MODELLING THE FLOW WITHIN AND ABOVE THE URBAN CANOPY LAYER

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Overview

- Addressing flow and dispersion at neighbourhood scale

- Model the Spatially averaged wind flow profiles using a fast response empirical model

- Features of real urban areas were incorporated, based on Digital Elevation Model (DEM) analyses

- Capability of the model in estimating real flow field was tested against published wind tunnel data

Methodology

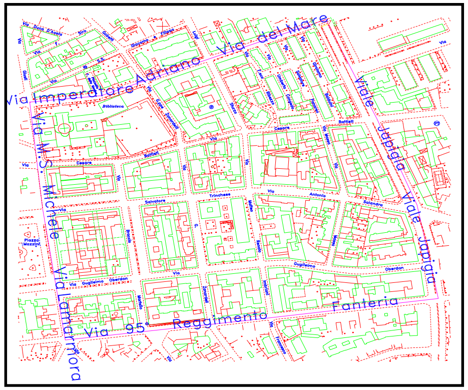
- The model is based on the momentum balance equation between the canopy layer and the atmospheric layer above

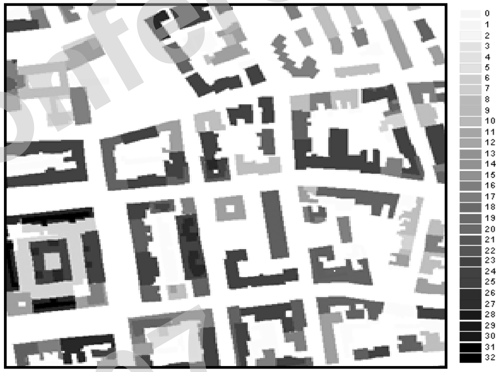
- Improving an existing model, firstly derived for vegetative canopy for application to real urban canopy

- Improvements in terms of boundary conditions and conceptual description of the urban area

- DEM-based analysis of urban morphology

DEM analysis





DEM analysis

- Morphological parameters derived from DEM analysis have been proved to be useful in describing flow and exchange in urban areas:

- λ parameters: λ_p (flow regimes, heat fluxes);
  λ_f (drag, wind profiles, heat fluxes);

- Sky view factor ψ: (exchange processes, heat and momentum fluxes)

- Morphological parameters are available for northern American and European cities;

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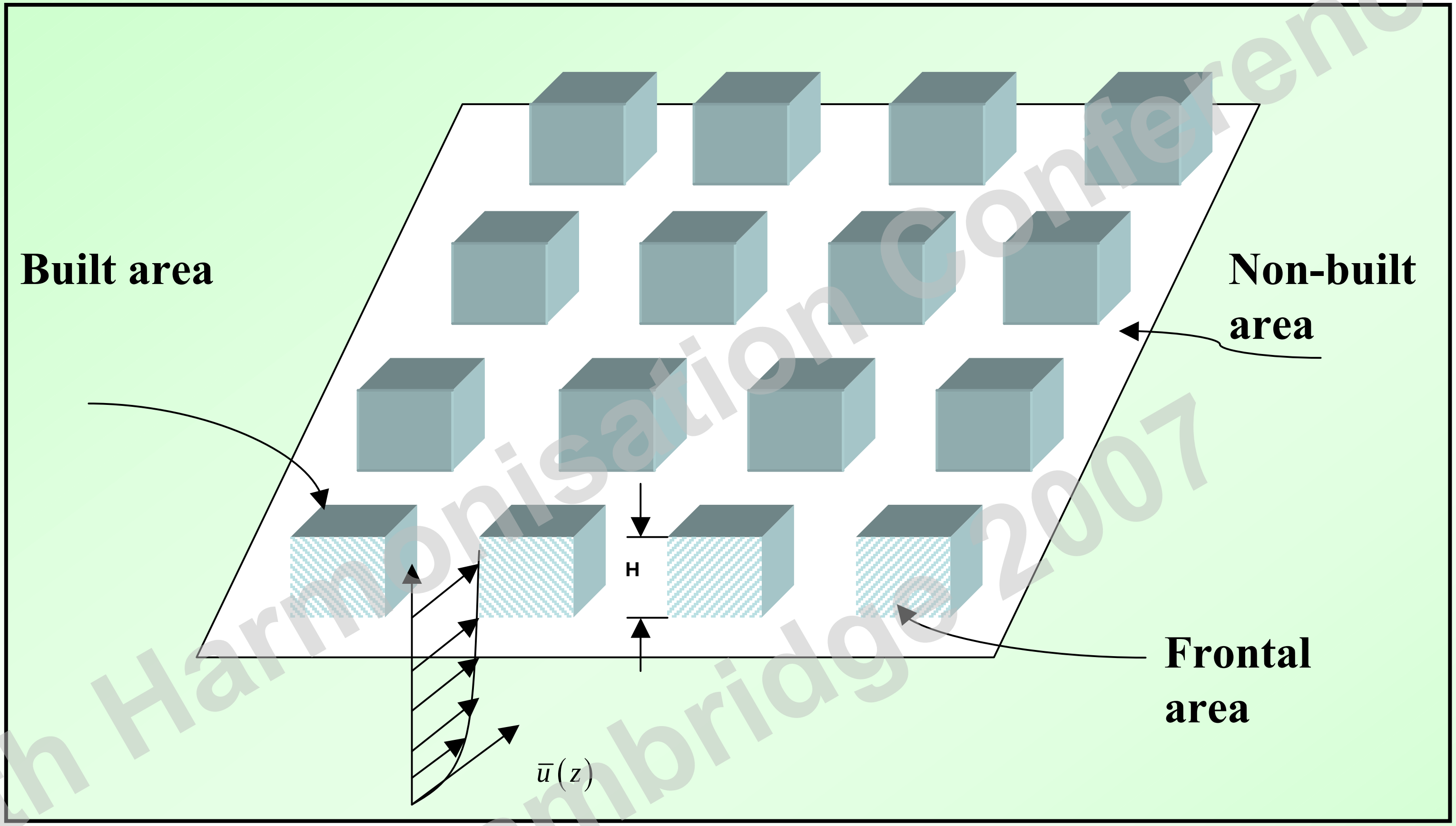
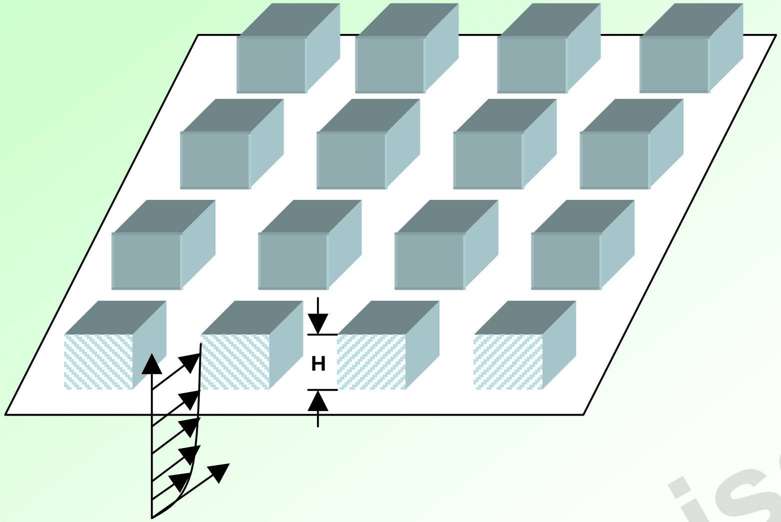
Morphological parameters



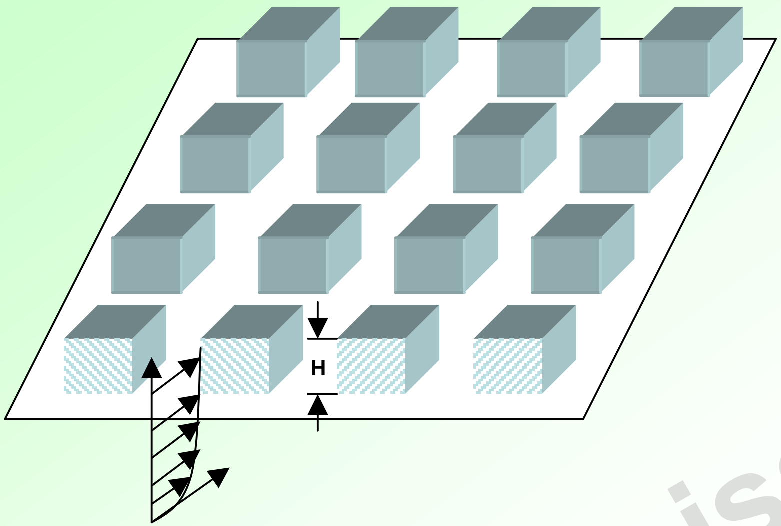
λ_p **Ratio between the BUILT AREA and the TOTAL AREA**

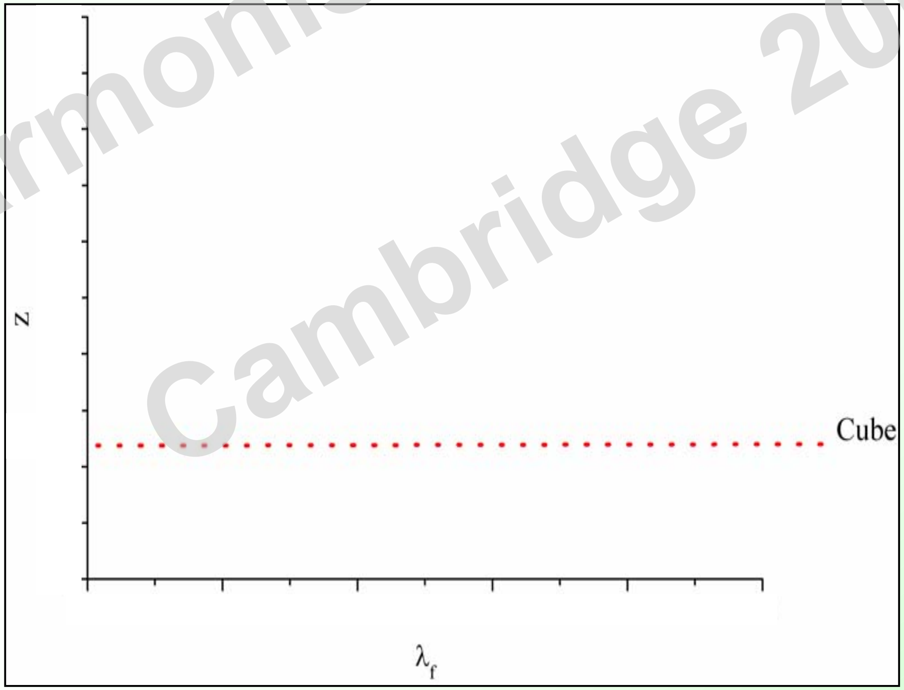
λ_f **Ratio between the FRONTAL AREA "seen" by the wind and the TOTAL AREA**

Typical modelling



Typical modelling





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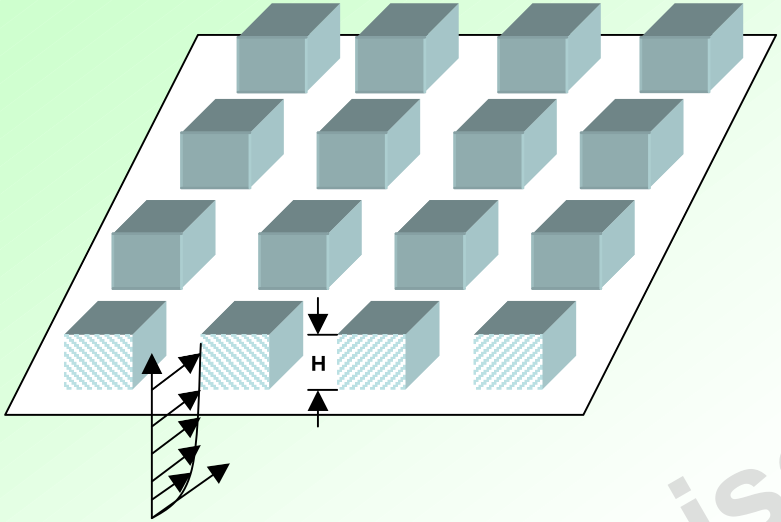
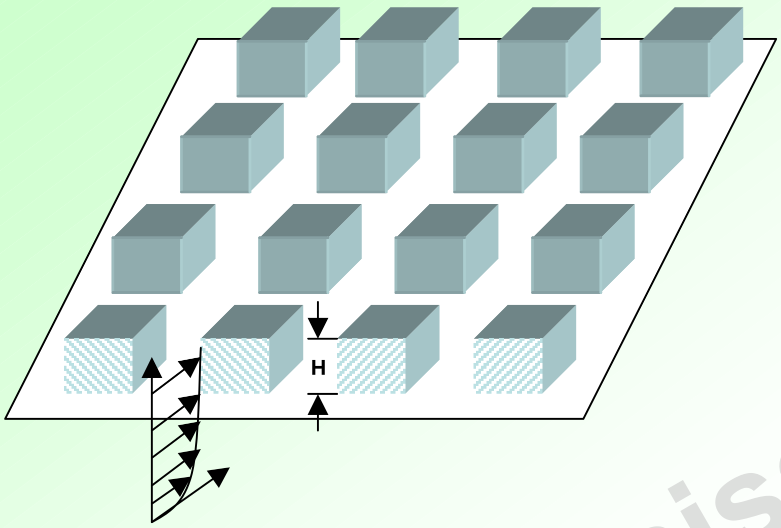


DEM + our model

Typical modelling



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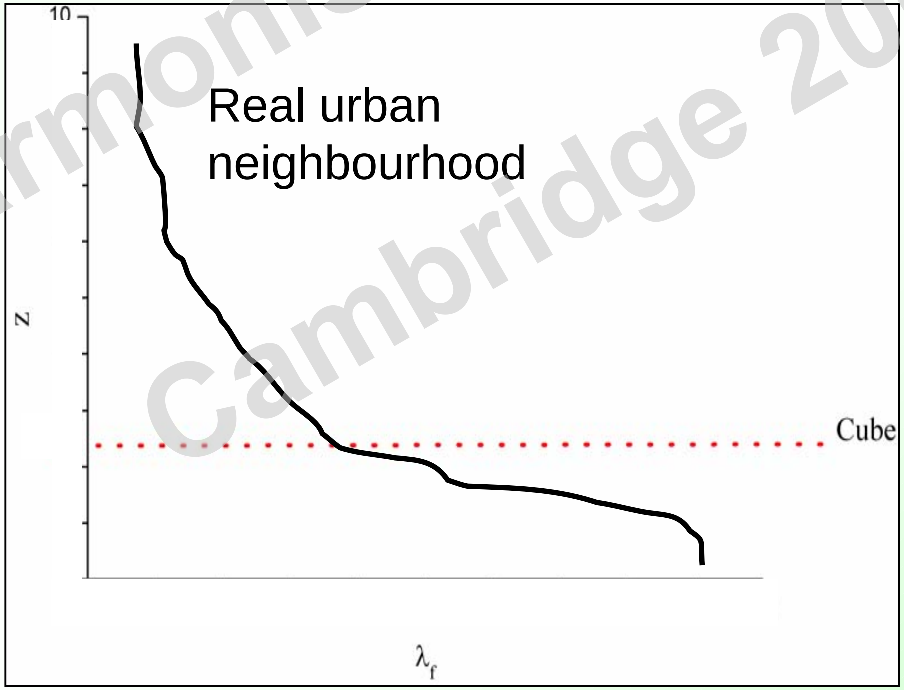
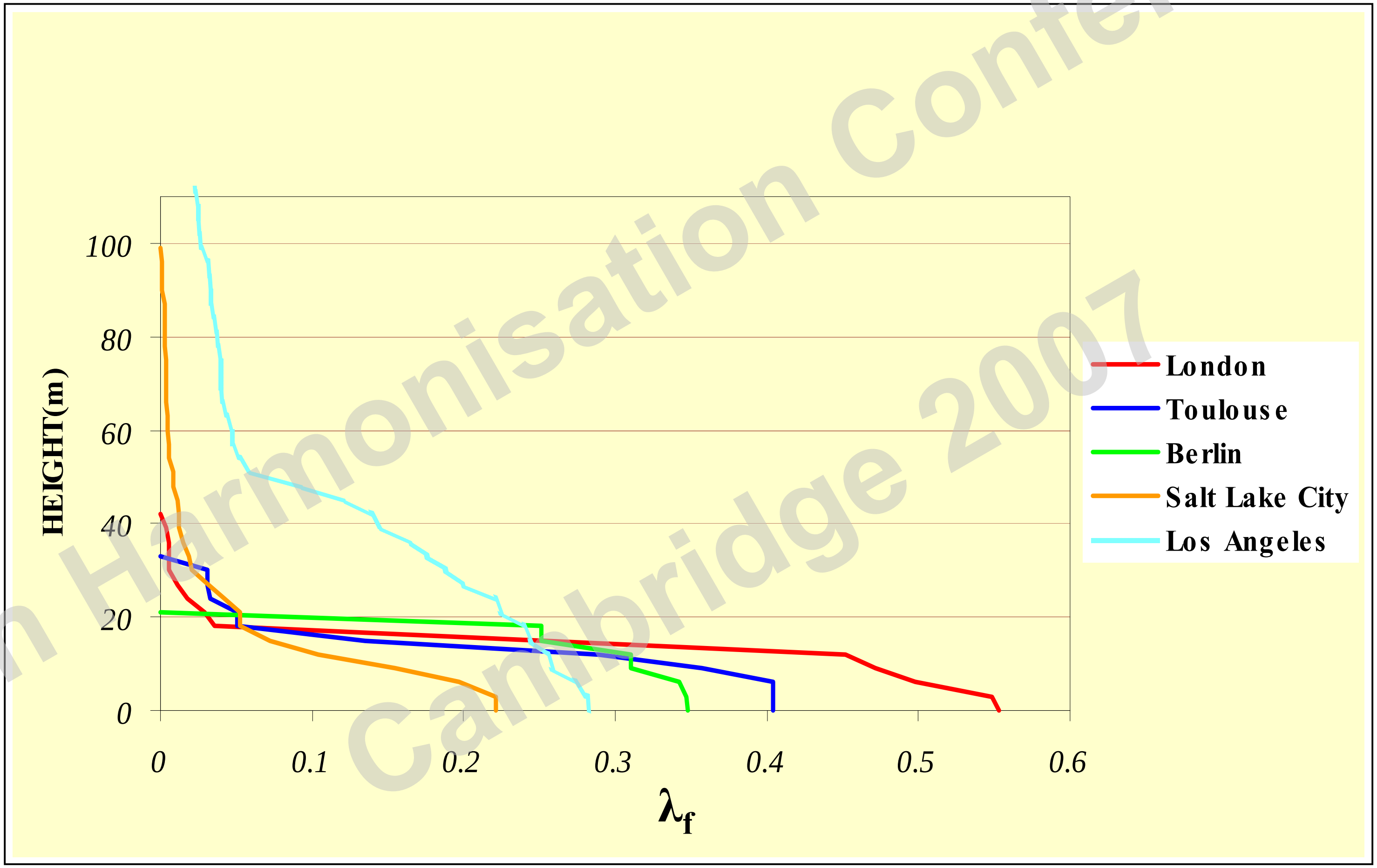


λ_f from DEM



Derivation of the mean wind profile $U(z)$

Momentum balance equation:

$$\frac{d}{dz}\left(l(z,\lambda_p)\frac{dU(z)}{dz} \right)^2 = \frac{\overline{C_{DH}}\lambda_f(z,\theta)}{2H}U^2(z)$$

Boundary Conditions

$U(z = bH) = U_{bH}, b \geq 1$

$\lambda_f(z,\theta)$ prescribed from DEM analysis

Derivation of the mean wind profile *U(z)*

Momentum balance equation:

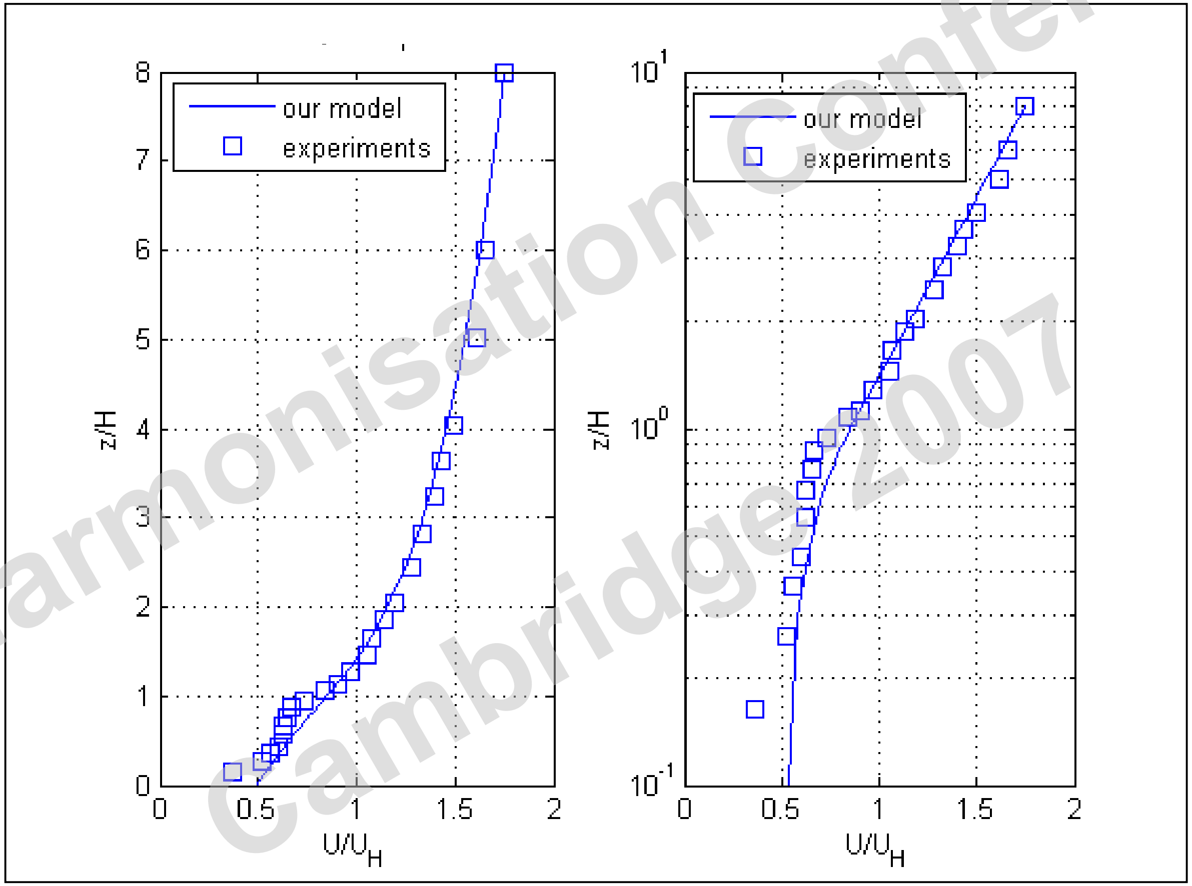
$$\boxed{\frac{d}{dz}\left(l(z,\lambda_p)\frac{dU(z)}{dz}\right)^2 = \frac{\overline{C_{DH}}\lambda_f}{2H}U^2(z)}$$

Boundary Conditions

$$U(z=bH)=U_{bH},\; b\geq 1$$

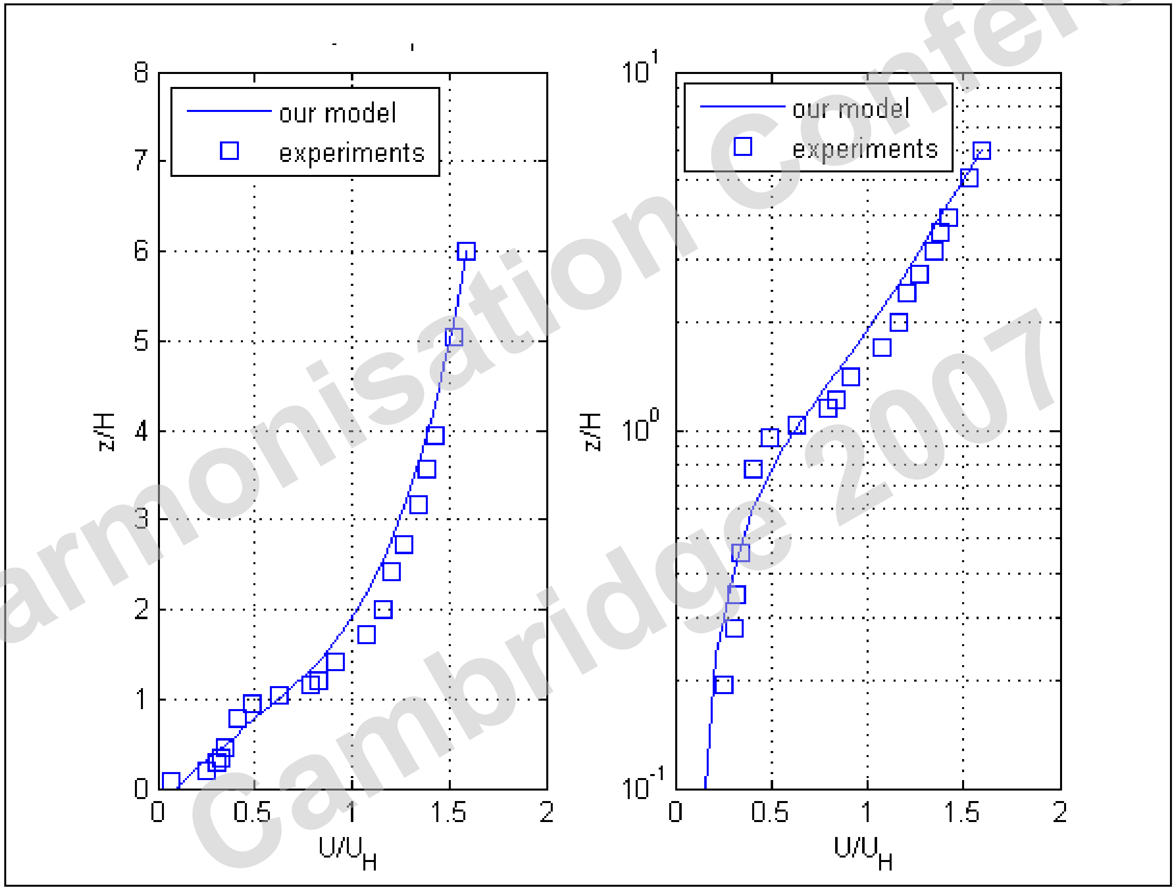
λ_f constant

Results: Evaluation over array of cubes



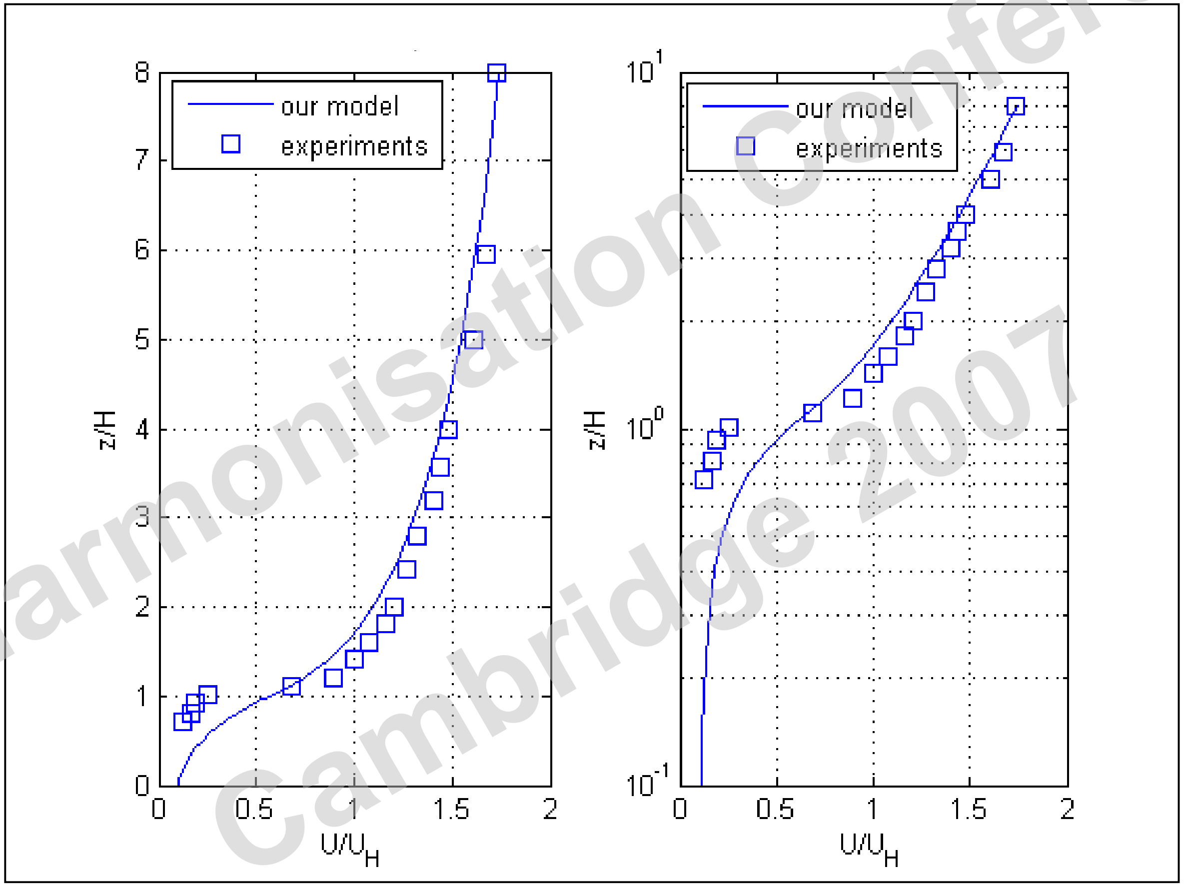
Cube arrays λ_p = 0.0625 Sparse canopy

Results: Evaluation over array of cubes



Cube arrays λ_p = 0.16. Intermediate canopy

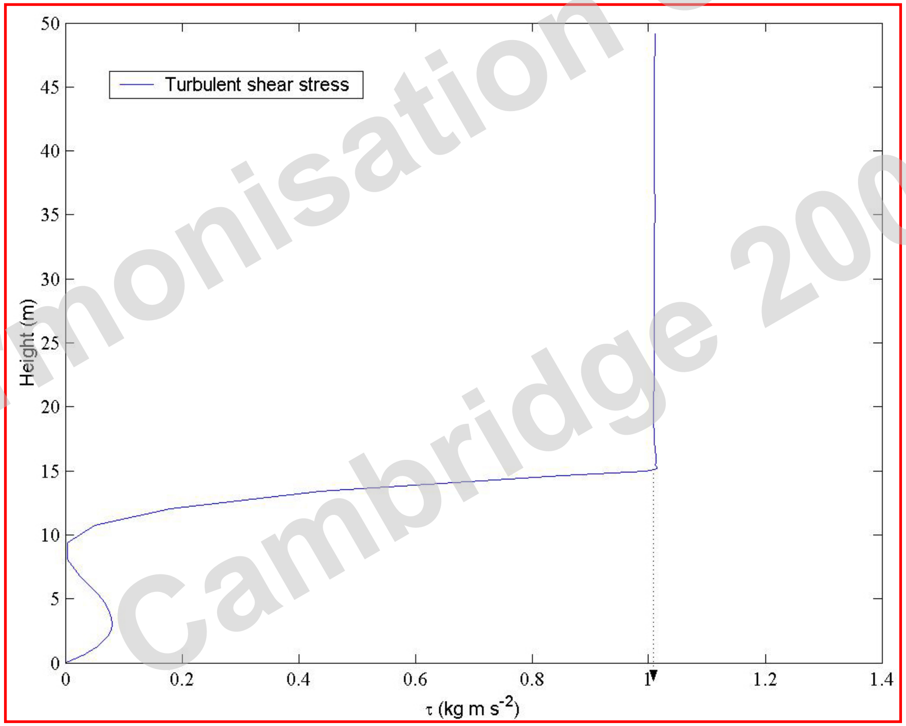
Results: Evaluation over array of cubes



Cube arrays λ_p = 0.44. Dense canopy

Derivation of the friction velocity u_*

Shear stress $$\tau = \rho u_*^2 \Rightarrow u_* = \sqrt{\frac{\tau}{\rho}} = \sqrt{\left(l^2 \frac{dU}{dz}\right)\frac{dU}{dz}}$$



Derivation of the friction velocity u_*

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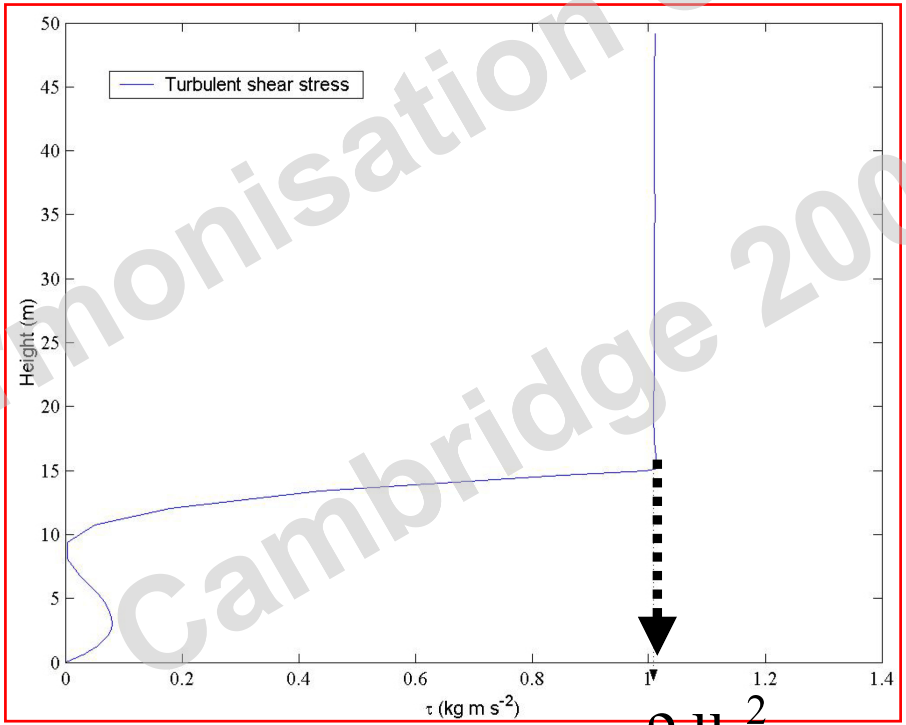


$\rho\, u_*^{\,2}$

Evaluation using wind tunnel data

u_* / u_H	Sparse	Intermed.	Dense
(Hall et al. 1998)	0.20	0.23	0.26
Our model	0.20	0.27	0.30

Derivation of the mean wind profile *U(z)*

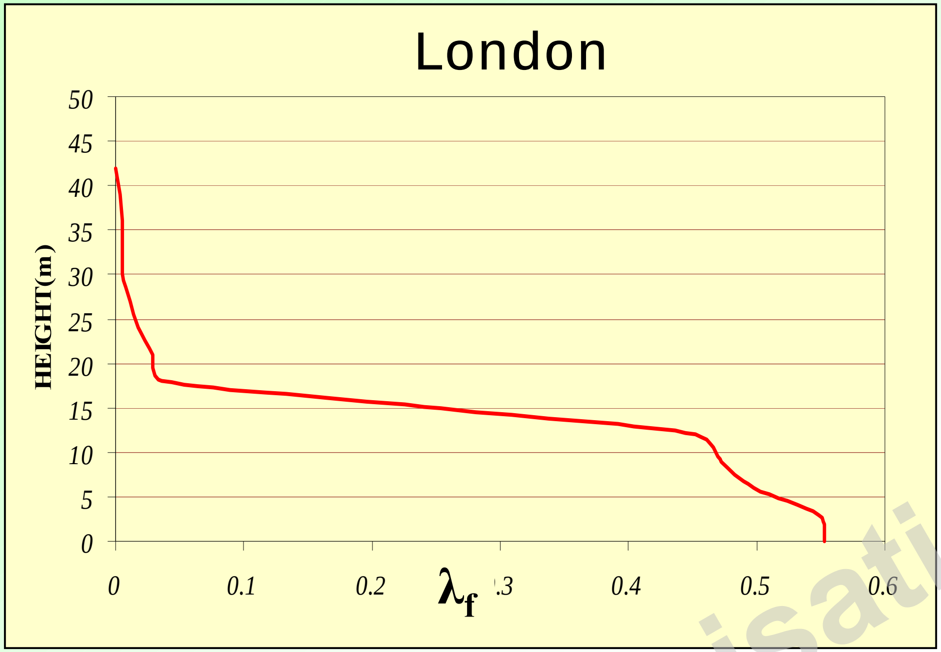
Momentum balance equation:

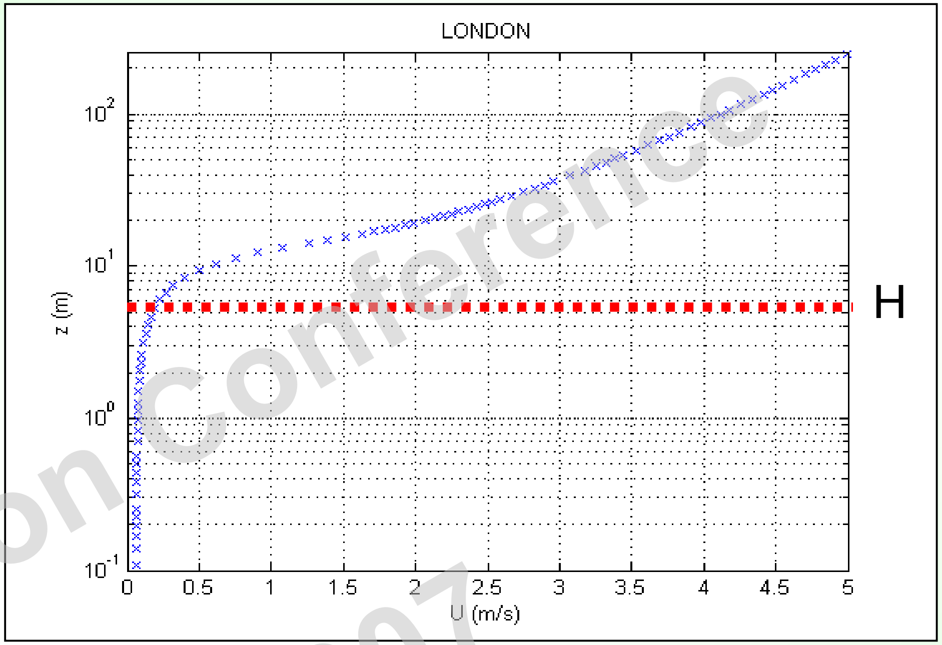
$$\frac{d}{dz}\left(l(z,\lambda_p)\frac{dU(z)}{dz} \right)^2 = \frac{\overline{C_{DH}}\lambda_f(z,\theta)}{2H}U^2(z)$$

Boundary Conditions

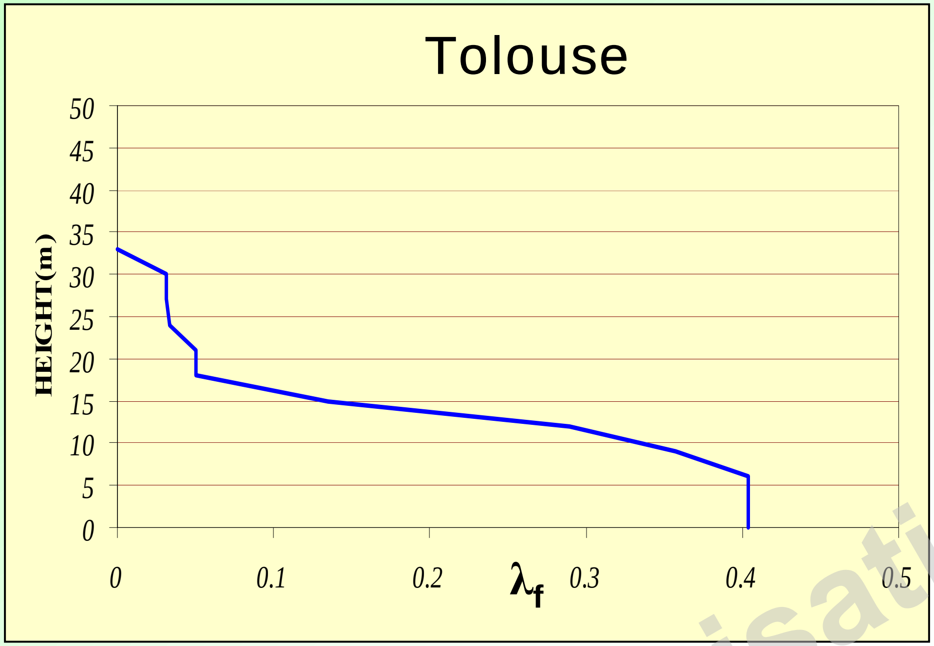
$U(z = bH) = U_{bH}, b \geq 1$

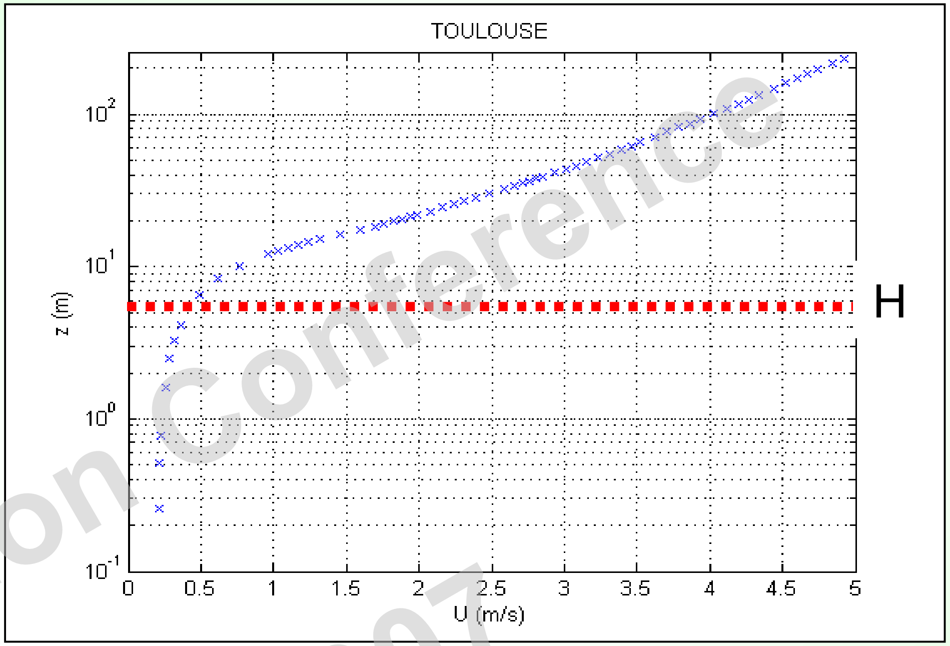
$\lambda_f(z)$ prescribed from DEM analysis



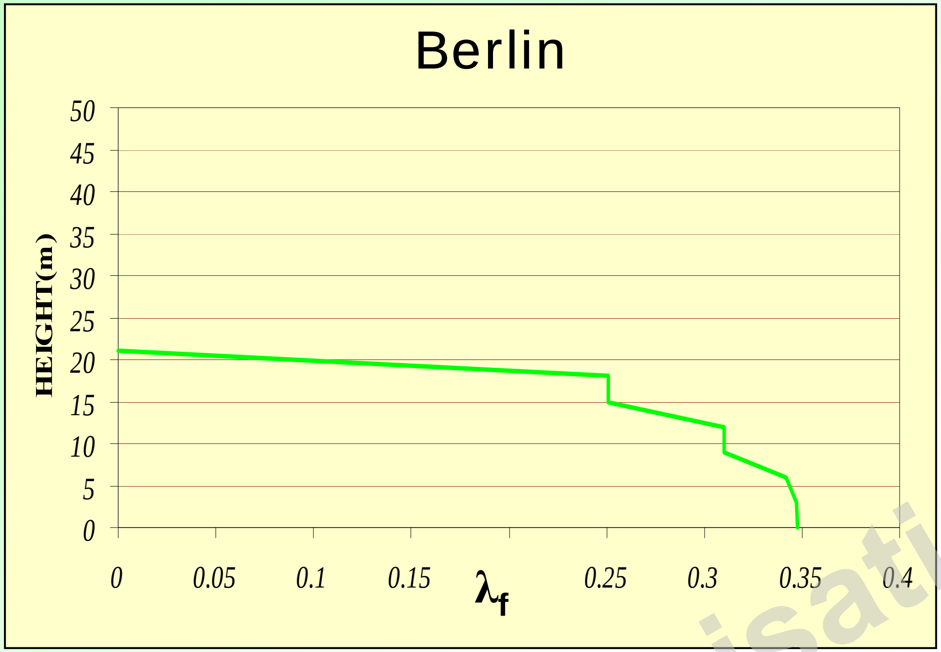


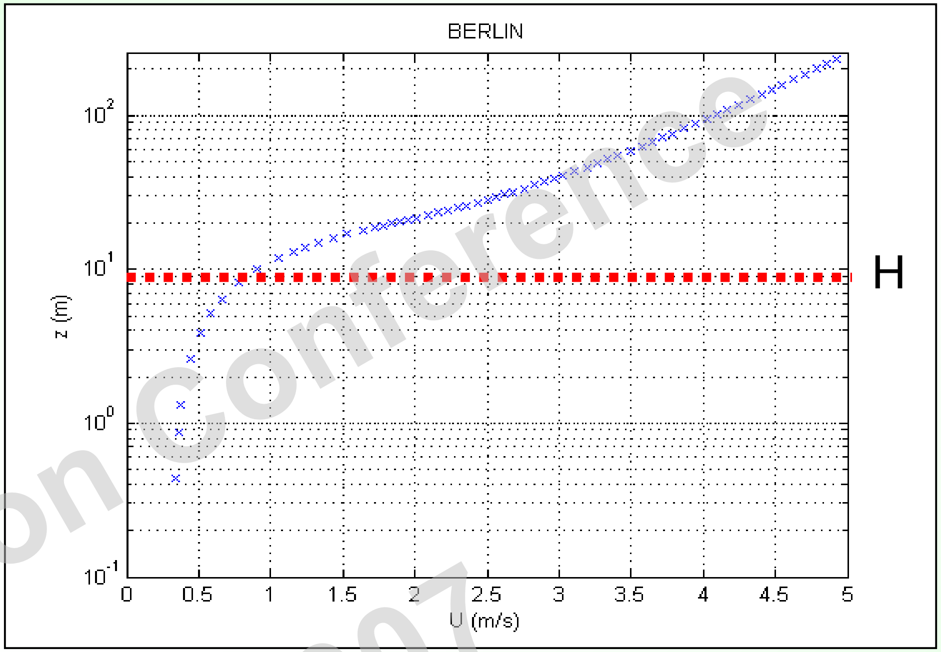
λ_p	Averaged λ_f	Averaged H (m)	σ_H (m)	d (m)	z_0 (DEM) (m)	u_* (model) ($m\ s^{-1}$)
0.55	0.32	13.6	5.0	11.9	0.30	0.36



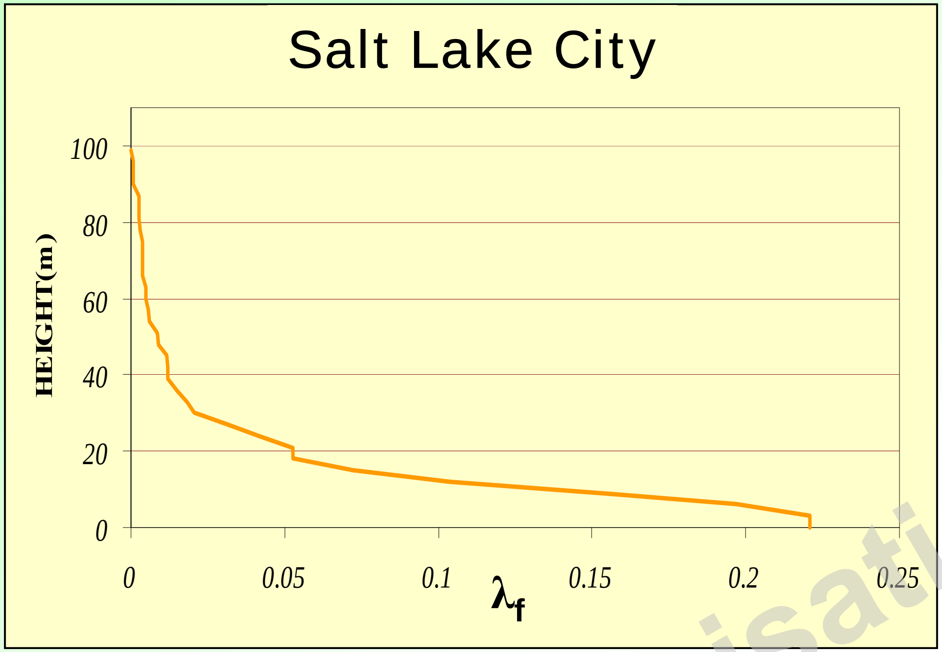


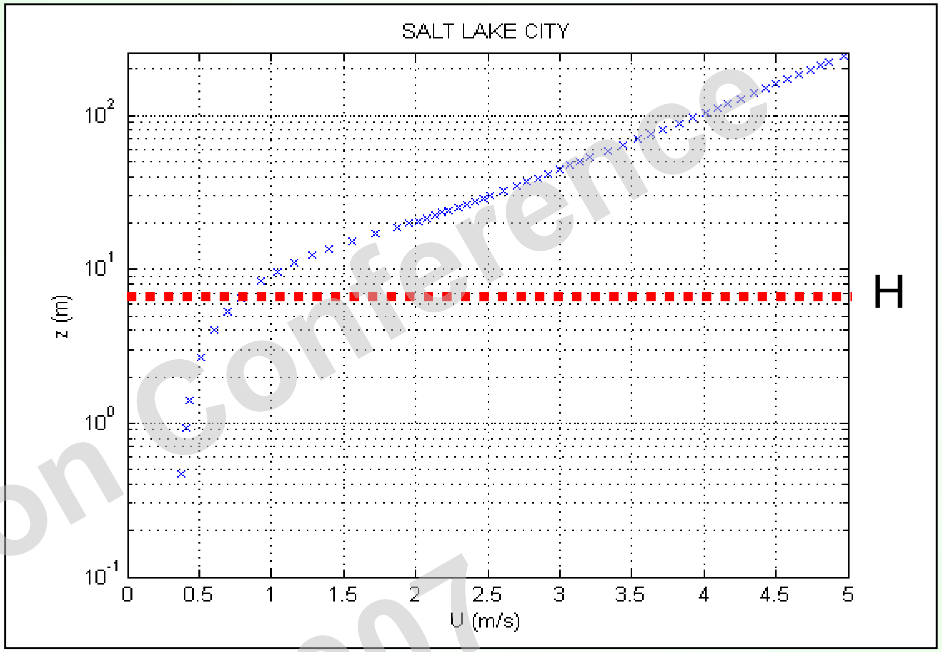
λ_p	Averaged λ_f	Averaged H (m)	σ_H (m)	d (m)	z_0 (DEM) (m)	u_* (model) ($m\ s^{-1}$)
0.40	0.32	15.3	6.1	10.9	0.92	0.40





λ_p	Averaged λ_f	Averaged H (m)	σ_H (m)	d (m)	z_0 (DEM) (m)	u_* (model) (m s^{-1})
0.35	0.23	18.6	4.3	11.4	1.08	0.37





λ_p	Averaged λ_f	Averaged H (m)	σ_H (m)	d (m)	z_0 (DEM) (m)	u_* (model) ($m\ s^{-1}$)
0.22	0.11	16.3	14.1	11.4	1.50	0.42

Conclusions and further work…

-A simple model for the flow over real urban neighbourhood was presented;

- Evaluation using wind tunnel data (for cube array) showed the capability of the simple model in predicting real flow field

- DEM technique was successively adopted for the purposes of providing realistic BC to the model

- The model showed the to be included into operational models for the assessing of urban air quality at the investigated scale

- Evaluation of the model using full-scale data is currently under investigation

Thanks to

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