Neighbourhood-scale Urban Dispersion Modelling Using a Canopy Approach

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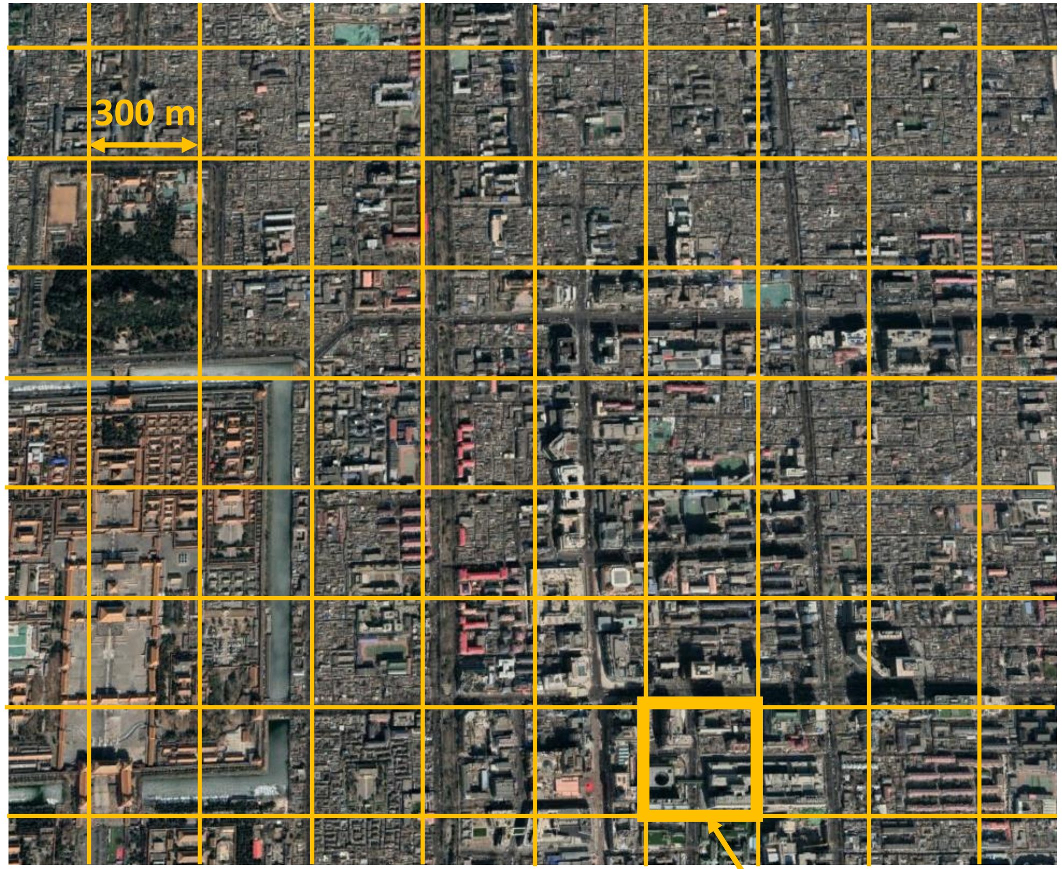
Introduction

- Buildings affect pollution dispersion and play a large role in determining concentration at street level
- We live at street level → important to predict concentrations accurately there
- Numerical weather prediction (NWP) is starting to resolve the "neighbourhood" scale (e.g. UK Met Office 300m model)
  - similar building geometry statistics
  - similar flow
  - improved modelling?



Beijing (Google Earth)

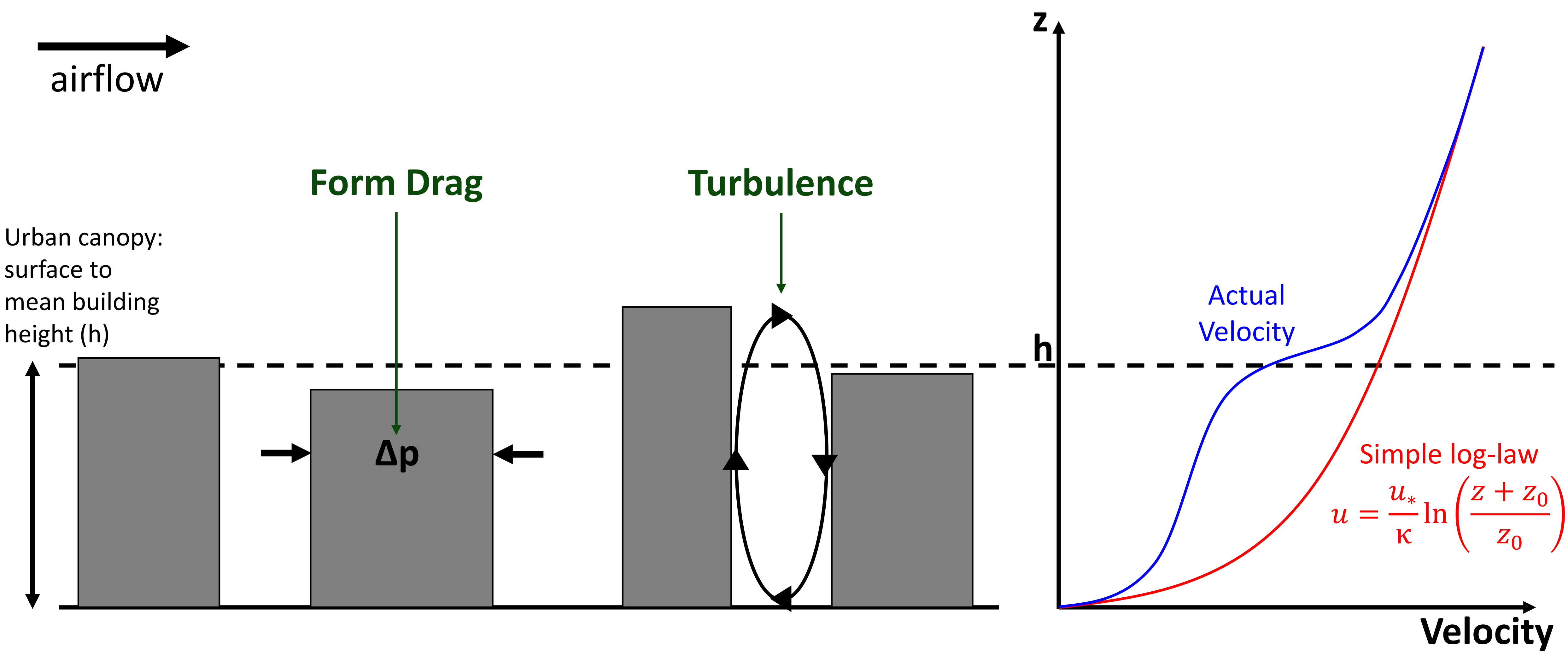
One "neighbourhood"

Outline

- Introduce a novel model for 1D velocity and pollution concentration profiles in the urban surface layer (profiles represent the horizontal average of the neighbourhood)

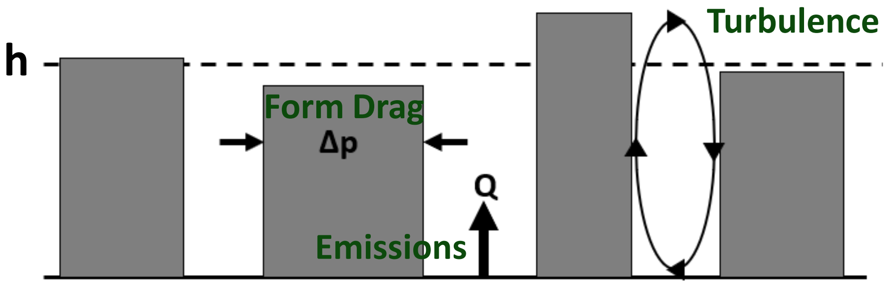
- Test model using three different parametrisations against a high-resolution model of the 3D flow and dispersion ("truth data")

Urban Surface Layer



Urban Surface Layer Model (USLM)

Based in part on Harman and Finnigan, 2008 (1)



Double averaged momentum equation -> Velocity

Turbulence (momentum flux) | Form Drag

$$\frac{d\left(\overbrace{{l_m}^2\left|\frac{du}{dz}\right|\frac{du}{dz}}\right)}{dz} = \begin{cases} \frac{u^2}{L_{drag}}, & z \leq h \\ 0, & z > h \end{cases}$$

Double averaged scalar equation -> Scalar concentration

Turbulence (scalar flux) | Scalar Surface Source

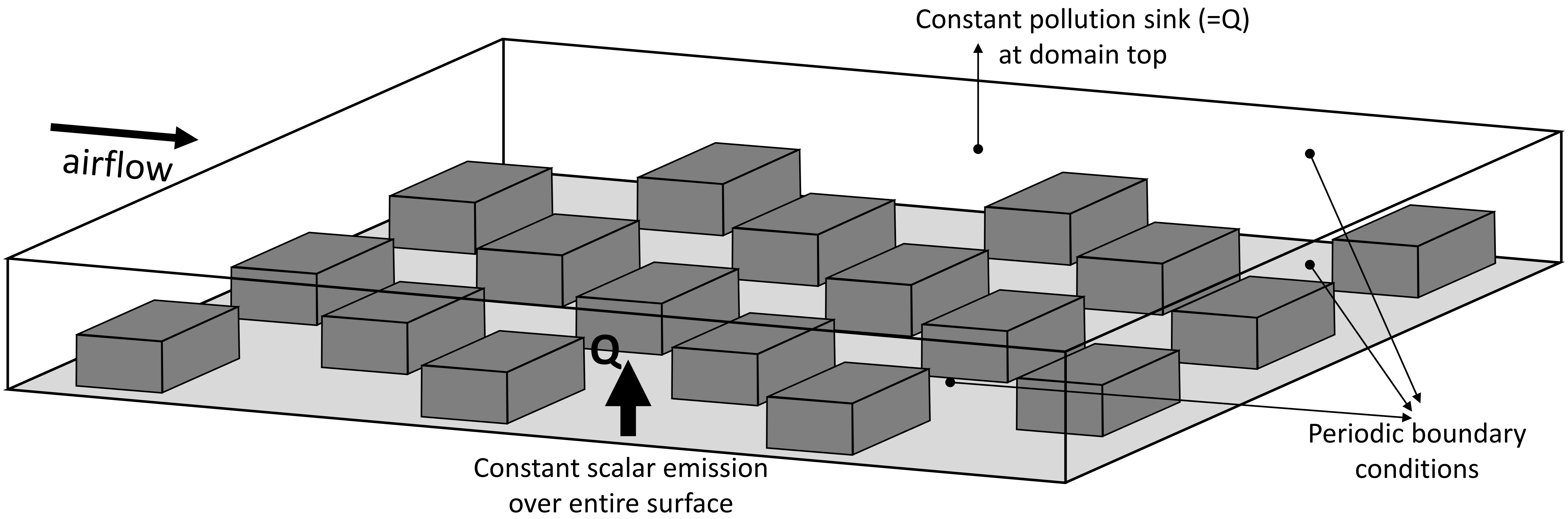
$$-\frac{d\left(\overbrace{l_m\left|\frac{du}{dz}\right| l_c \frac{dc}{dz}}\right)}{dz} = Q\delta(z)$$

Test three parametrisations of l_m, l_c in canopy:

1) Log-law
2) CB04 (Coceal and Belcher, 2004 (2))
3) Derived from LES ("truth data")

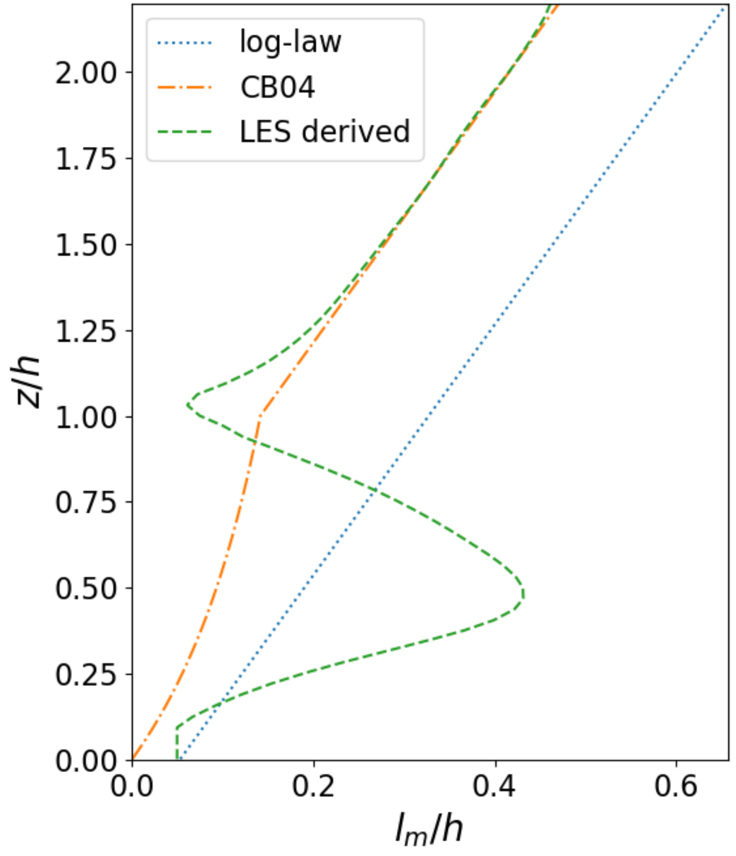
Large Eddy Simulation (LES) – "truth data"

- High resolution simulation of the 3D flow and dispersion in a staggered array of cubes (λ_p=0.25)



Velocity: USLM vs "truth"

Momentum flux = $l_m{}^2 \left|\frac{du}{dz}\right| \frac{du}{dz}$



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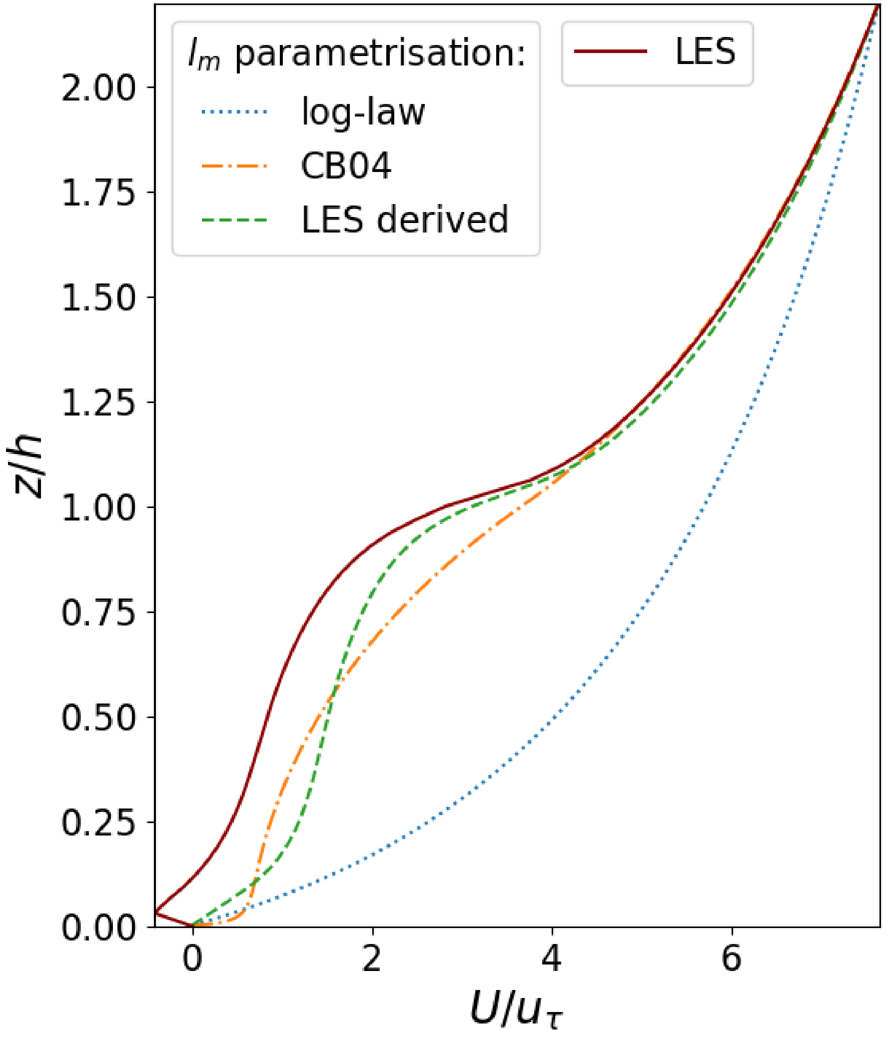
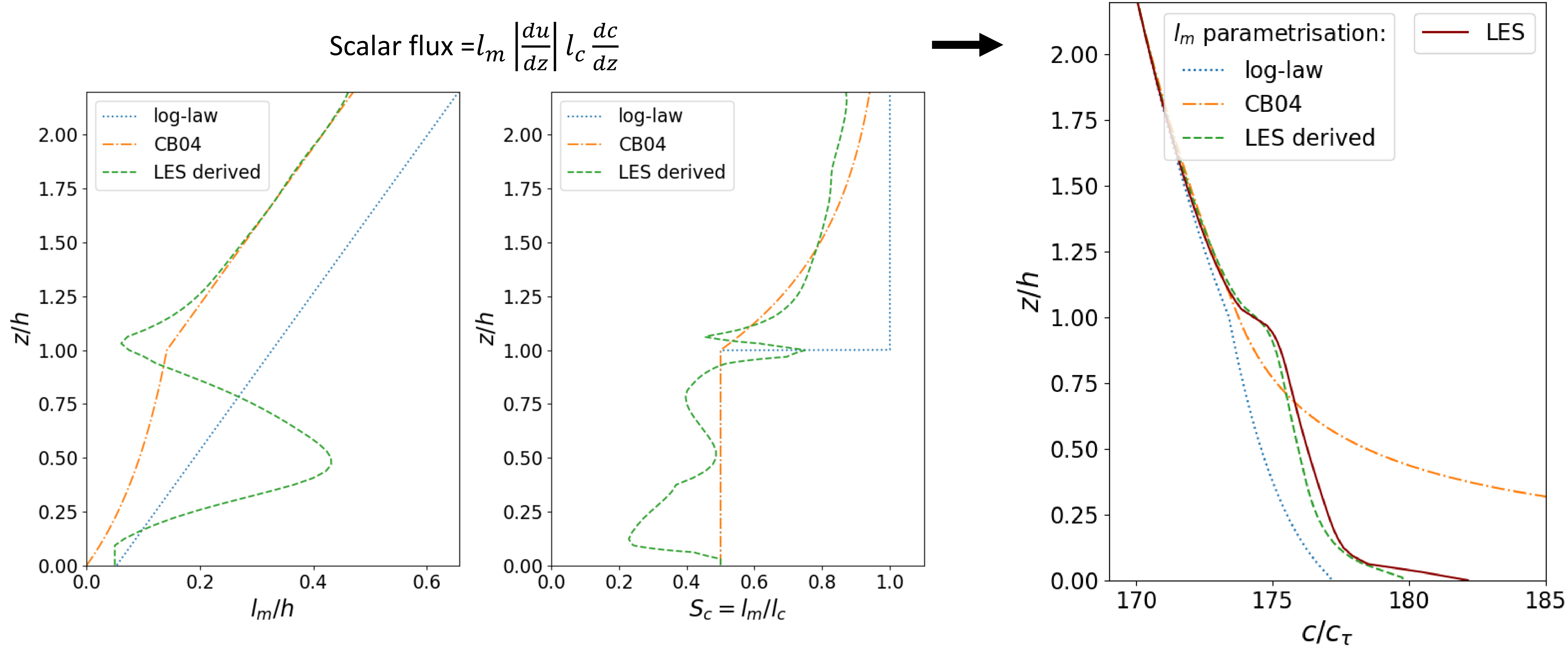


Scalar Concentration: USLM vs "truth"

Scalar flux $= l_m \left|\frac{du}{dz}\right| l_c \frac{dc}{dz}$



Conclusions

- Using a canopy approach in an USLM, it has been demonstrated that accurate prediction of velocity and (for the first time) scalar concentration can be made in the urban surface layer

- Improved velocity prediction with CB04 and LES derived compared to log-law which is used in most NWP

- Only LES derived accurately predicts scalar concentration
  → Development of new l_m and l_c parametrisations required

Thank You

References:

(1) Harman, I. N. and Finnigan, J. J. (2008), Scalar concentration profiles in the canopy and roughness sublayer. Boundary-Layer Meteorology, 129: 1573-1472.

(2) Coceal, O. and Belcher, S. E. (2004), A canopy model of mean winds through urban areas. Q.J.R. Meteorol. Soc., 130: 1349-1372.