Estimating the Wind Resource in Urban Areas

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Motivation

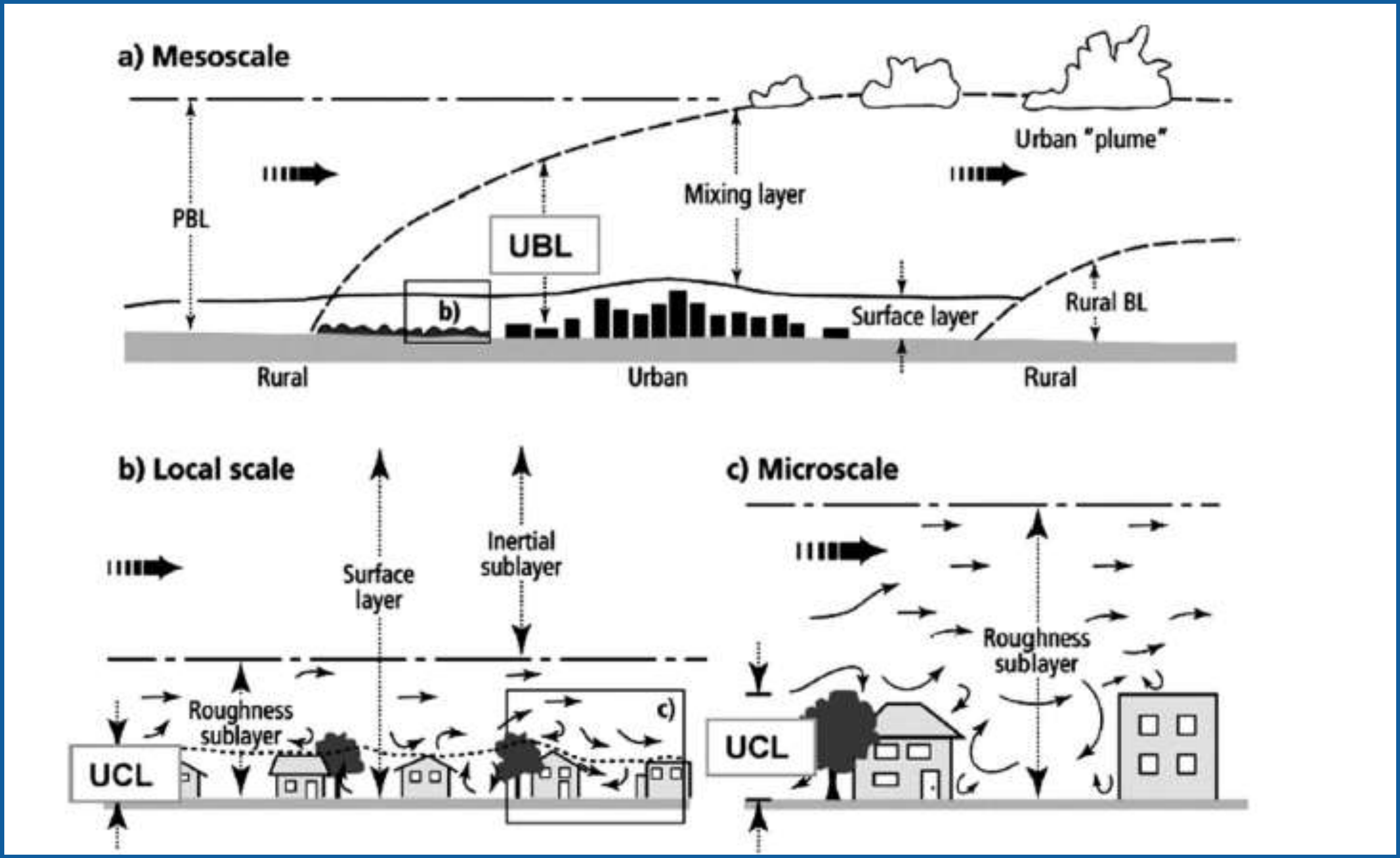
- Increased interest in micro-generation, including small wind turbines in urban areas.
- Field trials have shown that urban turbines are currently performing poorly
- Two approaches for improving performance
  - Improve turbine design
  - Optimise placement

UK Wind Atlas

- DECC wind speed database (NOABL)
- Wind speed at 10, 25, 45 m above ground level on 1 km resolution
- Produced by a mass consistent flow model assuming a uniform rural surface
- Large errors in urban areas
- Mean error of 42% across 14 urban sites

(DECC, 2012)

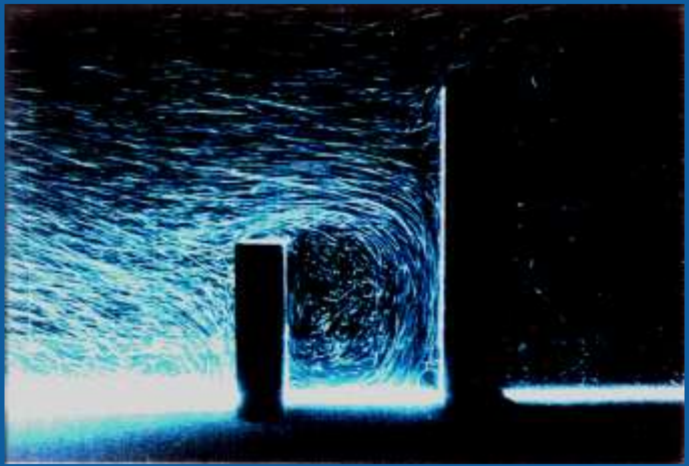
Urban Meteorology



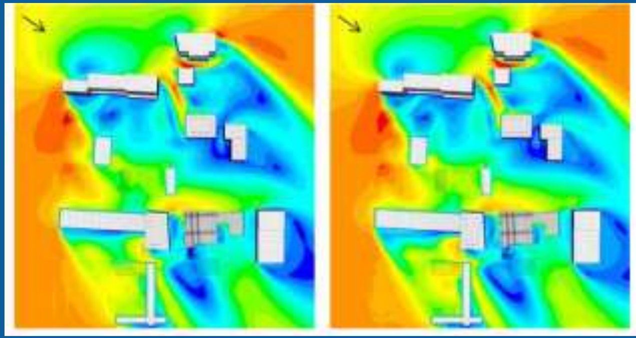
(Oke, 1997)

Roughness Sublayer

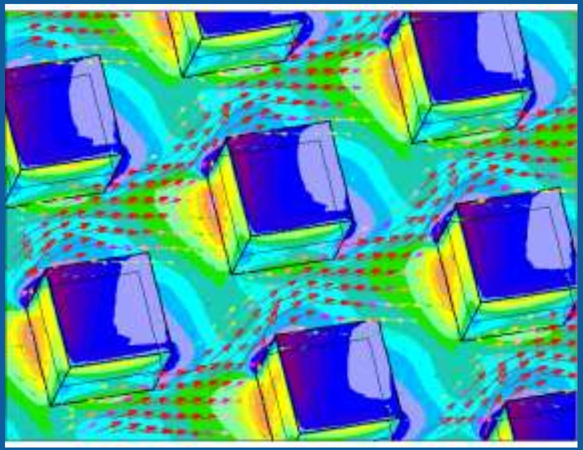
- CFD simulations
- Wind tunnel experiments



(Kato, 2012)



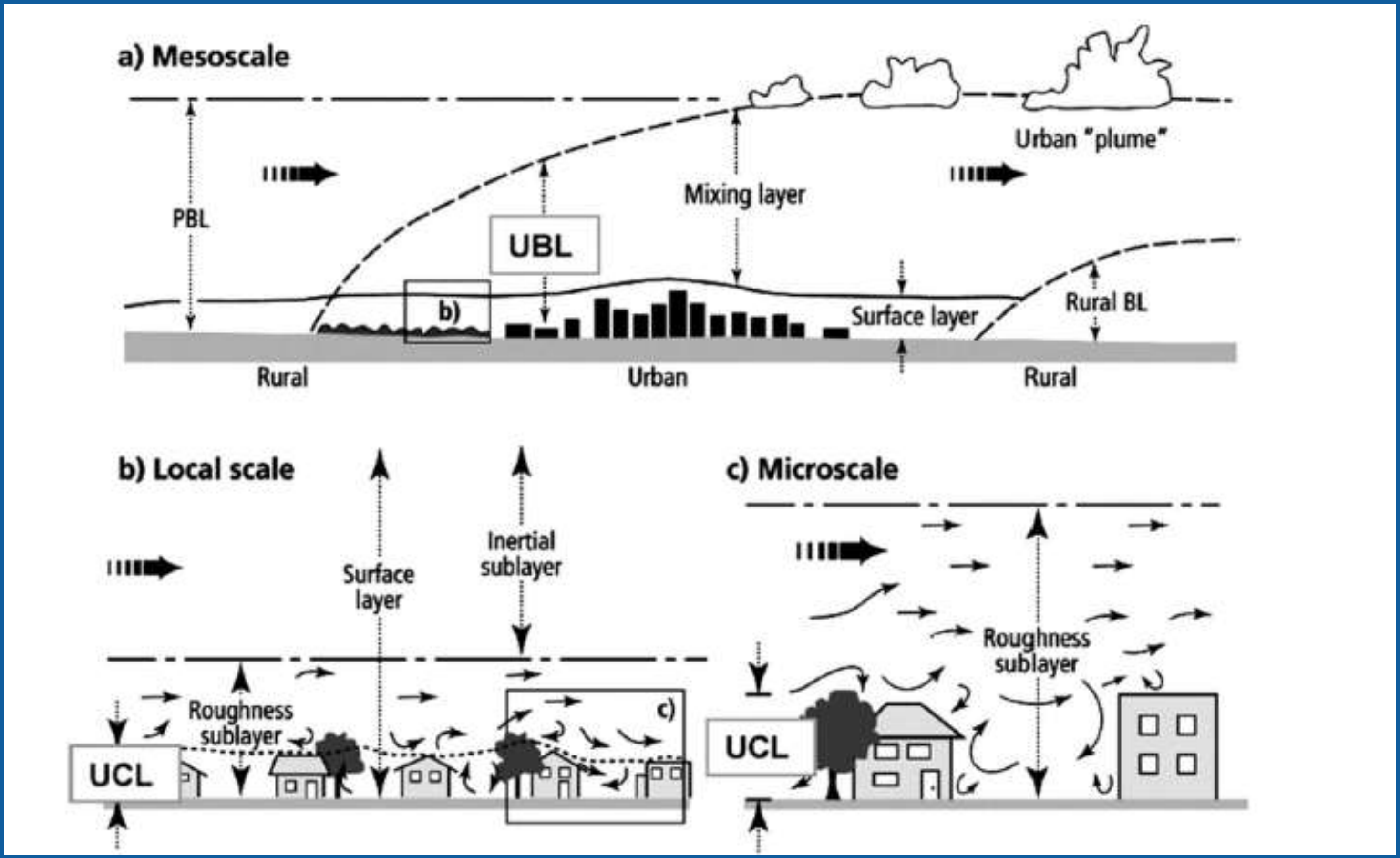
(Gousseau, 2011)



(Claus, 2007)

(Obsidian, 2012)

Urban Meteorology



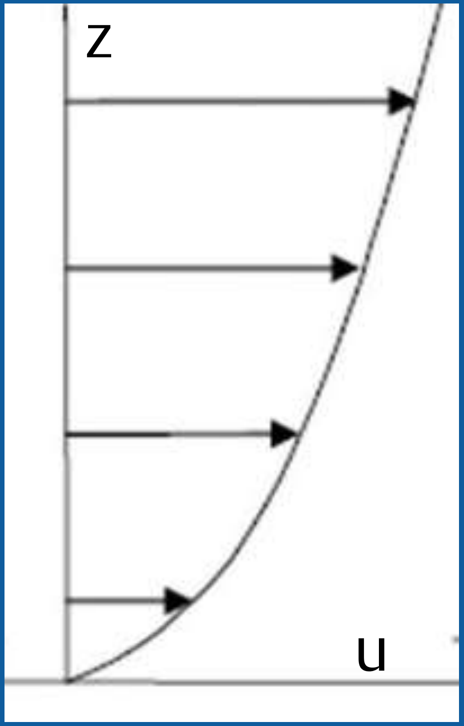
(Oke, 1997)

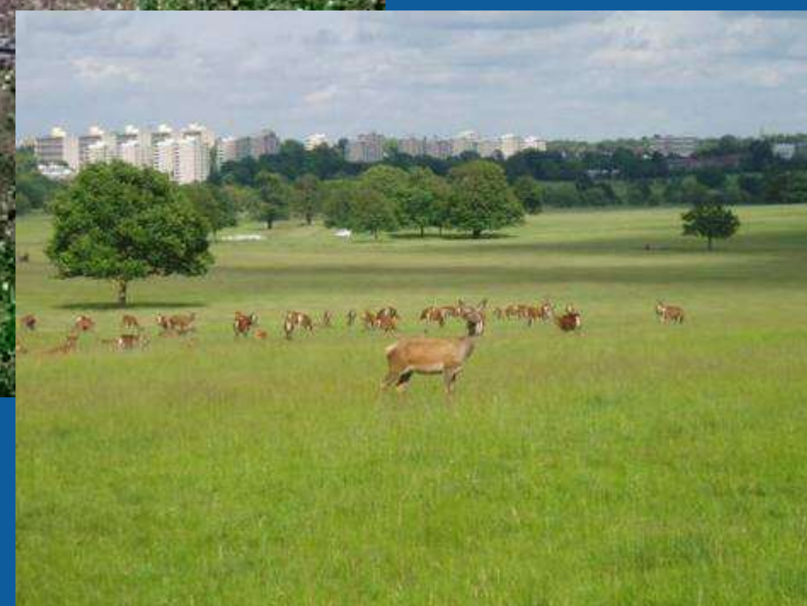
Inertial sublayer

- Wind speed considered horizontally homogeneous
- Wind speed, U, increases logarithmically with height

$$U(z) = \frac{u^*}{k} \ln\left(\frac{z}{z_0}\right)$$

u^* = friction velocity
k= von Karman constant
z= height
z_0= roughness length

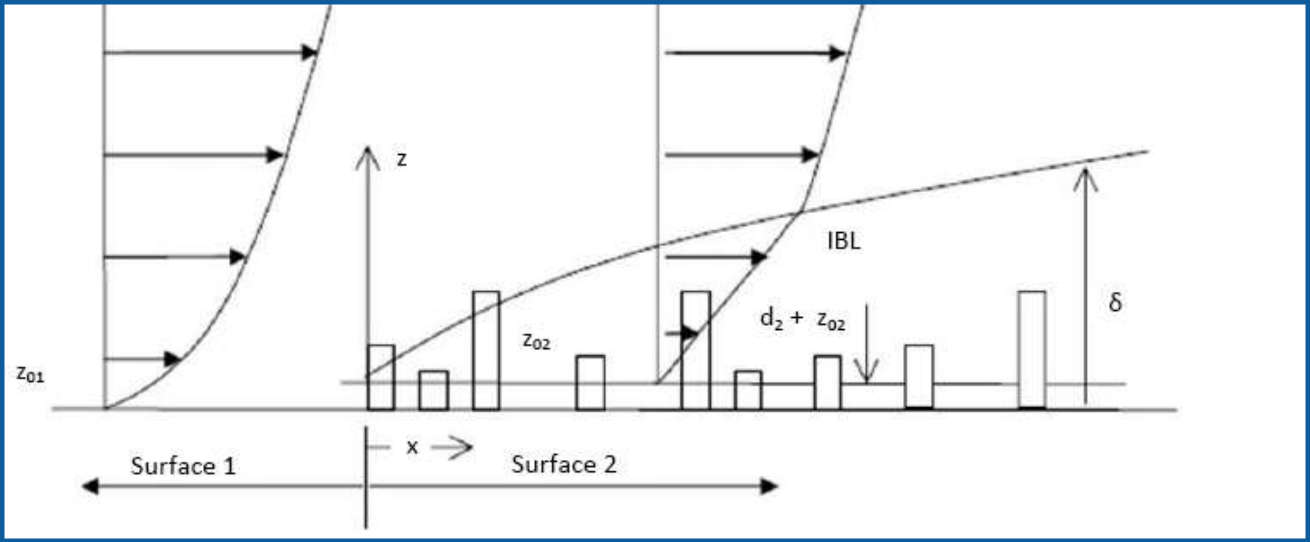




Internal Boundary Layer

- As flow passes from one surface to another an Internal Boundary Layer grows

$$U(z) = \frac{\ln\left[\frac{z-d}{z_{02}}\right]\ln\left[\frac{\delta}{z_{01}}\right]}{\ln\left[\frac{\delta-d}{z_{02}}\right]\ln\left[\frac{z_{ref}}{z_{01}}\right]} U_{ref}\left(z_{ref}\right)$$



(Mertens, 2003)

Method

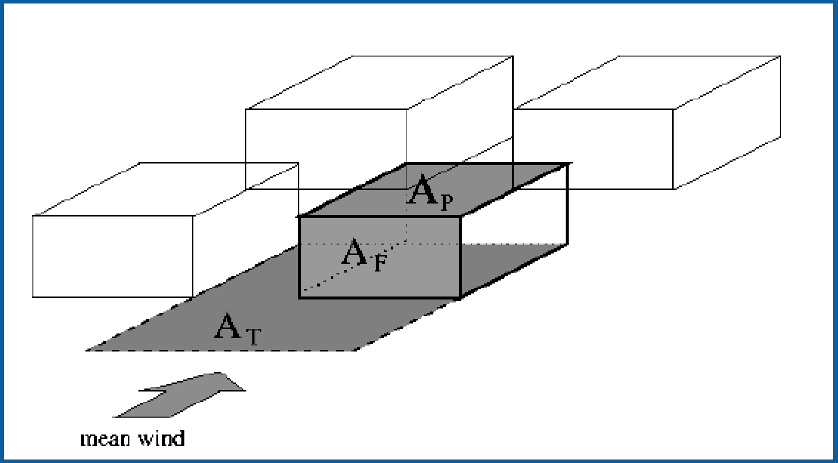
1. Divide the city into 1 km gridboxes
2. Estimate surface parameters

Surface Parameters

University of Reading

- Typical approach: Land use as proxy- can lead to large errors.

- Urban Morphology:
  - Plan area ratio, $\lambda_P = A_P / A_T$
  - Frontal area ratio, $\lambda_F = A_F / A_T$



(Grimmond and Oke, 1999)

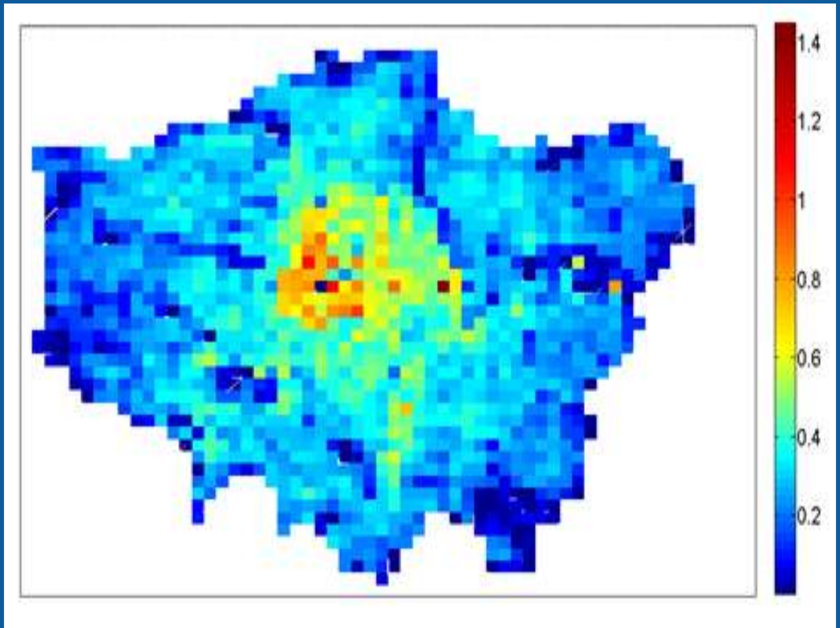
Macdonald et al. (1998)

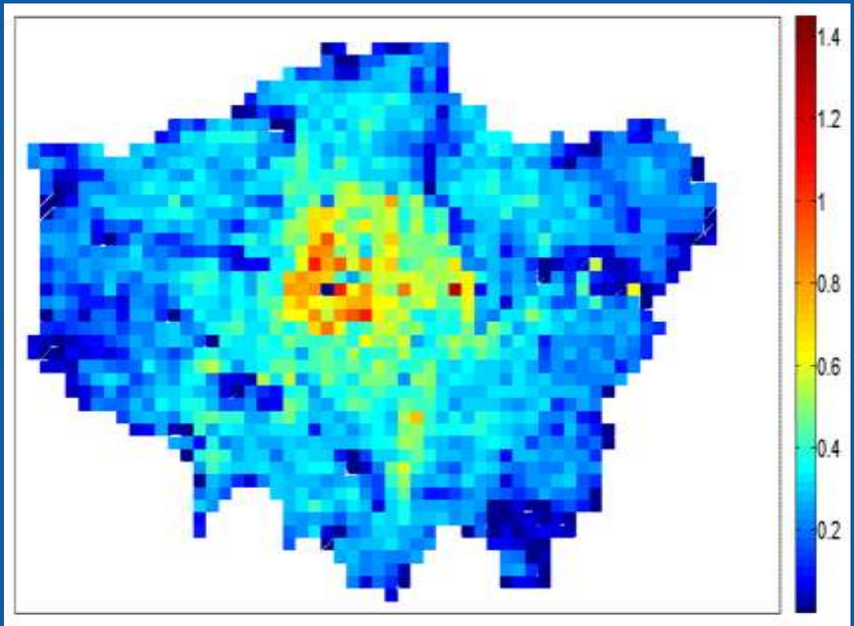
$$\frac{d}{h} = 1 + A^{-\lambda_P}(\lambda_P - 1)$$

$$\frac{z_0}{h} = \left(1 - \frac{d}{h}\right) exp\left(-\left(0.5\beta \frac{C_D}{\kappa^2}\left(1 - \frac{d}{h}\right)\lambda_f\right)^{-0.5}\right)$$

- LUCID project derived building dimensions for Greater London.

Roughness length, z_0



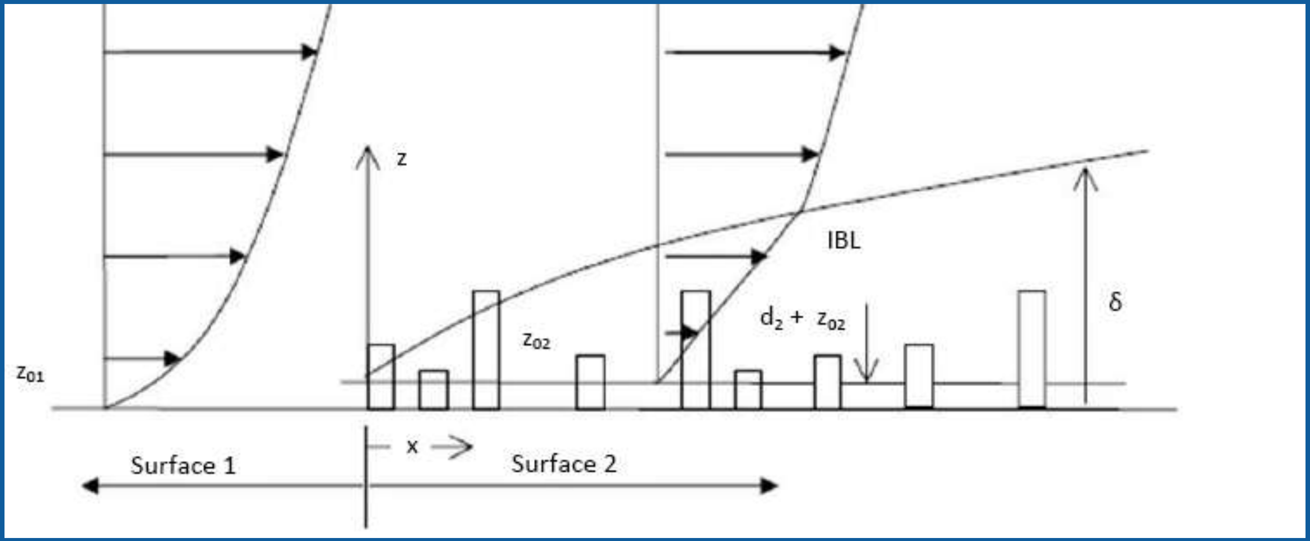


Method

1. Divide the city into 1 km gridboxes
2. Estimate surface parameters
3. Apply IBL wind profile equation for each change in roughness to estimate the gridbox mean wind speed for each wind direction

Internal Boundary Layer

- Reference rural wind speed provided by NOABL
- IBL wind profile equation applied for each change in roughness

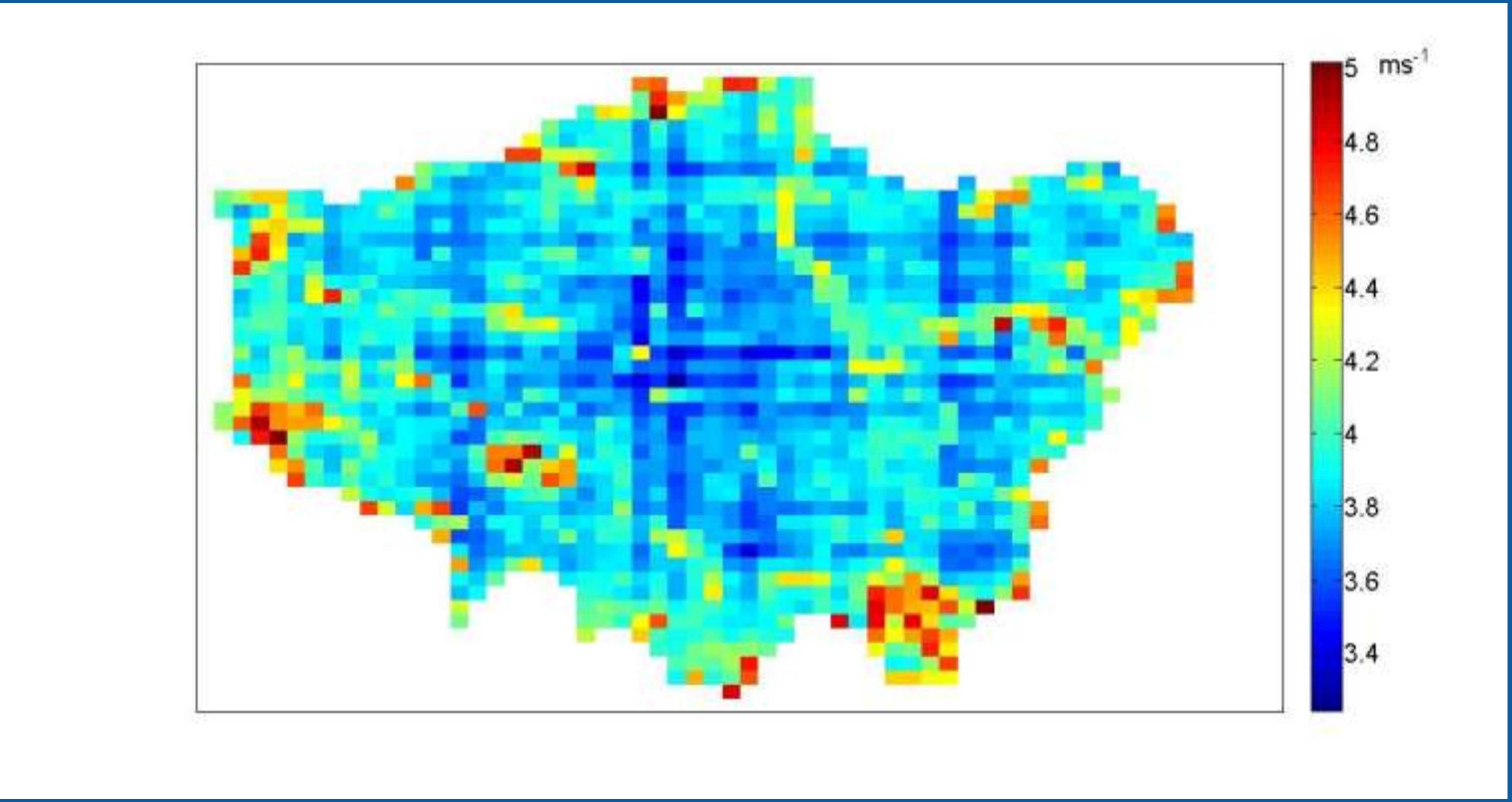


Method

1. Divide the city into 1 km gridboxes
2. Estimate surface parameters
3. Apply IBL wind profile equation for each change in roughness to estimate the gridbox mean wind speed for each wind direction
4. Consider wind rose data from nearby weather station (London Heathrow) to estimate frequency of the wind from each direction.

Mean wind speed

- At 5 m above mean building height

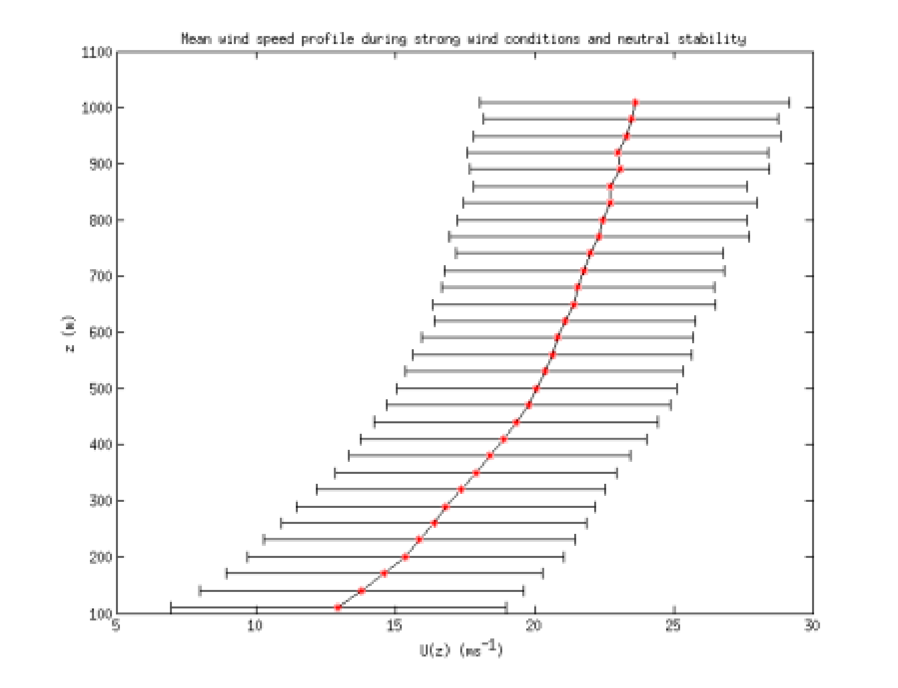


Validation

- Limited due to lack of wind observations in Greater London.
- Northolt: overestimate by 2%
  - NOABL: 25% overestimate
- Heathrow: overestimate by 16%
  - NOABL: 40% overestimate

Lidar wind profiles

- Advanced Climate Technology: Urban Atmospheric Laboratory (ACTUAL) project
- Doppler Lidar observations collected in Greater London
- Investigate the wind profile for different directions



Future work

- SODAR observations
- Urban Morphology data available for all urban areas in the UK
- Apply IBL correction to NOABL to derive new wind map