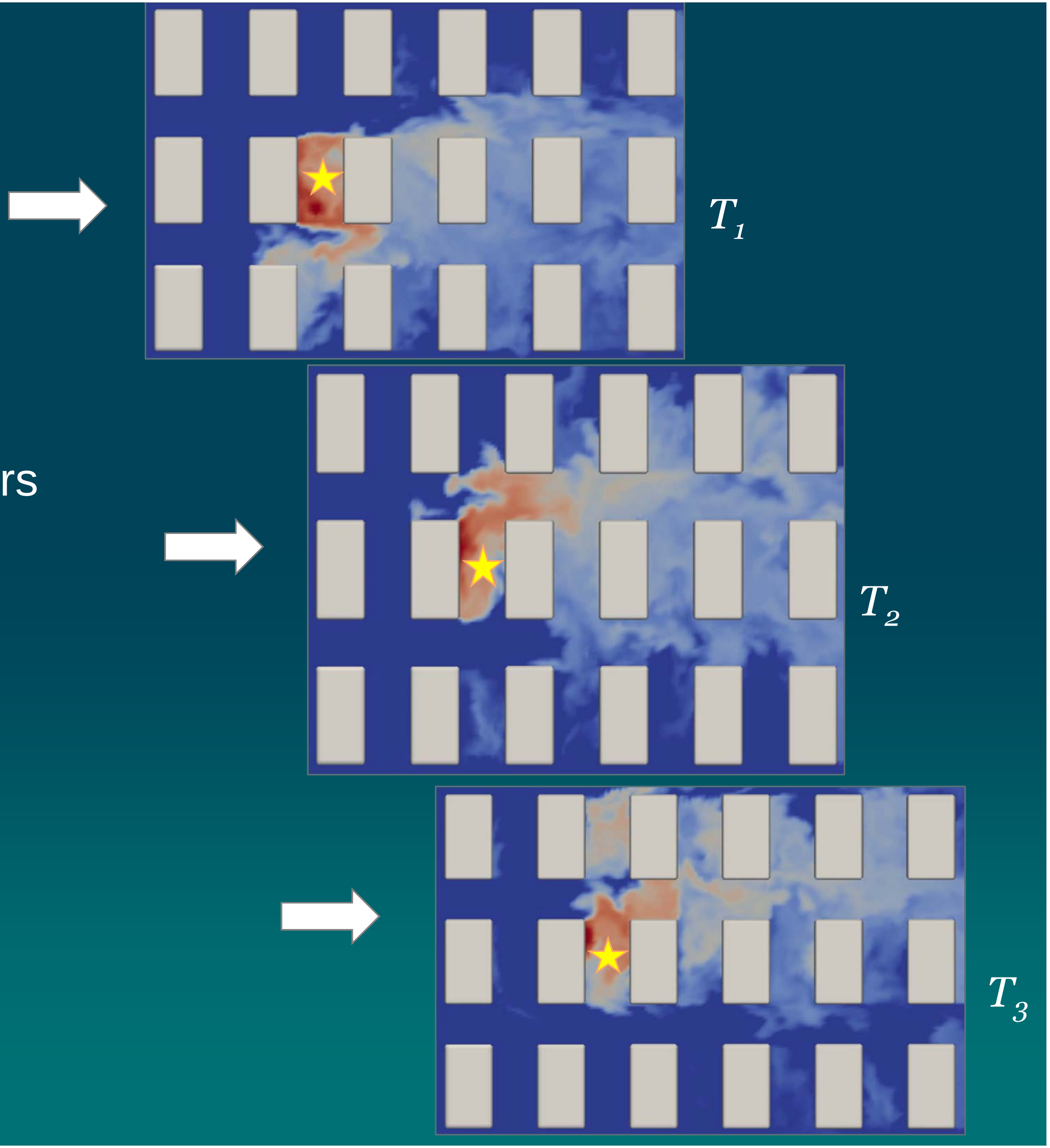
- mean dimensionless concentration C*

$$C^* = CUH^2/Q$$

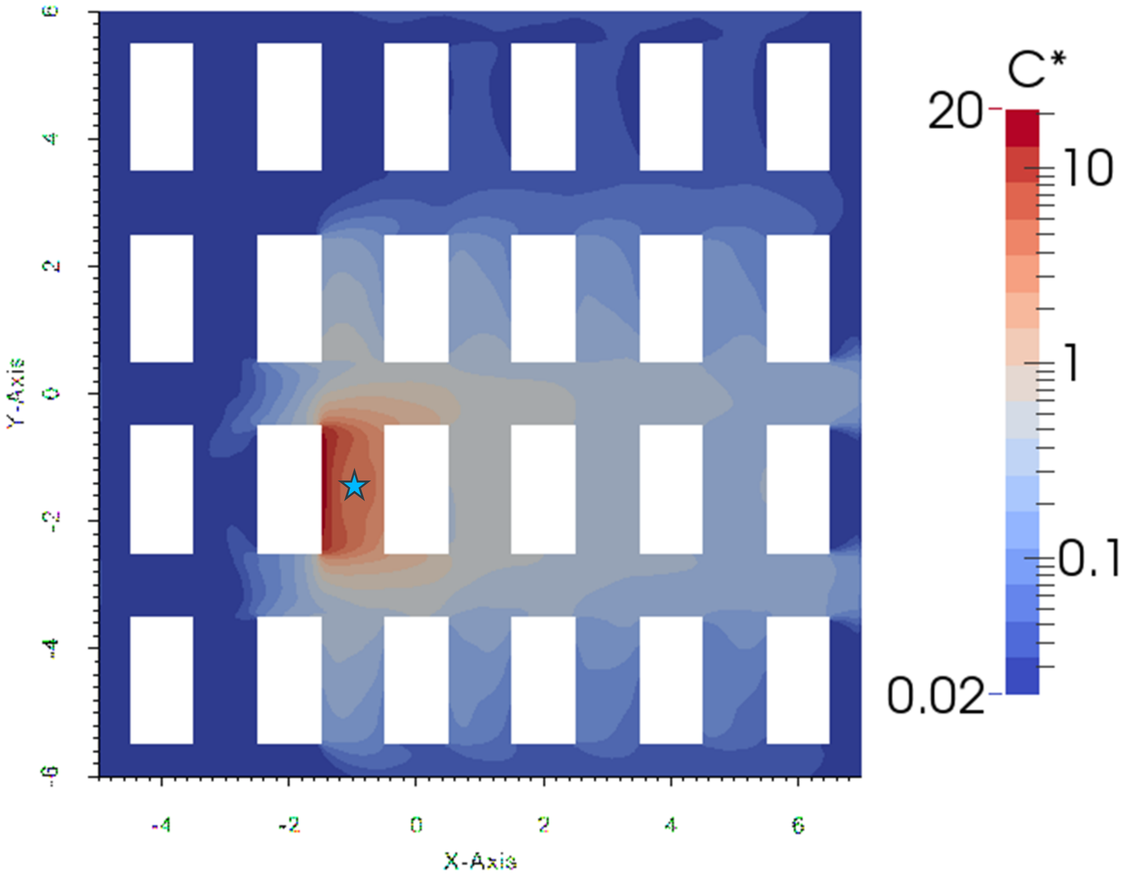
- concentration variance $c^{*\prime 2}$
- turbulent and advective concentration fluxes

Results normalized by mean wind velocity at z = 2.78 H

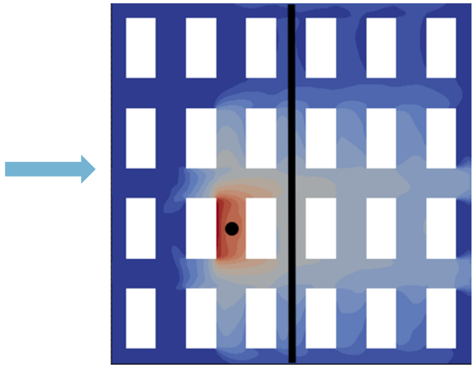
Instantaneous concentration contours are extremely complicated.



Wind direction 0°

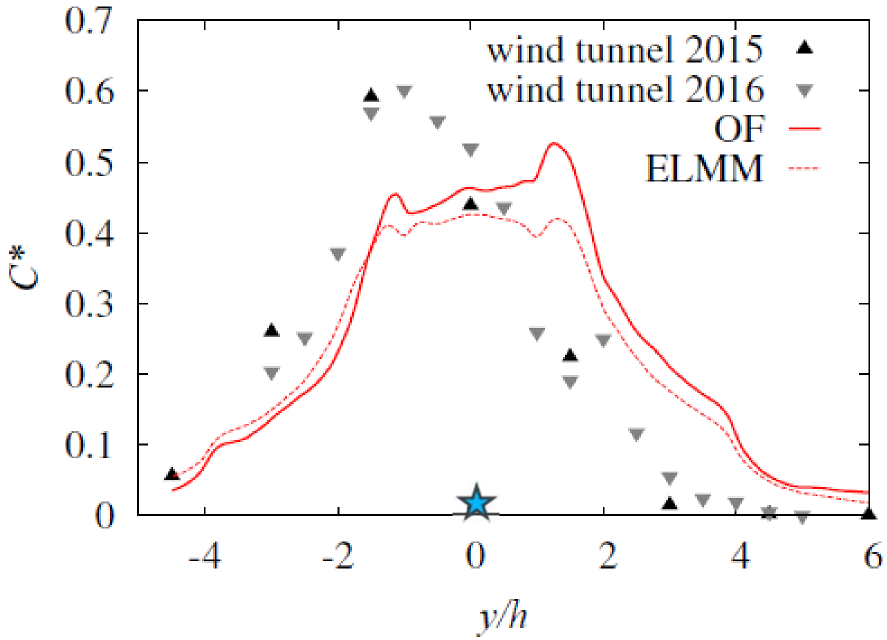


OpenFOAM, mean concentration z=0.5H

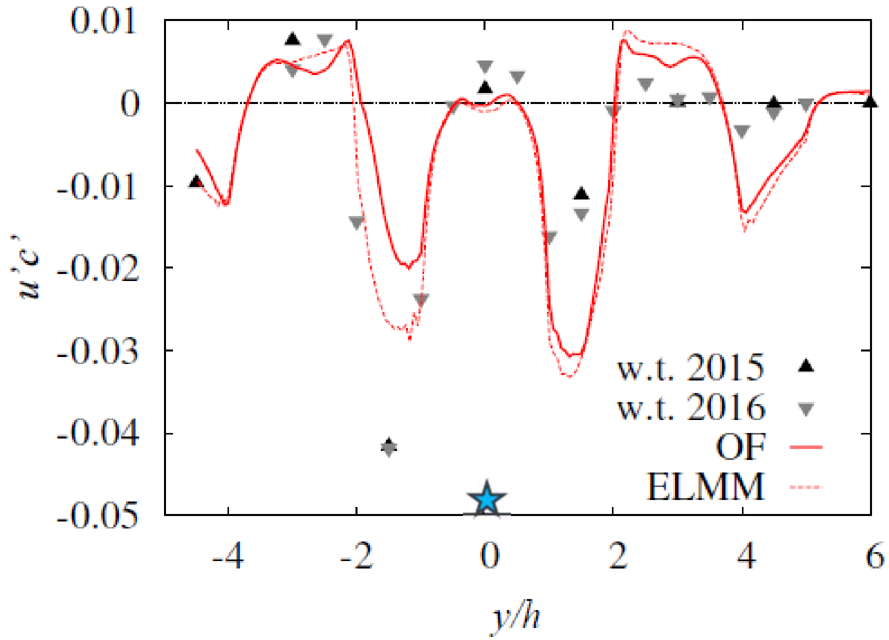


Wind direction 0°

$x = 1\,h,\ z = 0.5\,h$



mean concentrations

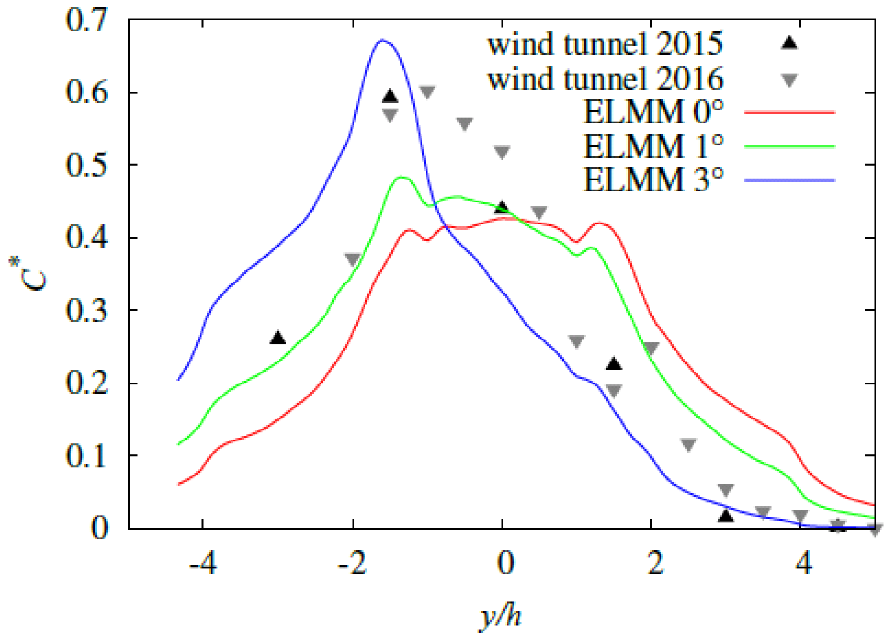


turbulent scalar fluxes

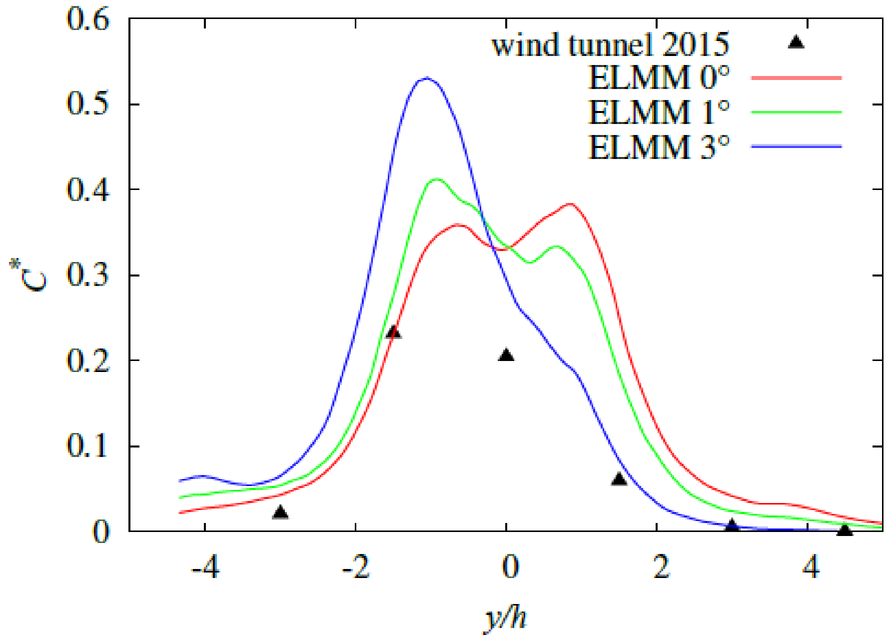
- Measurements show some asymmetry reproduced in the computations.

Wind direction sensitivity

x=h z=0.5h within the canopy



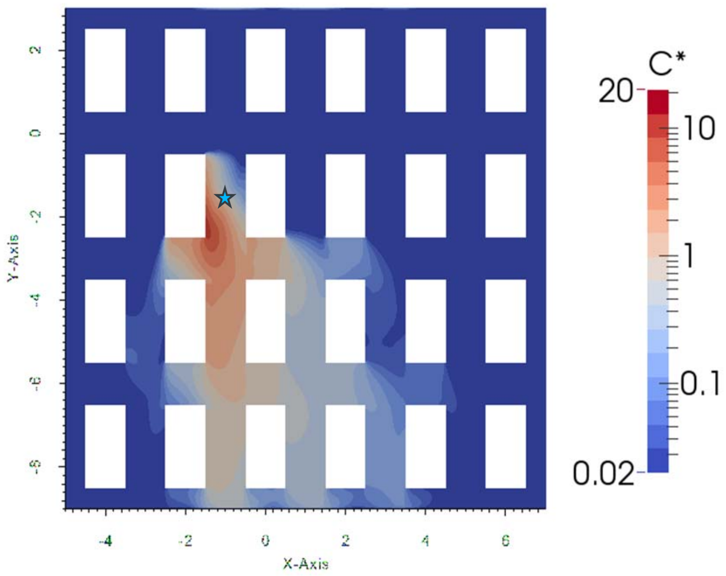
x=h z=1.5h above the canopy



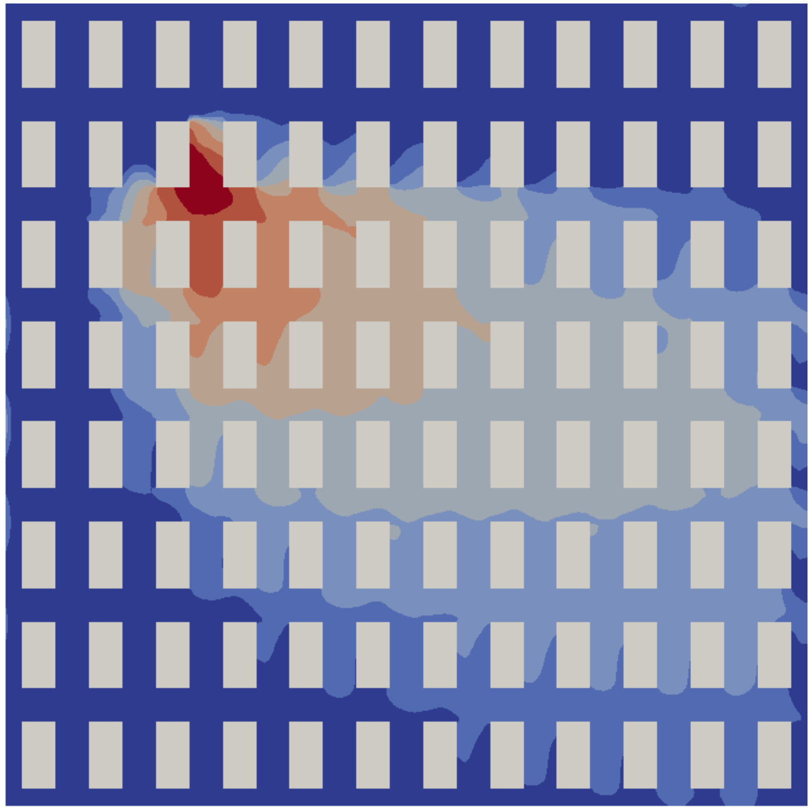
- LES shows considerable influence of a small change in the wind direction.

- Other possible uncertainties: source position, building alignment and orientation.

Wind direction 45°

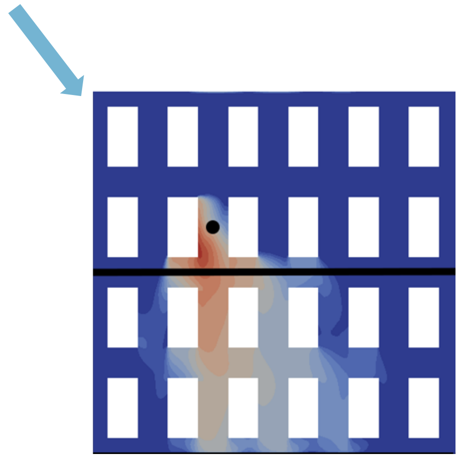


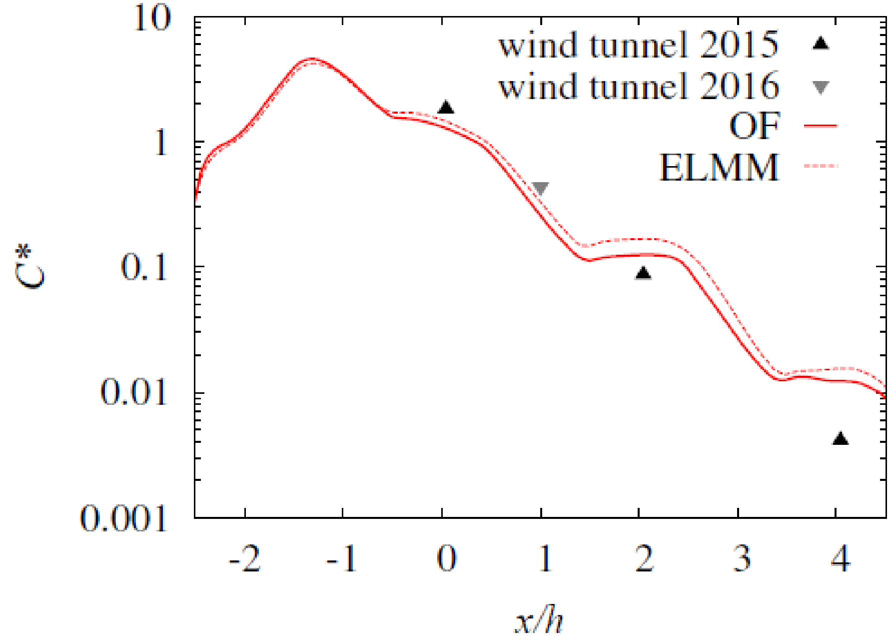
OpenFOAM, z=0.5H



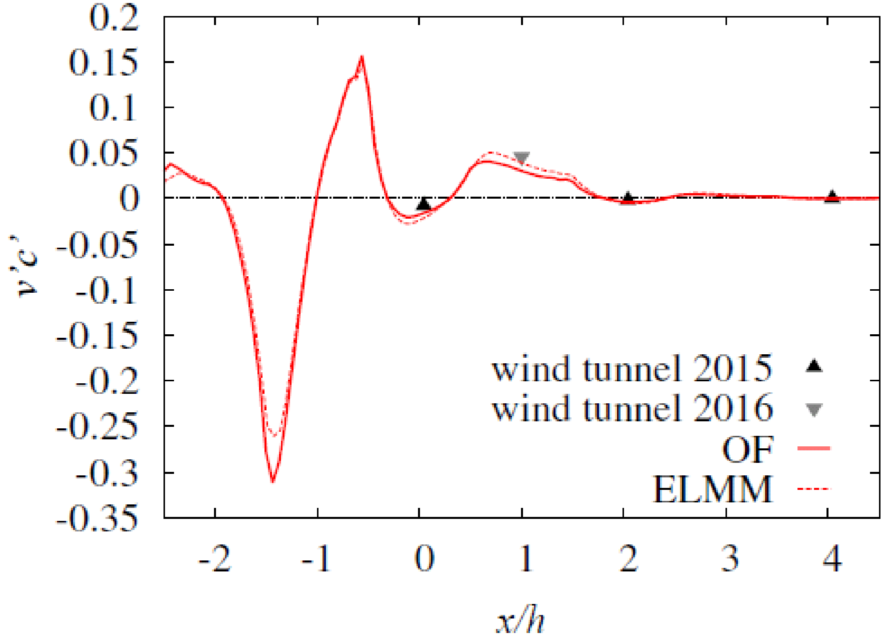
Wind direction 45°

$$y = -1.5\,h,\ z = 0.5\,h$$





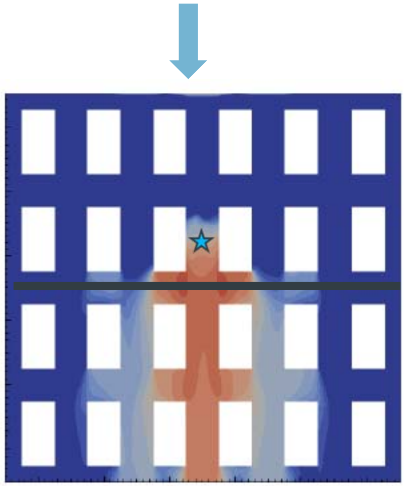
mean concentrations

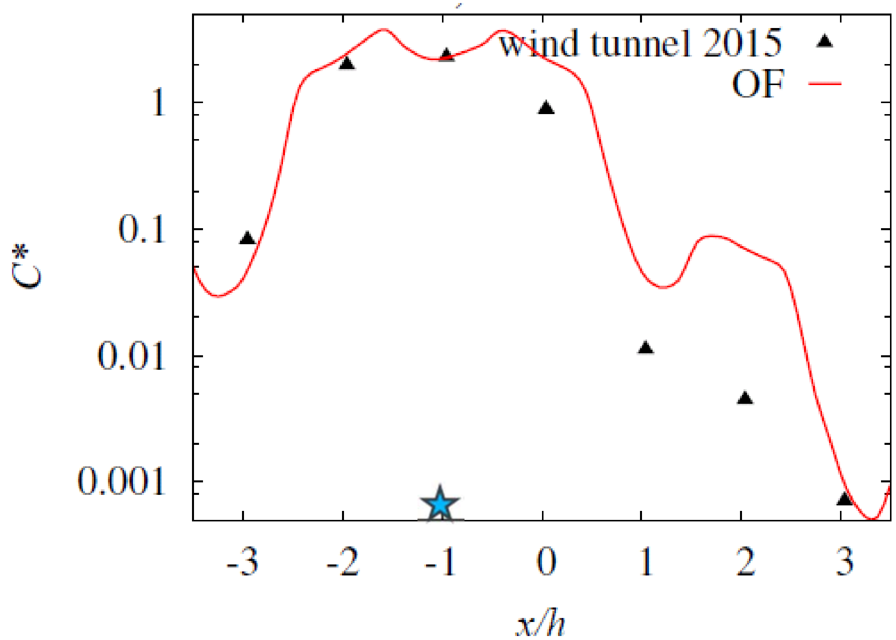


turbulent scalar fluxes

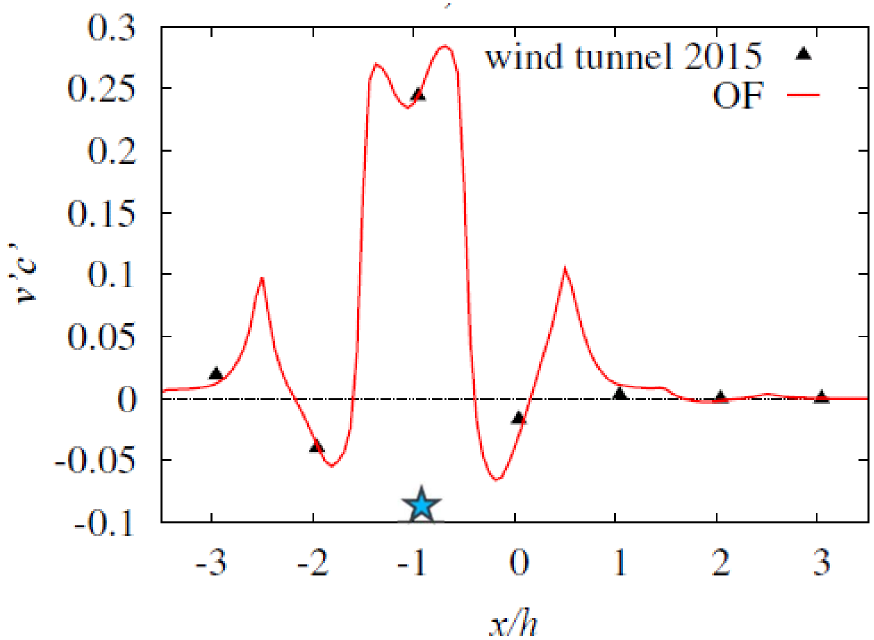
Wind direction 90°

$$y = -1.5\,h,\; z = 0.5\,h$$





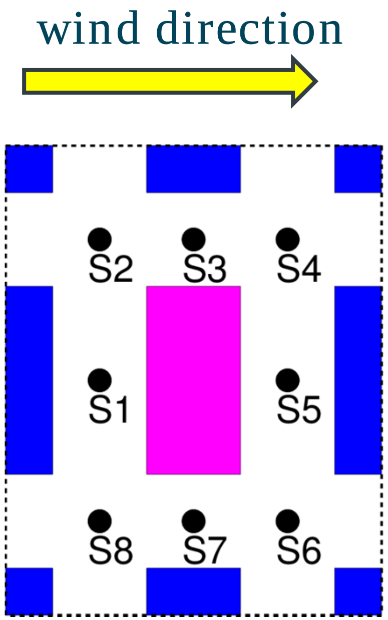
mean concentrations

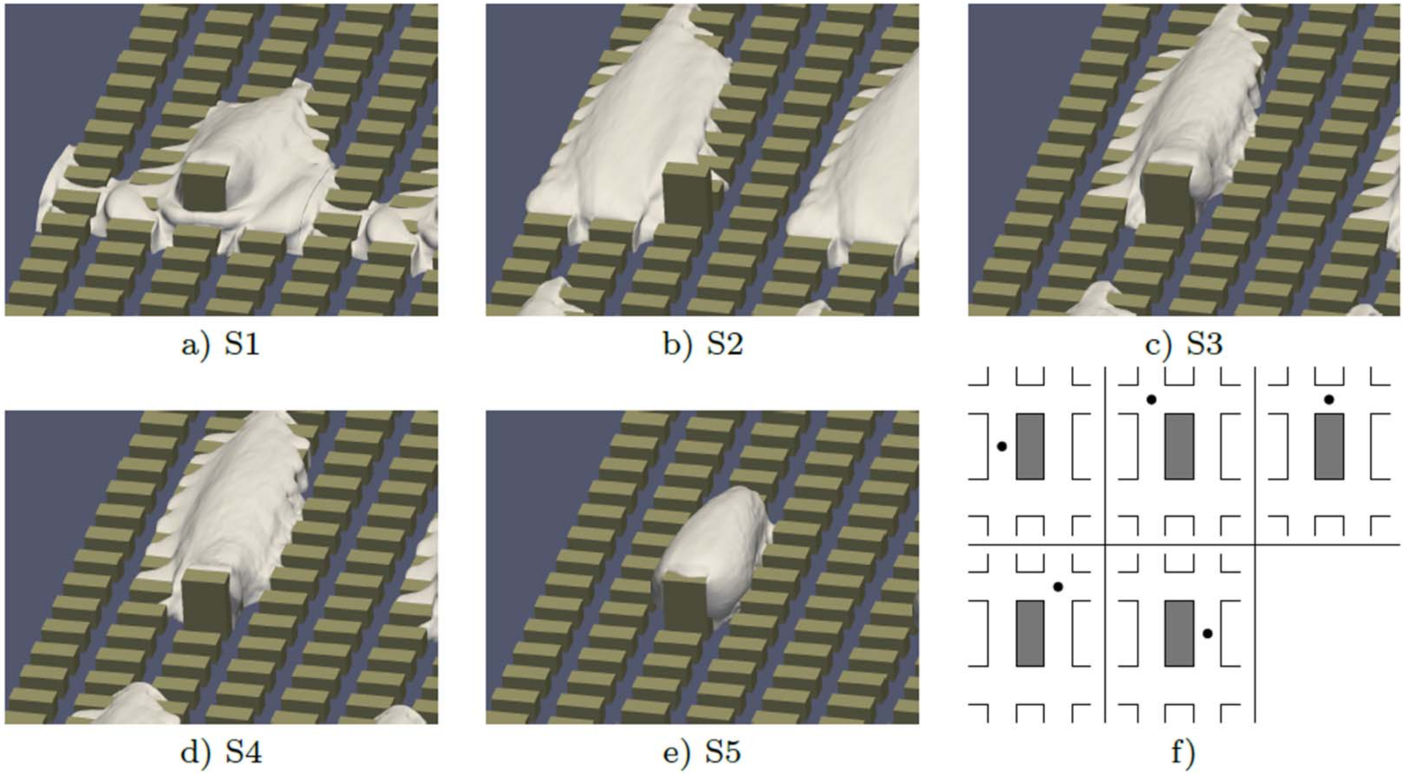


turbulent scalar fluxes

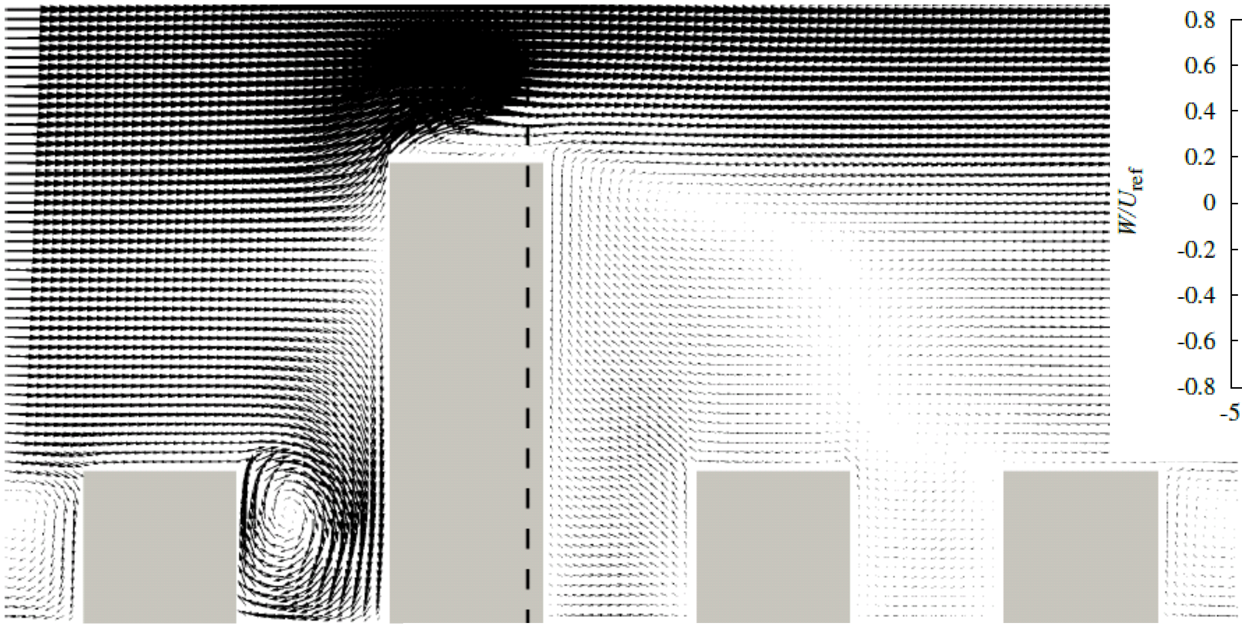
Tall building in wind direction 0°

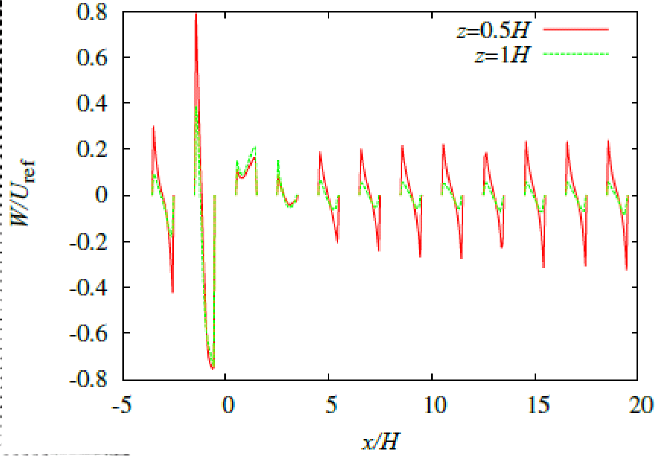
- Tall building height 3 h





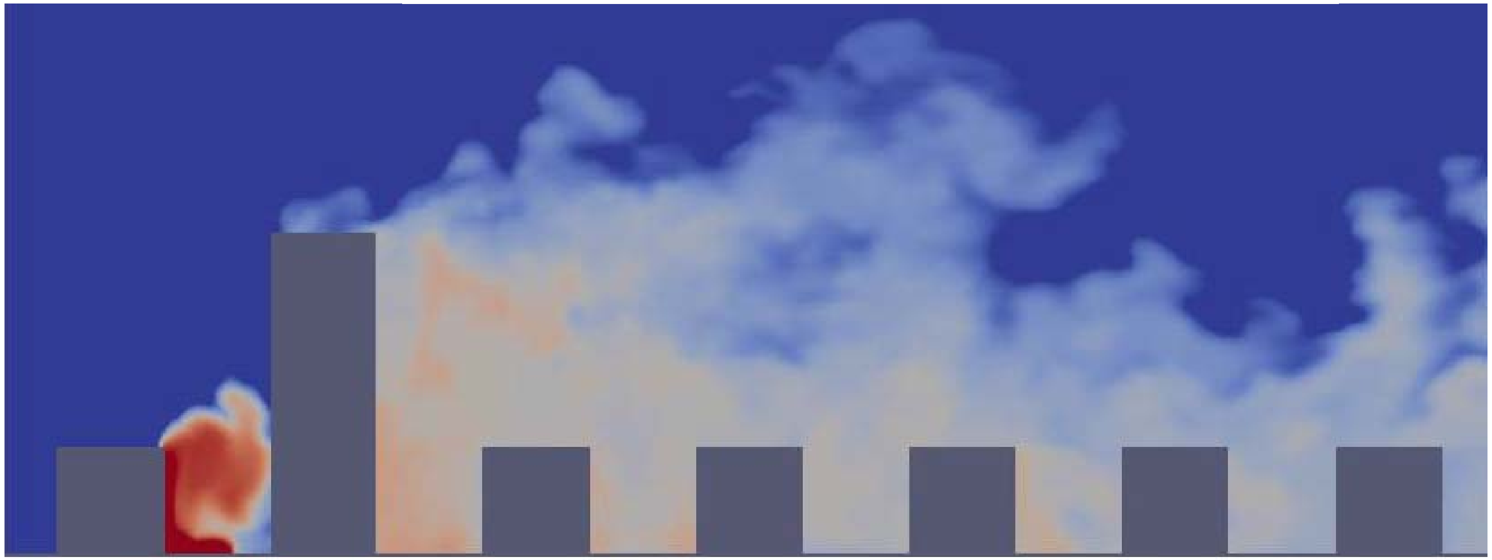
The isocontours of mean concentration $C^* = 0.1$





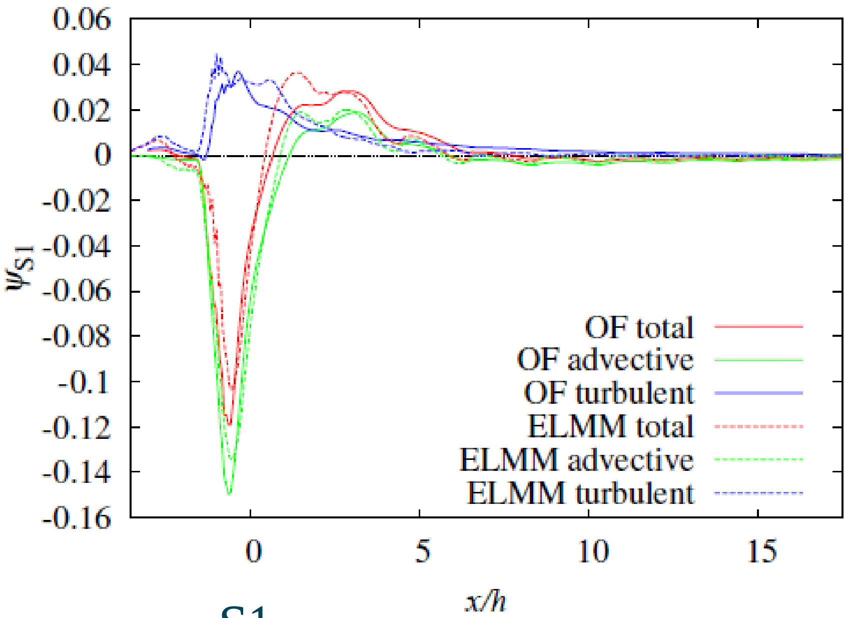
Vertical velocity at central plane

Mean flow vectors near the tall building

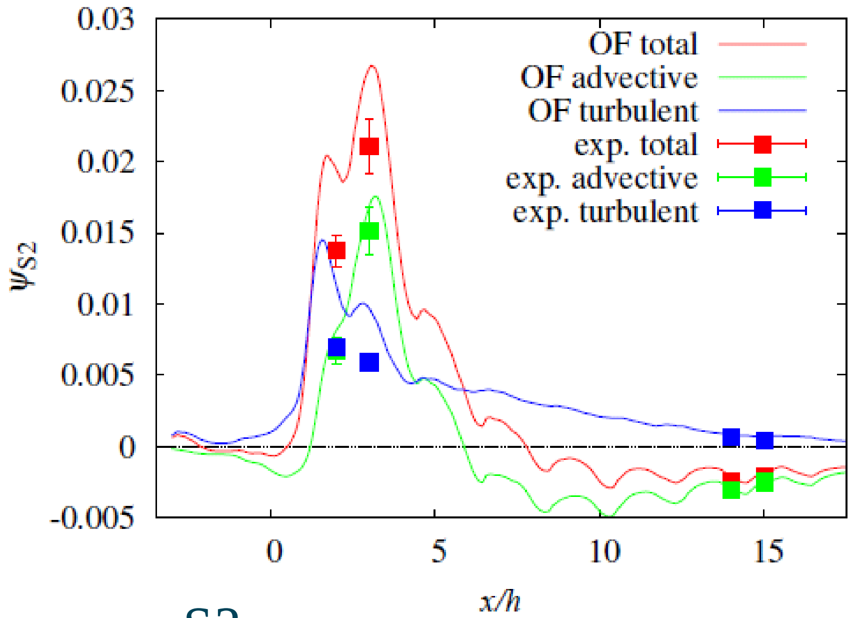


Instantaneous concentration near the tall building for S1

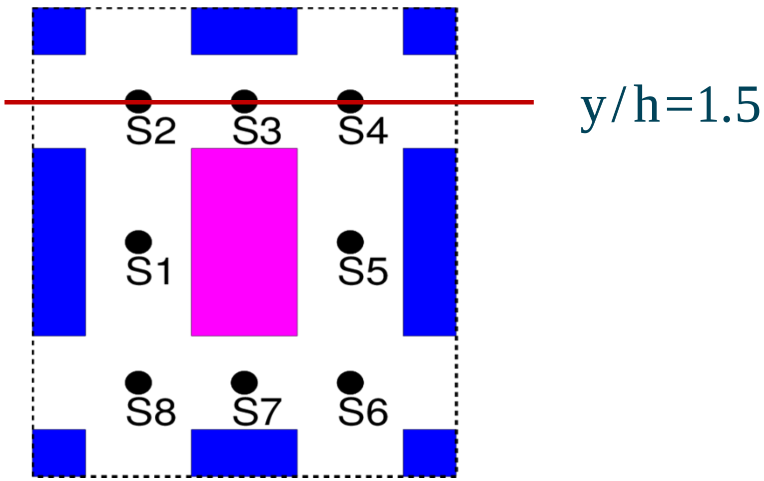
Vertical scalar fluxes along line $y/h = 1.5$, $z/h = 1$



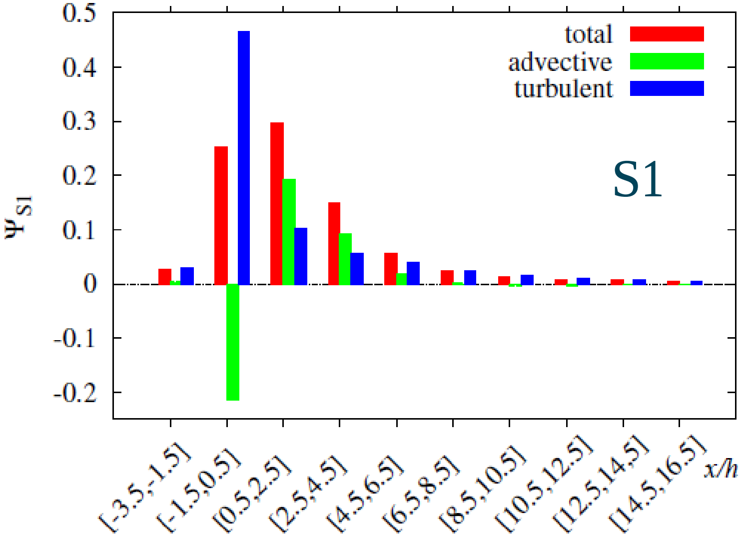
S1

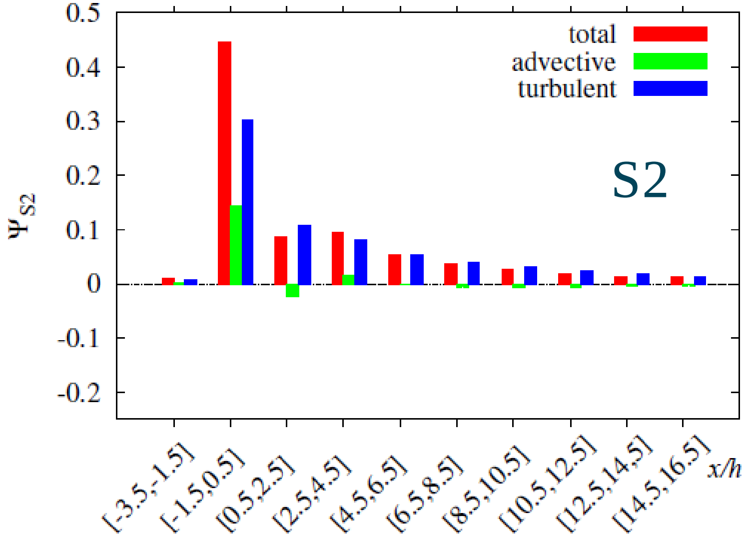


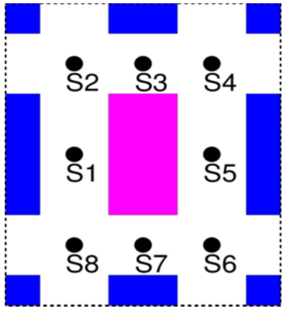
S2



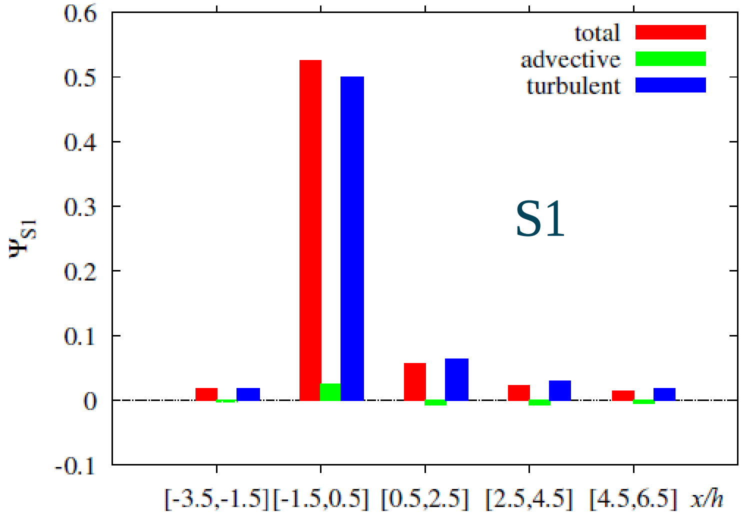
Scalar fluxes on surface z=h integrated over strips oriented in the y direction and of width 2h in the x

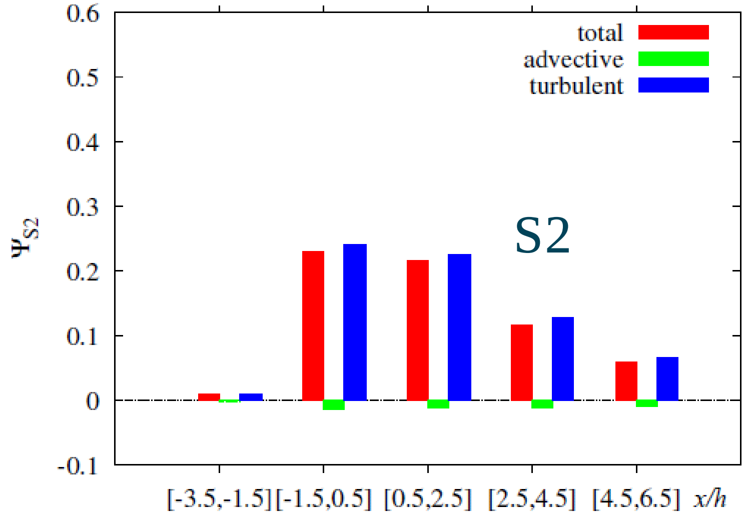






Tall building





Uniform height

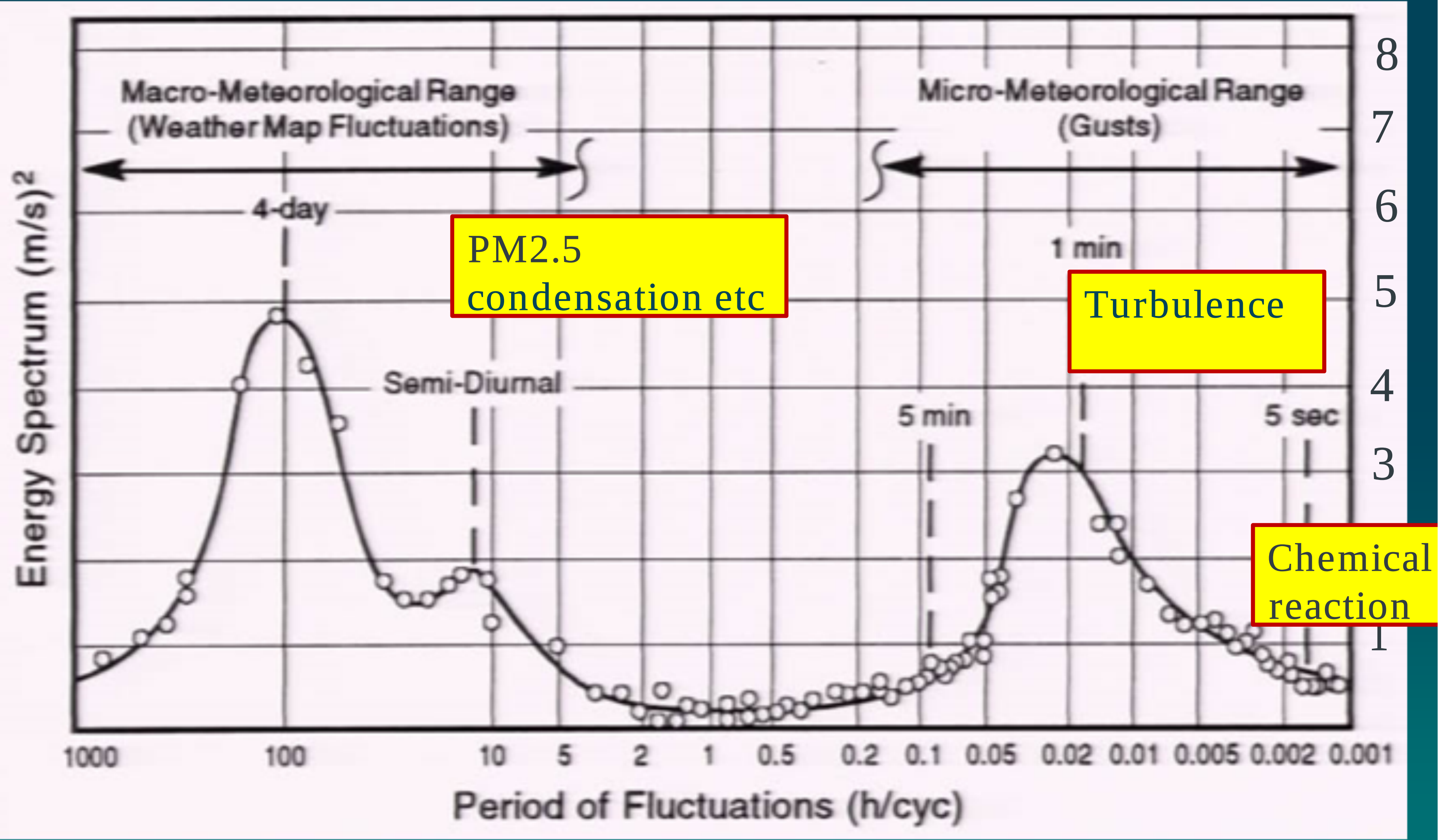
Conclusion & Discussion for CASE 1

- Measurements in an extensive array of this kind are particularly challenging.
- The present results illustrate the difficulty in achieving perfect flow symmetry for cases where the geometry would lead one to expect it, both for WT and LES.
- Vertical scalar fluxes at the roof height in the regular array were dominated by the turbulent flux component for all wind directions.
- Integration of the vertical scalar fluxes over a large portion of the computation domain shows that the tall building can cause either an increase or a decrease of the vertical transport of the passive scalar, depending on the source position relative to the tall building.

Challenges/ Opportunities

- Atmospheric Boundary Layer is TURBULENT
- Atmospheric wind is always UNSTEADY – weather scale motions
- Highly stable/unstable stratification (Blocken 2013).
- Flows over a large geometry (>10 km) but the small scales (~1 m) are crucial, e.g. a long span bridge sitting in a valley.
- Meteorological events, e.g. tornado, downbursts.
- Carrying out simulations in situations where a real-life simulation is impossible, such as the release of toxic substances (Wright and Hargreaves, 2013).
- … (this is NOT a complete list)

Time scale varies in more than 6 decades, and so does spatial scale

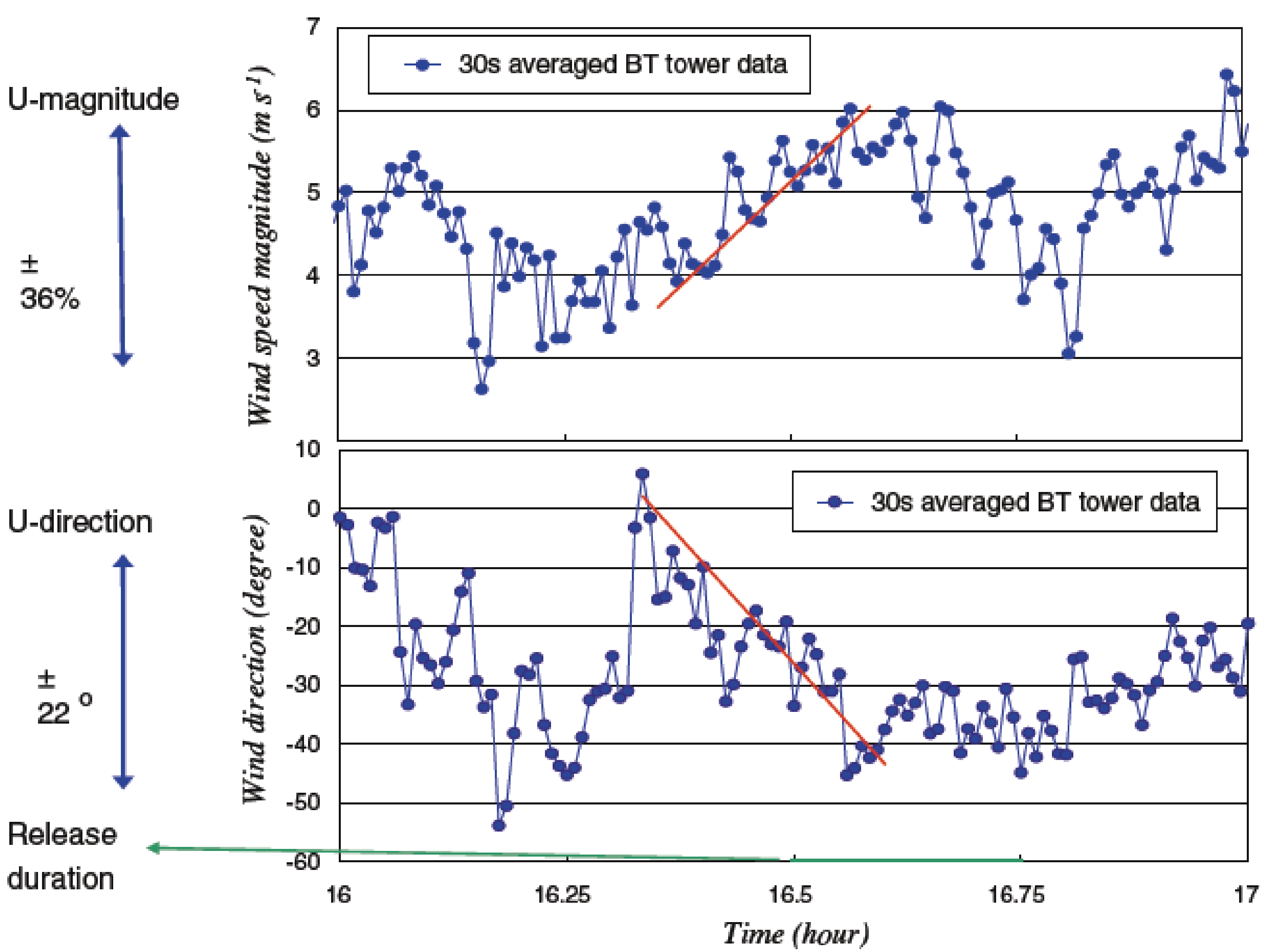


van der Hoven spectrum (1957)

Case 2, DAPPLE site – central London

The unsteadiness of weather scale variation of wind could be crucial for some process, e.g. dispersion in urban environments.

30-s averaged wind magnitude U and direction θ at top of BT tower, London (Xie, 2011)



Concentration contour (30 mins avg) of point/line source dispersion in near-source region.