Evaluation of a turbulent flow and dispersion model in a typical urban street canyon.

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Introduction

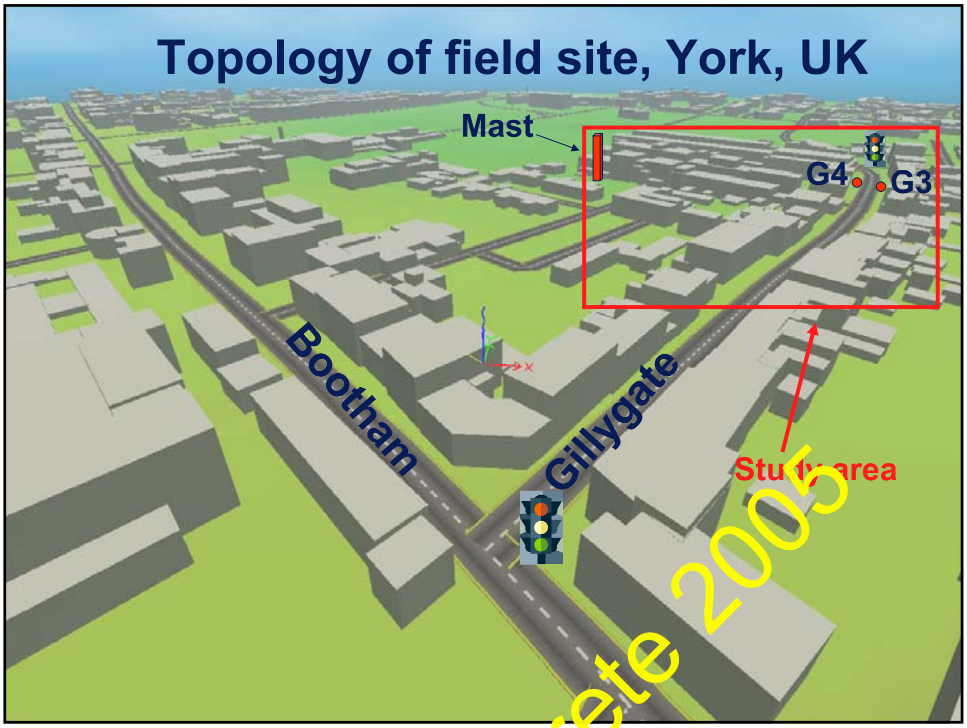
- Cities consist of complex road networks incorporating street canyons, intersections, side streets.
- Interaction of background air flows with complex structures affects dispersion of traffic related pollutants and thus roadside concentrations.
- Significant differences in road-side concentrations can occur over short distances within typical UK streets.
- Micro-scale CFD models are being increasingly used to attempt to model this variability and to identify pollution hot spots.

Issues

- For operational purposes CFD models often employ simplified representations of
  - street geometries
  - inflow conditions
  - turbulence closure
  - computational grid
- Pressing need to evaluate predictions for a variety of geometries of relevance to different urban environments.
- Accurate prediction of dispersion needs accurate estimation of emissions in street.

Purpose of Current Study

- To evaluate predictions from a coupled k-ε flow model (Miskam v4.21, Eichorn, 1996) and Lagrangian particle dispersion model with field measurements from a site with complex geometries.
- Comparisons will include measurements of turbulent flows ***and*** concentrations of a traffic related tracer at field site.
- The sensitivity of the model predictions to grid structure and input parameters will be evaluated.
- Look at effect of variable emissions on model dispersion.

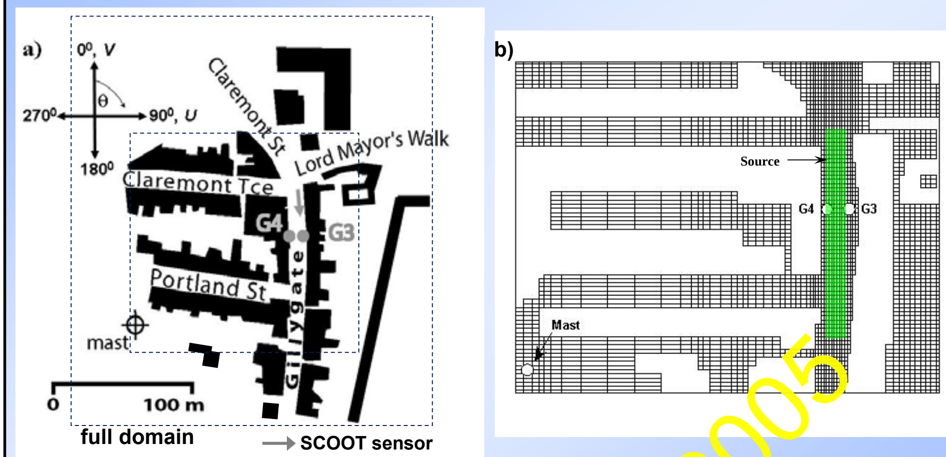


Field Measurements

(Boddy et al. 2005)

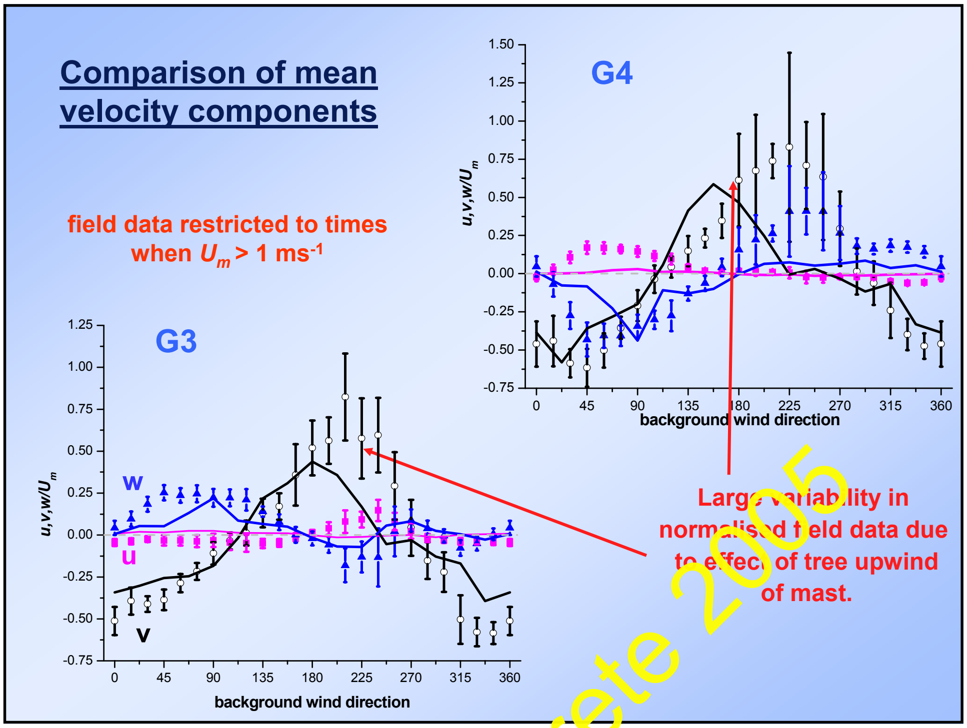
- **Simultaneous in street and background wind speed and direction** at 20Hz.
- **Carbon monoxide (CO) concentrations** (5-15-minute averages) - electrochemical sensors incorporated within *Learian* streetboxes attached to lampposts.
- **Bi-directional traffic flow and occupancy** (15-minute averages) in each street using the Split Cycle Offset Optimisation Technique (SCOOT).
- Approximate street canyon aspect ratio:
  - Gillygate $H/W = 0.75$
- Gillygate has high vehicle flows, with lengthy congested periods.
- All field data shown are 15 minute averages

Model Domain and Grid Structure

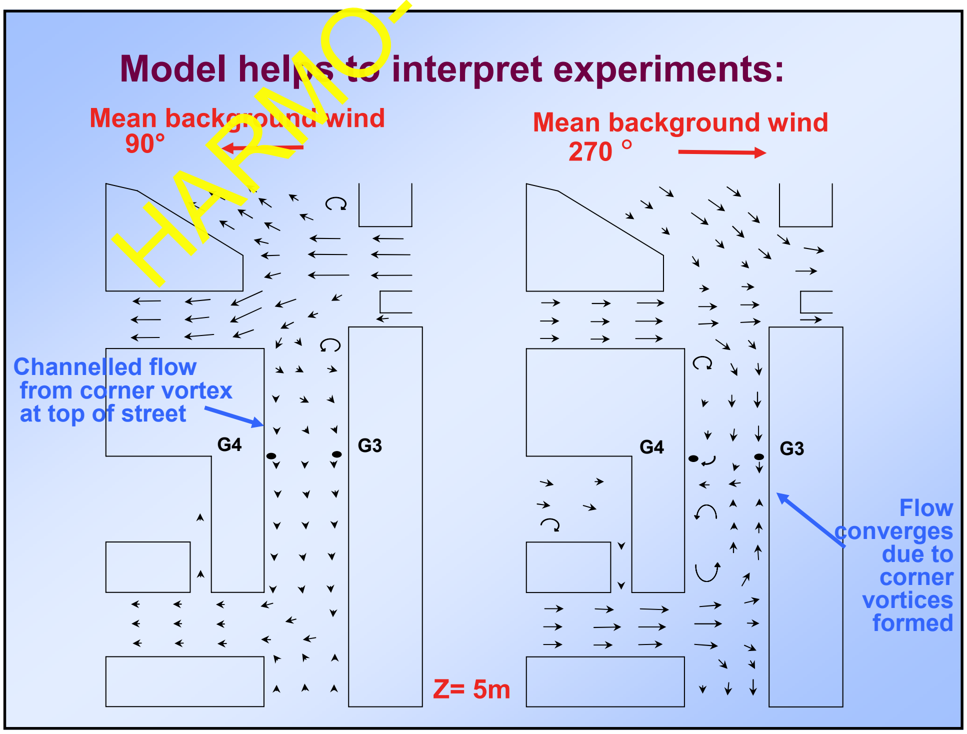


Flow Model Structure

- MISKAM uses a k-ε turbulence closure
- no-slip lower boundary condition
- zero vertical velocity at top of domain - 100 m
- a logarithmic layer assumed between solid surface and nearest grid points
- logarithmic wind profile and neutral static stability assumed at inflow boundaries – z_0 = 10 cm
- sensitivity to inflow roughness length tested
- domain extends 270 m in the cross-street direction and 400 m in the along-street direction
- base resolution 1 m, 2 m and 1 m in cross-street, along-street and vertical directions respectively
- sensitivity to grid resolution tested



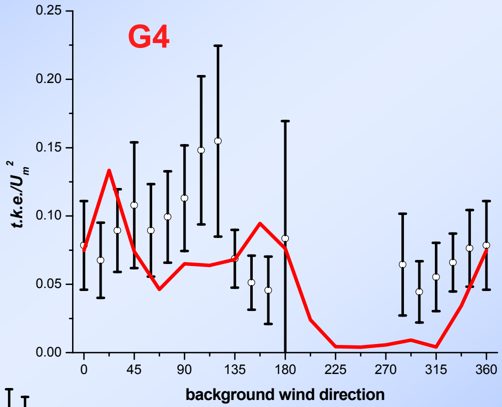
Comparison of mean velocity components
field data restricted to times when U_m > 1 ms^{-1}
G4
G3
w
u
v
$u,v,w/U_m$
background wind direction
Large variability in normalised field data due to effect of tree upwind of mast.

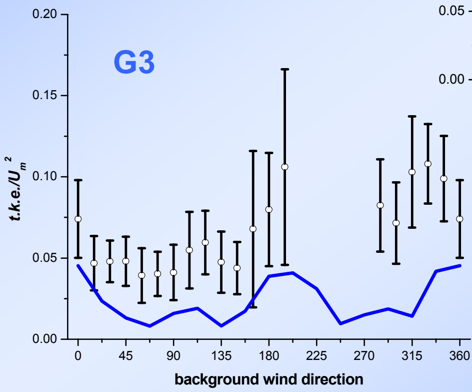


Model helps to interpret experiments:
Mean background wind 90°
Mean background wind 270 °
Channelled flow from corner vortex at top of street
G4
G3
Flow converges due to corner vortices formed
Z= 5m

Comparison of mean t.k.e.

model captures peaks for parallel background winds and differences between windward and leeward levels





t.k.e. generally underestimated by model

model structure does not allow for intermittency

Dispersion Model

- mean wind and turbulence dissipation from MISKAM used as inputs to Lagrangian stochastic dispersion model –uses well-mixed formulation (Thomson 1987)
- Reynolds stresses calculated using the Boussinesq eddy viscosity hypothesis
- pollutant source specified as box within which particles initially randomly located and given random velocity distribution - Gaussian about mean wind
- source volume 100 m by 9 m by 1 m
- 50,000 particles tracked through the model domain

$$C = \frac{Q \sum_i t_i}{NV}$$

Q - emission rate of the source,

$\sum_i t_i$ total time all particles spent in gridbox,

N - total number of particles

V - gridbox volume

Normalisation

Non-dimensional concentration:

$$K = \frac{CU_m HL}{Q}$$

Um **- background wind speed at mast**

H **- canyon height**

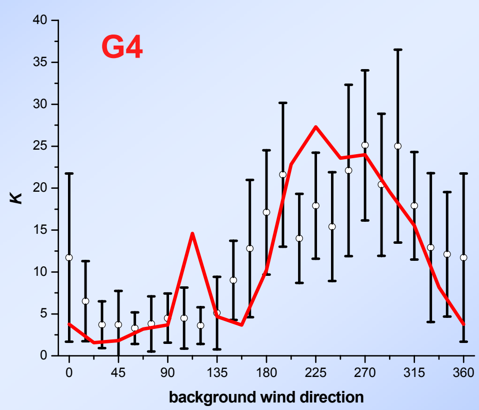
L **– canyon length**

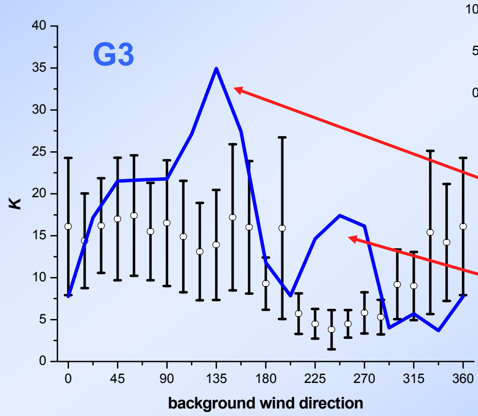
Currently Q is assumed to be proportional to overall traffic flows.

Effect of this assumption tested.

Comparison of normalised concentrations

field data restricted to times when U_m>2 ms^{-1} and traffic > 100 veh hr^{-1}

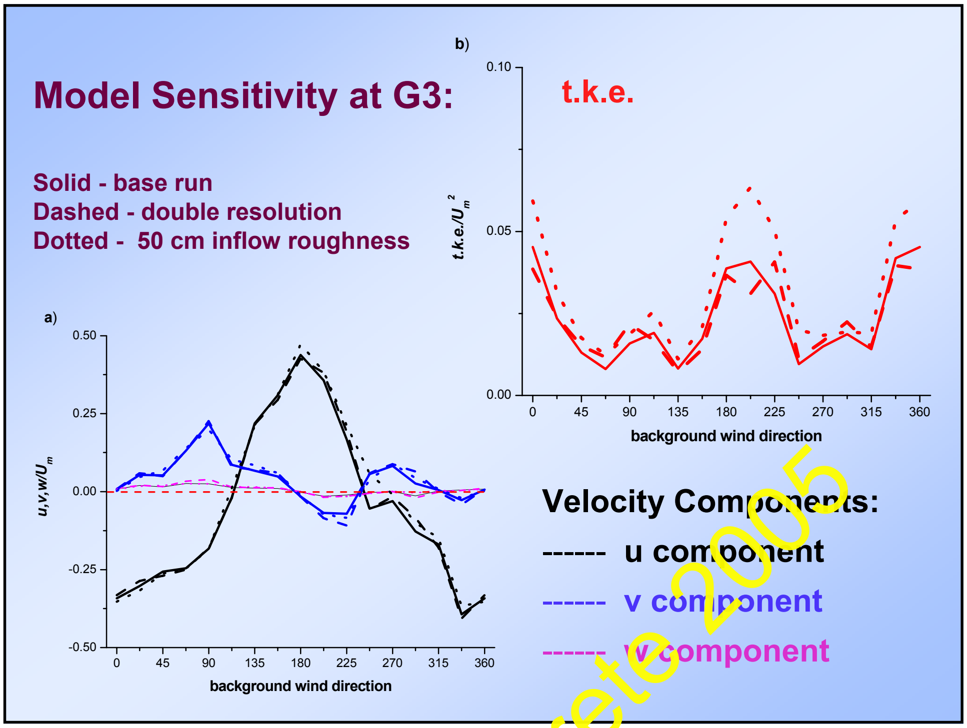


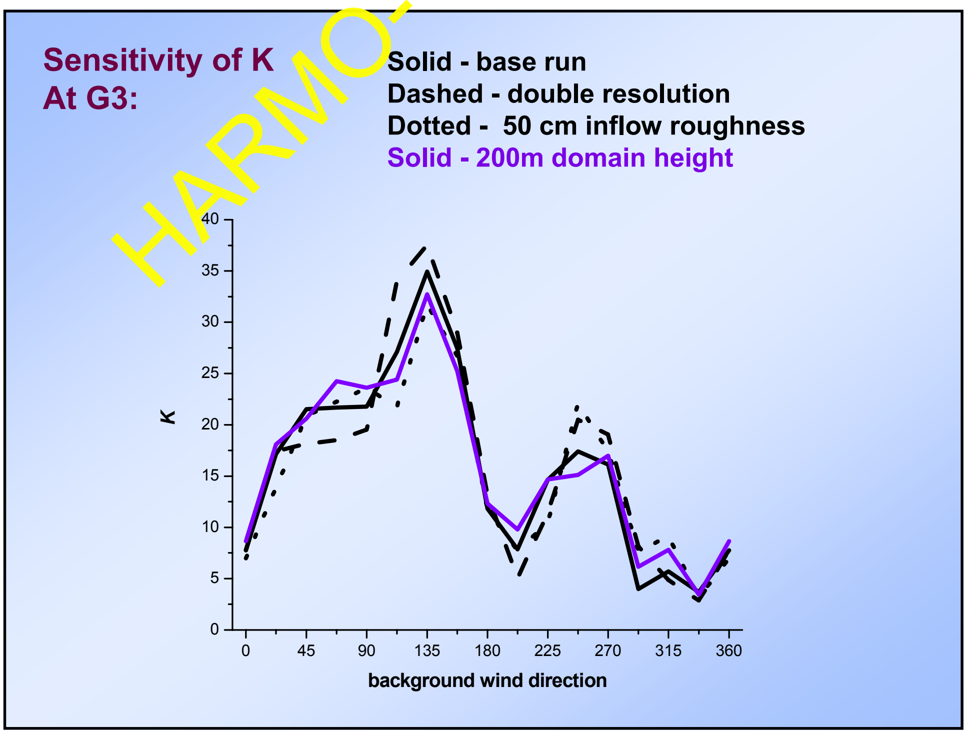


model overestimates normalised concentrations on leeward canyon side

and in converged flow regime

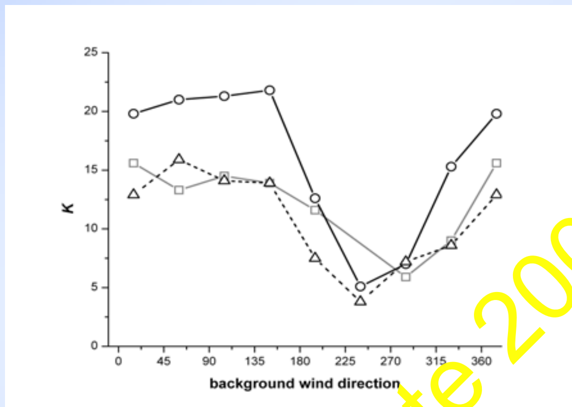
possible influence of intermittency and traffic produced turbulence


Model Sensitivity at G3:
Solid - base run
Dashed - double resolution
Dotted - 50 cm inflow roughness
a)
u,v,w/U_m
background wind direction
b)
t.k.e.
t.k.e./U_m^2
background wind direction
Velocity Components:
------ u component
------ v component
------ w component

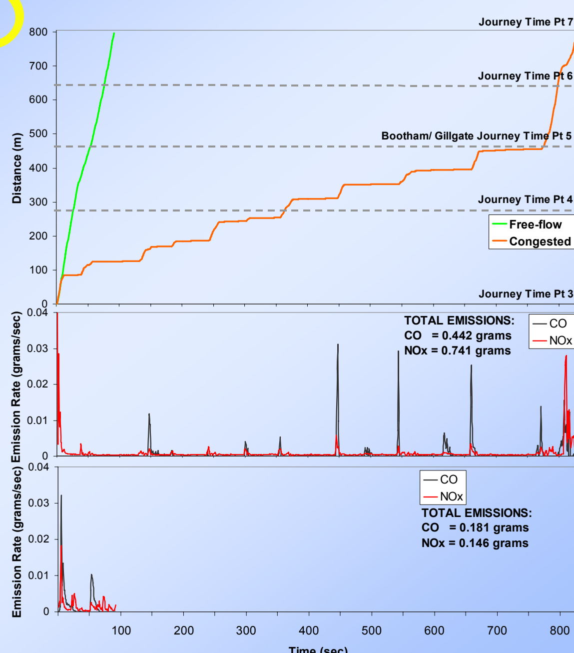

Sensitivity of K
At G3:
Solid - base run
Dashed - double resolution
Dotted - 50 cm inflow roughness
Solid - 200m domain height
K
background wind direction

Influence of traffic characteristics

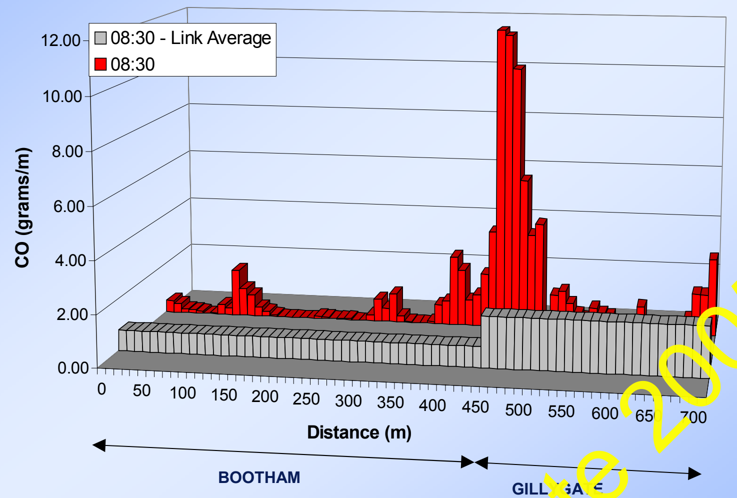
***K* vs. θ_m at G3 split by traffic occupancy at inbound sensor:**
—□— occupancy ≤ 12 %,
---Δ--- 12% < occupancy ≤ 62%,
—○— occupancy > 62 %.



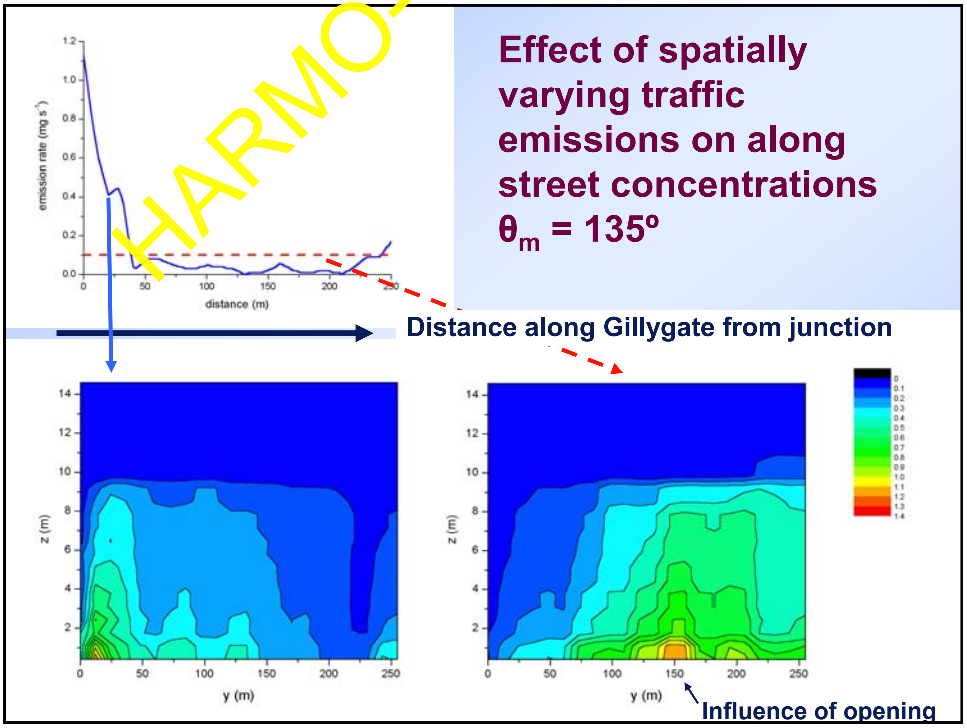
Influence of congestion on emissions – measurements using instrumented vehicle



Modelled emissions using micro-scale traffic and emissions model.



Effect of spatially varying traffic emissions on along street concentrations $\theta_m = 135^o$

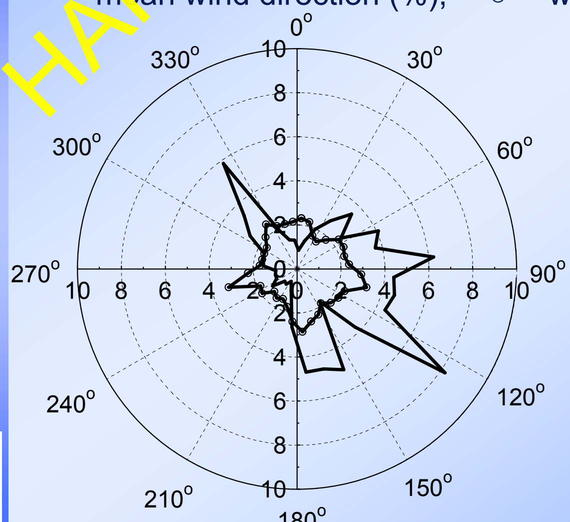


Discussion

- The k-ε flow model MISKAM is capable of providing reasonable representation of the mean velocity components in a fairly complex urban geometry.
- There is some underestimation of t.k.e. possibly due to the turbulence closure model used, intermittency in the background winds in the field, and the lack of representation of traffic produced turbulence.
- For the model set up chosen, there was a low sensitivity to the grid and input parameters for most wind directions.
- A region of converged flow due to channelling down adjacent side streets showed higher sensitivities to model structure.
- Predicted normalised concentrations were most sensitive to the description of traffic emissions.
- In future modelling studies it will be important to represent the influence of congestion on both the levels and spatial location of emissions.

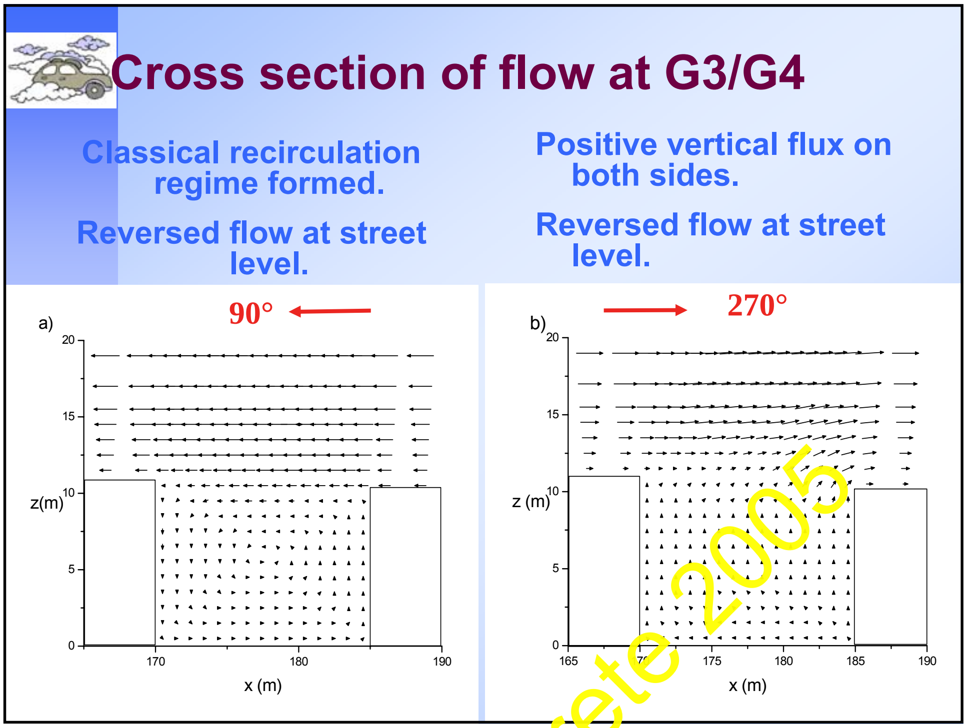
Measured Background Flows

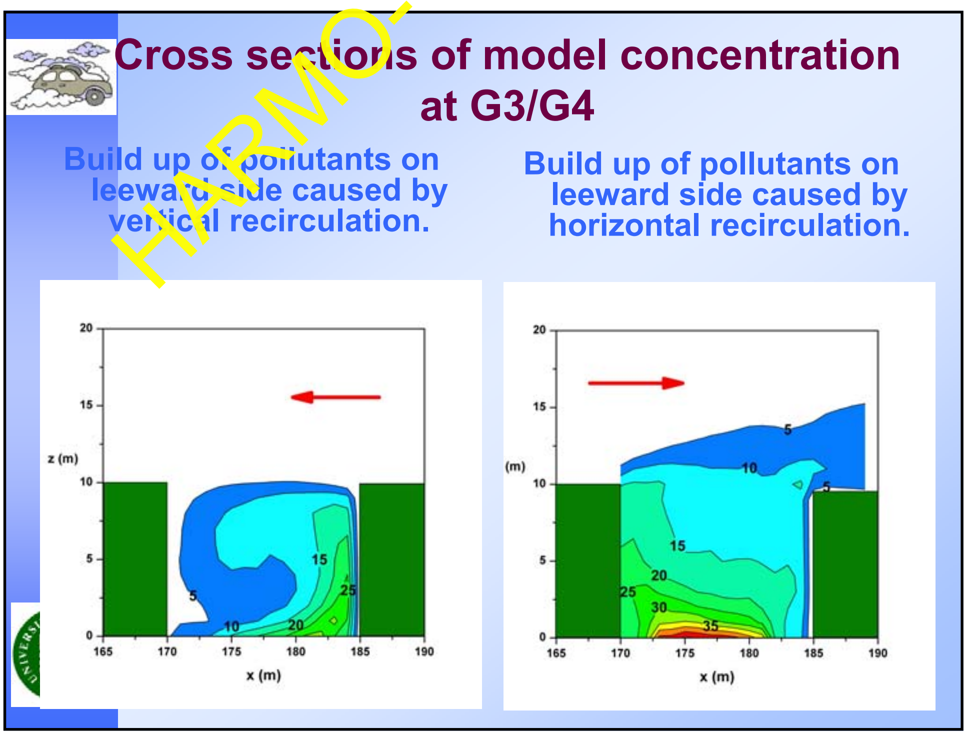
Frequency distribution of:
—— mean wind direction (%); —○— wind speed (ms^{-1}).



Note that mast reference measurement θ_{ref} affected by upwind tree for winds from 180-270º

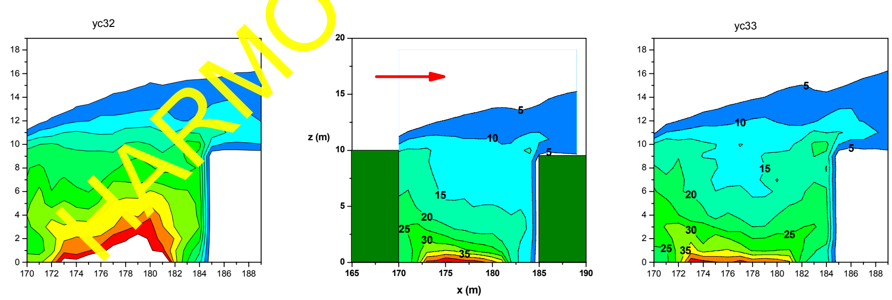
Data excluded when mast wind speed fell below 2 ms^{-1}


Cross section of flow at G3/G4
Classical recirculation regime formed.
Reversed flow at street level.
Positive vertical flux on both sides.
Reversed flow at street level.
a)
90°
z(m)
x (m)
b)
270°
z (m)
x (m)

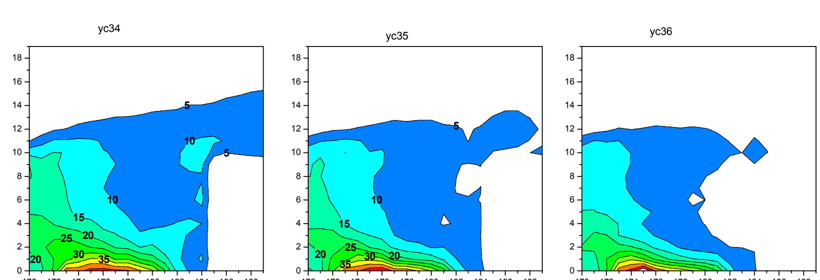

Cross sections of model concentration at G3/G4
Build up of pollutants on leeward side caused by vertical recirculation.
Build up of pollutants on leeward side caused by horizontal recirculation.
z (m)
x (m)
x (m)

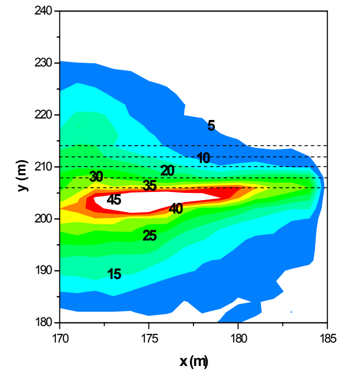
Influence of spatial variability in emissions

- Clearly in congested conditions the spatial location of traffic queues will affect local pollutant concentrations.
- The proximity of queuing traffic operating under stop-start conditions is a key influence.
- Attempts have been made to model the spatial variability of traffic emissions along the link in Gillygate using micro-simulation traffic models with modal emissions factors (CMEM).
- A sensitivity study has then been performed using the dispersion model to assess the influence of spatially distributed emissions on road-side concentrations in Gillygate.

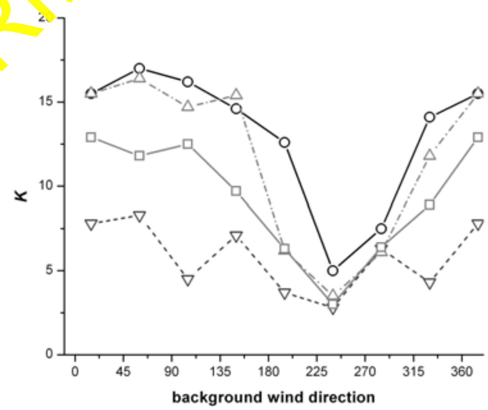


Cross-sections across street at 2m intervals from G3/4

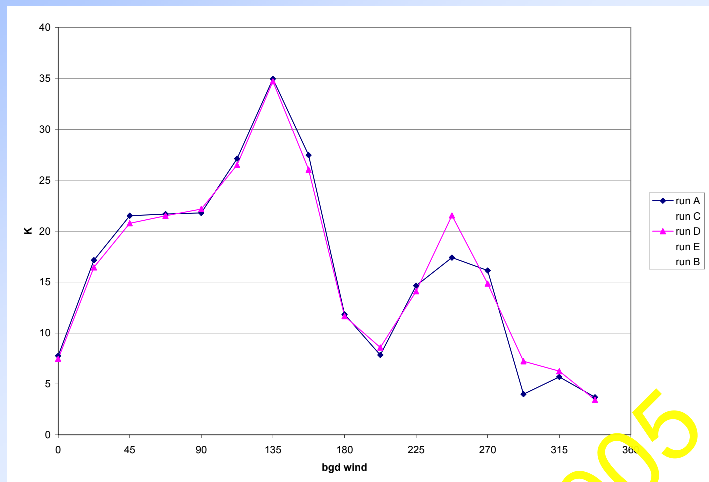




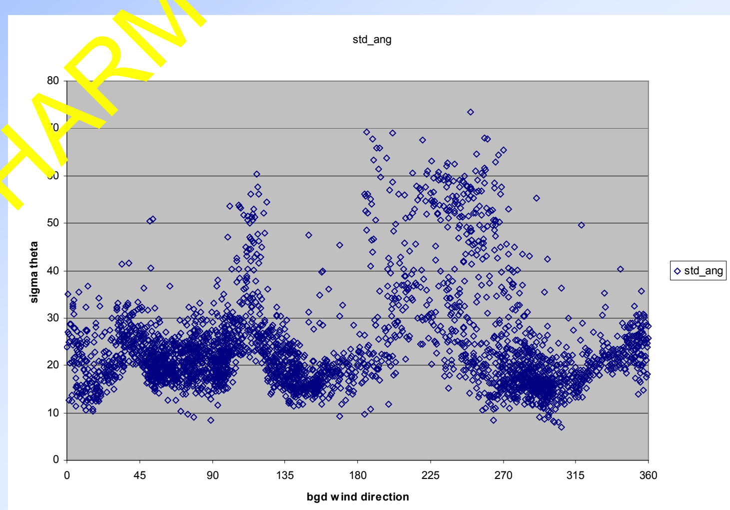
Plan view of normalised concentrations for winds from 270°



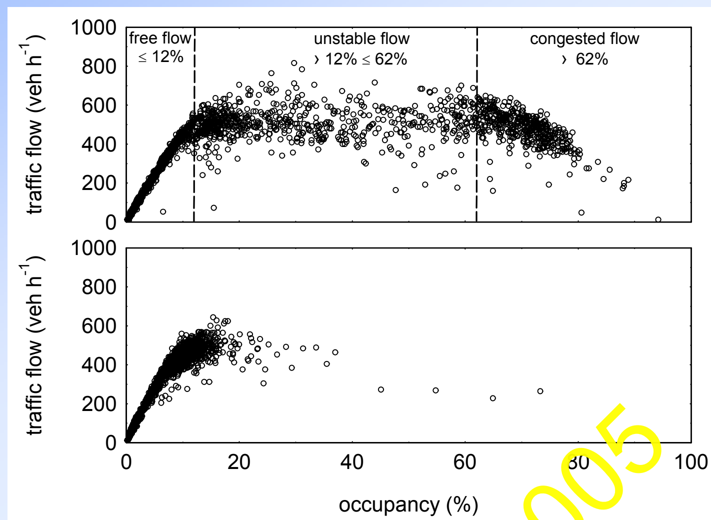
Field measurements of *K* split by mast wind speed



Comparison of model runs with 1m and 2m source heights



Standard deviation of wind angle θ
wind speed > 1 ms^{-1}



Traffic flow and occupancy at inbound and outbound SCOOT sensors