The DAPPLE Dispersion Project: Comparison of full scale and wind tunnel experiments with CFD

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Acknowledgements to:
DAPPLE Consortium members
John Lally, Westminster City Council, BT

University of Reading

EPSRC
Engineering and Physical Sciences Research Council

Urban pollution dispersion depends on complex flow patterns around streets and intersections

DAPPLE

Arnold et al. 2004, STOTEN

Dispersion of Air Pollutants and their Penetration into the Local Environment

dapple

London-based research projects

DAPPLE (2002-2009) – street level dispersion

REPARTEE (2006-2007) – vertical pollutant distribution

ACTUAL (2009-2014) – building design interactions with urban climate at a range of scales

ClearfLo (2010-2013) – air quality at city scale

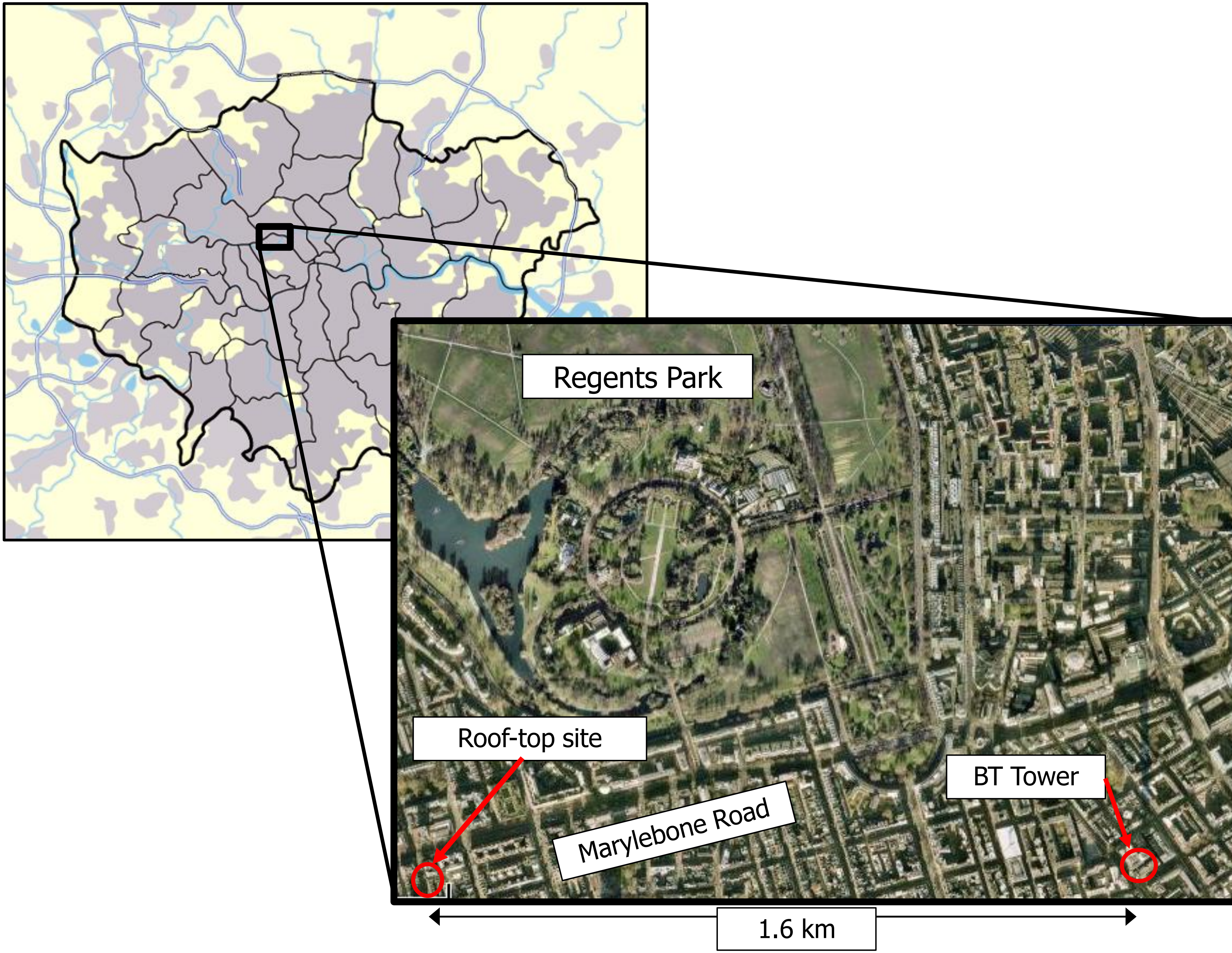
DAPPLE I (2002-06) Main Activities

- Traffic movement
- Emissions
- Pollutant monitoring (CO, NOx, CO2...)
- Wind and meteorology
- Urban tracer studies (3xPFCs, SF_6)
- Wind tunnel modelling
- Computer modelling (LES -> empirical)
- Personal exposure rate measurement (location, CO, fine particles)
- Analysis -> Practical outputs -> knowledge transfer

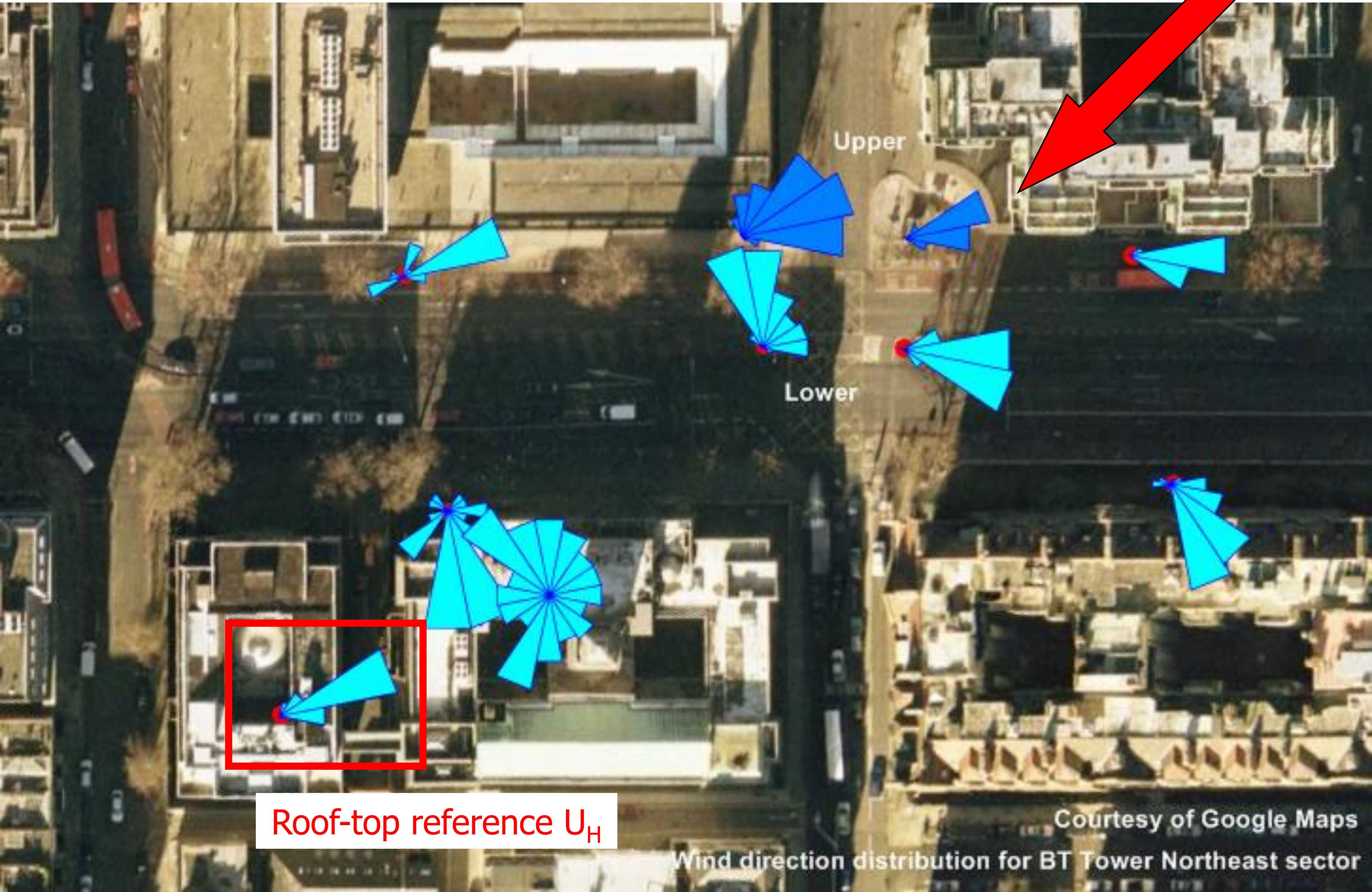
Consortium leader: Prof Alan Robins, Uni of Surrey

Reading, Leeds, Imperial, Bristol, Cambridge

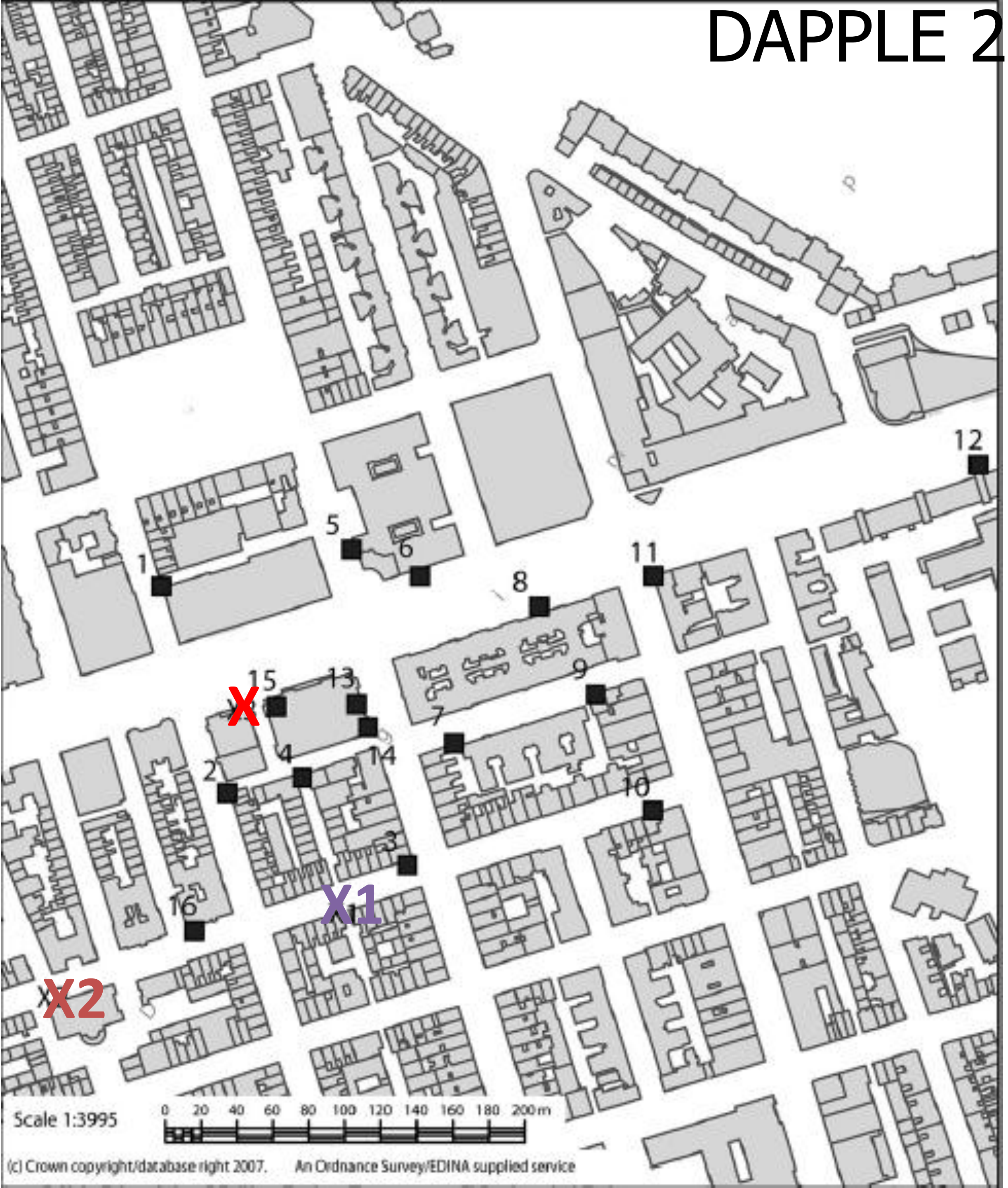
www.dapple.org.uk


Regents Park
Roof-top site
Marylebone Road
BT Tower
1.6 km

2004 campaign
BT Tower NE wind direction



DAPPLE 2004 tracer release

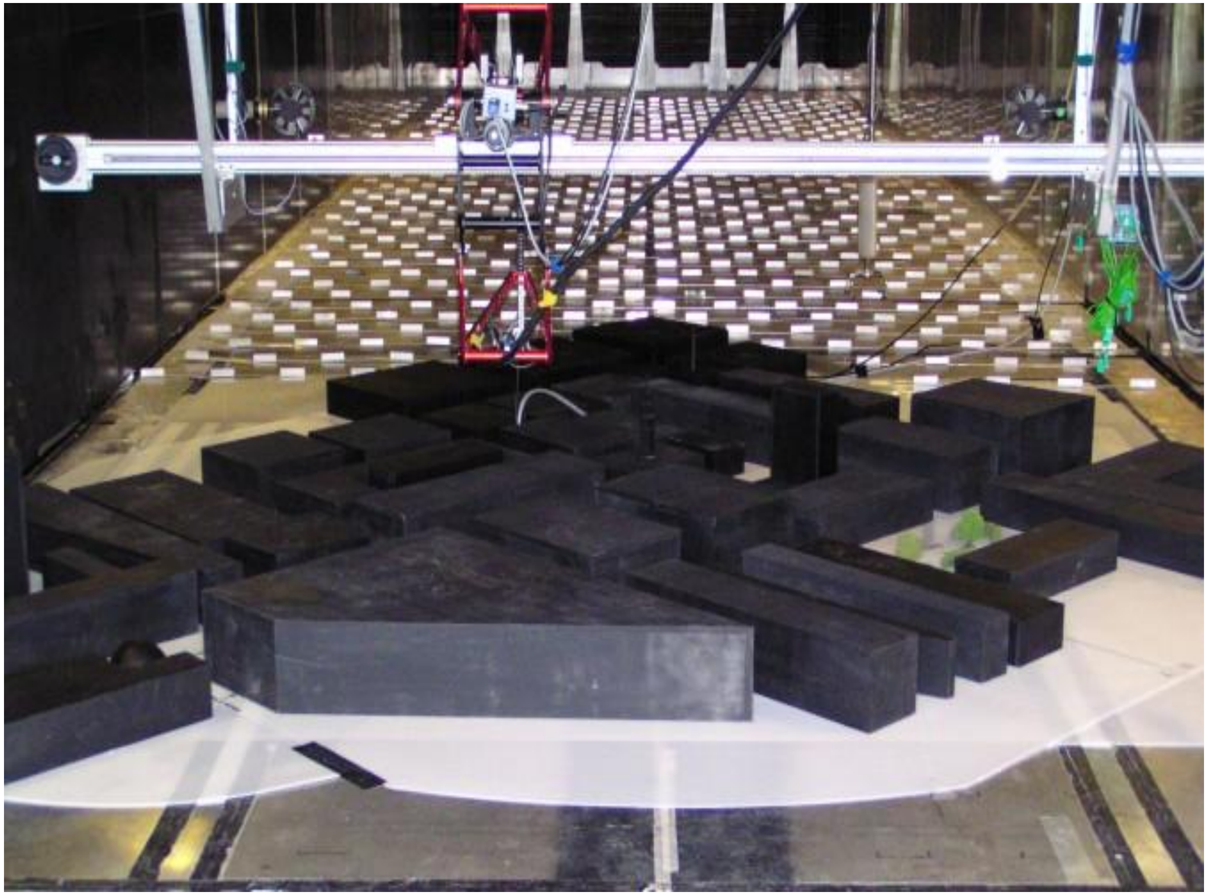


Release: 2m, 15 min. 2 from X1.

Samples: 1.5m, 30 min

- 15: inside WCC
- 13: rooftop, 14: street (1.5m)

DAPPLE wind tunnel work (Prof Alan Robins, EnFlo)



- Scale 1:200
- Reference wind speed: U_r =2.5m/s
- Extensive tracer releases, flow measurements

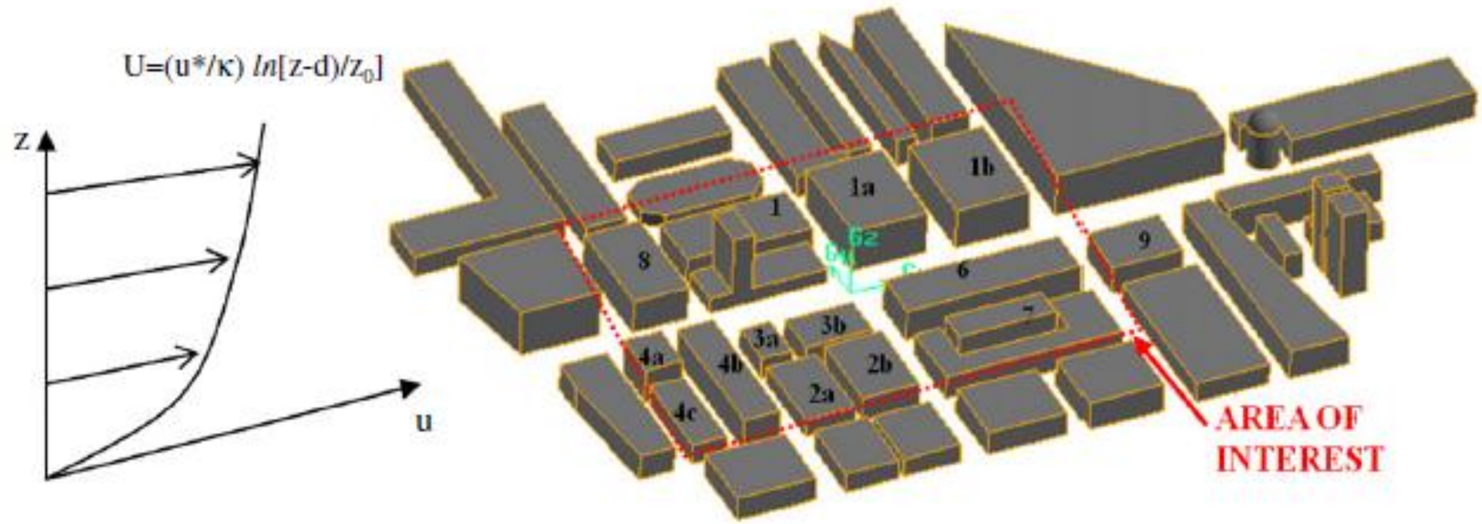
Three DAPPLE CFD studies

Panagiotou I, Neophytou MKA, Hamlyn D, Britter RE (**2013**) City breathability as quantified by the exchange velocity and its spatial variation in real inhomogeneous urban geometries, STOTEN, 442, 466-477

Xie Z-T, Castro IP (**2009**) Large-eddy simulation for flow and dispersion in urban streets, Atmos. Env., 42(13), 2174-2185

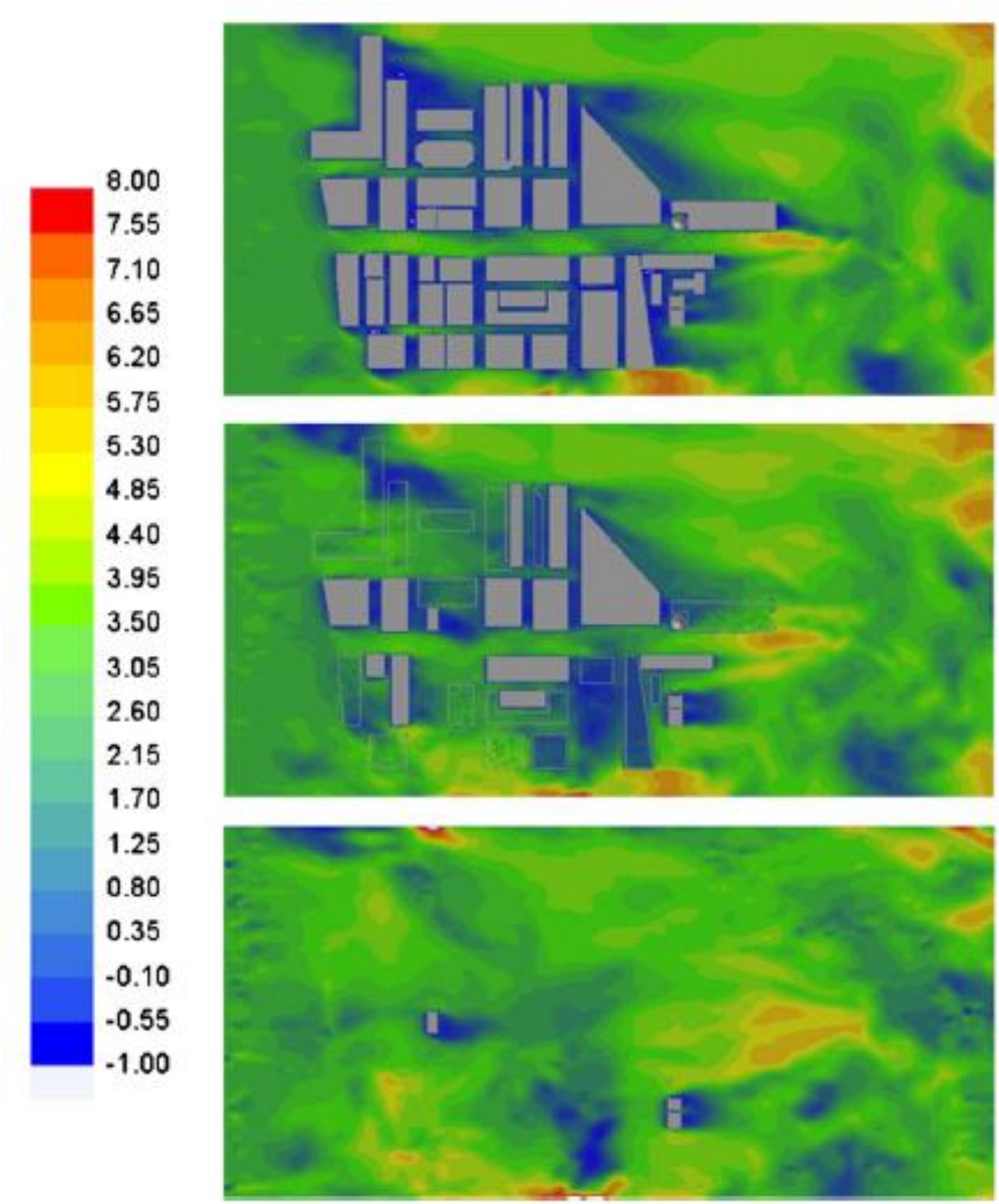
Xie Z-T (**2011**) Modelling street-scale flow and dispersion in realistic winds – towards coupling with mesoscale meteorological models, Boundary-Layer Meteorol., 141(1), 53-75

Panagiotou et al. 2013 – set-up



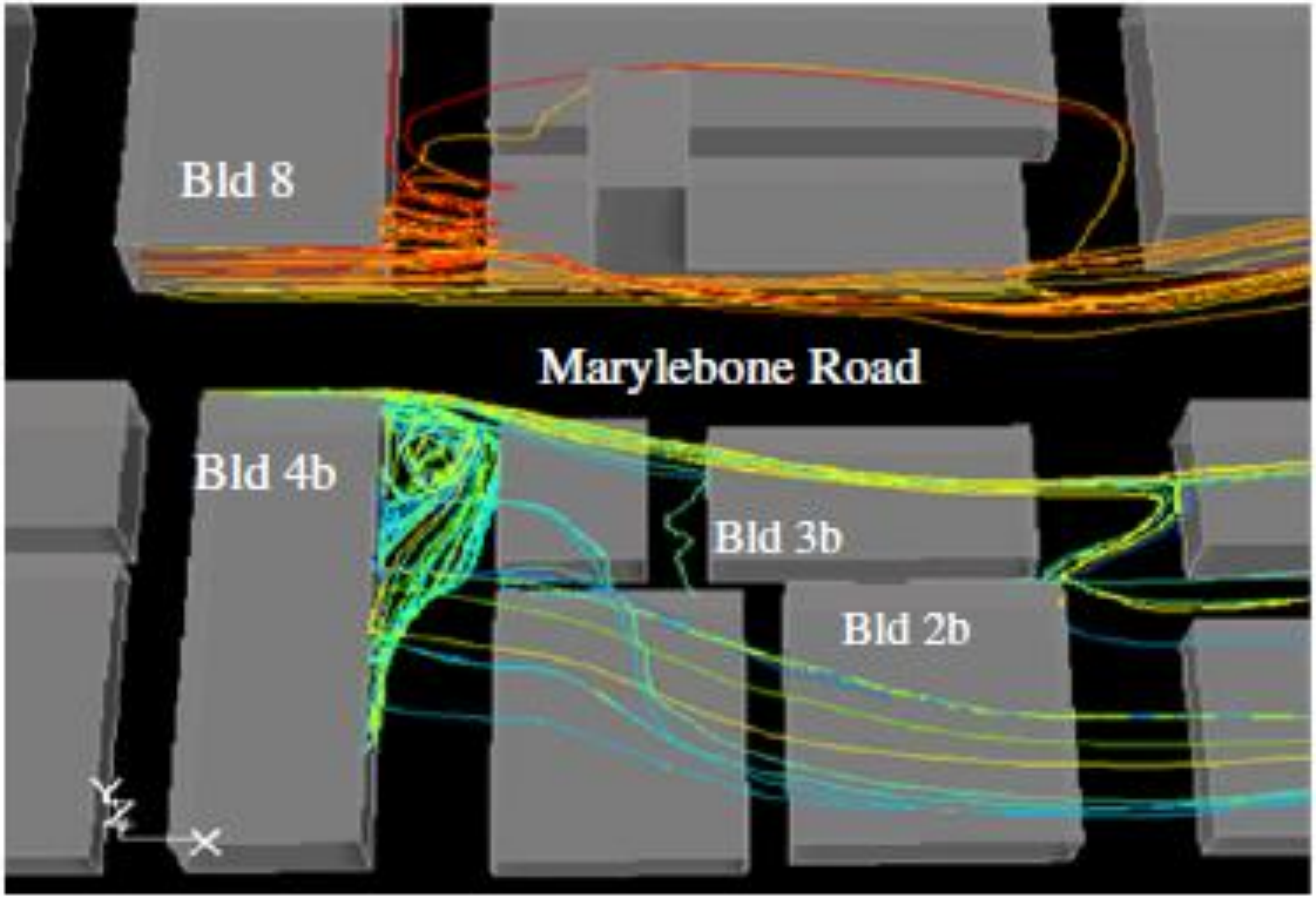
- RANS (FLUENT), with Reynolds Stress Turbulence model (permits anisotropic turb typical in obstacle wakes)
- 1:200 model; average building height H= 0.11m,
- Packing densities λ_f = 0.25, λ_p = 0.5

Panagiotou et al. 2013 – streamwise windspeed



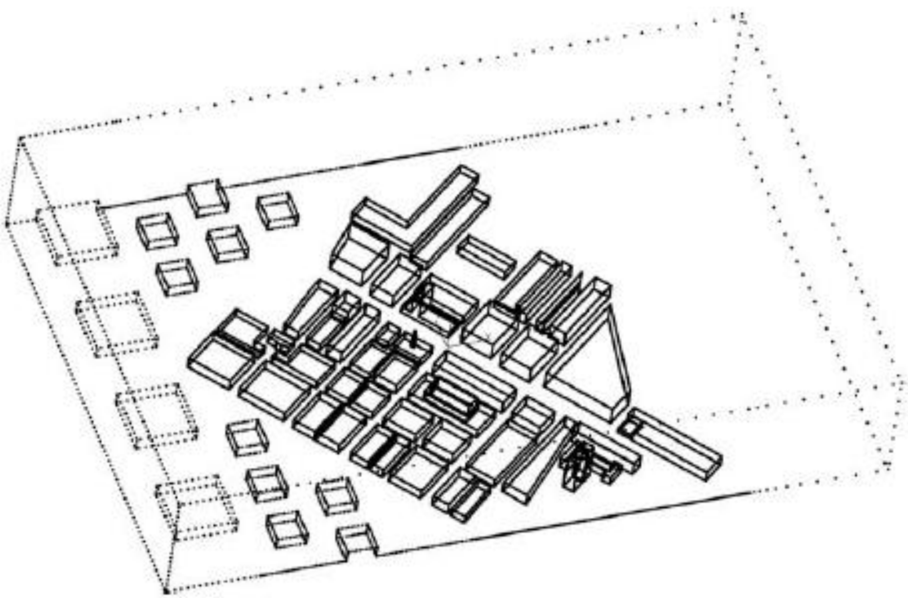
- z = H/2
- z = H
- z = 2H

Panagiotou et al. 2013 – particle visualisation



- Exchange of air between street and flow above
- Building scale vortices combined with along street channelling

Xie and Castro 2009 – set-up



- Polyhedral mesh

(nearwall H/15, c. 1m)

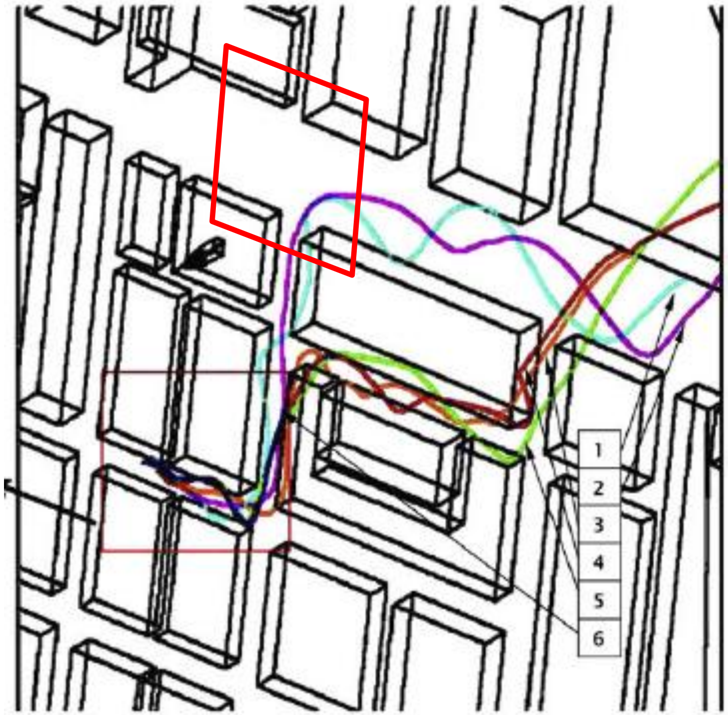
- Inlet:

Digital filter inlet condition, realistic lengthscales (Xie and Castro 2008);

Wind and stress profile matching windtunnel;

Periodic bo. co.'s did not give accurate results!

Xie and Castro 2009 – urban flow features



- Separation not captured using k-ε (not shown)

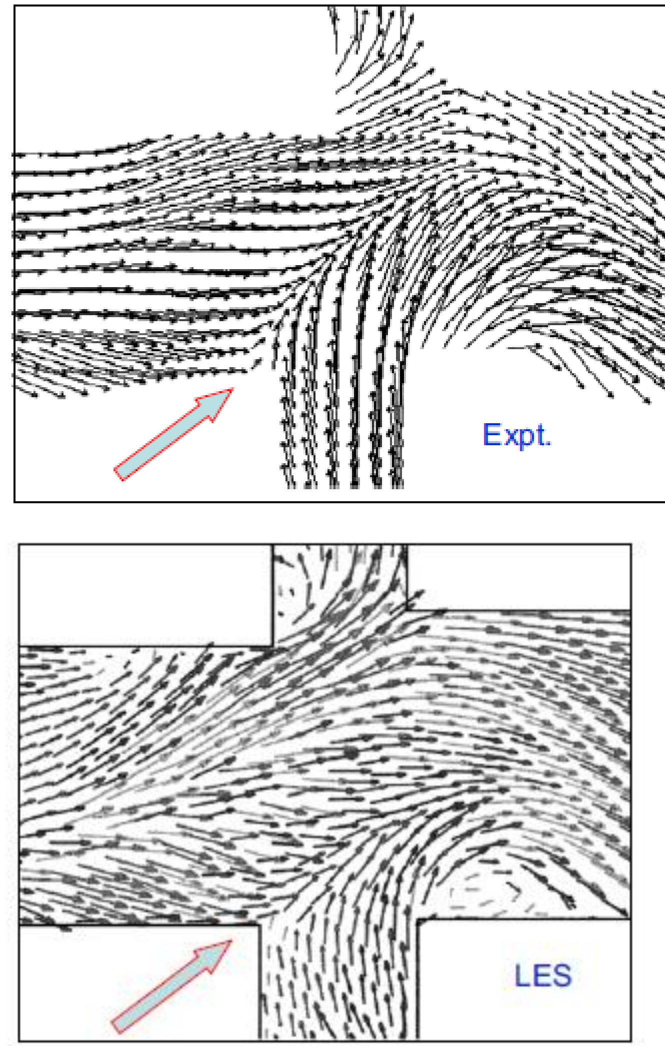
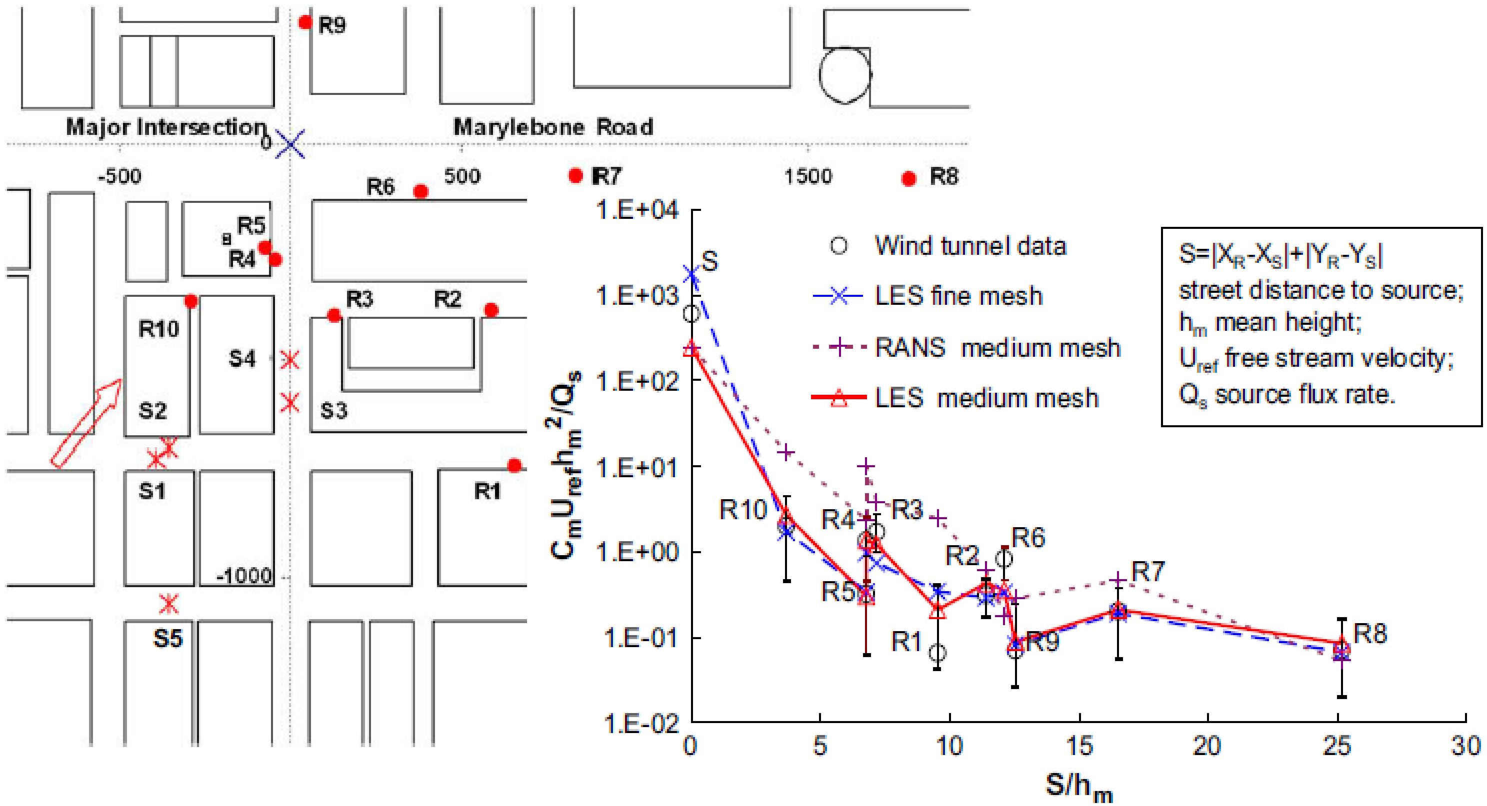


Fig. 7. Time-mean velocity vectors at $z = 0.23h_m$ on the major intersection.

Xie and Castro 2009 – tracer concentrations

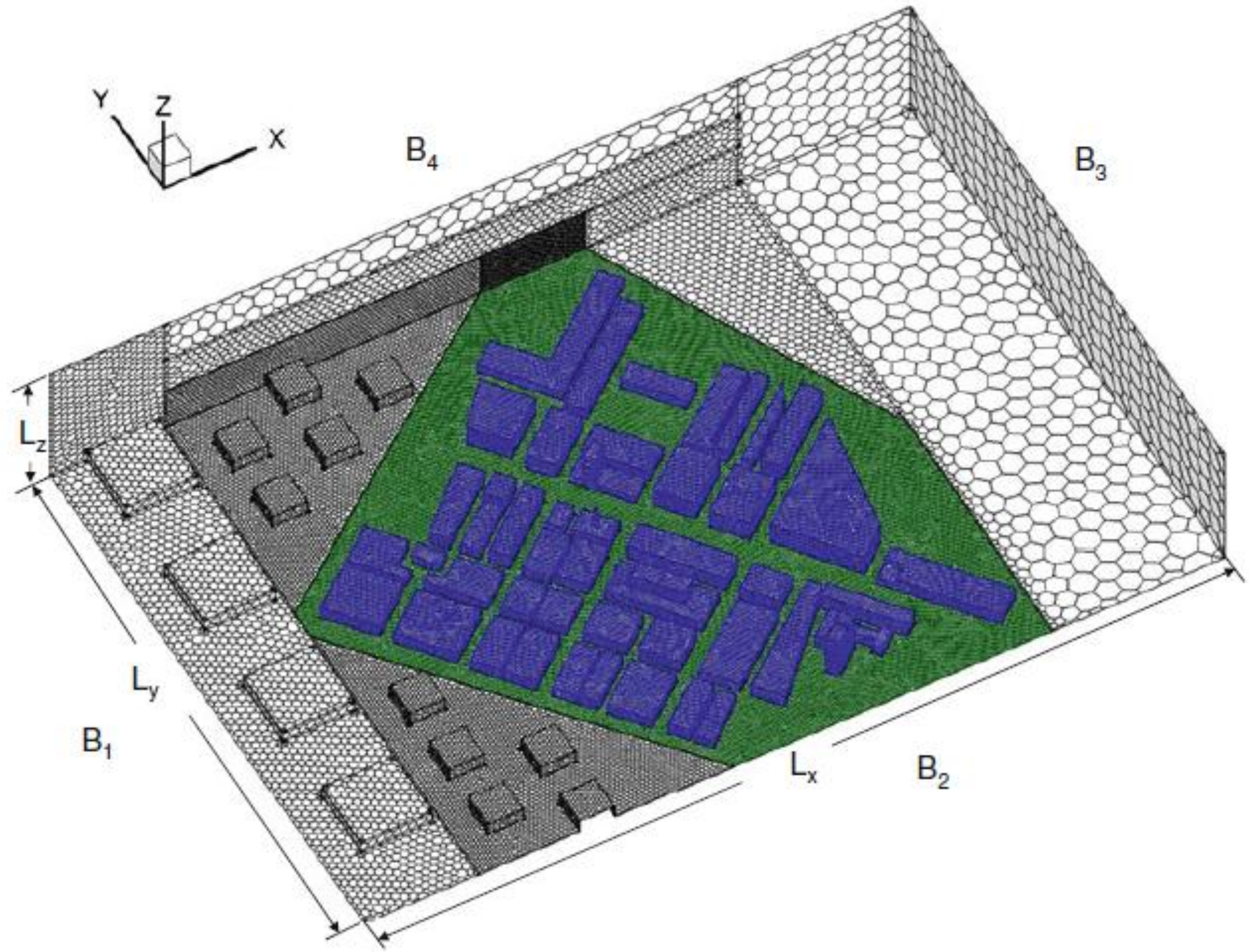


- Excellent agreement with windtunnel
- RANS overestimates street level concentrations

Xie 2011 “Modelling street-scale flow and dispersion in realistic winds – towards coupling with mesoscale meteorological models”

- Deriving realistic, large-scale varying inlet conditions using observed winds on BT Tower

Xie 2011 - mesh



- Inlet varies according to varying wind direction

Xie 2011 – BT Tower wind data

- 15 min tracer release at fullscale from 16:30
- 30 min sample from 16:30 to 17:00
- 10 Hz data in 30 second averages from BT Tower

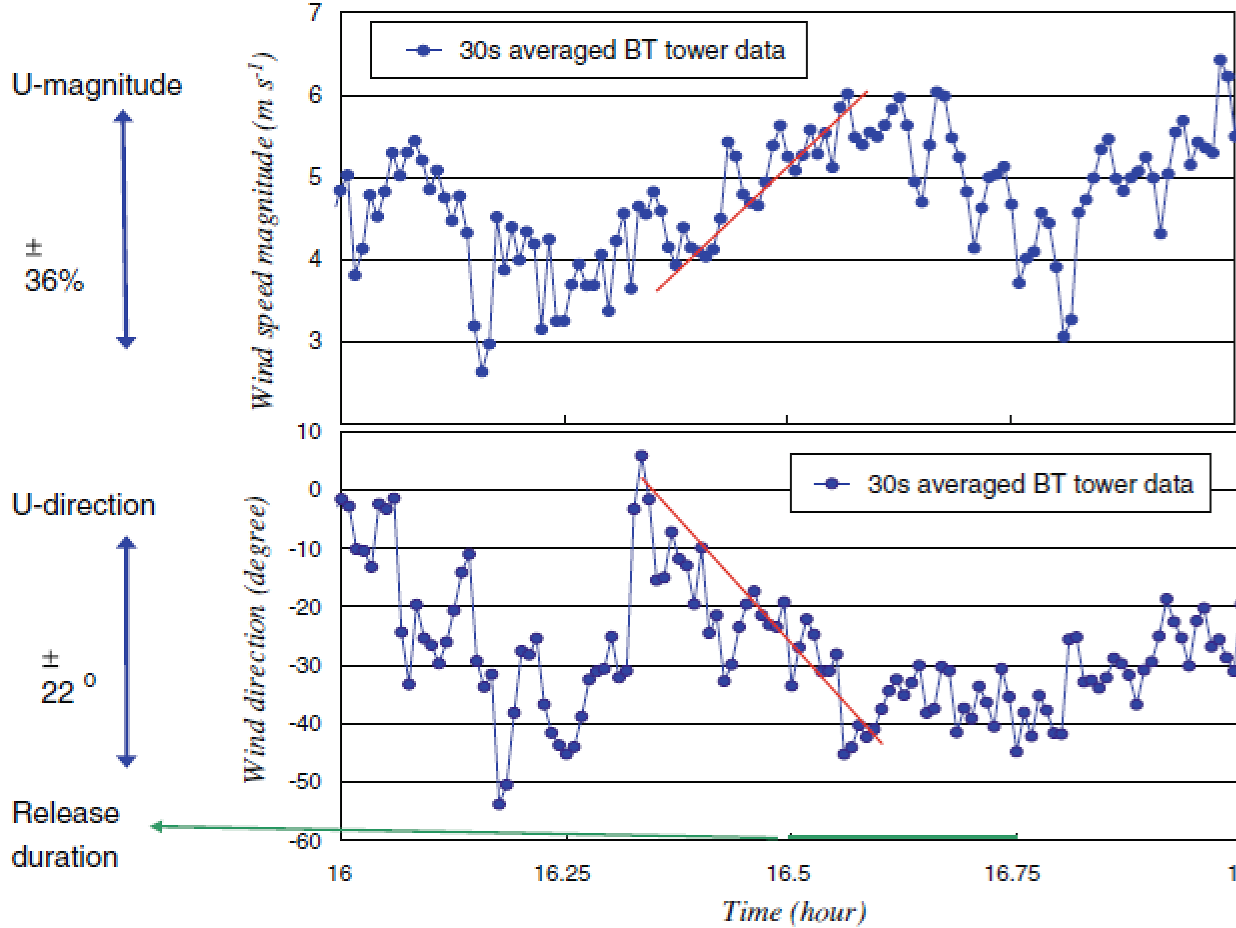
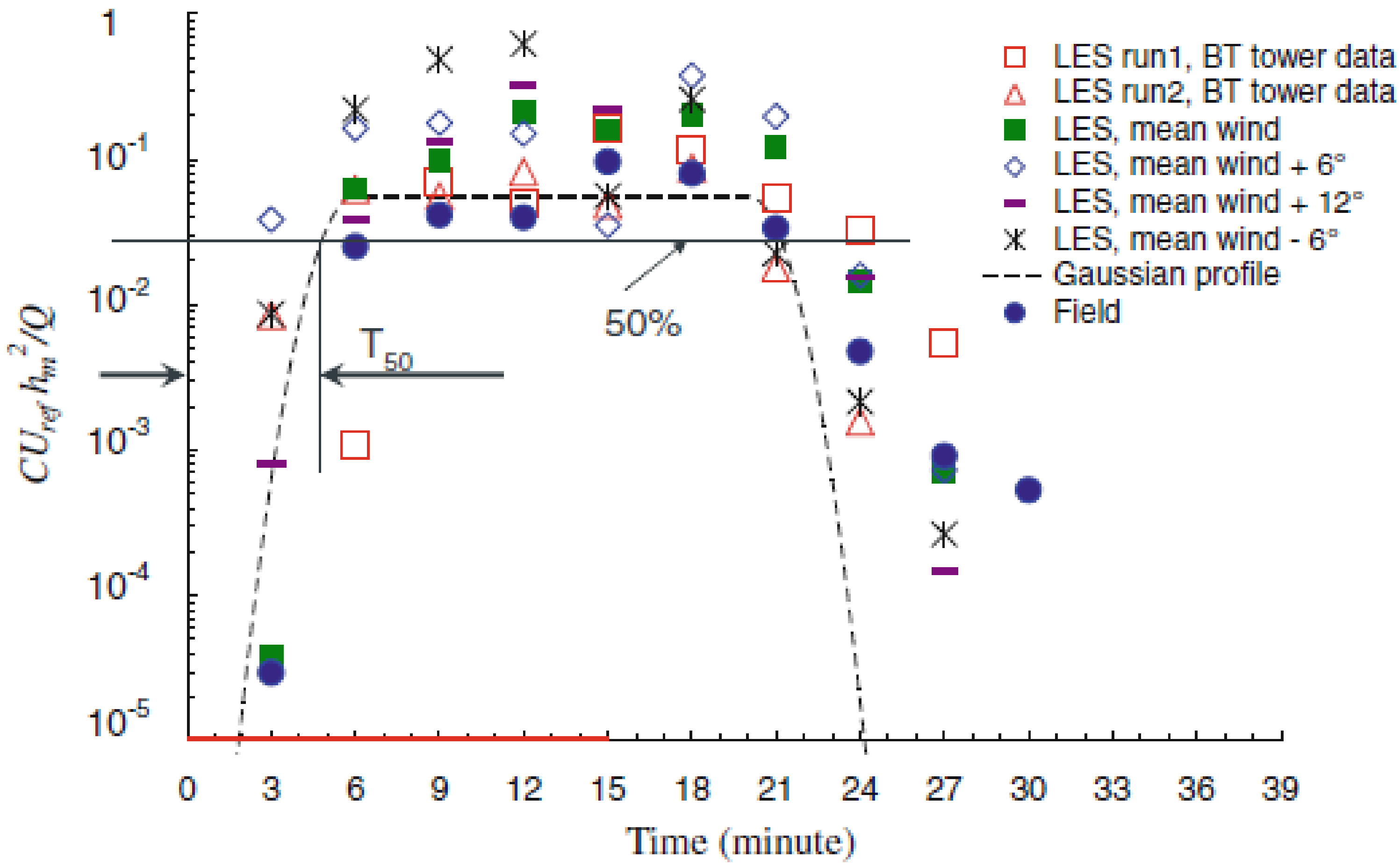


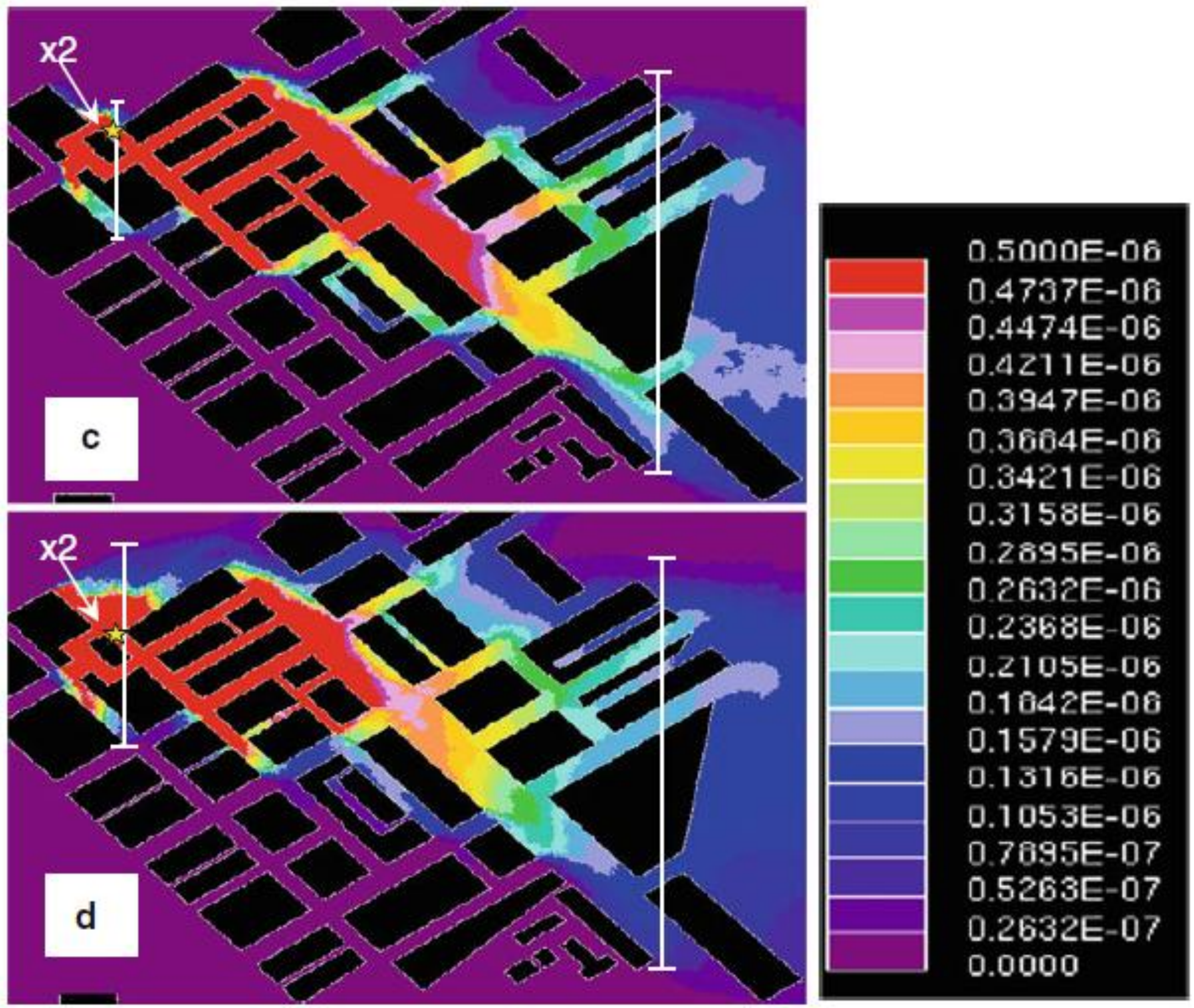
Fig. 6 30-s averaged wind magnitude U and direction θ (bearing clockwise to the Marylebone-Rd direction, i.e. x_t in Fig. 1) at the BT Tower top with a mark indicating 15-min release duration

Xie 2011 – tracer concentrations



Xie 2011 tracer distribution

- Contours of 30min averaged concentration
- c) 30min averaged data
- d) 30 sec averaged data



London-based research projects

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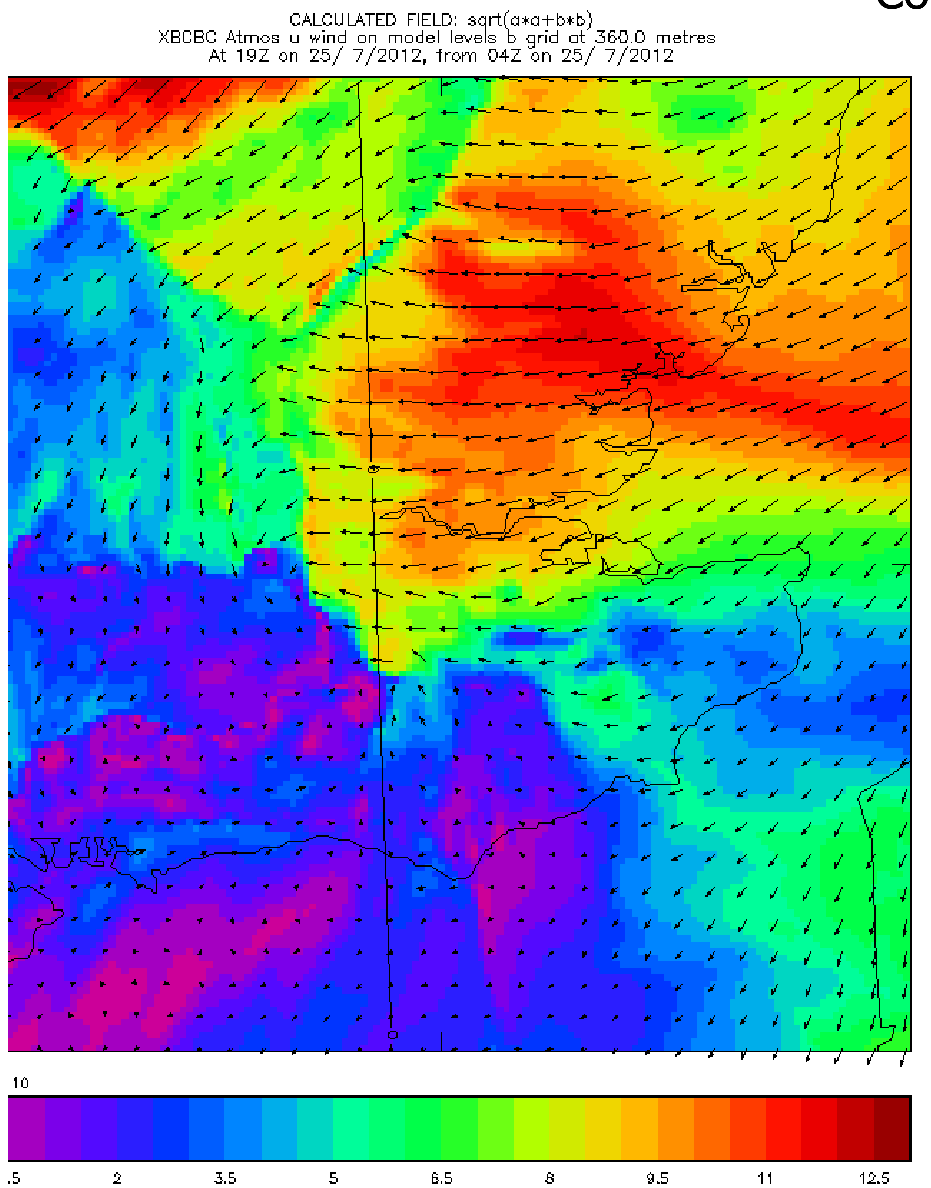
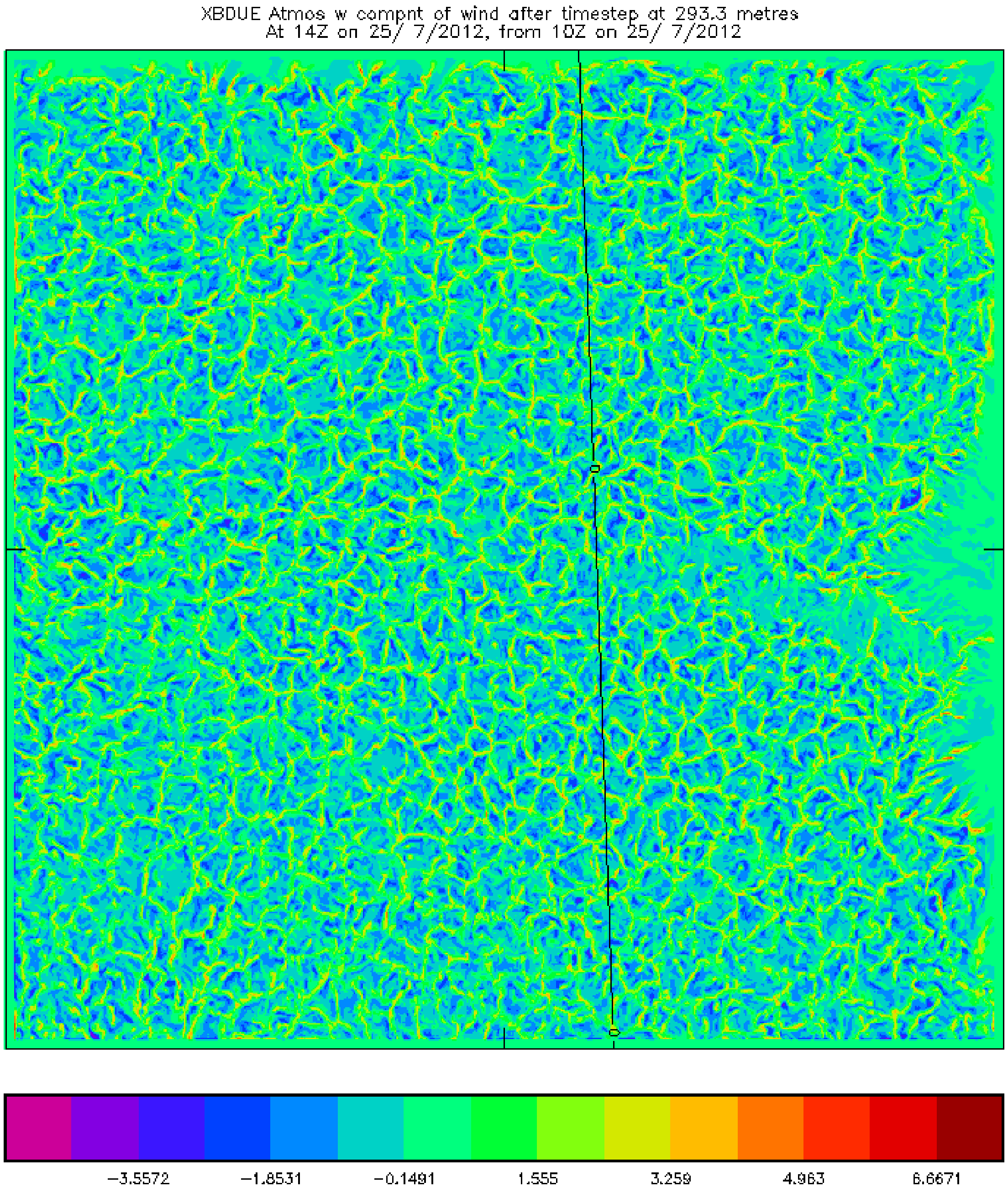
Mesoscale modelling

Courtesy Humphrey Lean, MetOffice Reading



- Regional and city scale flow causes low frequency perturbations
- Numerical Weather Prediction (NWP) models
- Grid typically 12, 4, 1.5km
- 25th July 2012, 19:00 – sea breezes cross London



25th July 2012

Vertical velocity at 293m

Unified Model, 100m grid resolution

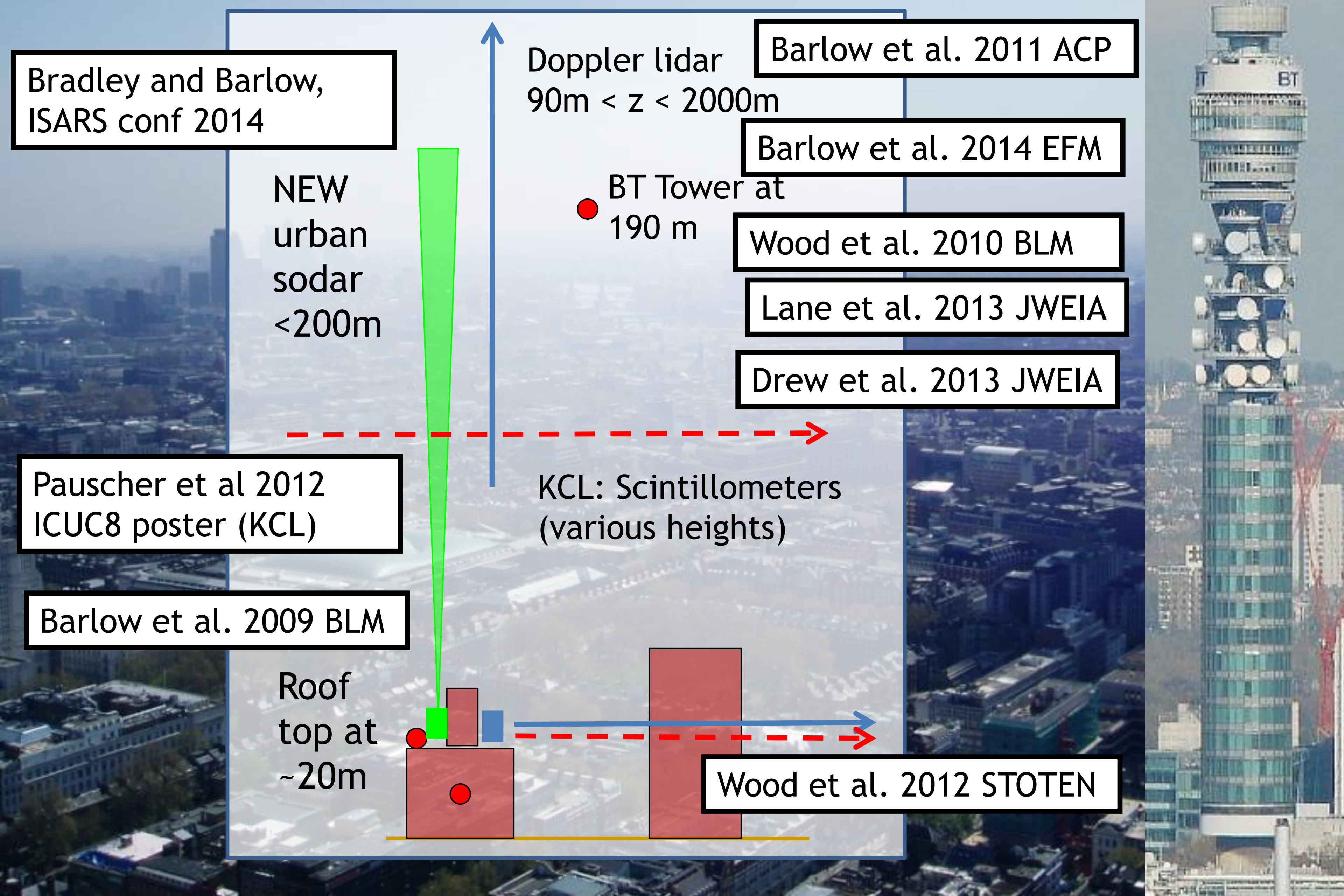
LES mode

Urban surface heat flux parameterization

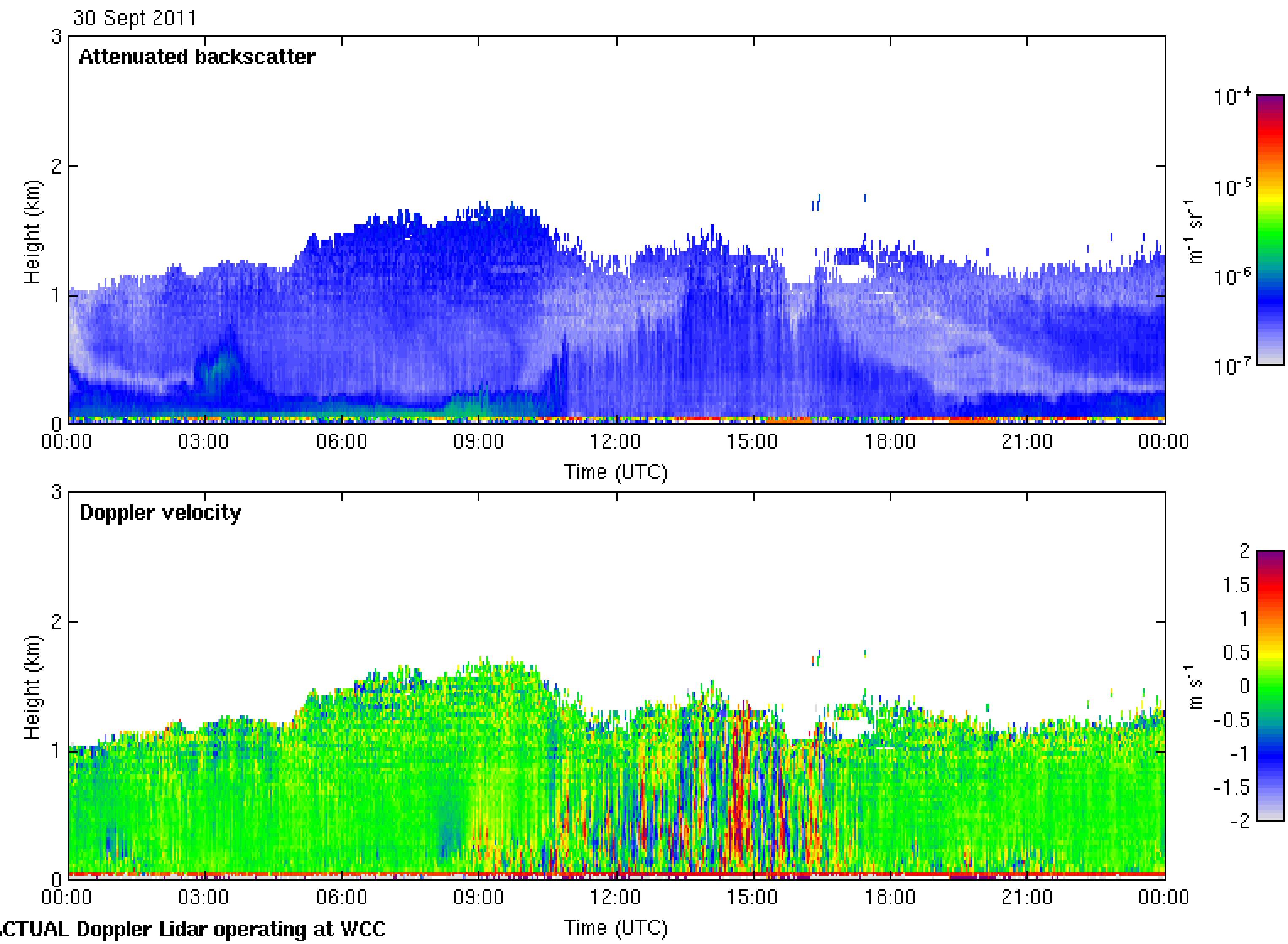
Enhanced roughness

Thanks to
Humphrey Lean,
UK Met Office

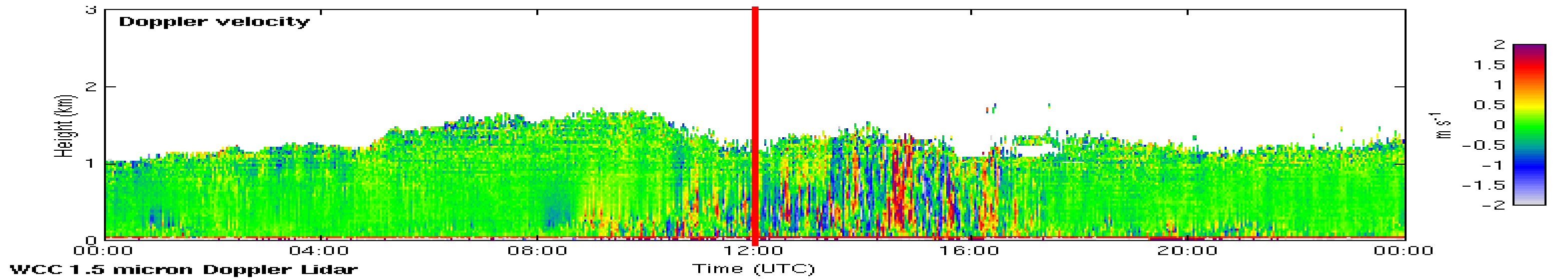
ACTUAL: observing flow at range of scales



Doppler lidar 30th September 2011

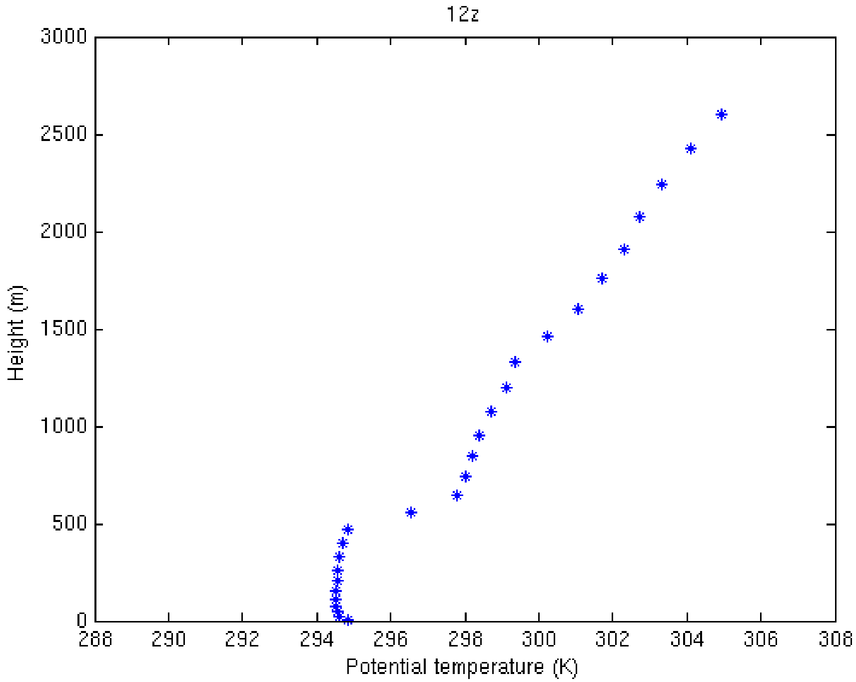


ACTUAL Doppler Lidar operating at WCC

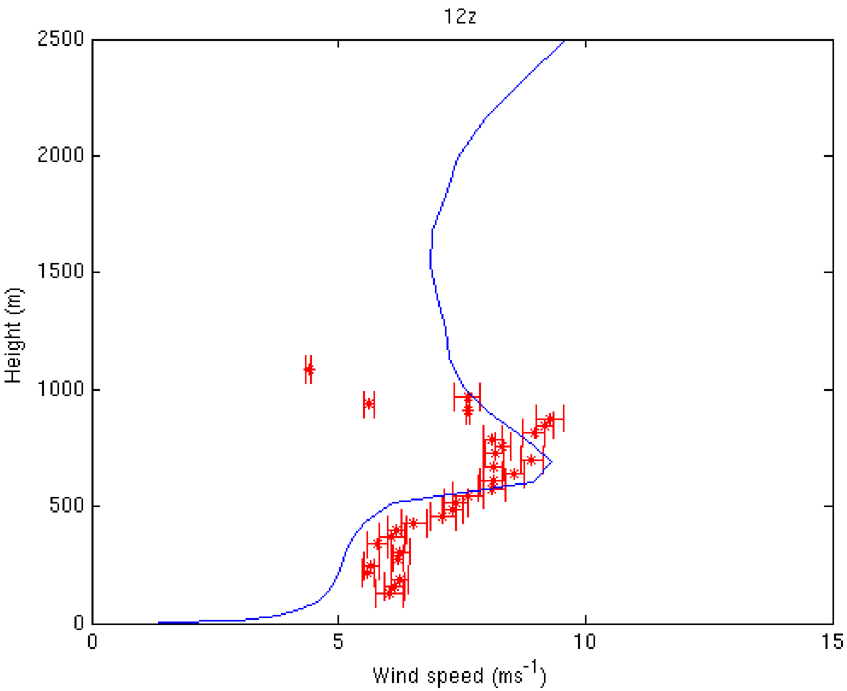


12:00

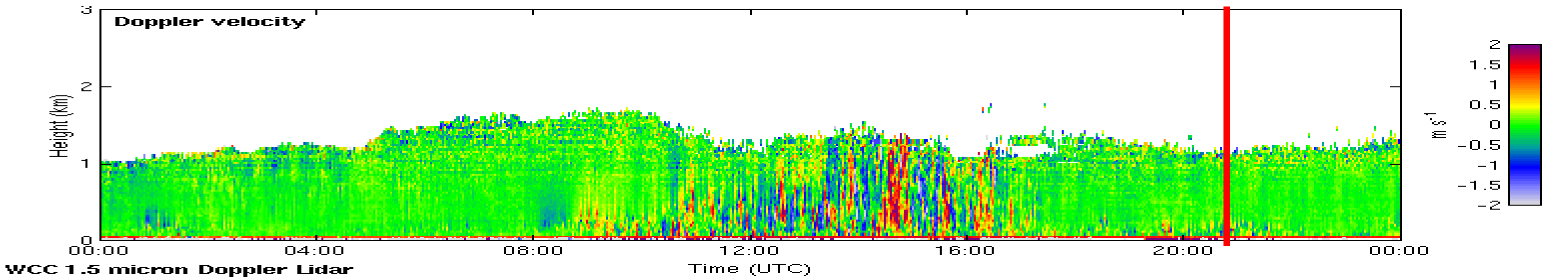
Potential temperature



Wind-speed

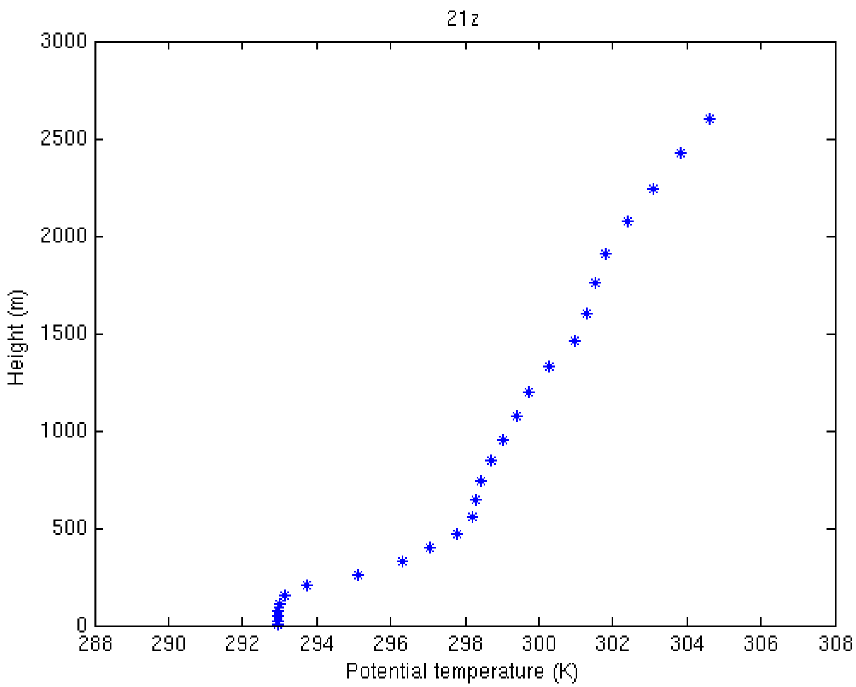


- Met Office Operational UKV model

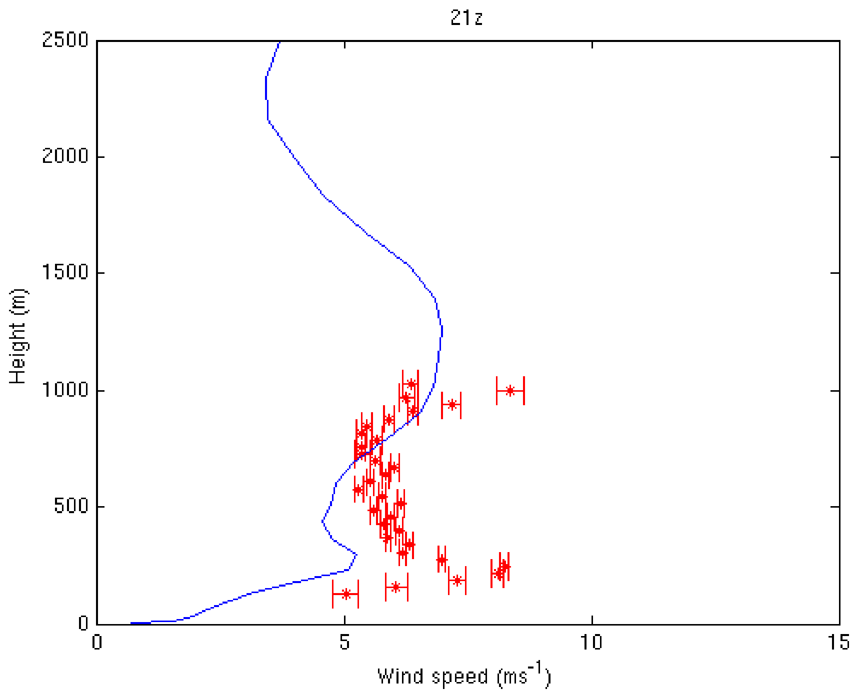


21:00

Potential temperature



Wind-speed



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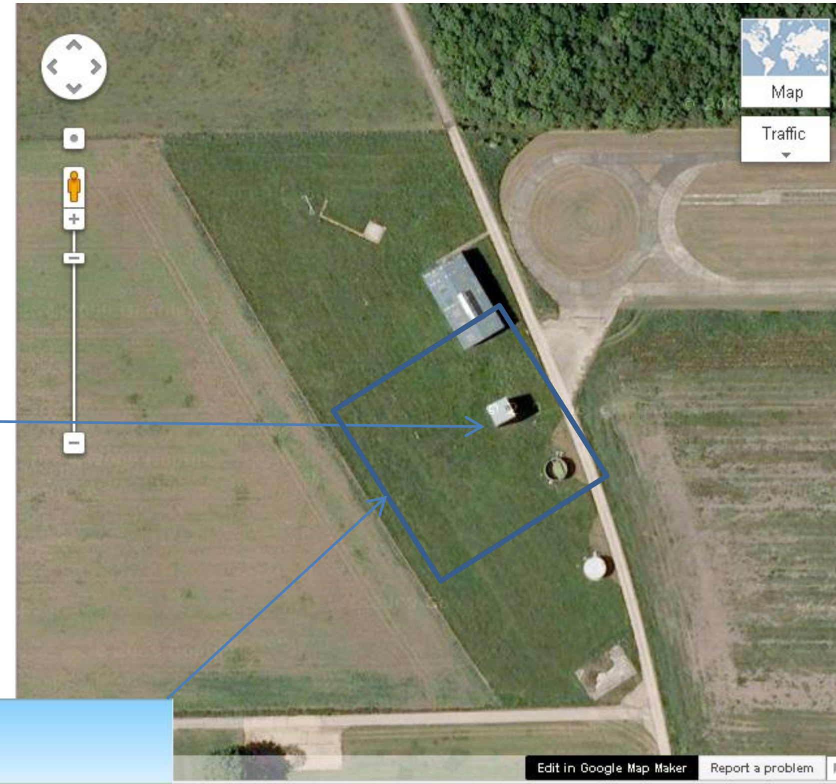
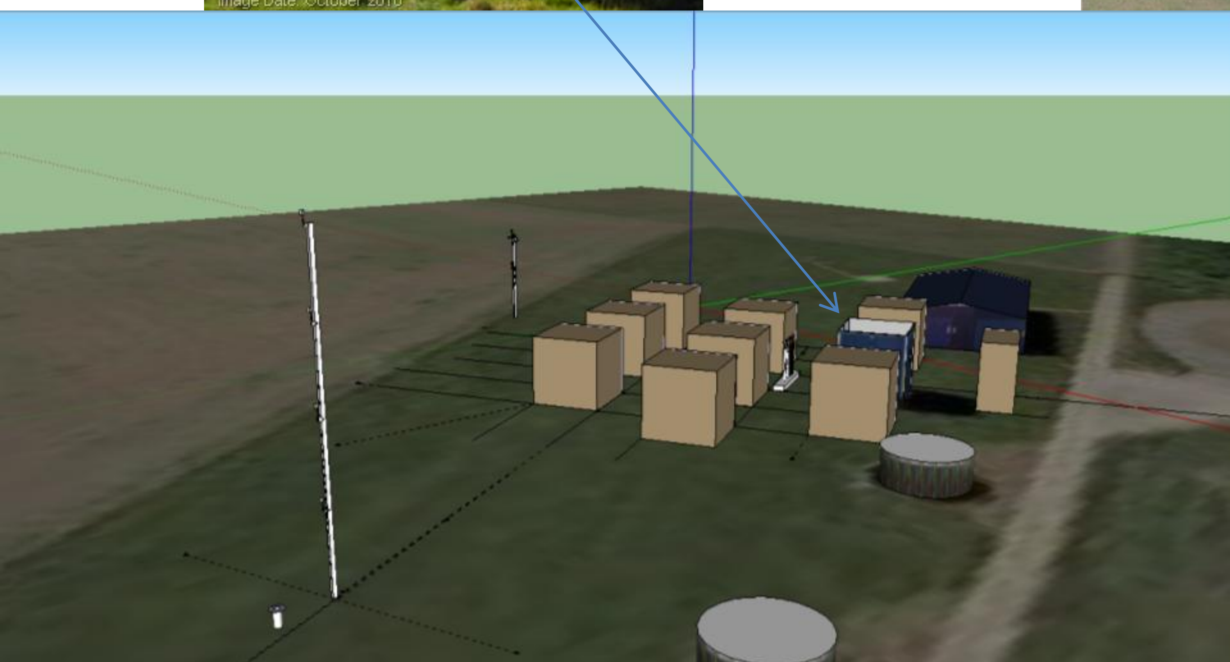
Refresh (2013-2018) – human-centred building design, coupling indoor-outdoor environments

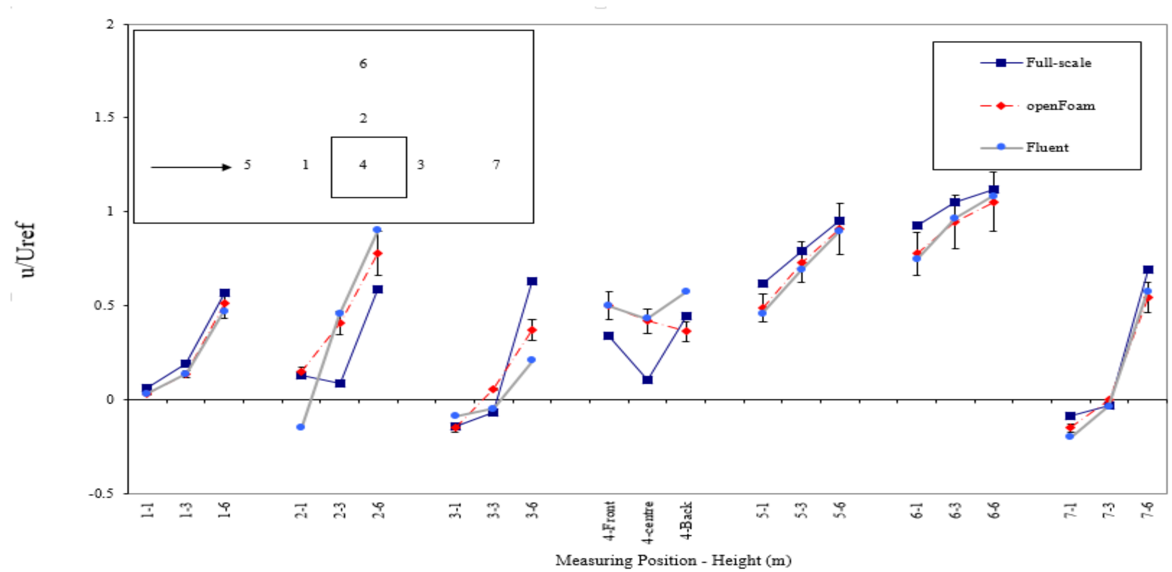
Refresh @ Silsoe autumn 2014

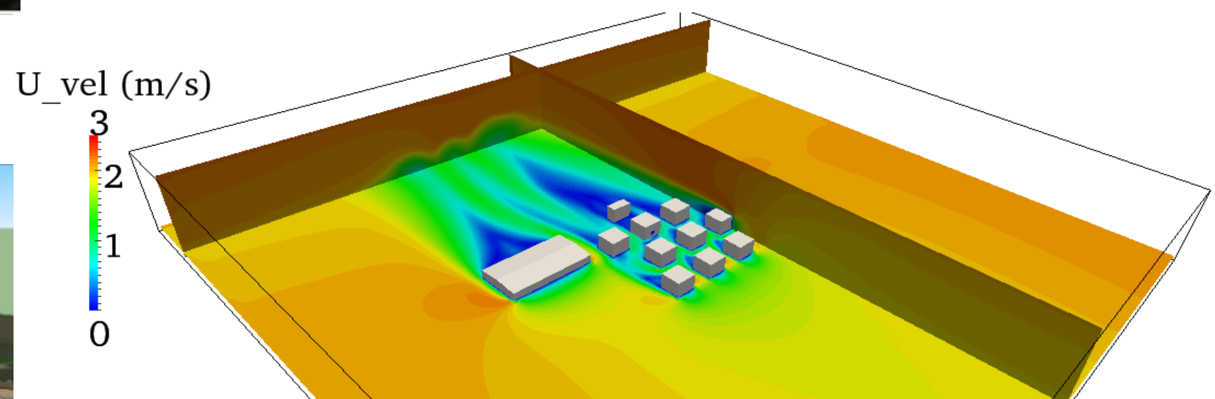


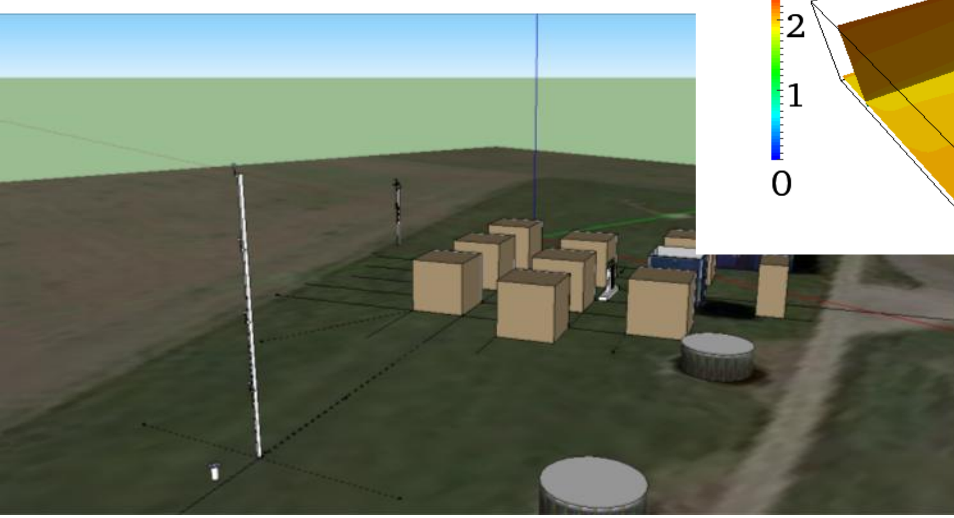


Thanks to
Hannah Gough
PhD student @ Reading

Refresh CFD simulations… work in progress







Thanks to
Marco-Felipe King,
PDRA @ Leeds

Conclusions

- LES reproduces unsteady urban turbulence well – pay attention to inlet conditions!
- Current mesoscale model capability reasonably good at capturing city flow features above building height
- Combination of windtunnel and fullscale observations powerful
- Next step: analyse impact of all flow scales on ventilation

Please visit www.actual.ac.uk to see more London data!

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