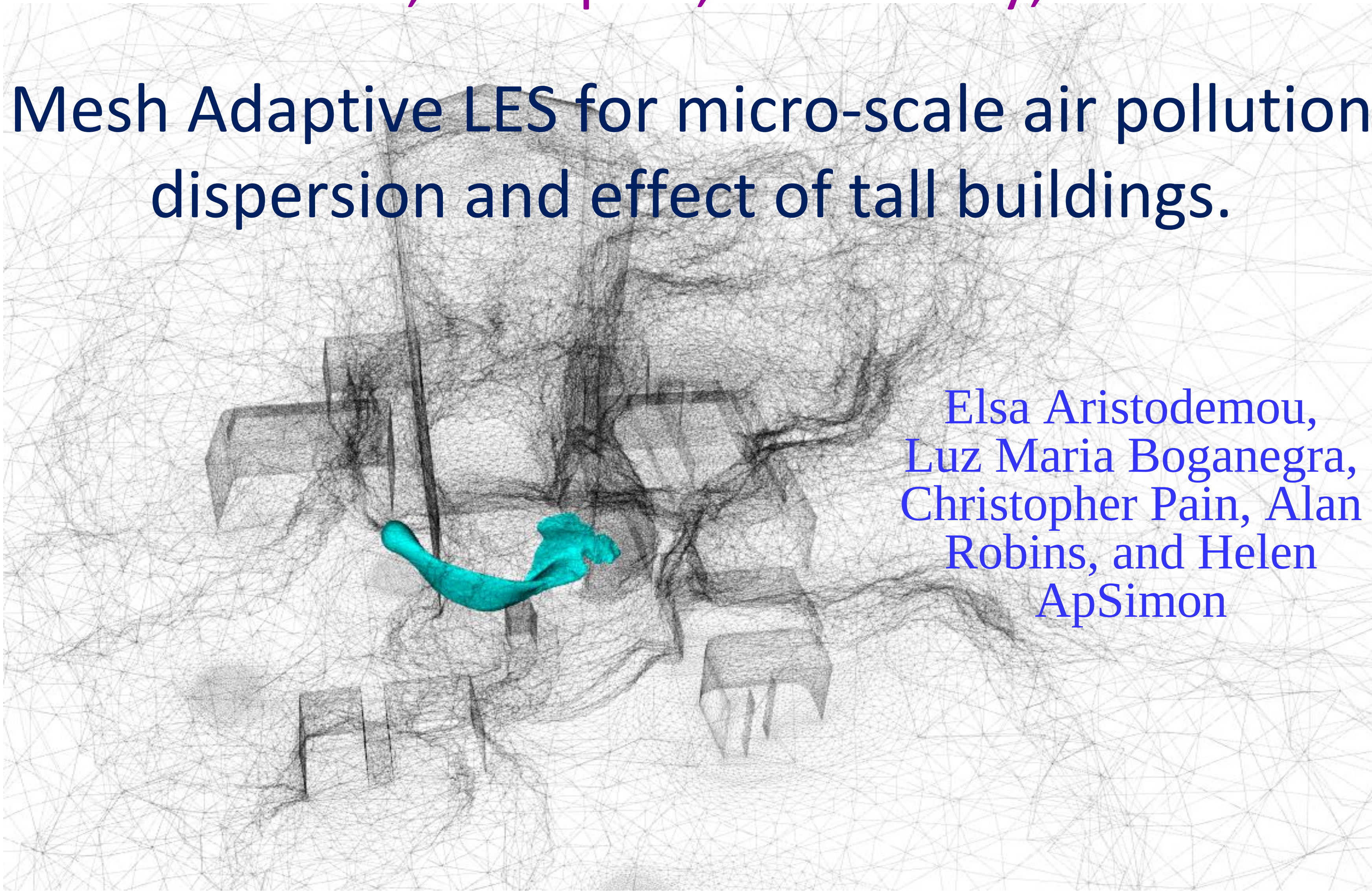
HARMO17, Budapest, 9 – 12 May, 2016.

Mesh Adaptive LES for micro-scale air pollution dispersion and effect of tall buildings.



Elsa Aristodemou, Luz Maria Boganegra, Christopher Pain, Alan Robins, and Helen ApSimon

London South Bank University

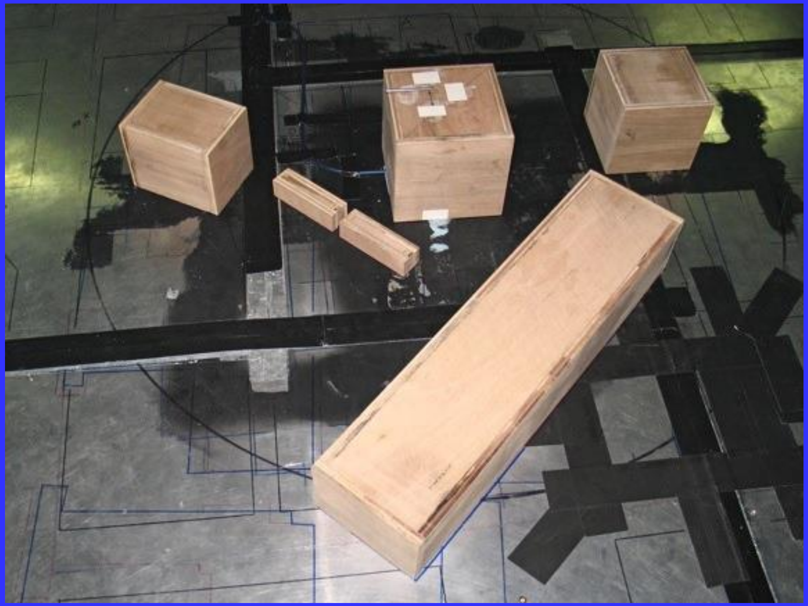
Imperial College London

University of Surrey

Outline

- Motivation/Combined Heat & Power plant emissions
- The Wind tunnel Experiments
- Large Eddy Simulation within the FLUIDITY software
- Validation case
- Additional LES cases
- The "Walkie-Talkie" simulation (if there is time)
- Conclusions

The Enflo Wind Tunnel Geometry (Robins, 2013)



Working section: 20 x 3.5 x 1.5 m

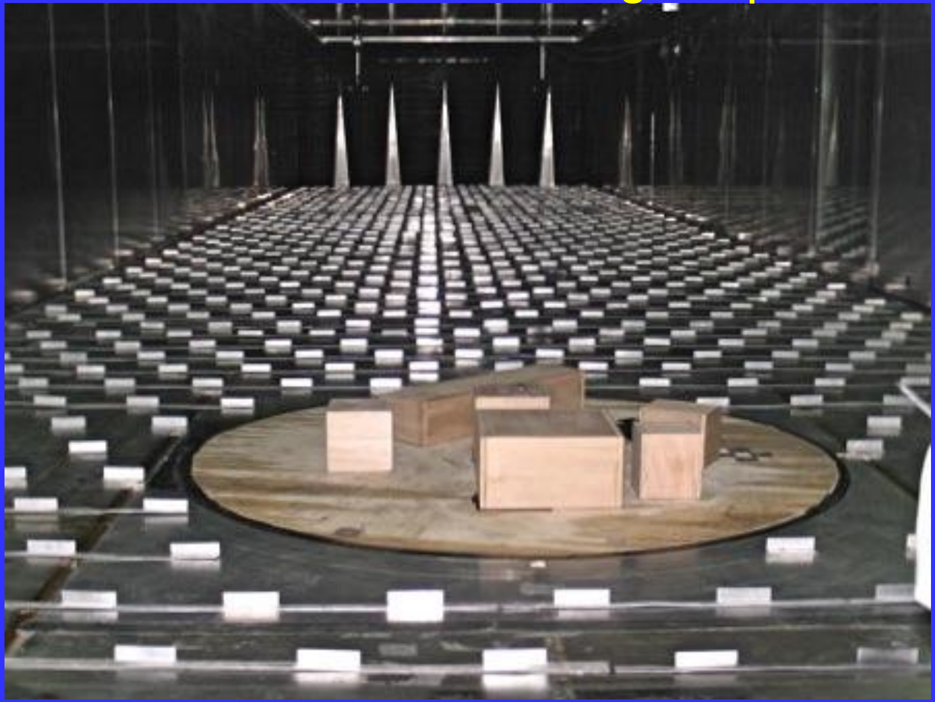
(Length x Width x Height)

Overall length: 27.2 m

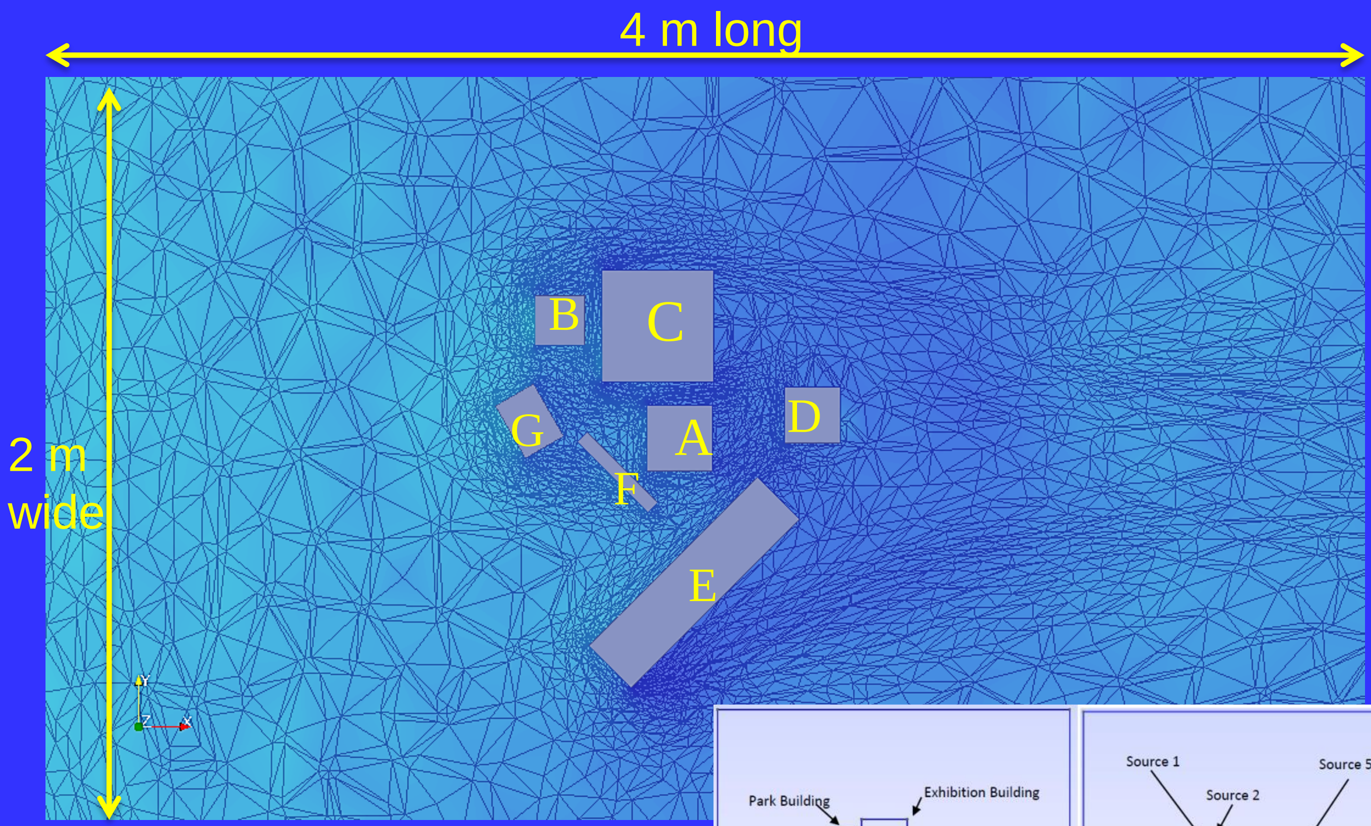
Geometry of interest was at the scale of 1:200.

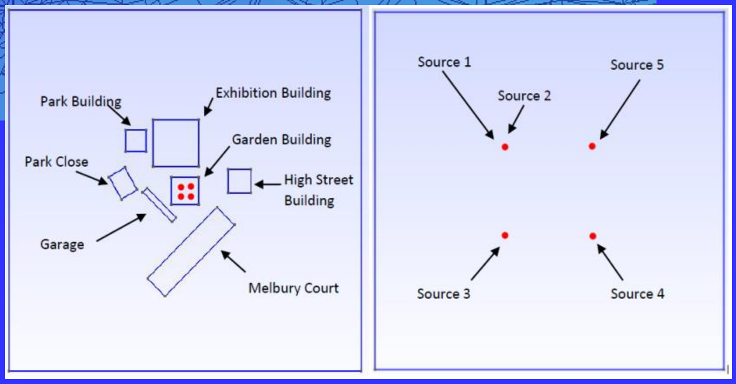
Several Cases were run. We look at First case, with All buildings in place.

- Generates neutral, stable and unstable boundary layers
- Has three dimensional, computer controlled traversing gears, tracer supply systems, calibration facilities, a turntable and extensive condition monitoring.
- Operates under full computer control,



The Geometry within the FLUIDITY software plan view with adaptive mesh

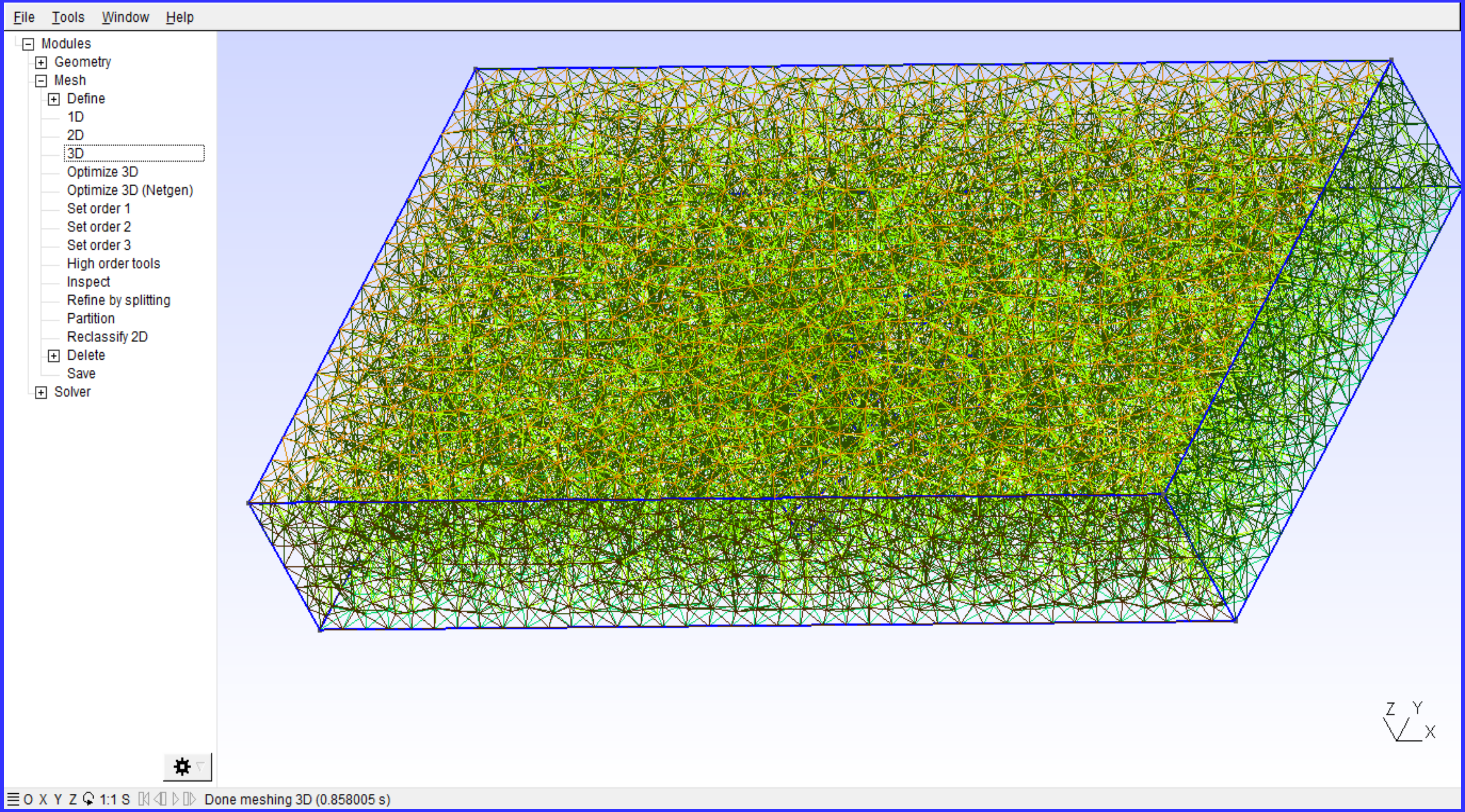




Wind Tunnel
Case Case1

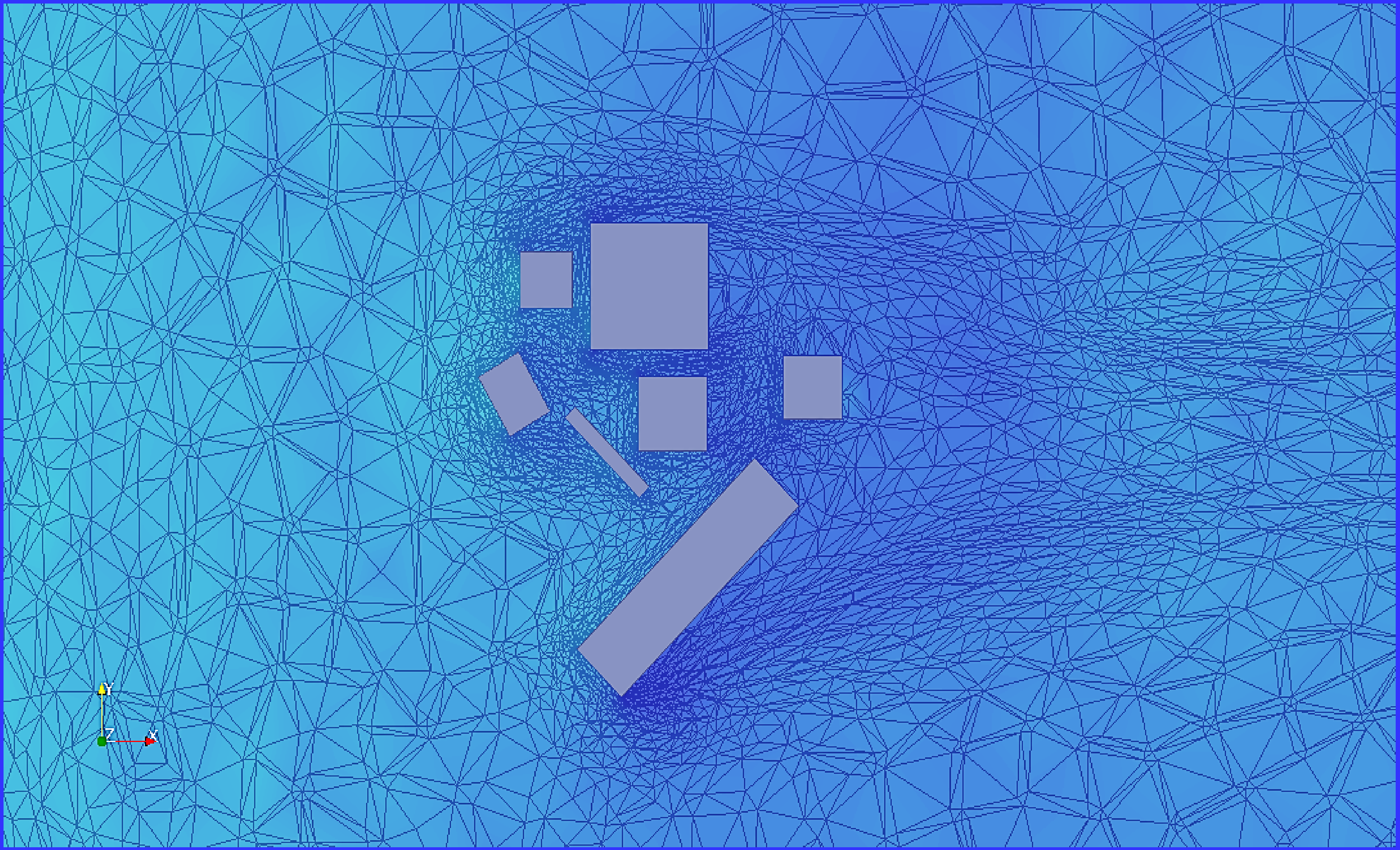
Block	Height (m)
A	0.1428
B	0.1238
C	0.1315
D	0.1228
E	0.0971
F	0.0315
G	0.1152

Initial Tehtrahedral Mesh (GMSH pre-processor) as input in the FLUIDITY software



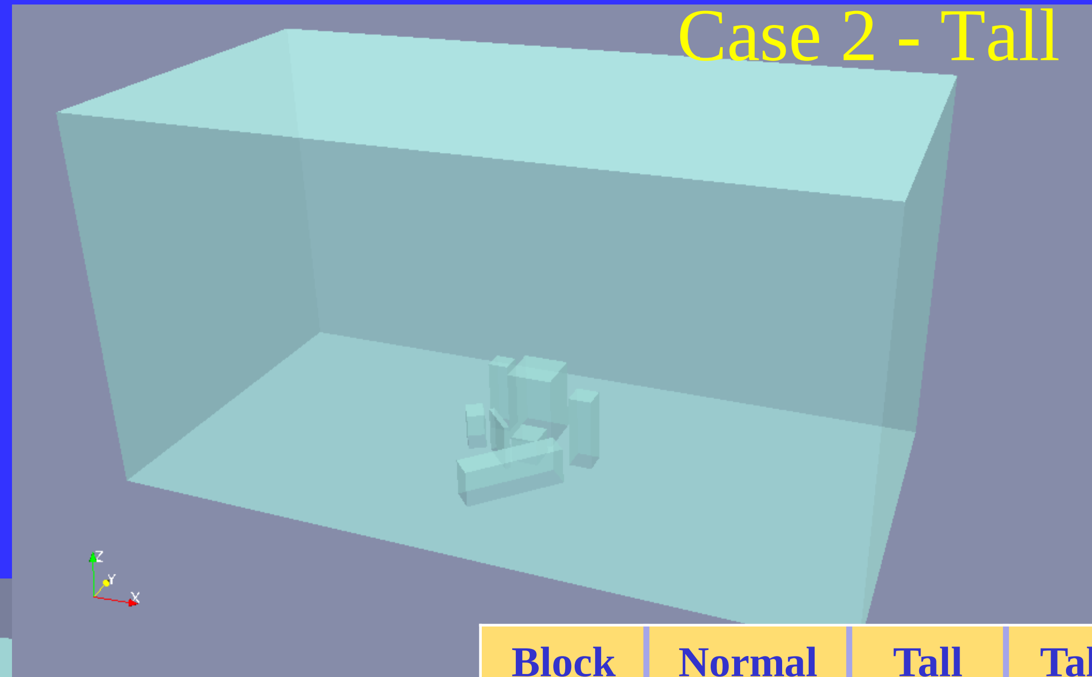
This mesh is subsequently adapted, based on certain metrics associated with physical parameters: velocity and concentrations:

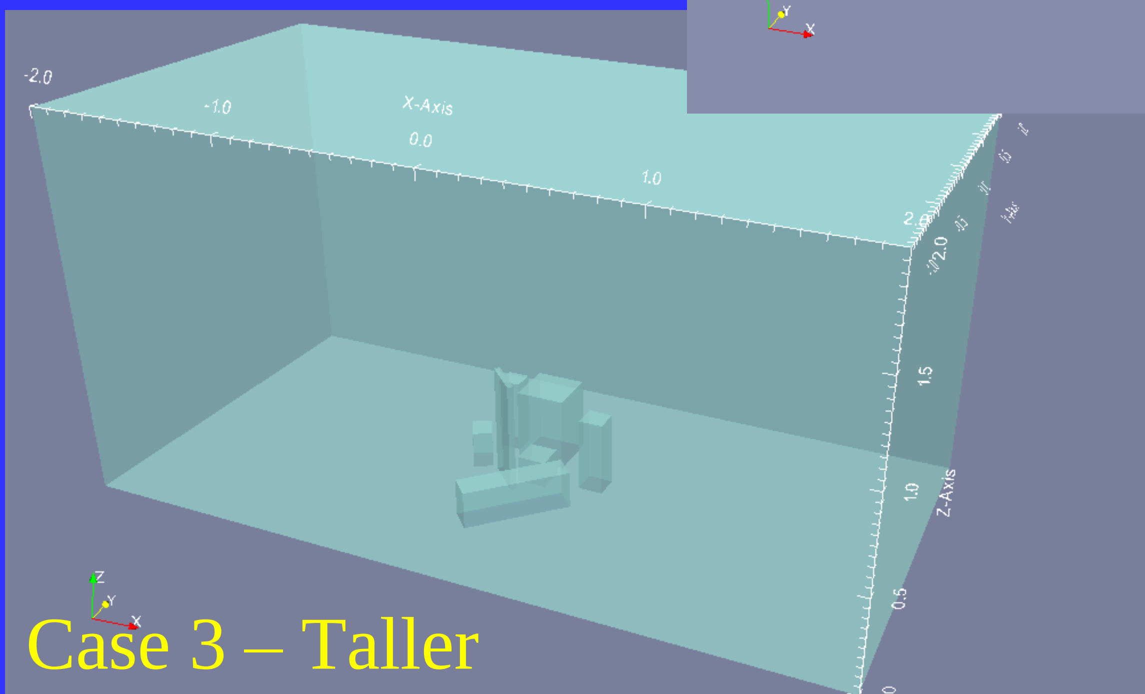
Adaptive Mesh



Final Number of Elements ~ 1,000,000 ; No of nodes: ~ 175,000

Additional FLUIDITY cases: Cases 2 and 3



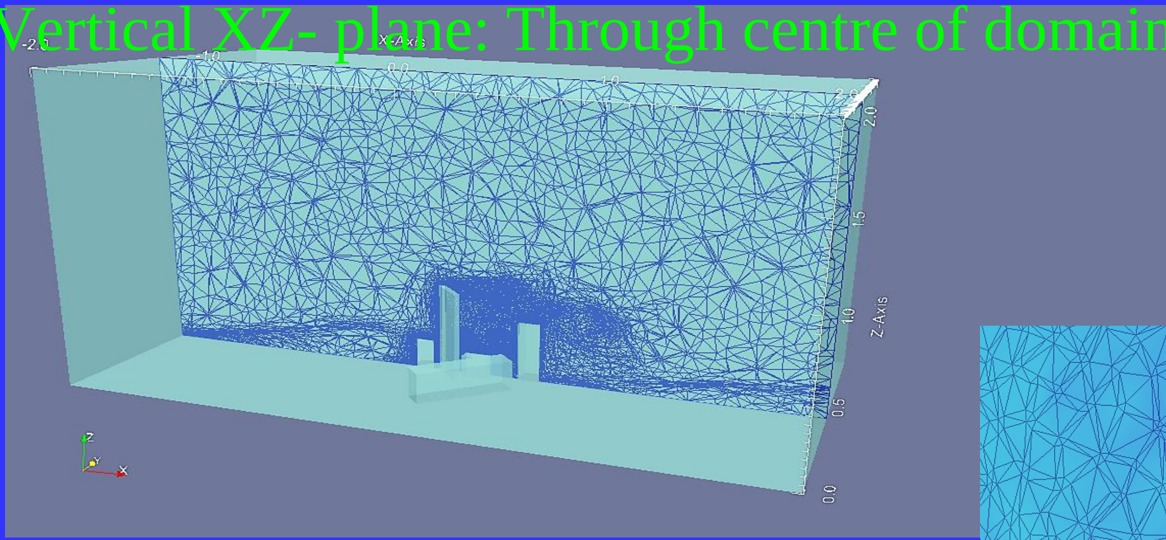


Block	Normal Case1	Tall Case2	Taller Case3
A	0.1428	0.1428	0.1428
B	0.1238	0.4	0.4
C	0.1315	0.4	0.4
D	0.1228	0.4	0.4
E	0.0971	0.2	0.2
F	0.0315	0.2	0.2
G	0.1152	0.25	0.6

London South Bank University, Imperial College London and University of Surrey, HARMO17, Budapest 2016

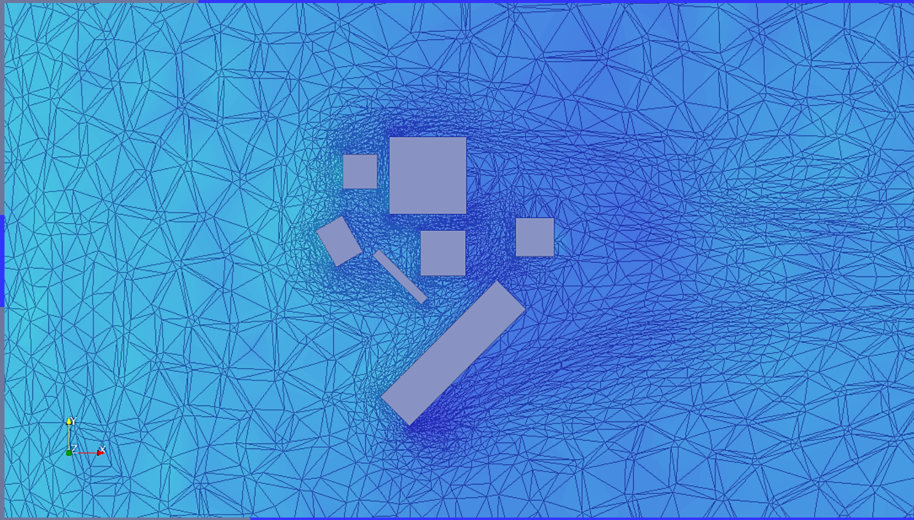
Results presented on three planes

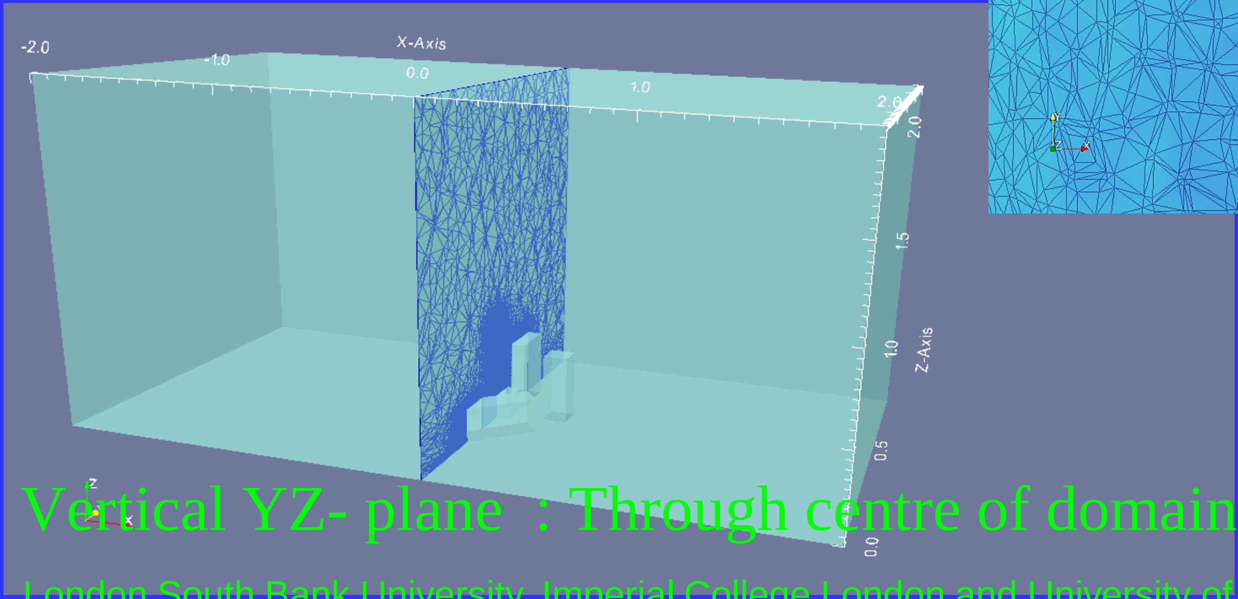
Vertical XZ- plane: Through centre of domain



Horizontal XY- plane

At Height of Source





Vertical YZ- plane : Through centre of domain

Mesh-adaptive LES within the FLUIDITY software

(http://fluidityproject.github.io/) *Pain et al. http:/www.amcg.th.ic.ac.uk*

- Unstructured finite element mesh - Adaptive anisotropic elements, efficiently representing boundary layers and anisotropic flow features.

- Allows resolution in the domain where needed (e.g. streets) with spatially 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.

- Adaptive mesh allows representation of moving objects (e.g. vehicles, pedestrians) using a 2-phase fluid approach.

- Parallel mesh-adaptivity for large scale problems; up to 100k processors – on powerful supercomputers.

Large Eddy Simulation (LES) with sub-grid modelling

(1) Filtered Navier-Stokes with Smagorinsky sub-grid model:

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

(2) Filtered Advection-Diffusion for a passive scalar

$$\frac{\partial \tilde{c}}{\partial t} + \frac{\partial(\tilde{c}\tilde{u})}{\partial x_j} = \frac{\partial}{\partial x_j}\left[D\frac{\partial(\tilde{c})}{\partial x_j} + \tilde{c}\tilde{u}_j - (cu)_j\right]$$

Anisotropic Eddy Viscosity ν_t that depends on Variable filter width Δ, where:

Δ = 2*local element size (h_ζ, h_η, h_ξ).

Large Eddy Simulation (LES) with sub-grid modelling

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

$$\nu_t = l_S{}^2 \left|\tilde{S}\right|$$

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

Anisotropic Eddy Viscosity ν_t that depends on Variable filter width Δ, where:

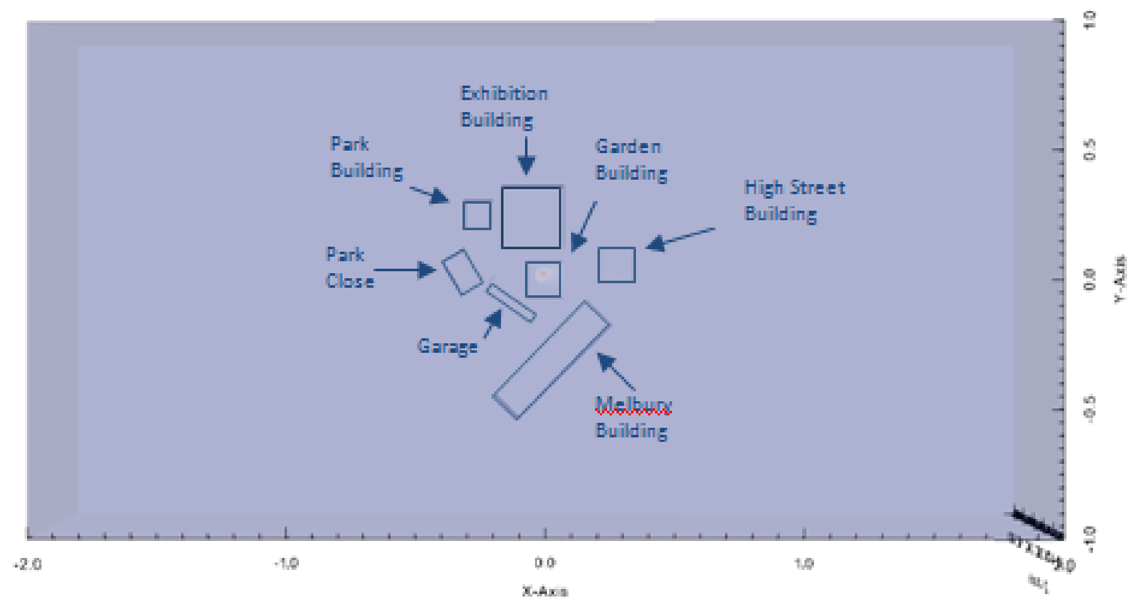
Δ = 2*local element size (h_ζ, h_η, h_ξ).

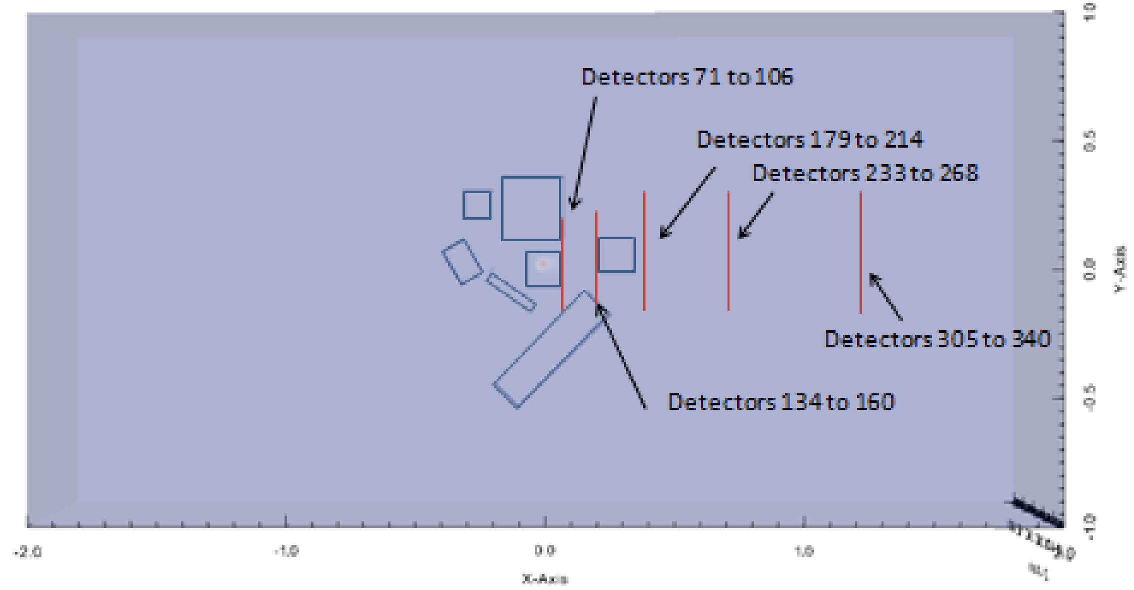
- Resolved flow field: numerically solved.
- Sub-filter scales: modelled using a
- Smagorisnky-type Subgrid scale model.

C_s=Smagorinsky constant = 0.11

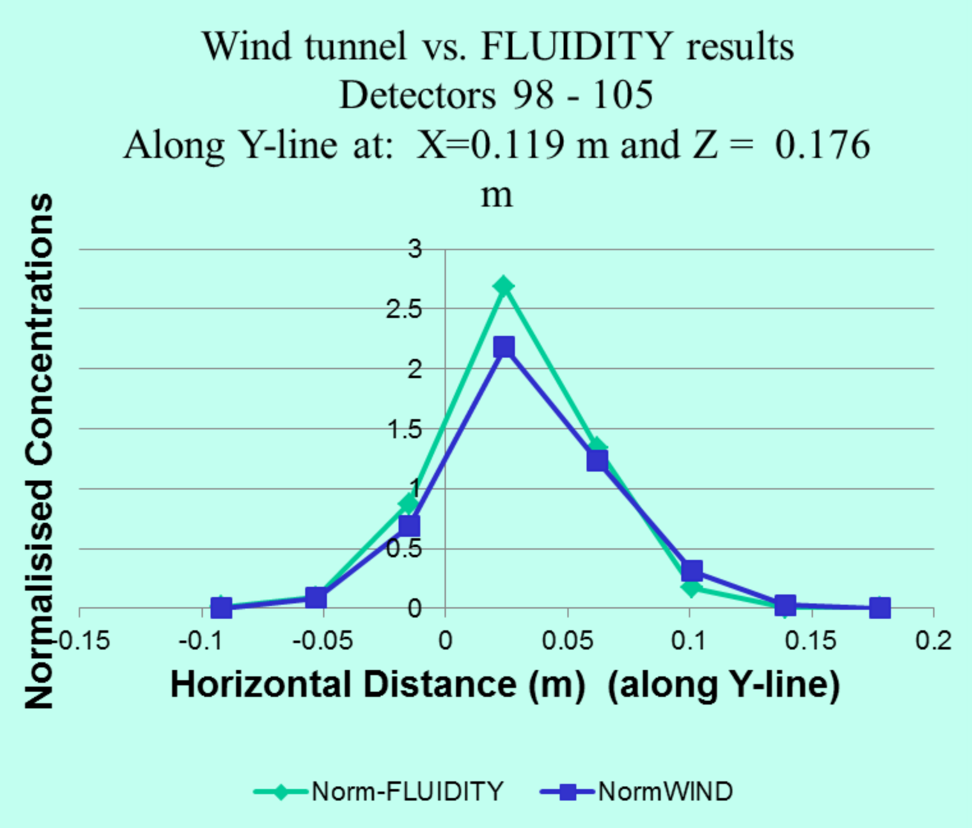
Δ=variable filter width: dependent on the element lengths

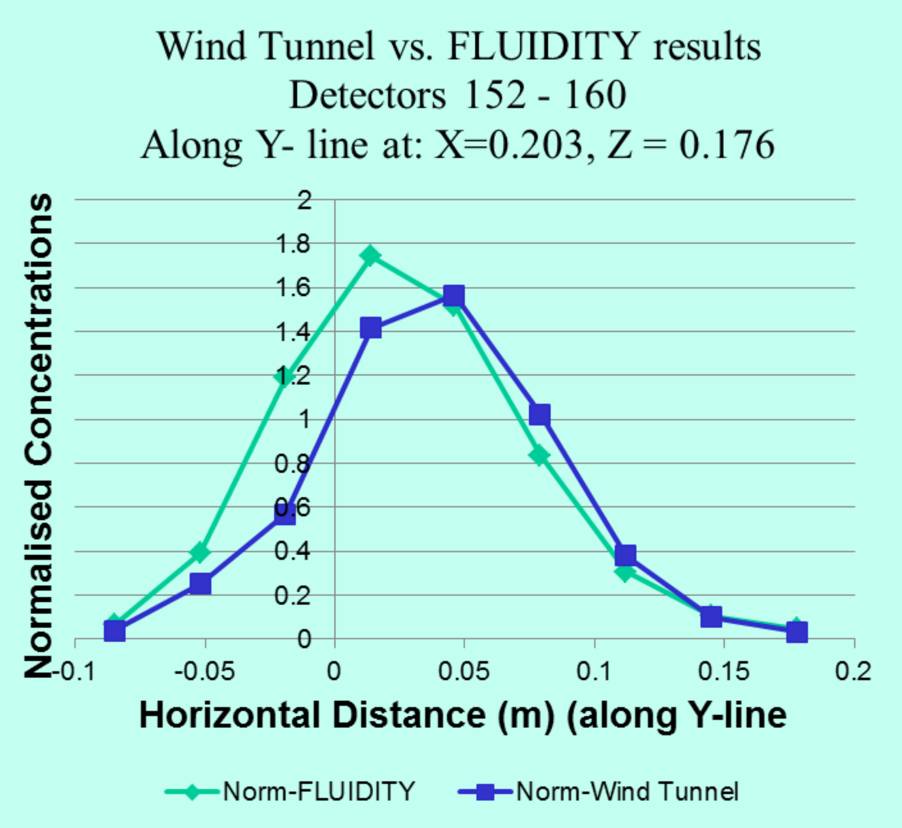
Plan view of Lines where Detectors are



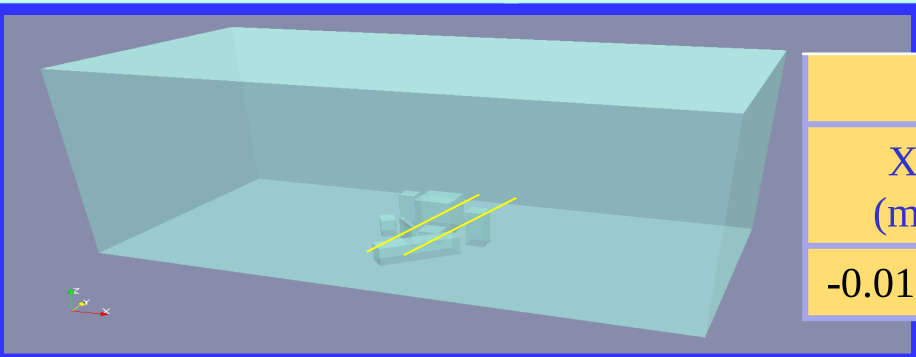


Validation: Wind Tunnel Case – Mean Concentrations



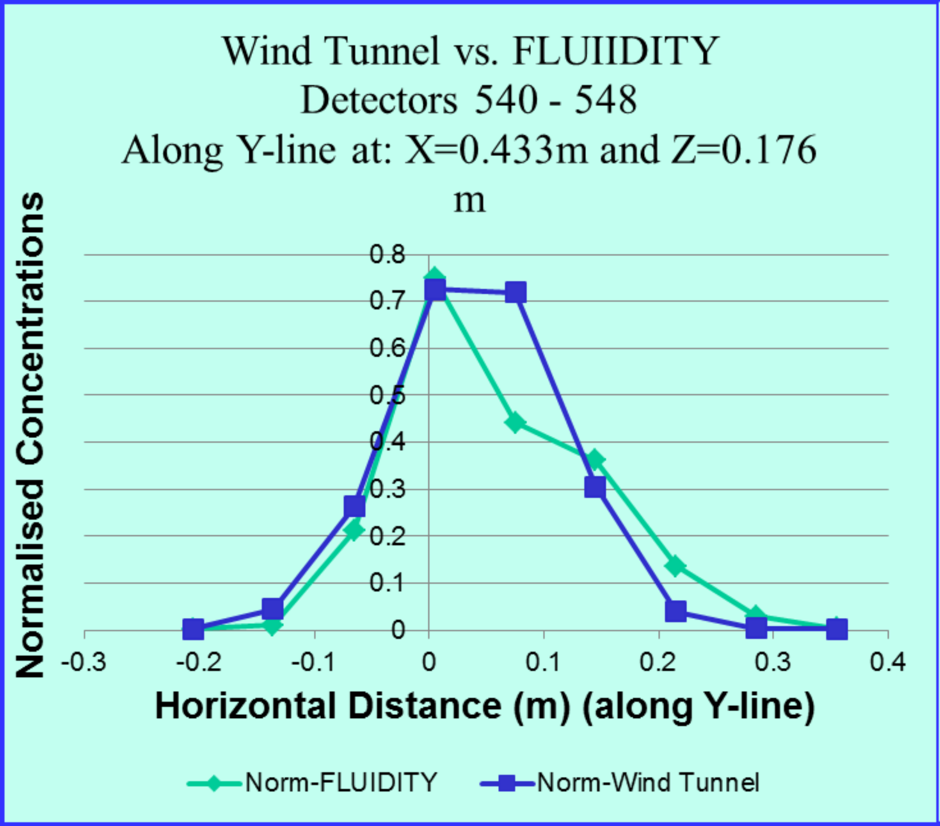


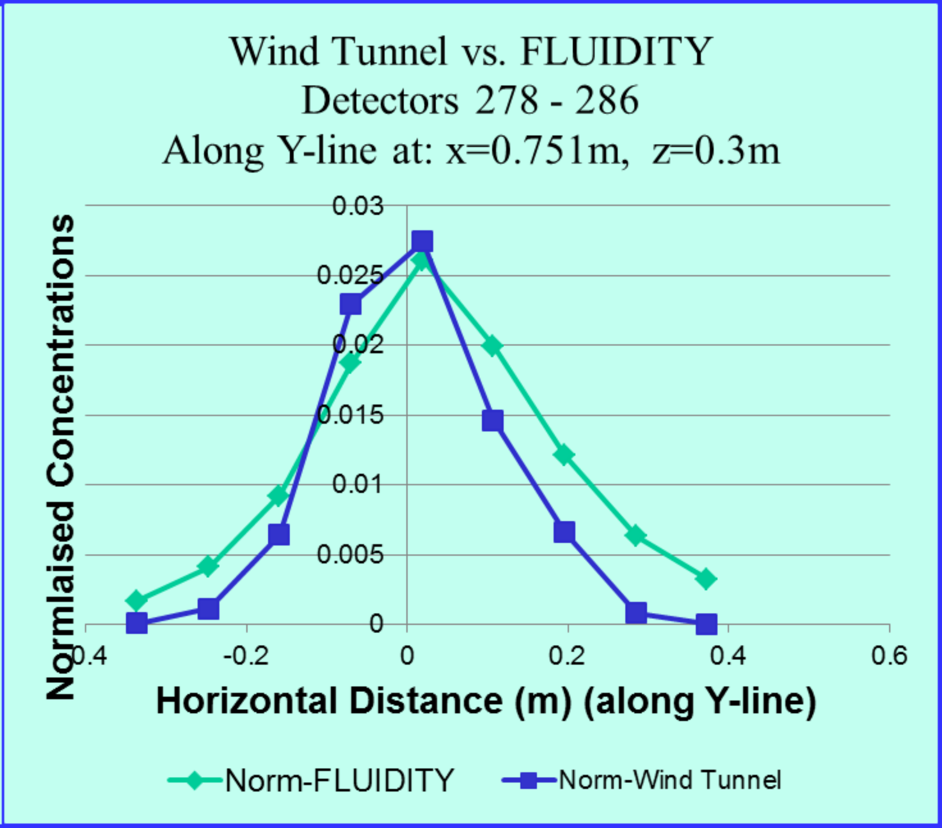
Detectors higher than the source



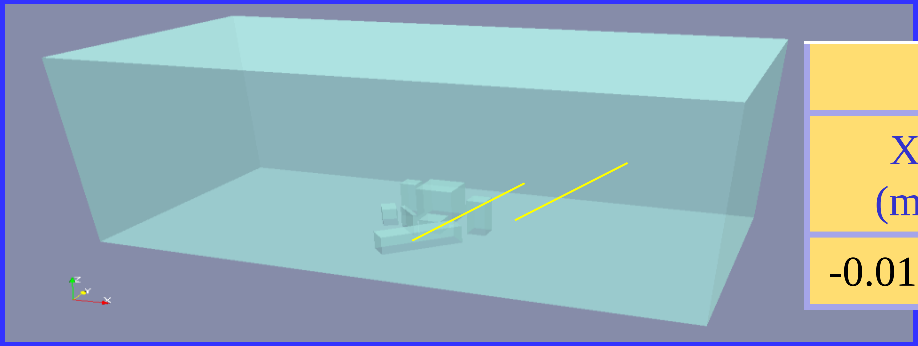
Location of Source		
X (m)	Y (m)	Z (m)
-0.01875	0.01875	0.1508

Validation: Wind Tunnel Case – Mean Concentrations



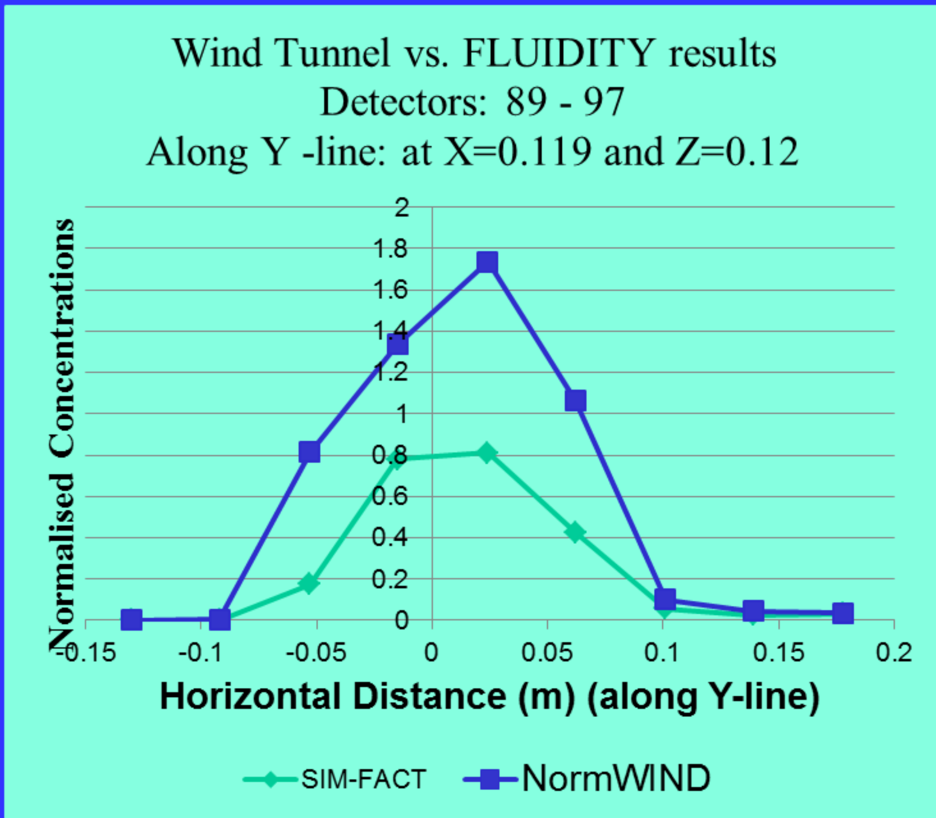


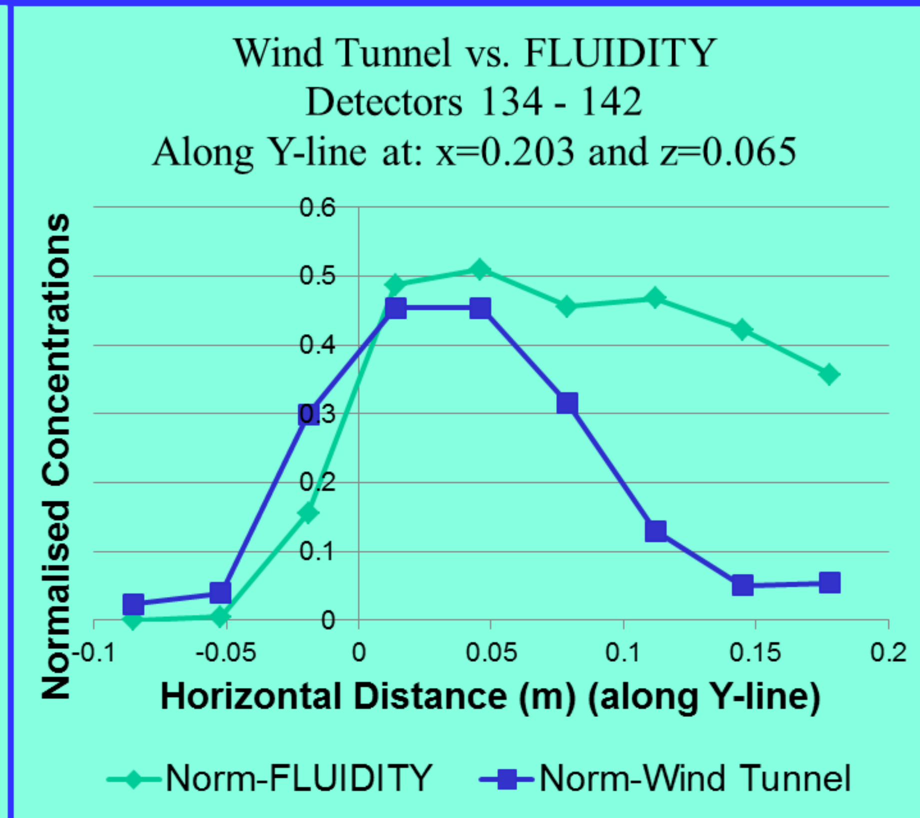
Detectors higher than the source



Location of Source		
X (m)	Y (m)	Z (m)
-0.01875	0.01875	0.1508

…*and*…..just to show that not all is “perfect”!

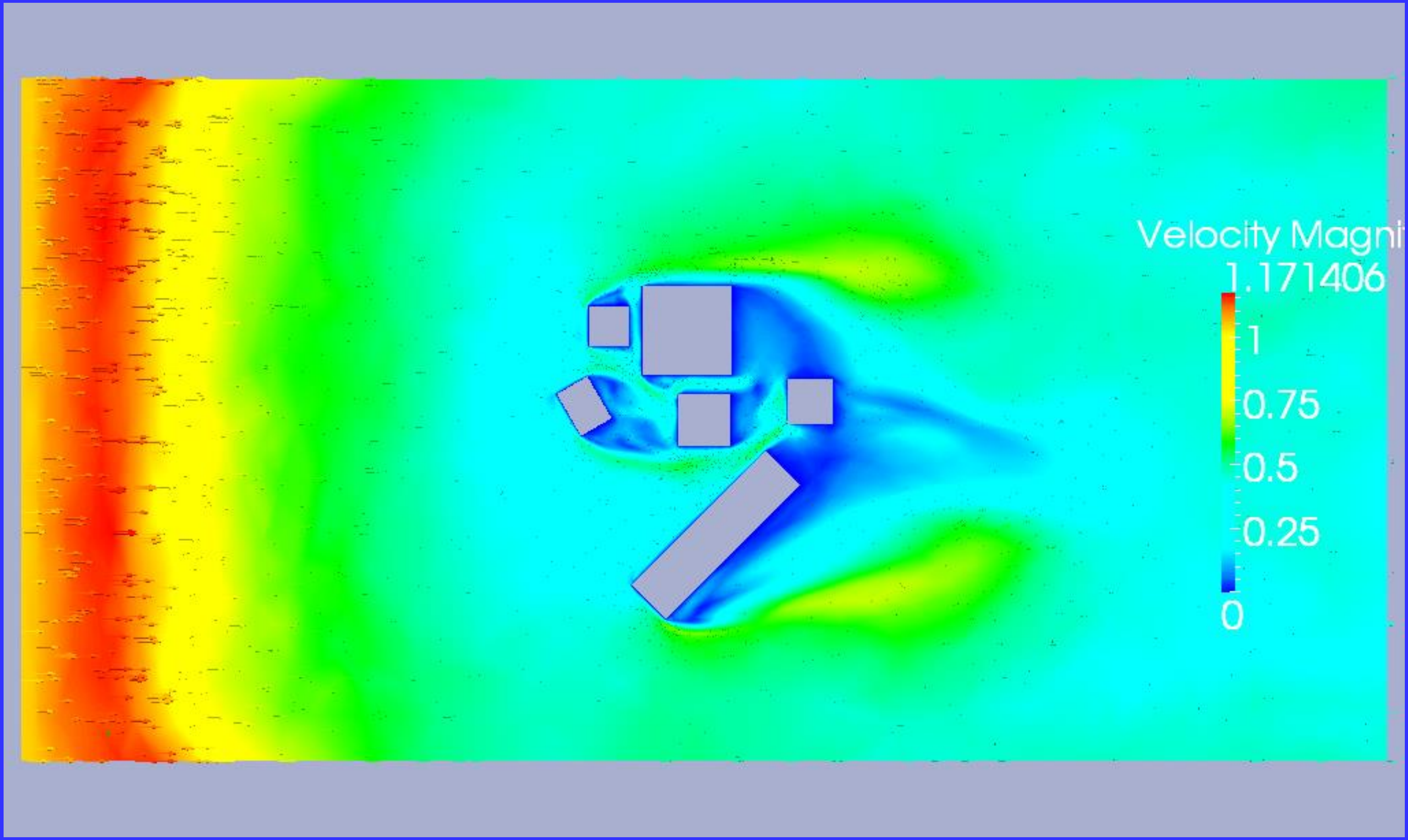




Detectors below the source

Location of Source		
X (m)	Y (m)	Z (m)
-0.01875	0.01875	0.1508

Velocity field at near ground level – H=0.065m

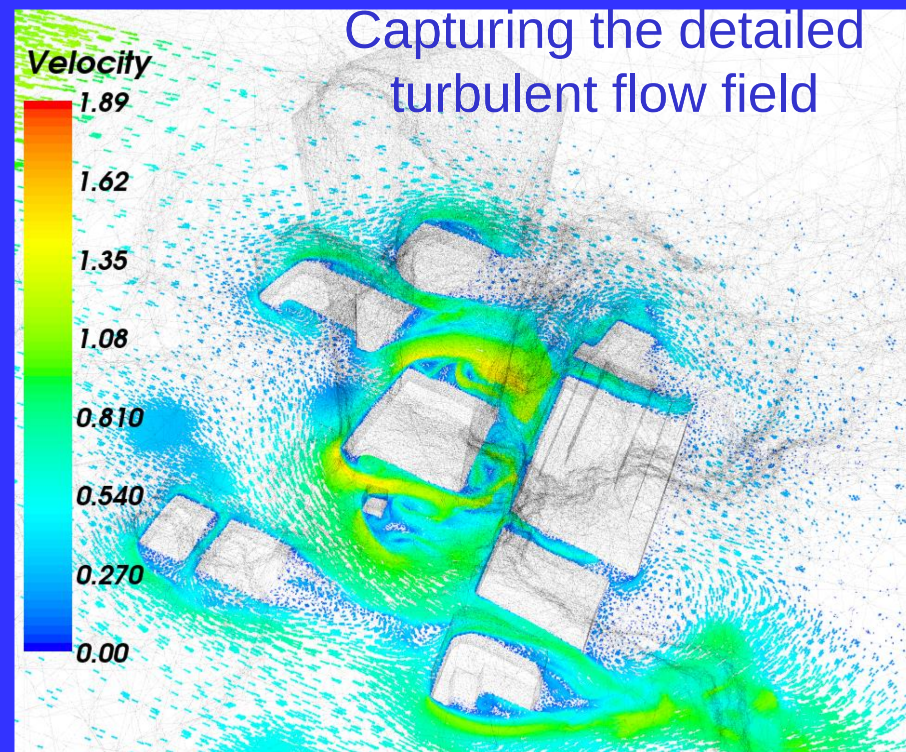


What is the effect of High Buildings on Dispersion?

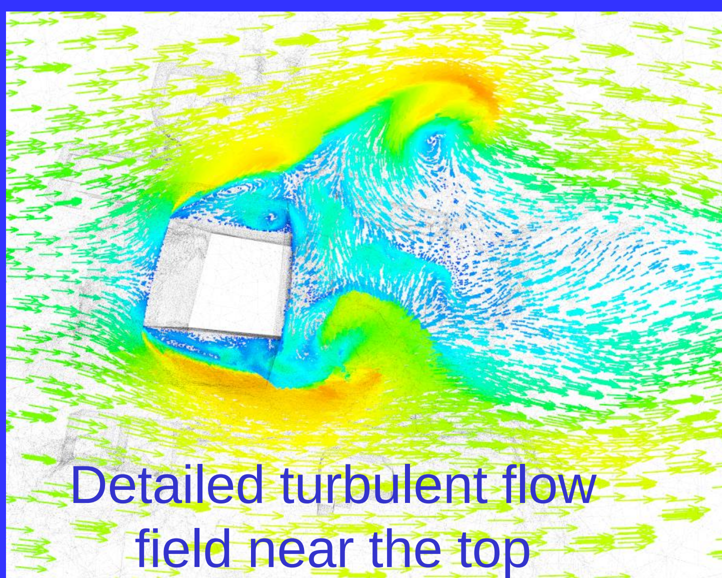
The “infamous” Walkie-Talkie building

London, UK, cityscape is changing fast with a large number of high buildings being developed.

Hence, motivation to study the effect of such high buildings on the dispersion of air pollutants.

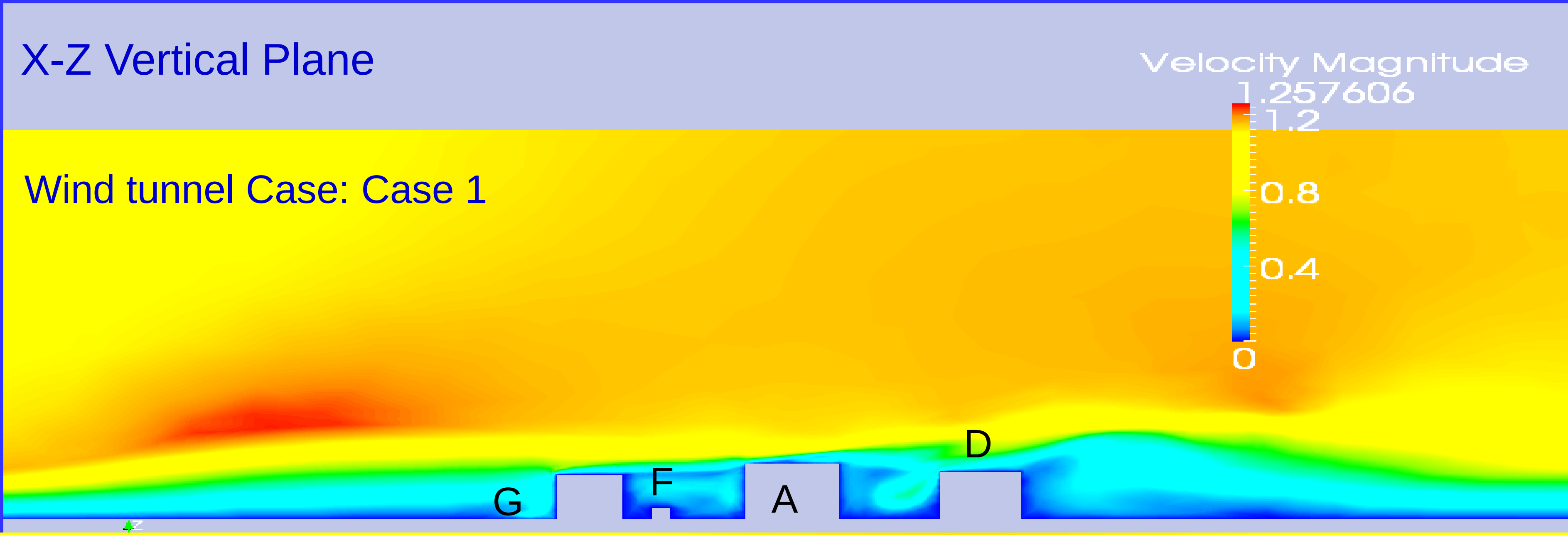


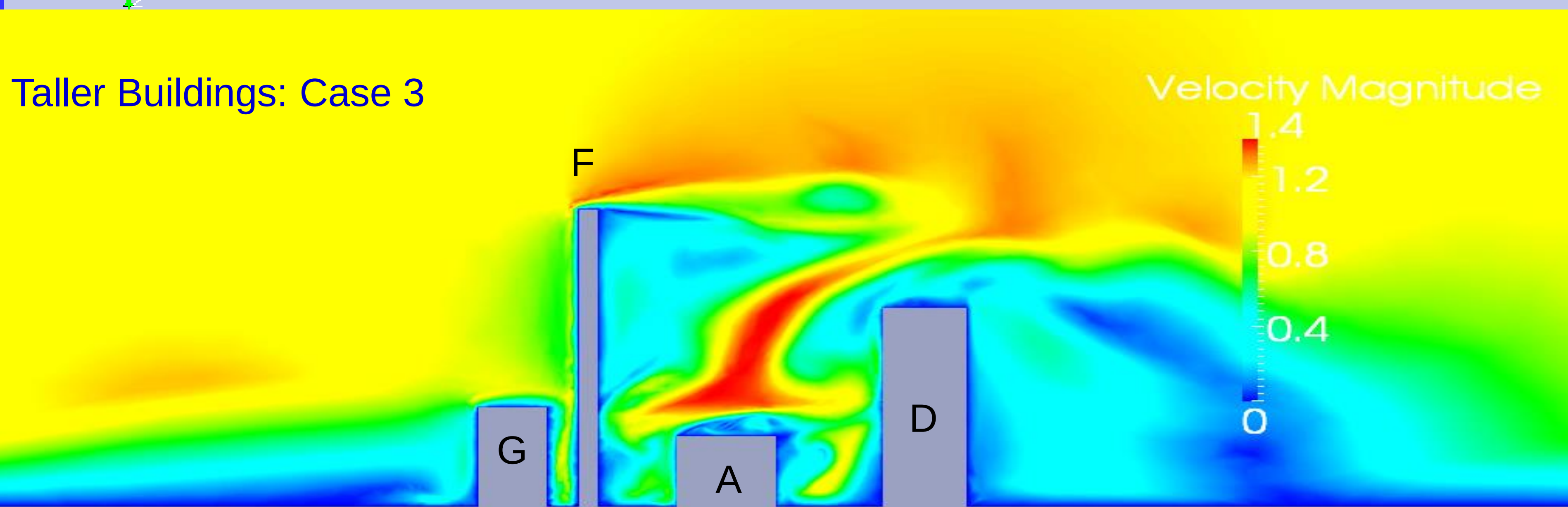
Capturing the detailed turbulent flow field



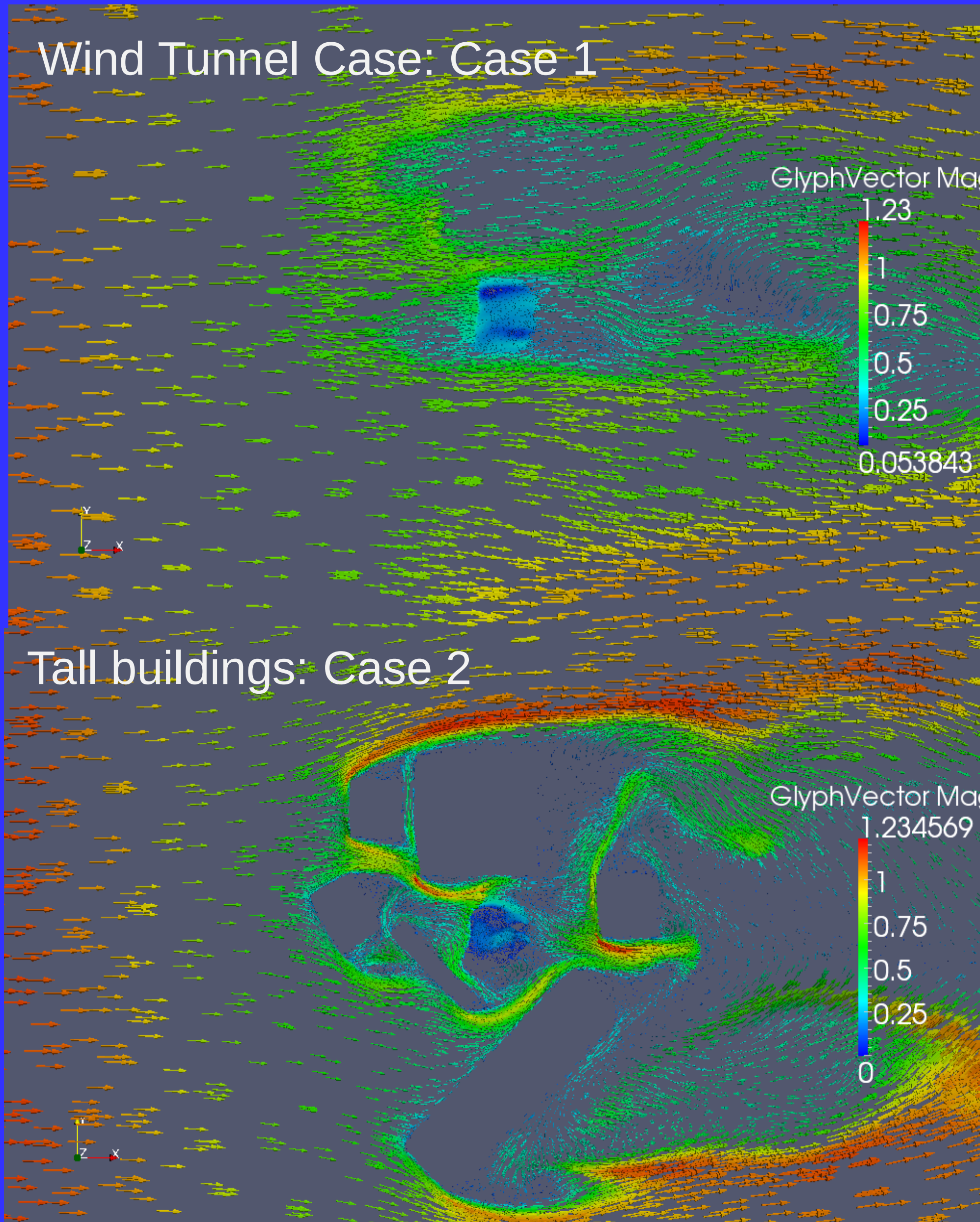
Detailed turbulent flow field near the top

Building Height effect on Velocities

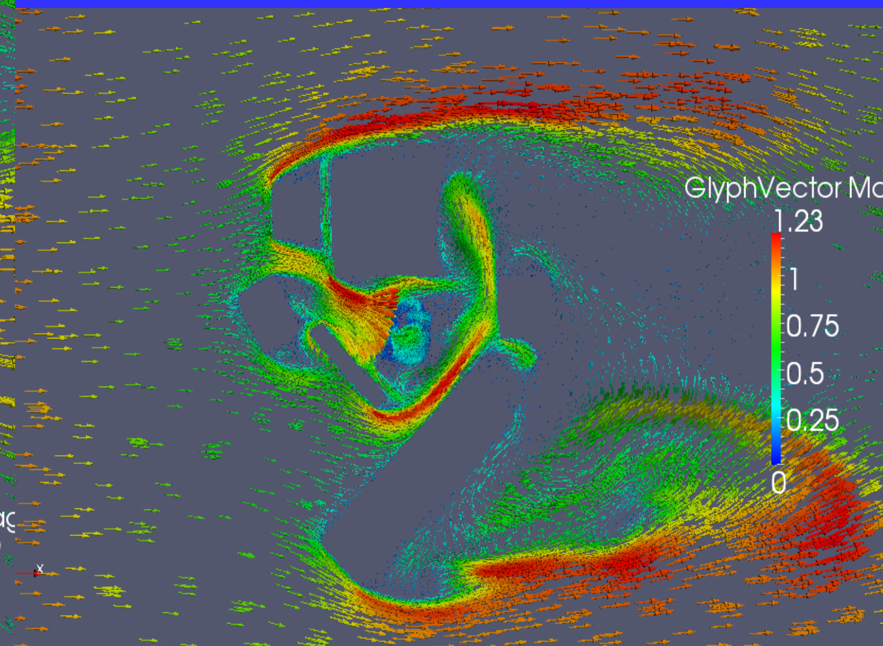




Effect of Building Height on Velocities

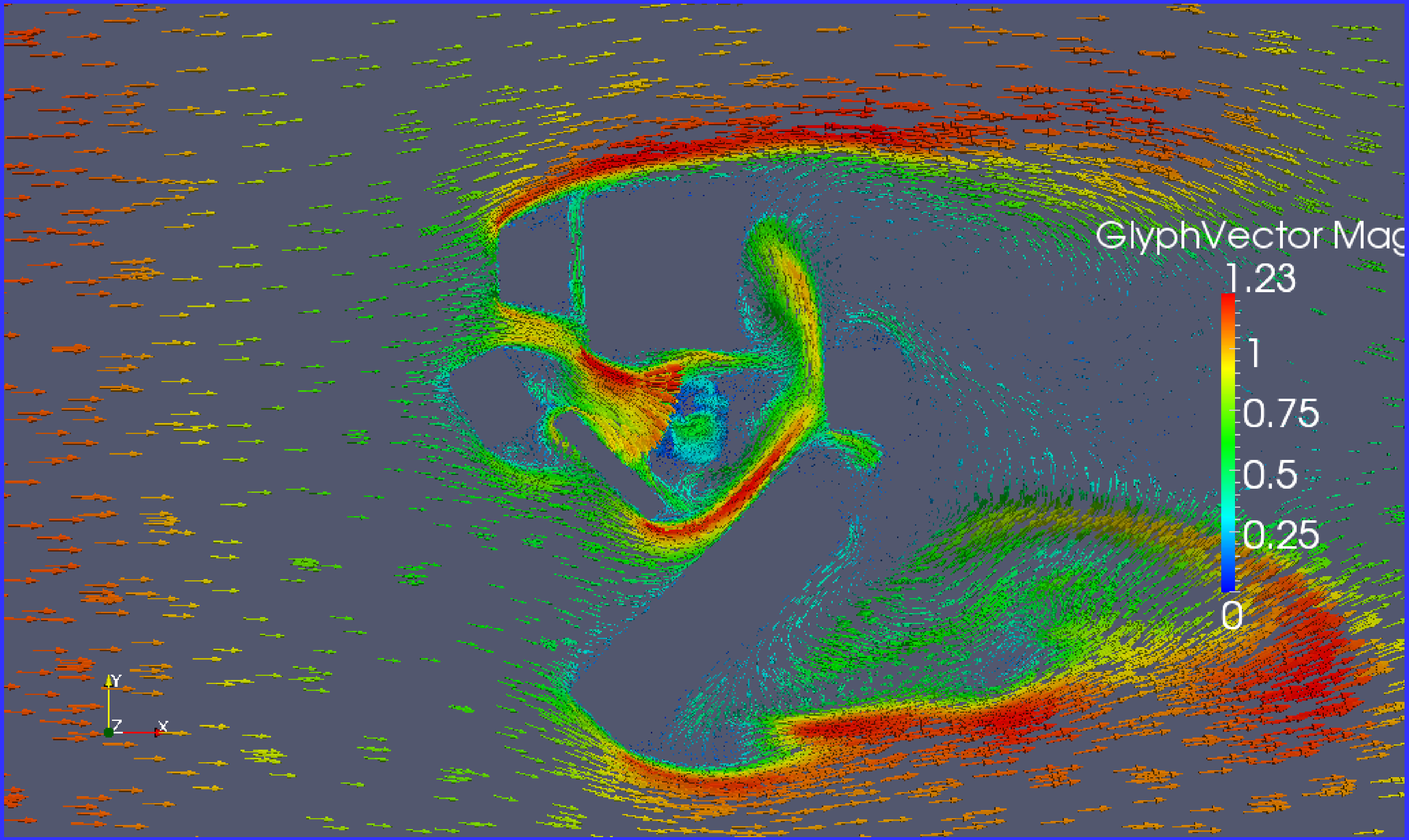


Horizontal X-Y plane
at Source Height

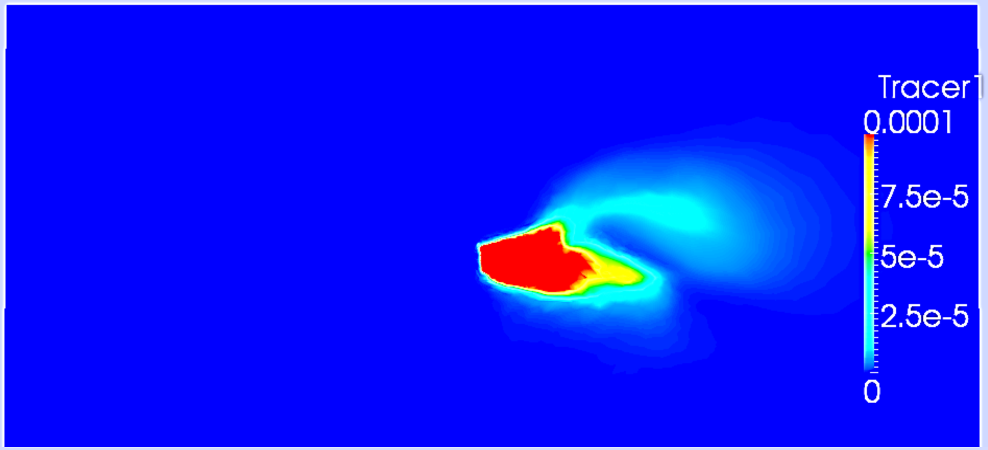


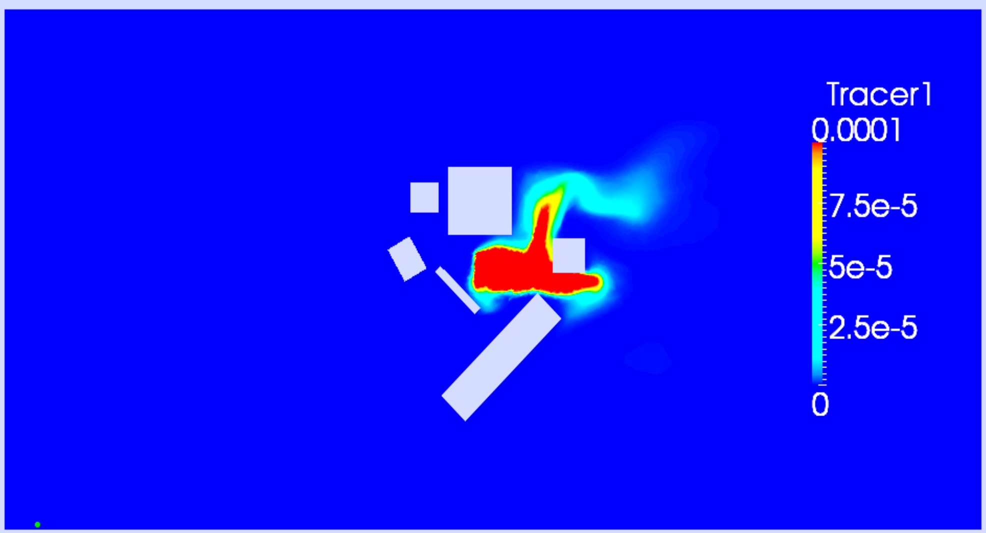
Taller buildings: Case 3

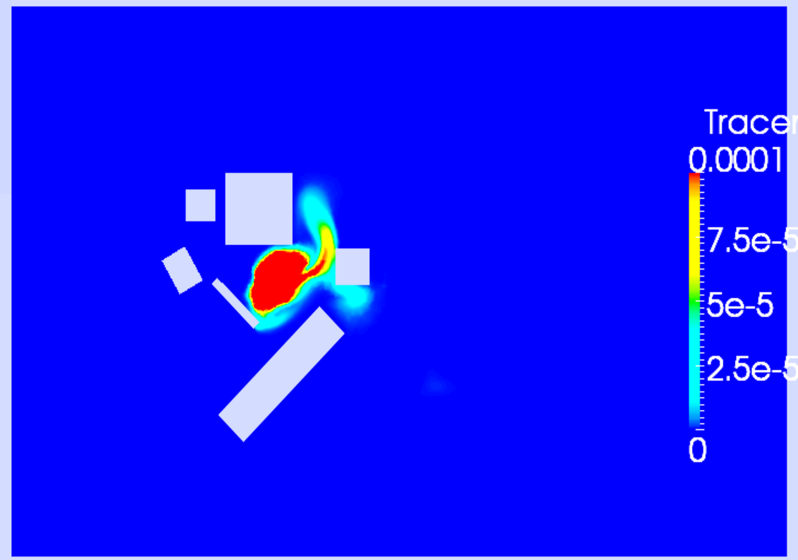
…and to do justice to the results: a clearer image for Case 3



Effect of the instantaneous flow field on dispersion

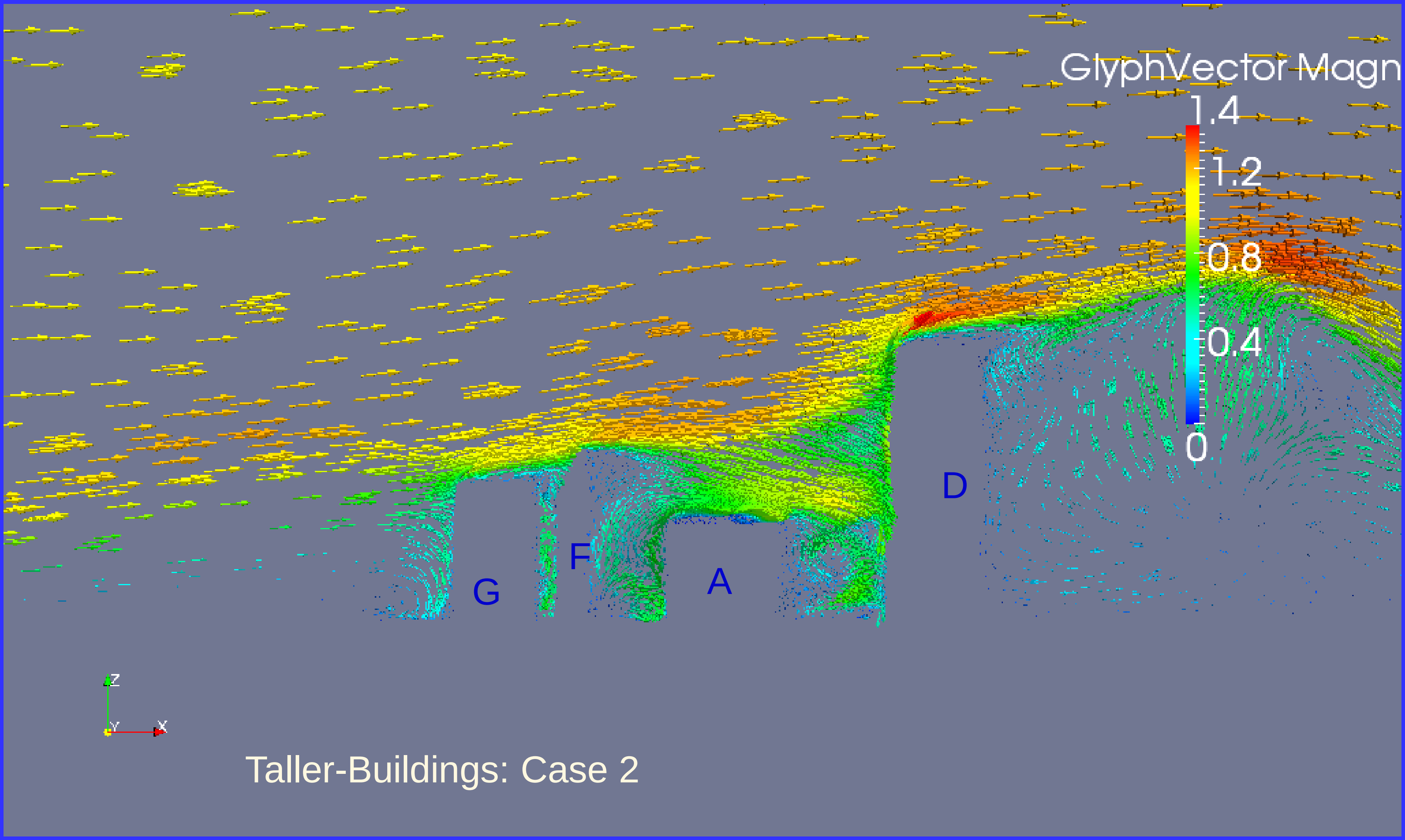






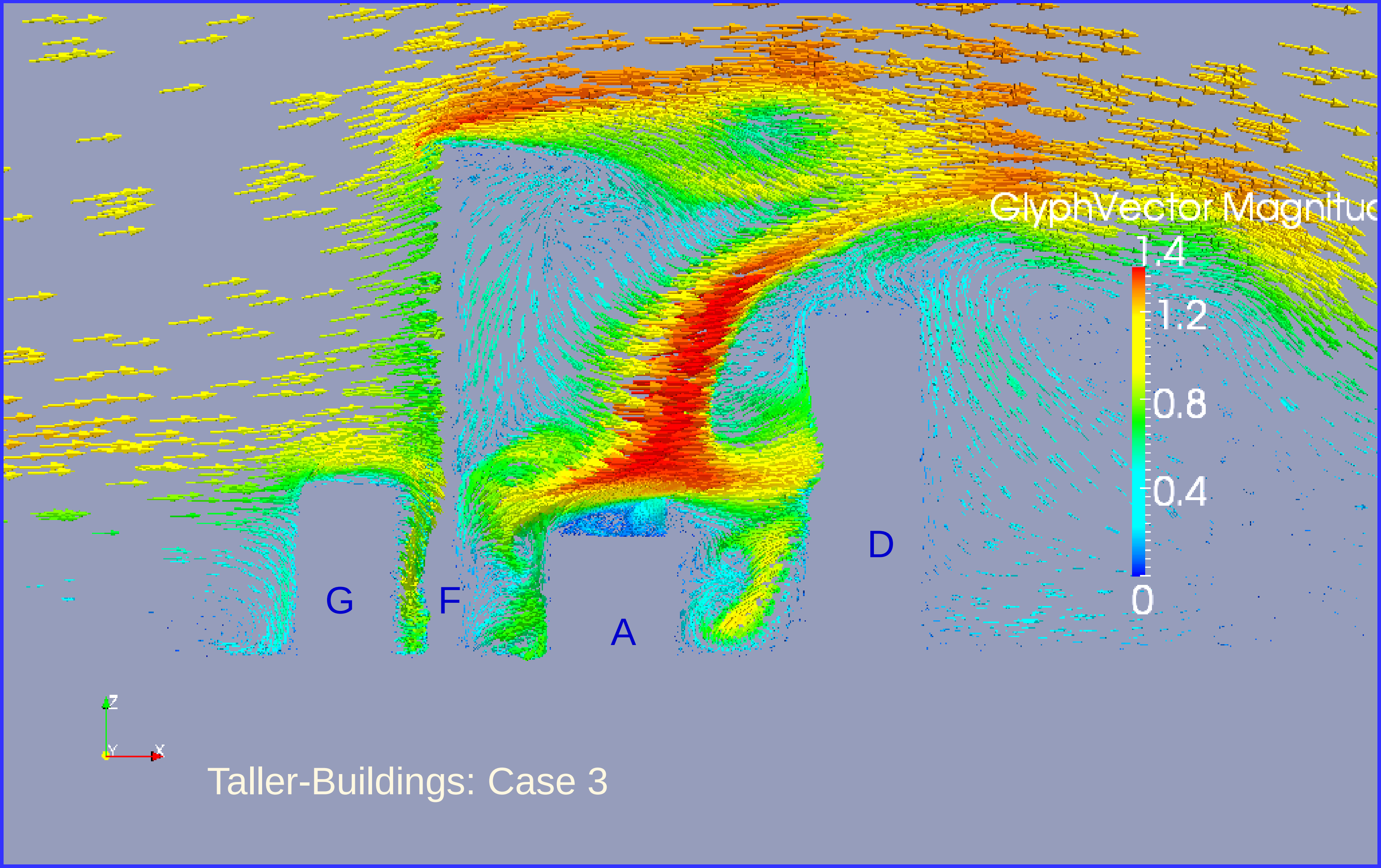
Building Height effect on Velocity Vectors

X-Z Vertical Plane



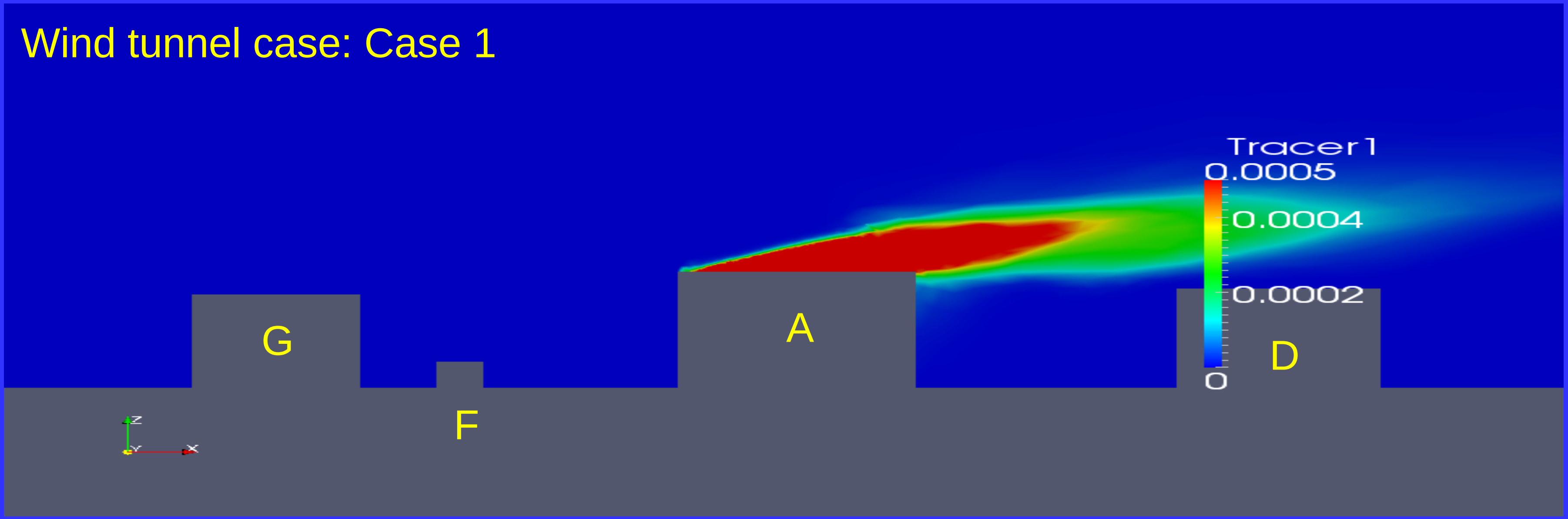
Effect of Building Height on the Turbulent flow field

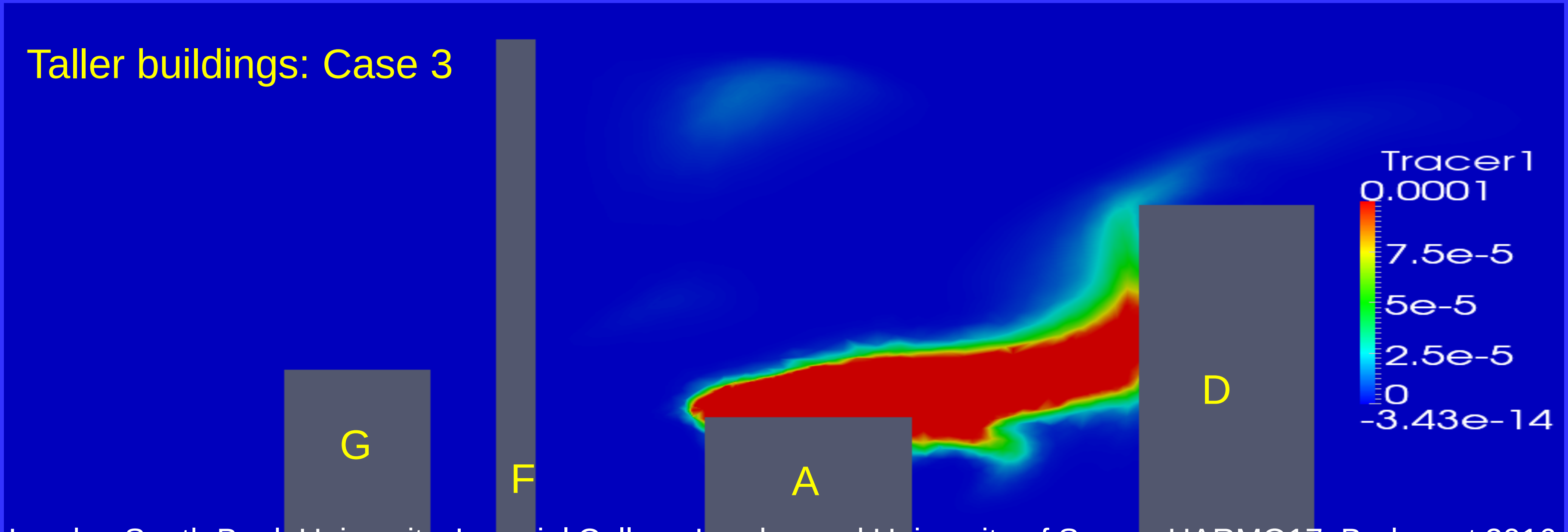
X-Z Vertical Plane



Building Height effect on Tracer Dispersion

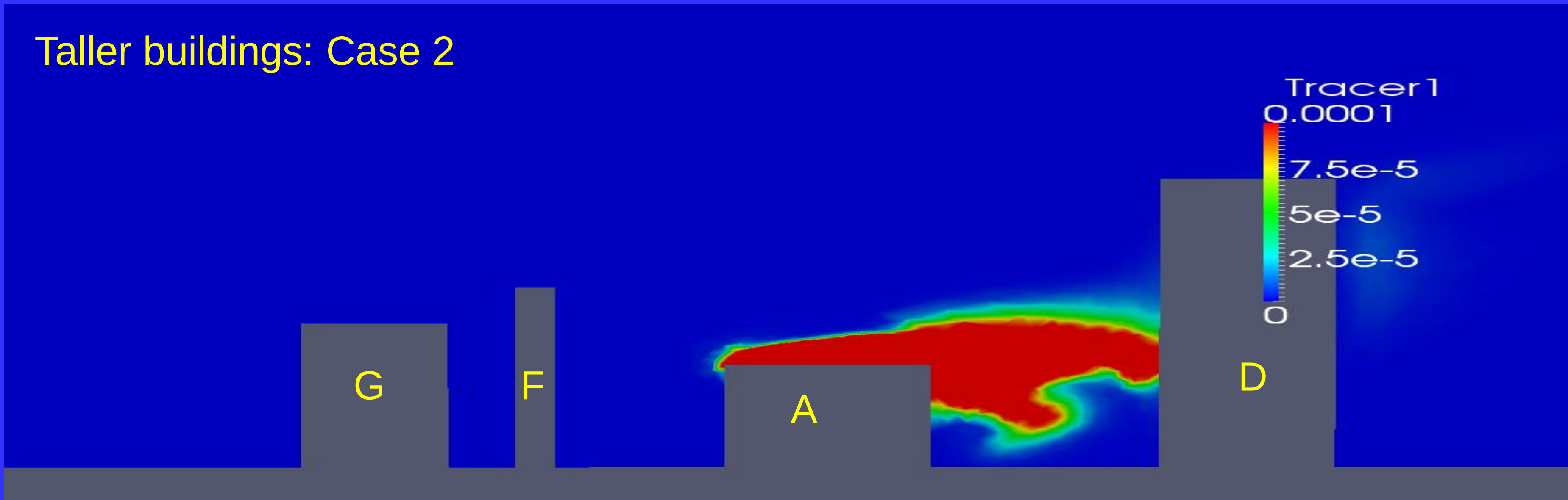
X-Z Vertical Plane

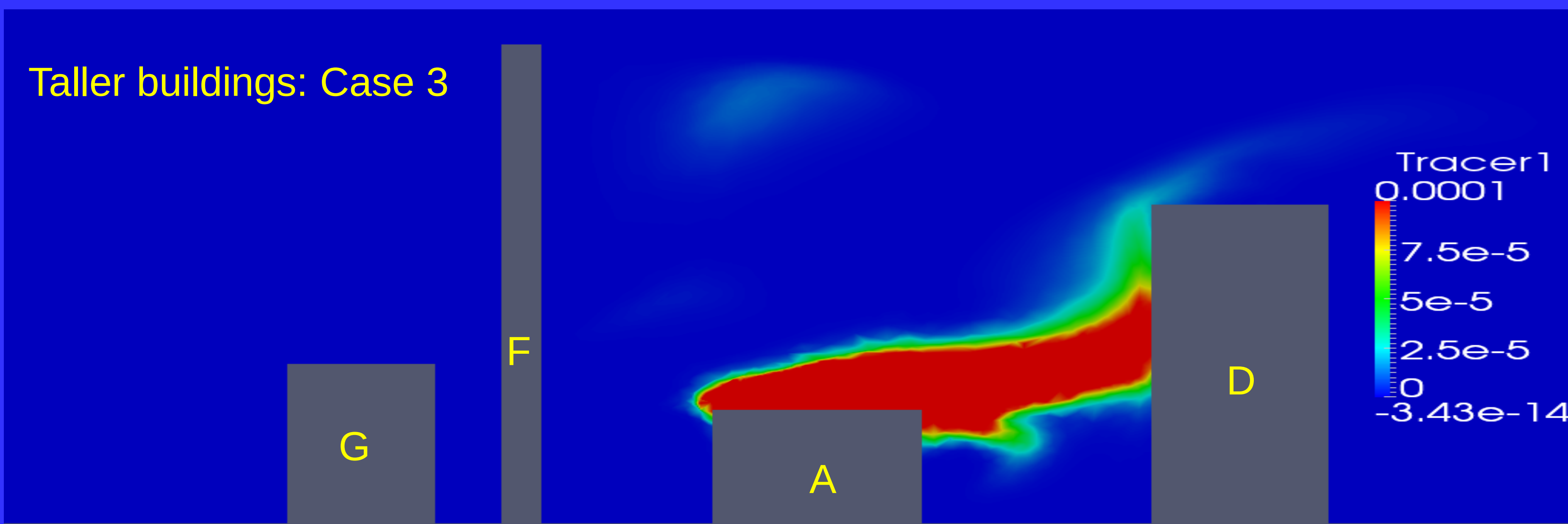




Building Height effect on Tracer Dispersion

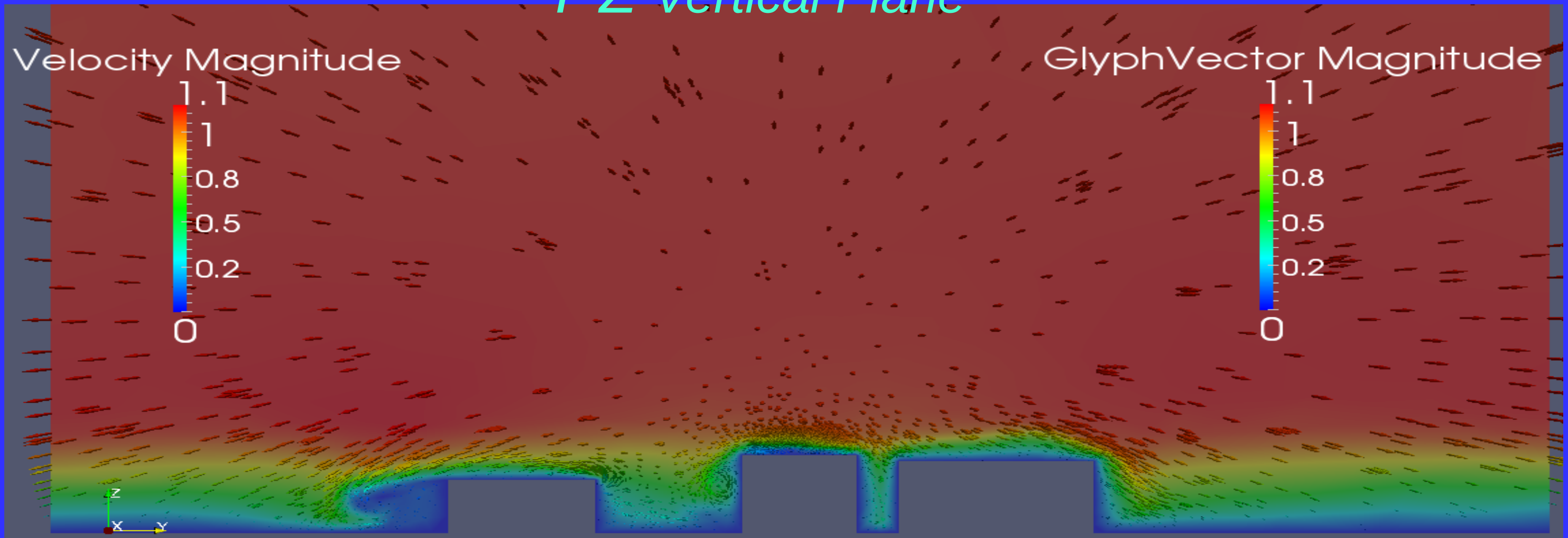
X-Z Vertical Plane



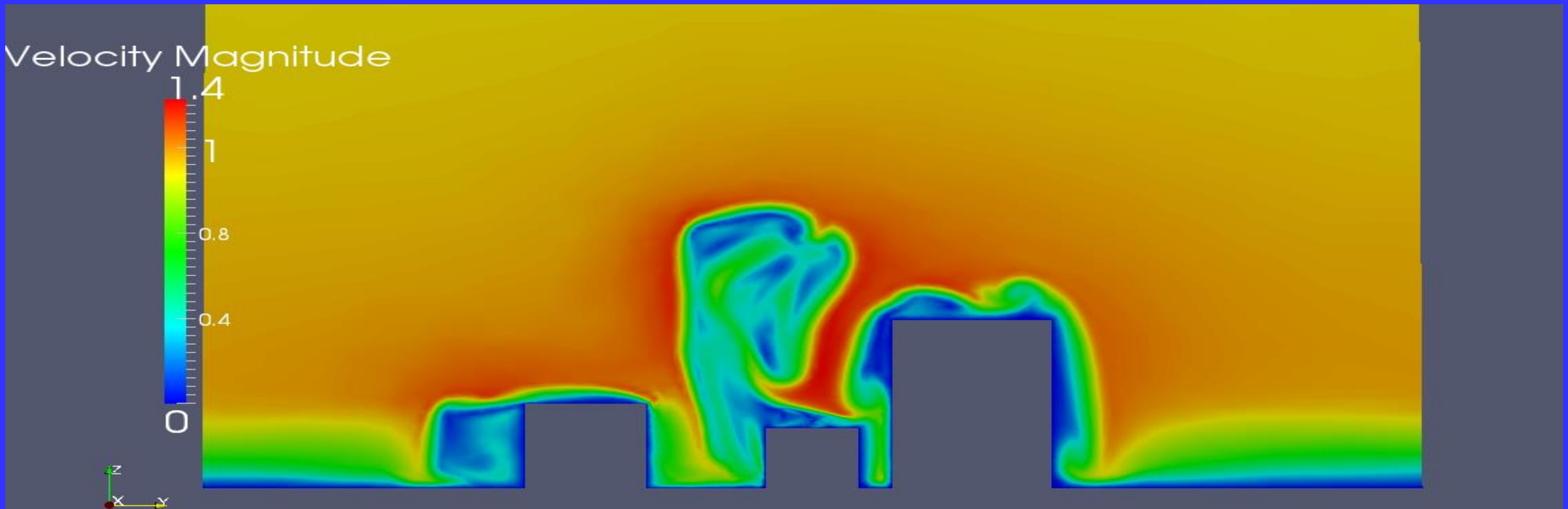


Effect of Building Height on the Turbulent flow field

Y-Z Vertical Plane



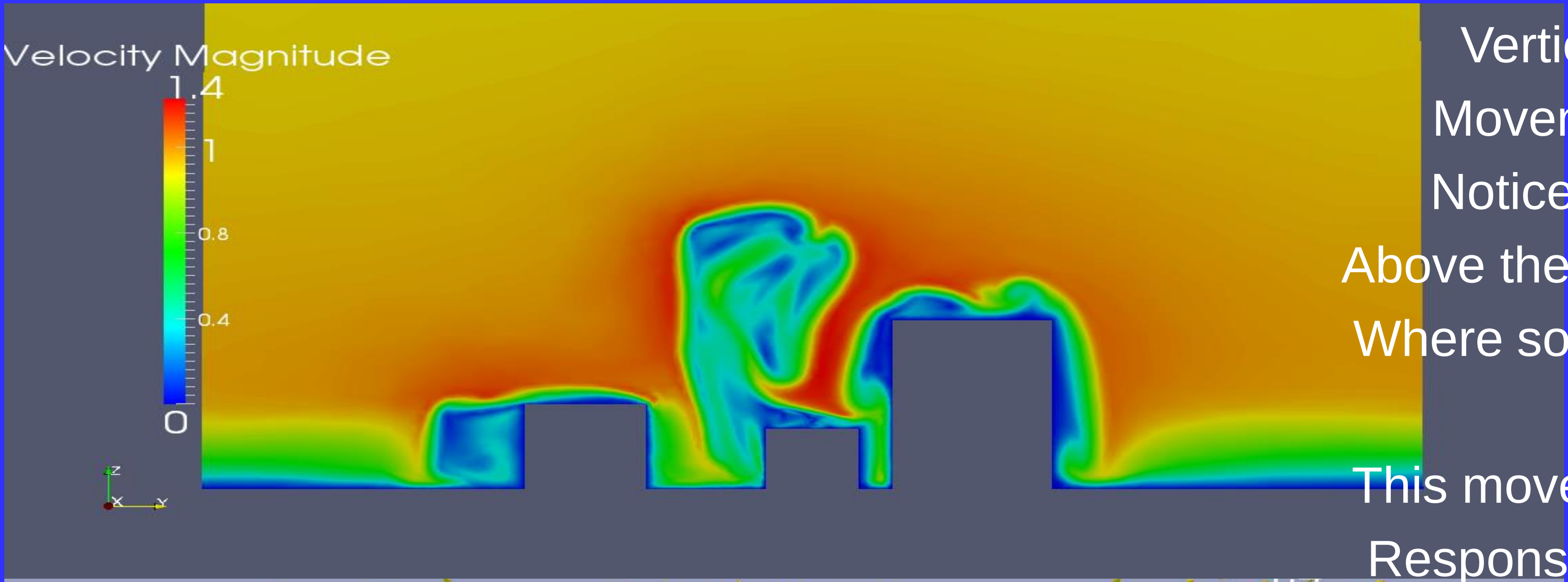
Wind tunnel case: Case 1

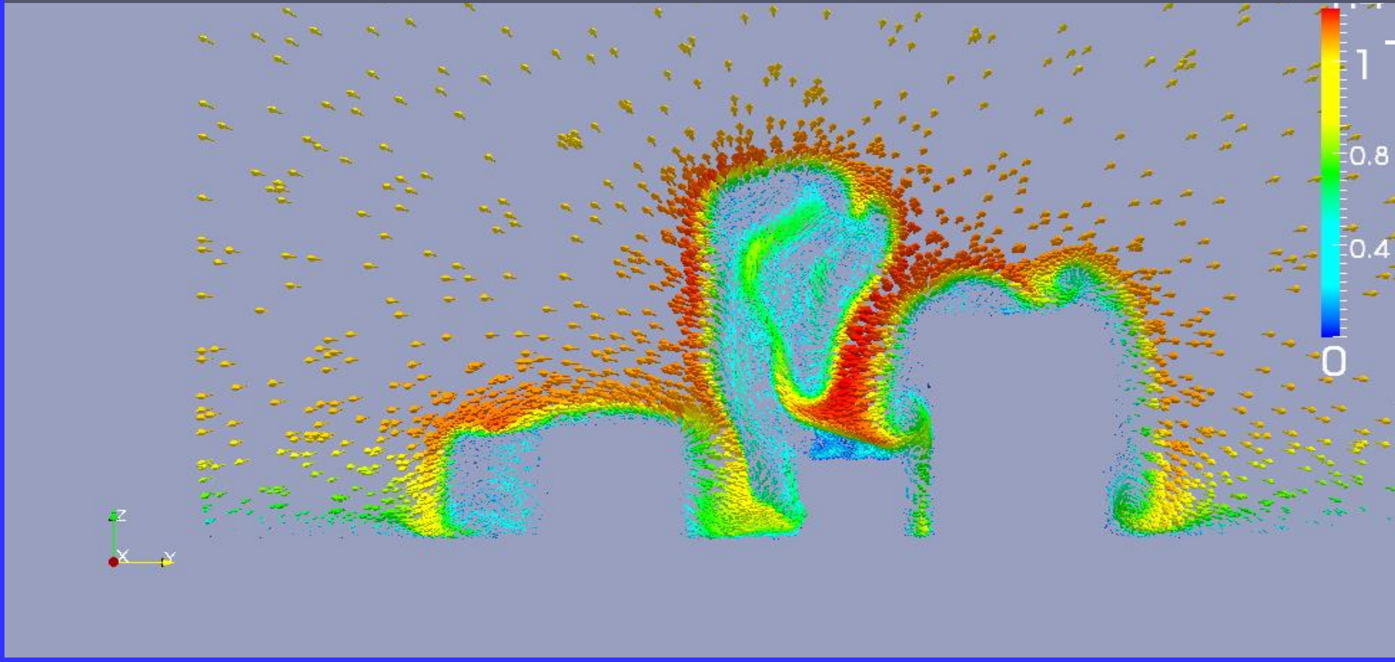


Taller Buildings: Case 3

Velocity contours and Velcocity vectors

Y-Z plane



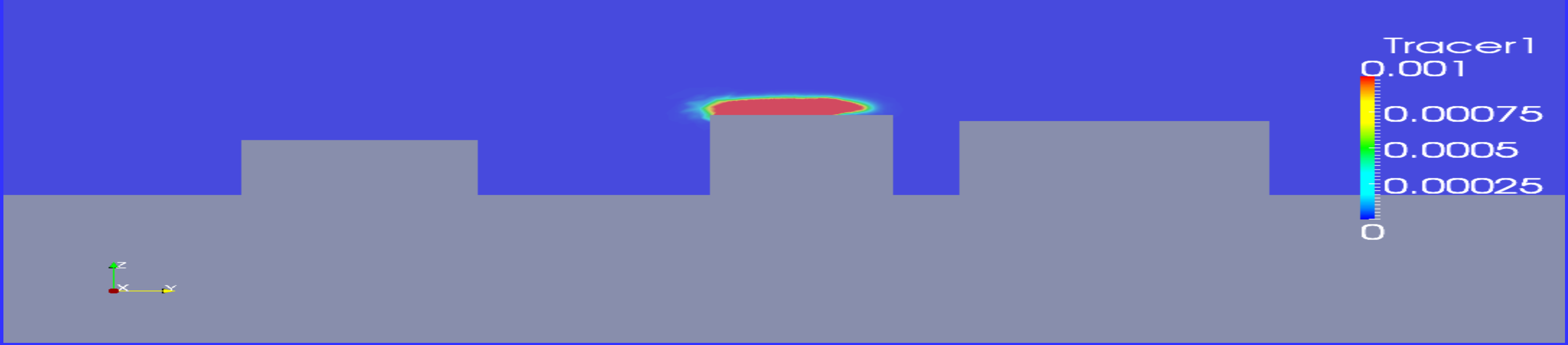


Vertical
Movement
Noticeable
Above the building
Where source is.

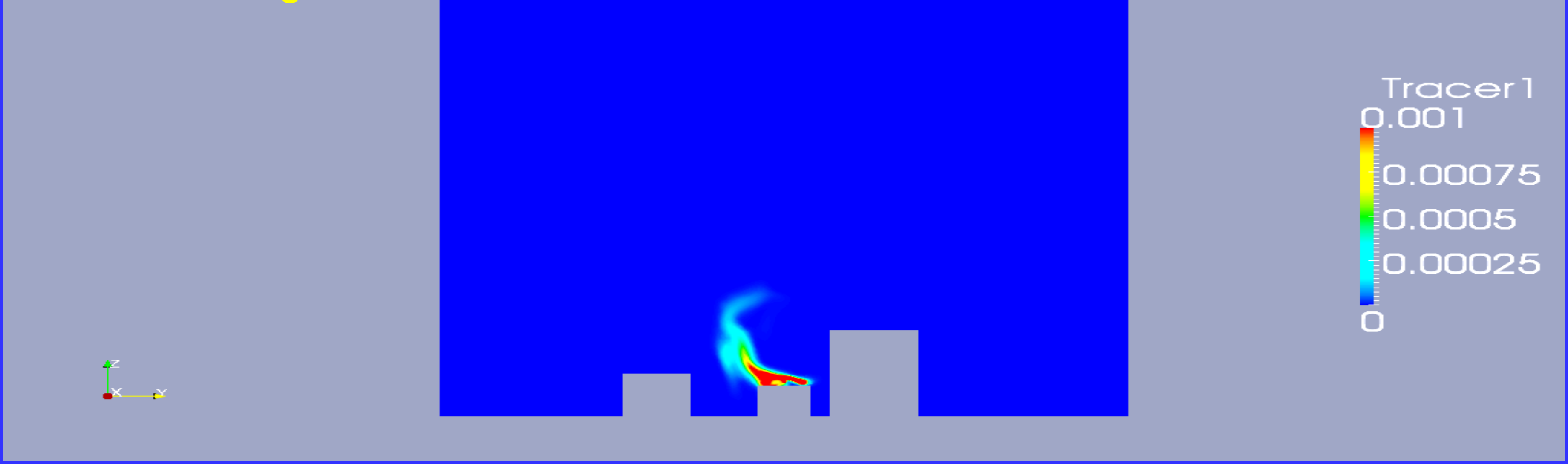
This movement is
Responsible for
The upward lifting of
The pollutant, seen
In the next slide.

Effect on Dispersion : *Y-Z Vertical Plane*

Wind tunnel case: Case 1



Taller Buildings: Case 3



Summary/Conclusions

- Validation still in progress but so far very promising

- At the micro-scale levels, detailed CFD modelling with high resolution meshes is very important in determining path of contaminants

- Optimal building design/height (in particular): CFD can show some unexpected outcomes – as Case 3 showed.

Thank you for your attention

Acknowledgements

Although of course already as co-authors on this work, still special thanks to:

- *Prof Christopher Pain:* for the development of the FLUIDITY, without whose support this innovative mesh-adaptive CFD work could not be achieved.
- *Prof Alan Robins*: for the provision of the wind tunnel data and fruitful discussions on their interpretation.
- *My two past Master students at LSBU:* (i) Carlos Andres Bernal Castro, for the set-up of the Walkie-Talkie geometry and (ii) Luz Maria Valencia Boganegra for the wind-tunnel geometry.