Imperial College London

dapple

Modelling the Causes of Vehicle Exhaust Exposure Microepisodes

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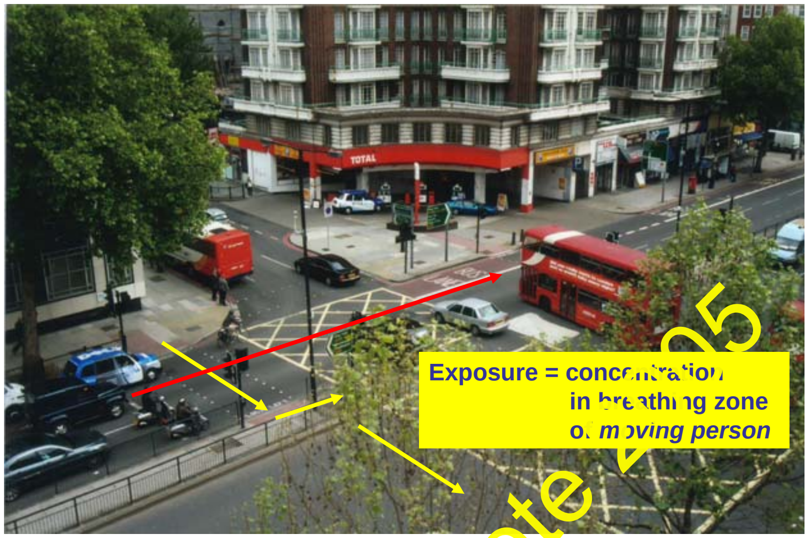
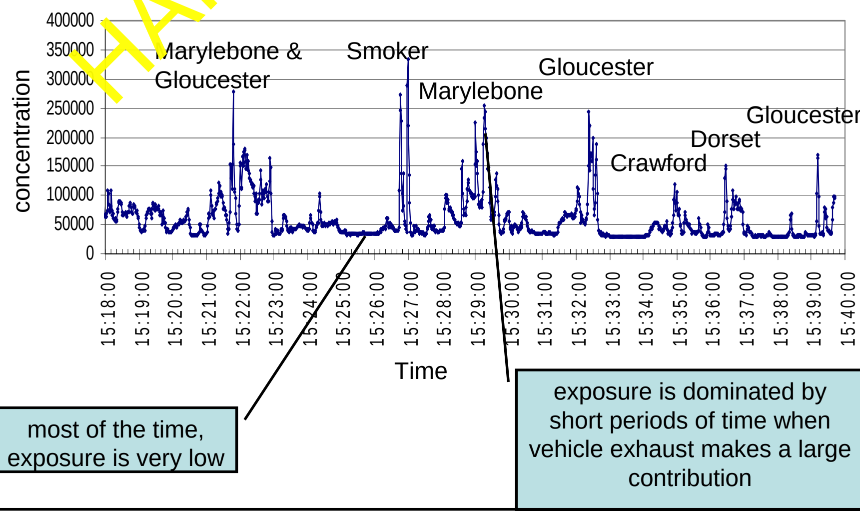
Marylebone Road and Gloucester Place Street Canyon Intersection

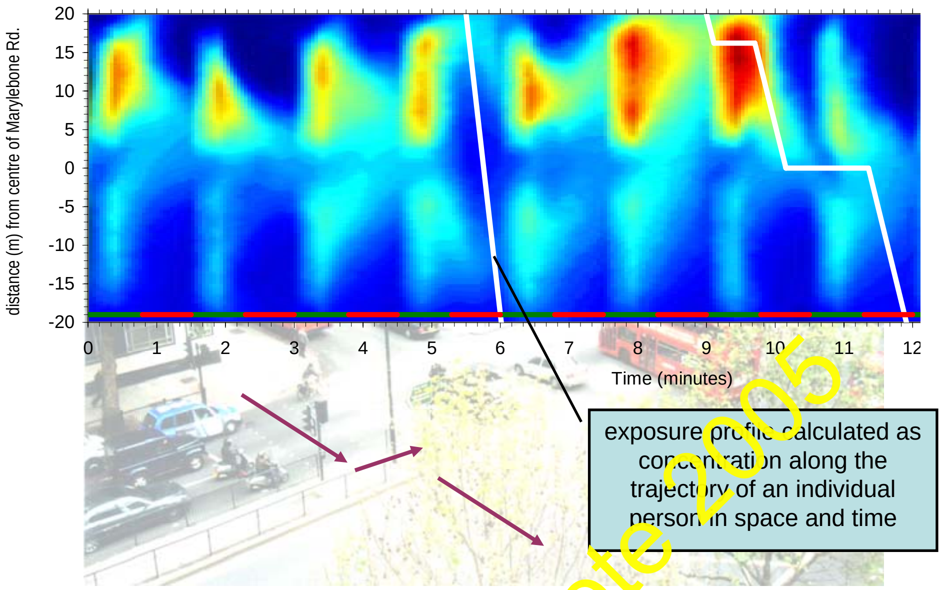
(see earlier work of Scaperdas *et al.* e.g. Rhodes Harmo conference, EUROTRAC SATURN, *Atmos.Env.* **33,** 661-674 (1999) etc.)



Exposure measurements made on 07/05/03 during the first DAPPLE Field Campaign



Concentration isopleths as a function of time and distance across Marylebone Rd



Objectives

- Apply large eddy simulation to model personal exposure profiles of a pedestrian crossing west Marylebone Road at the signalled intersection of Marylebone and Gloucester Place in Central London;
- To understand the transient flow patterns around the intersection;
- To understand spread, grow and decay of the concentration field around the intersection;
- To explore the causes of air pollution exposure microepisodes.
- Calculate exposure of a pedestrian crossing a street

Large Eddy Simulation with Smagorinsky-type sub-grid model

Filtered Navier-Stokes with Smagorinsky sub-filter scale model

$$\frac{\partial \tilde{u}_i}{\partial t} + \tilde{u}_j \frac{\partial \tilde{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[2(\gamma + \gamma_t)\tilde{S}_{ij}\right]$$

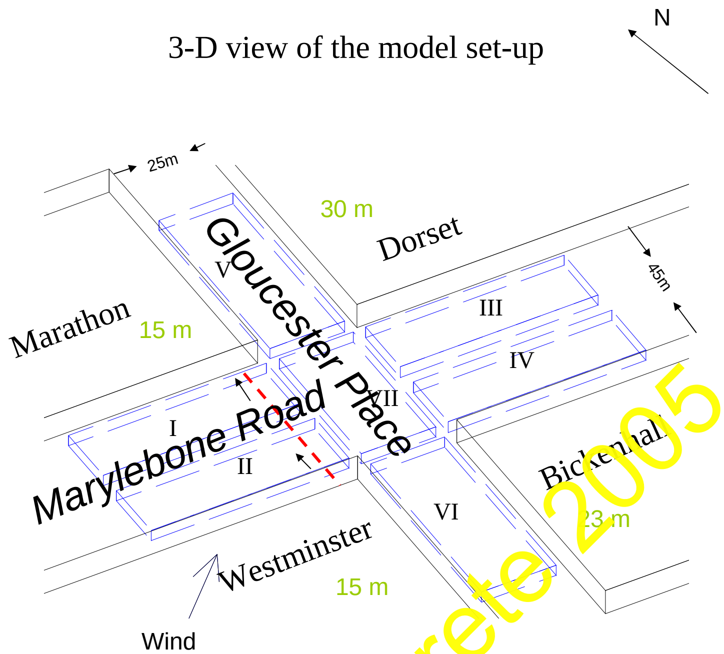
$$\tilde{S}_{ij} = \frac{1}{2}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right)$$

$$\gamma_t = l_S{}^2 \left|\tilde{S}\right| = (C_S \Delta)^2 \left|\tilde{S}\right|$$

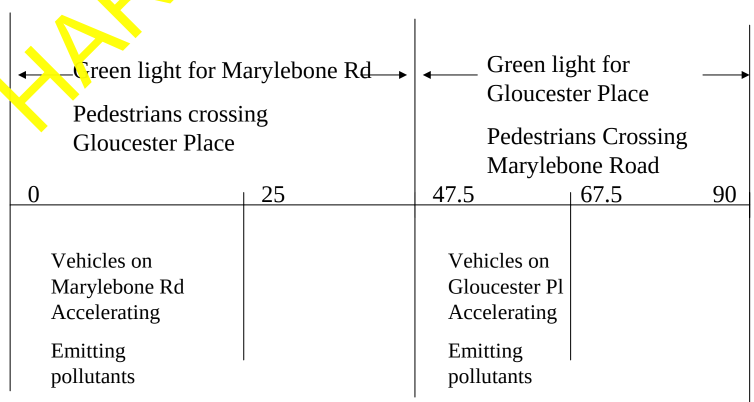
Mesh-Adaptive FLUIDITY CFD

- **Adaptive anisotropic elements, efficiently representing boundary layers and anisotropic flow features.**
- **Allows resolution in the domain where needed (e.g. streets) with *spatially and temporally* variable max & min anisotropic element length scales, as well as interpolation errors.**
- **adaptive mesh to resolve what we are interested in e.g. the pollutant concentrations.**
- **parallel mesh adaptivity for large scale problems.**

3-D view of the model set-up

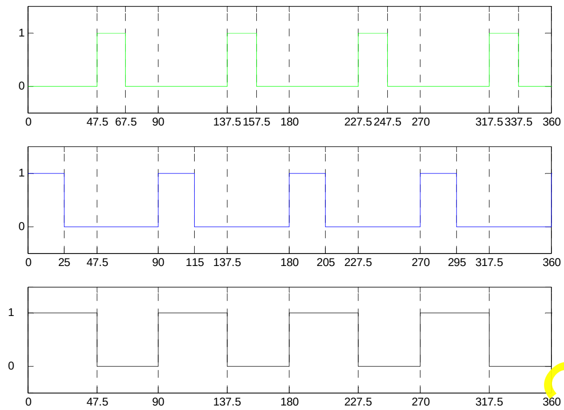


Simplified diagram of activity of vehicles and pedestrians at the intersection of Marylebone road and Gloucester place.



Traffic sources change according to change of traffic lights. In the graph (c), the traffic light is for Marylebone Road.

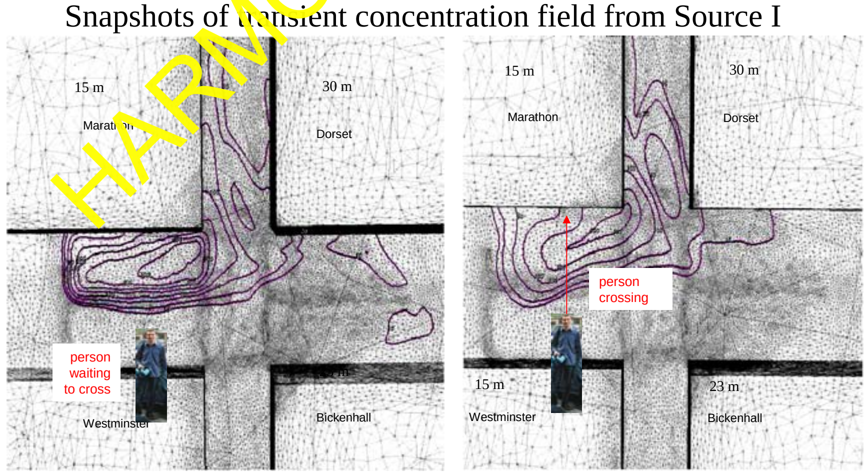
(a)
(b)
(c)



(a) Sources V&VI ;(b) Sources I to IV; (c) Traffic light for Marylebone Road. Source VII is a continuous source.

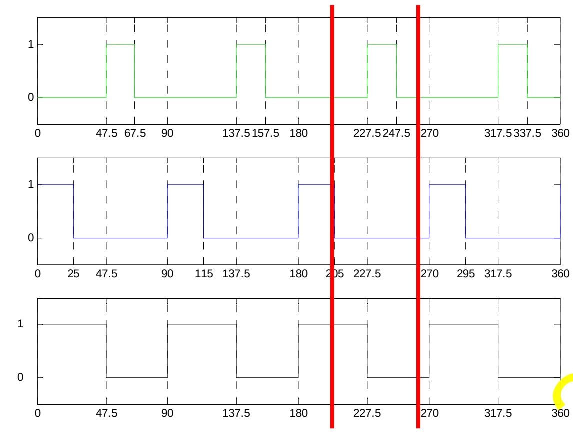
Emission is unity when a source is on and zero when it is off.

Snapshots of transient concentration field from Source I



Concentration distributions due to Source I at horizontal section z=2.0 m from the ground. left – t = 470.67 s , right – t = 530.67 s.

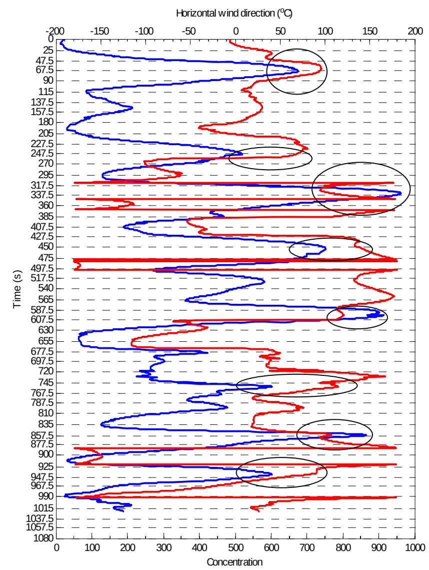
Note: the emission is on during 450-475 s and during 540 – 565 s.



Peak exposure

- In the proximity of the source(s)
- Walking though a source volume intermediately after the source ceases to emit.

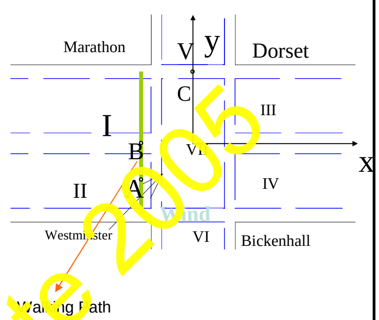
Relationship between concentration, emission and wind



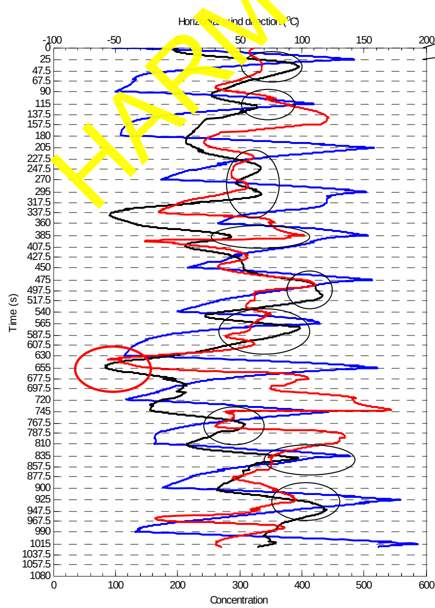
Horizontal wind direction and concentration due to source VII measured at receptor C

Red solid line – horizontal wind direction

Blue dash line – concentration.



Relationship between concentration, emission and wind

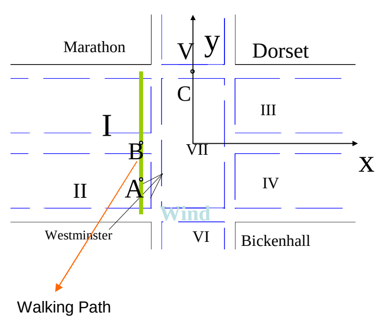


Emission is on

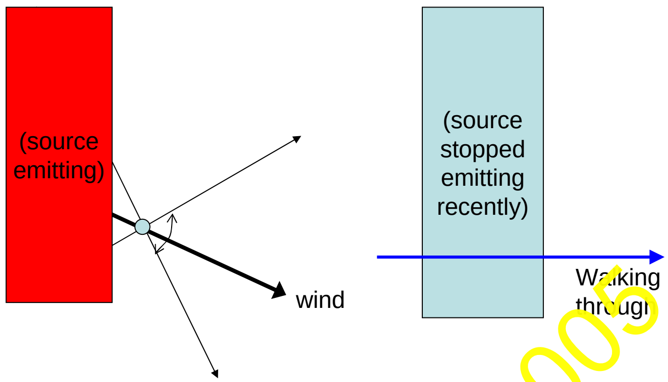
Horizontal wind direction measured at B and concentration due to source II measured at receptor A and B

Red solid line – horizontal wind direction at B,

Blue dash line – concentration at A, dash Black dot line – concentration at B.

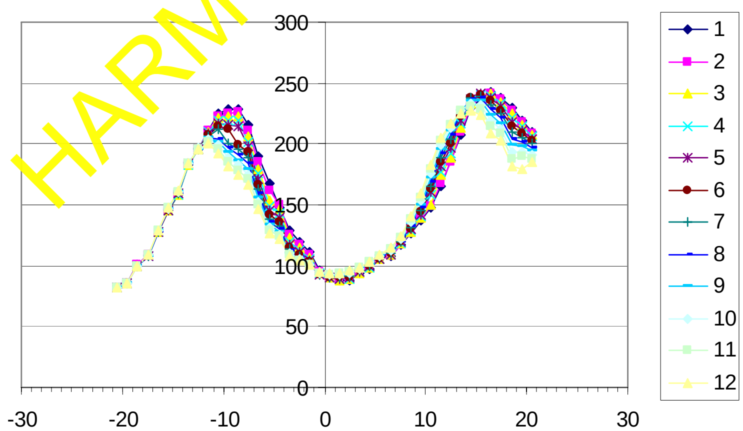


Causes of peak exposure



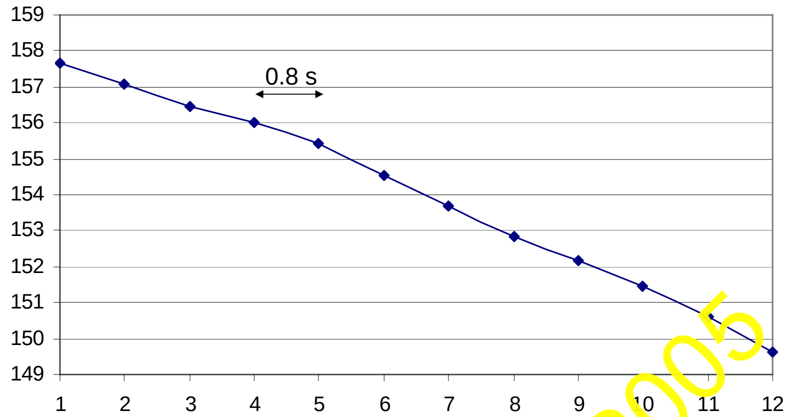
- magnitude of peak exposure in either case may also be modulated by unsteadiness of flow
  note that timescale of flow unsteadiness is similar to time taken to walk across the road

Within-cycle exposure profiles



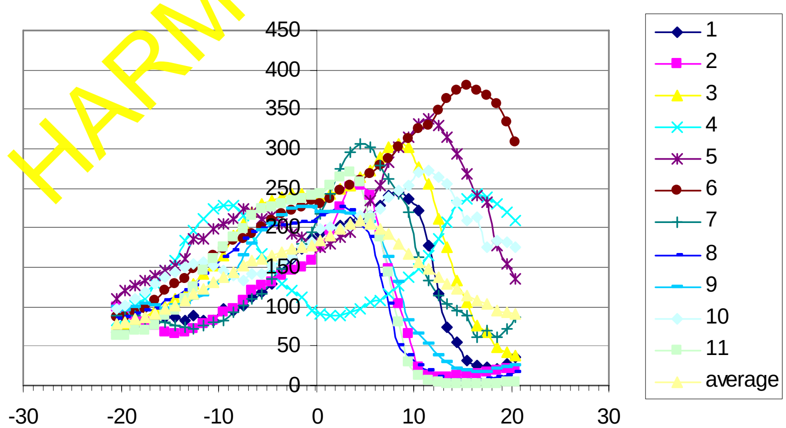
Exposure of a pedestrian hypothetically crossing west Marylebone Road at different times with 0.8 s apart within traffic cycle 4. Sample 1 – leave kerbside at t=317.5 s immediately when the favoured light take effect. Sample 2 – 318.3 s; and Sample 12 – 326.3 s, 0.7 s before the next traffic light begins.

Within-cycle variability of exposure: average per profile



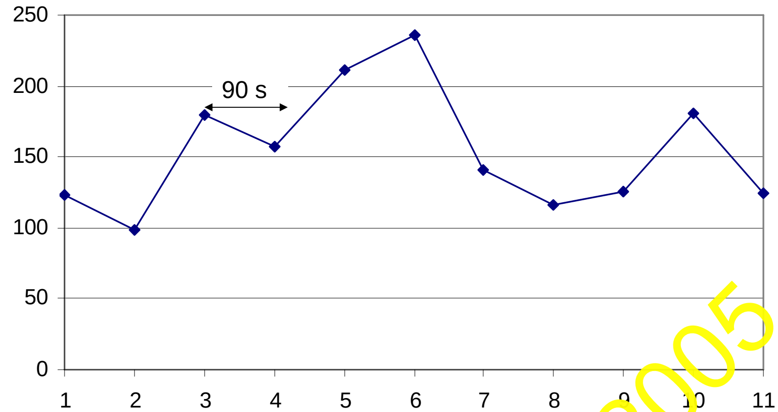
Average exposure of a pedestrian hypothetically crossing west Marylebone Road at different times with 0.8 s apart within traffic cycle 4.

Inter-cycle exposure profiles



Exposure of a pedestrian supposedly crossing west Marylebone Road during different traffic cycles immediately after the favoured light takes effect.

Inter-cycle variability of exposure



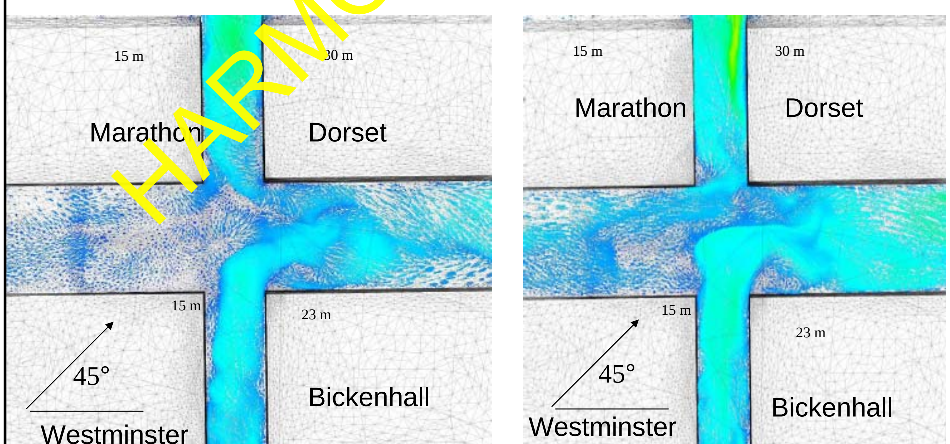
Average exposure of a pedestrian supposedly crossing west Marylebone Road during different traffic cycles immediately after the favoured light takes effect.

Conclusions

- The novel large eddy simulation method produces airflows in the vicinity of the intersection of interest and provides time-varying velocity and concentration fields
.
- Concentration decrease dramatically at the proximity of the source(s) outwards but decay rather slow within the time scale of 1 minute.
- A peak exposure at a receptor (microepisode), is shown to be primarily linked to the event that pollutant from a dominant source is blown directly to the receptor, i.e., the wind aligns the source with the receptor.
- A peak exposure also take place when a pedestrian walking through a source area soon after the source is off.
- Variability of exposure samples within a traffic cycle is as small as ±5% whilst that of exposure samples between different cycles is more than a factor of 2 (standard deviation = 28%).

Thank You

General Flow Patterns



Wind velocity vector at horizontal sections at t = 384 s. arrows point to wind direction and length of vector indicate wind speed. left – z = 2.0m, right – z = 7.5 m. The incident wind above roof level blows at 45º from the direction of Marylebone Road as shown. Note: the widths of Marylebone Road and Gloucester Place are 45m and 25 m respectively.

A comparison of mesh-adaptive LES with wind tunnel data for flow past buildings: Mean Flows and velocity fluctuations

Authors: Elsa Aristodemou [1,2], Tom Bentham[3], Christopher Pain[1], Roy Colvile[2], and Alan Robins

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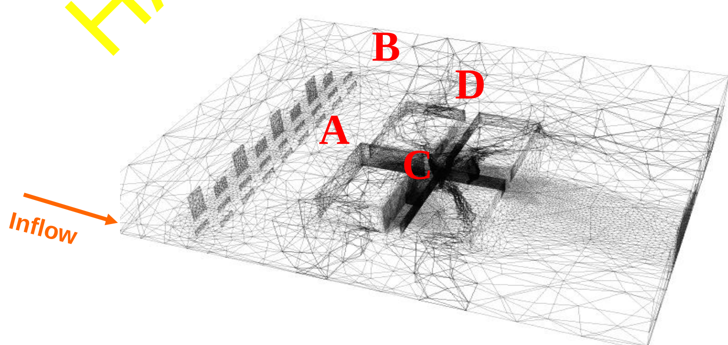
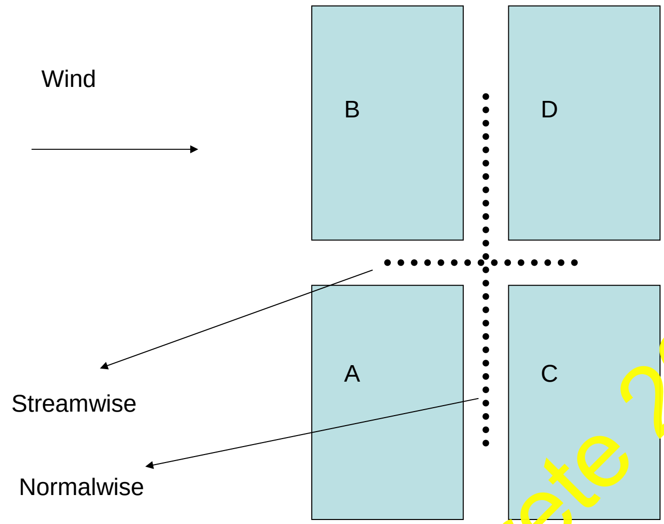
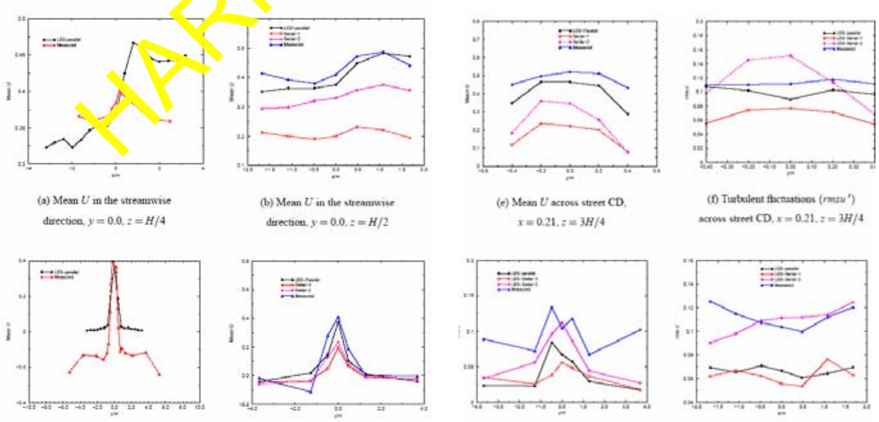


Example of Adaptive Grid

Measuring points



Comparison of measured and simulated velocity U component -- streamwise



(a) Mean U in the streamwise direction, $y = 0.0$, $z = H/4$

(b) Mean U in the streamwise direction, $y = 0.0$, $z = H/2$

(e) Mean U across street CD, $x = 0.21$, $z = 3H/4$

(f) Turbulent fluctuations ($rms\ u'$) across street CD, $x = 0.21$, $z = 3H/4$

(c) Mean U along the normal street, $x = 0.0$, $z = H/4$

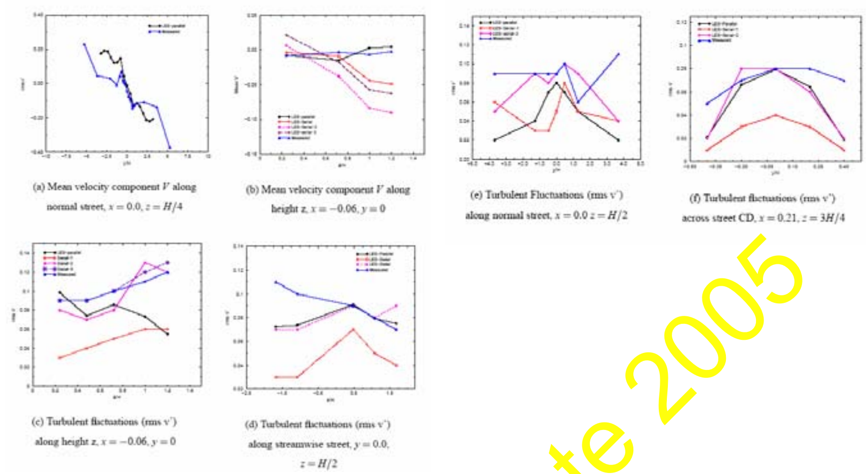
(d) Mean U along the normal street, $x = 0.0$, $z = H/2$

(g) Turbulent fluctuations rms u' along the normal street, $x = 0.0$, $z = H/2$

(h) Turbulent fluctuations (rms u') streamwise, $y = 0.0$, $z = 3H/4$

(from Aristodemou et al.)

Comparison of measured and simulated velocity V component -- normalwise



(a) Mean velocity component V along normal street, $x = 0.0$, $z = H/4$

(b) Mean velocity component V along height z, $x = -0.06$, $y = 0$

(e) Turbulent Fluctuations (rms v') along normal street, $x = 0.0$ $z = H/2$

(f) Turbulent fluctuations (rms v') across street CD, $x = 0.21$, $z = 3H/4$

(c) Turbulent fluctuations (rms v') along height z, $x = -0.06$, $y = 0$

(d) Turbulent fluctuations (rms v') along streamwise street, $y = 0.0$, $z = H/2$

(from Aristodemou et al.)

General performance

Scenario	Direction	Mean U	rms u	Mean V	rms v
JS	streamwise	< 5% - 22%	< 2% - 28%	< 5% - 50%	< 5% - 36%
JS	normal	< 10% - 33%	< 30% - 65%	< 5% - 50%	< 10% - 60%
JD	streamwise	< 5% - 22%	< 2% - 28%	< 5% - 50%	< 5% - 36%
JD	normal	10% - 25%	10% - 67%	10% - 85%	22% - 50%
JU	streamwise	< 10% - 32%	< 12% - 38%	< 10% - 50%	< 10% - 40%
JU	normal	15% - 25%	10% - 50%	10% - 30%	< 5% - 30%

Table 1: Some Typical Minimum and Maximum Relative Errors for all three configurations.

(from Aristodemou et al.)