Inflow Estimation and Sensor Placement in High-Resolution Urban Wind Flows

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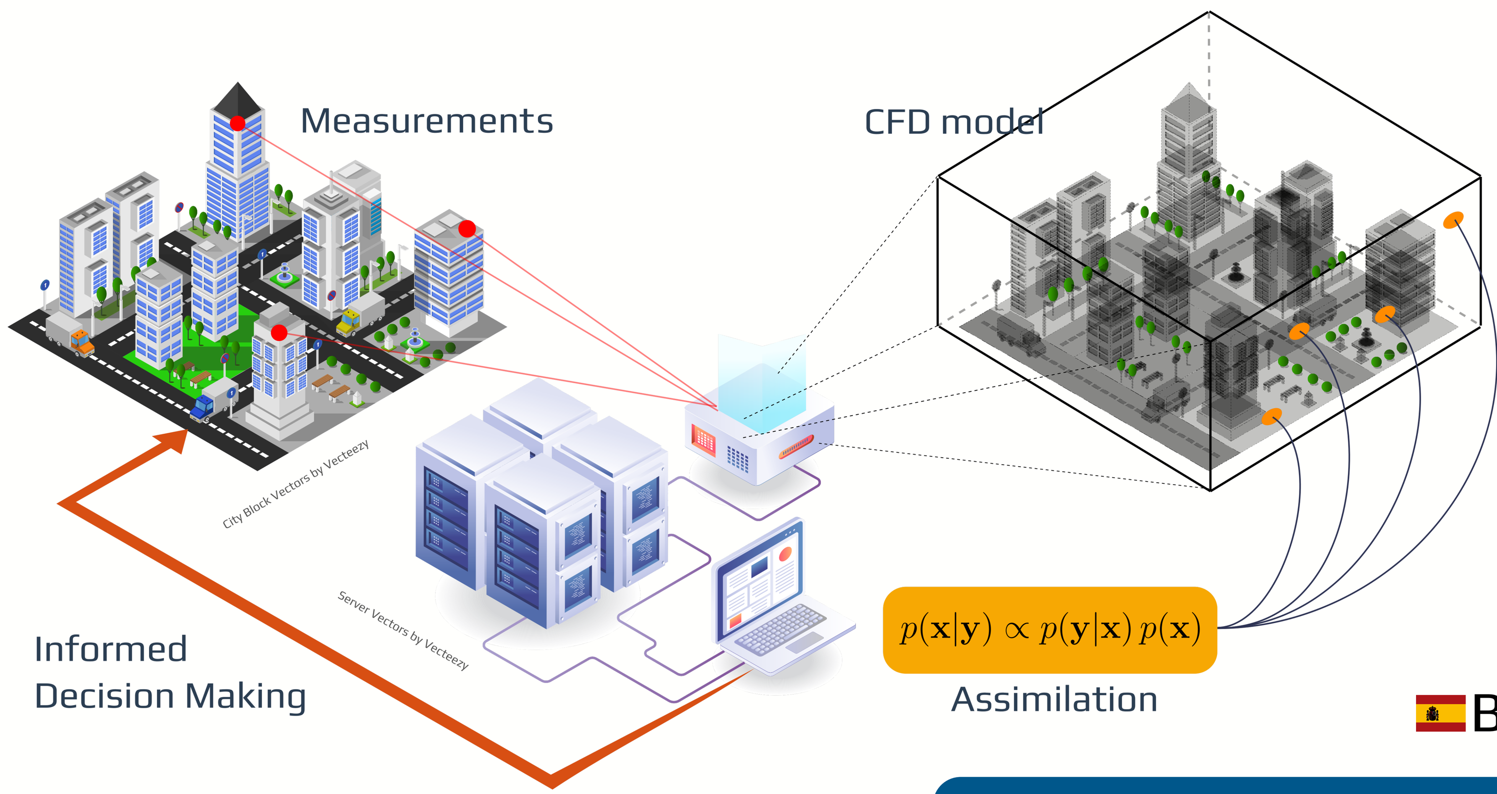
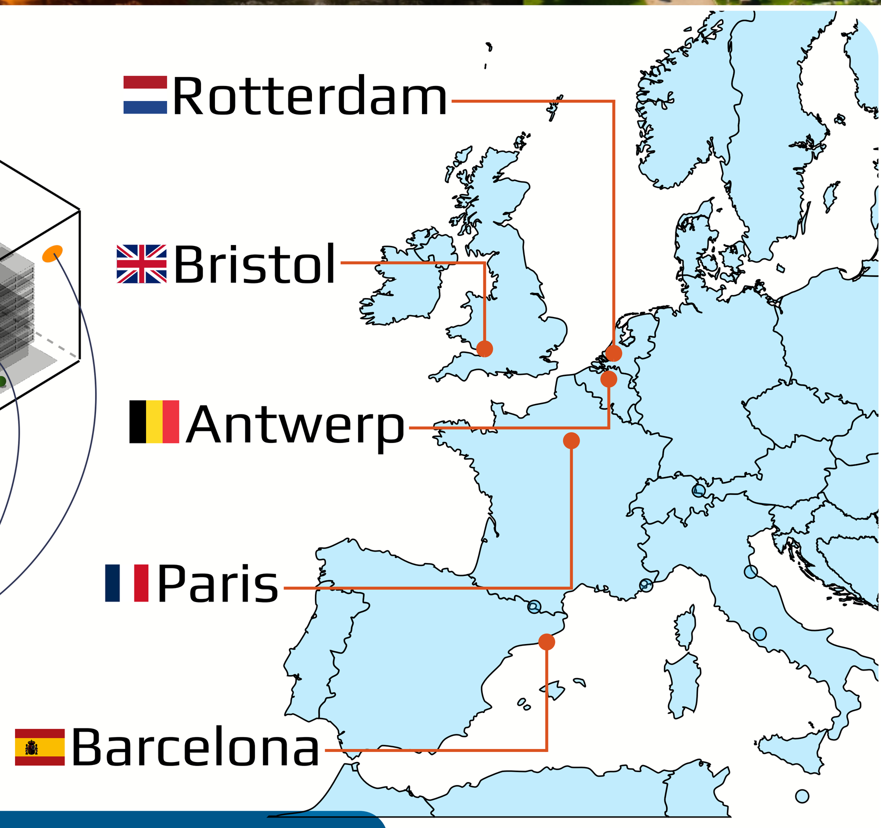
What are we doing?

Data assimilation → Uncertainty quantification
High-resolution CFD → Resilient urban planning
Realistic geometry → Heat/pollution modelling





CFD Model

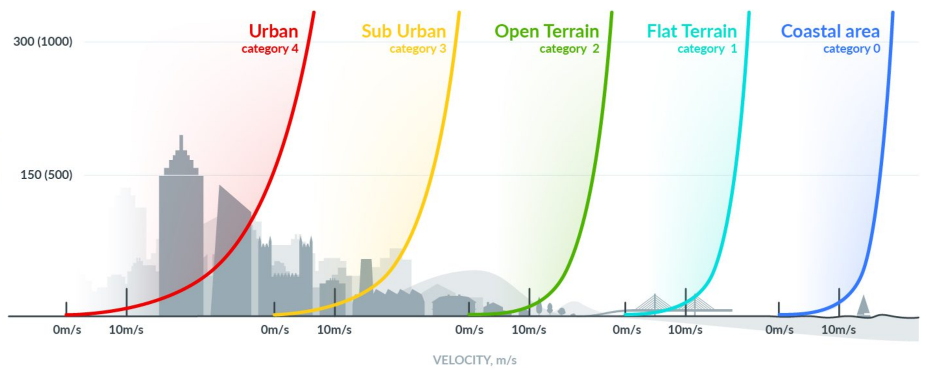
Why use RANS?

It's fast! (-ish) → More geometry

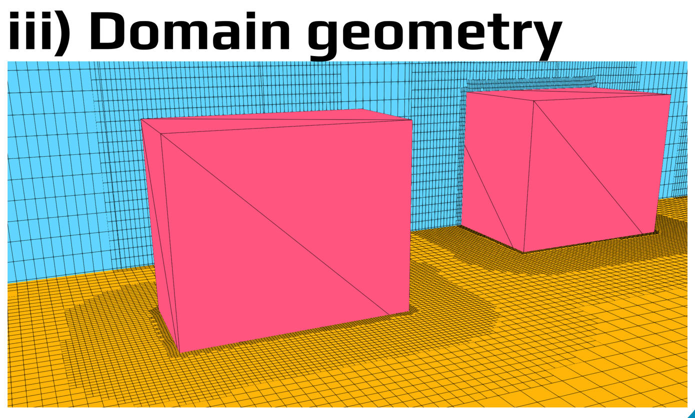
Horizontally homogeneous inlet ABL | Steady flow | $k-\varepsilon$ turbulence model | Neutral stratification | OpenFOAM

Log-law

$$\boldsymbol{u}(z) = \frac{u_*}{\kappa}\ln\left(\frac{z+z_0}{z_0}\right)\begin{pmatrix}\cos(\alpha_{\text{inlet}})\\ \sin(\alpha_{\text{inlet}})\\ 0\end{pmatrix}$$

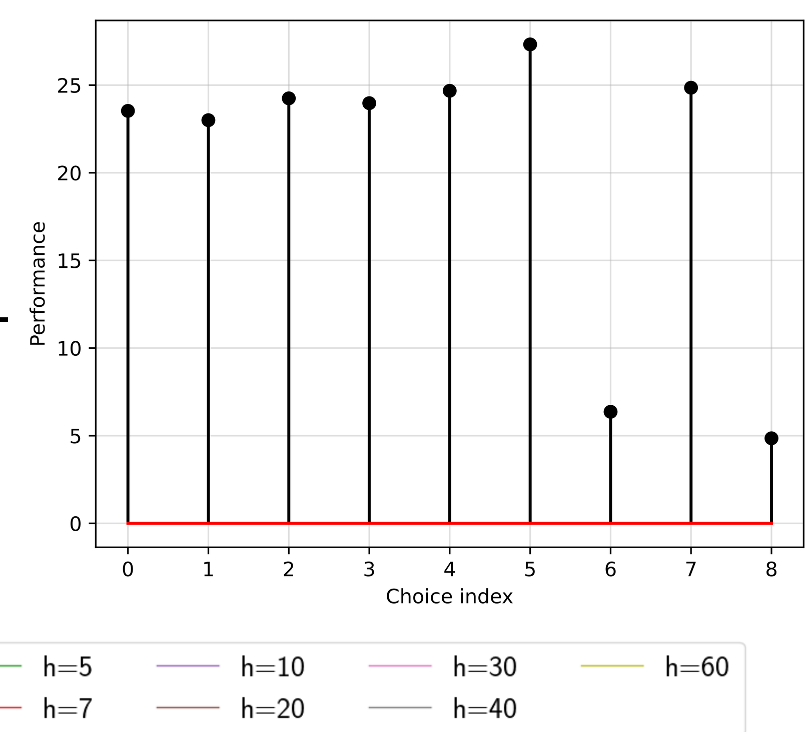


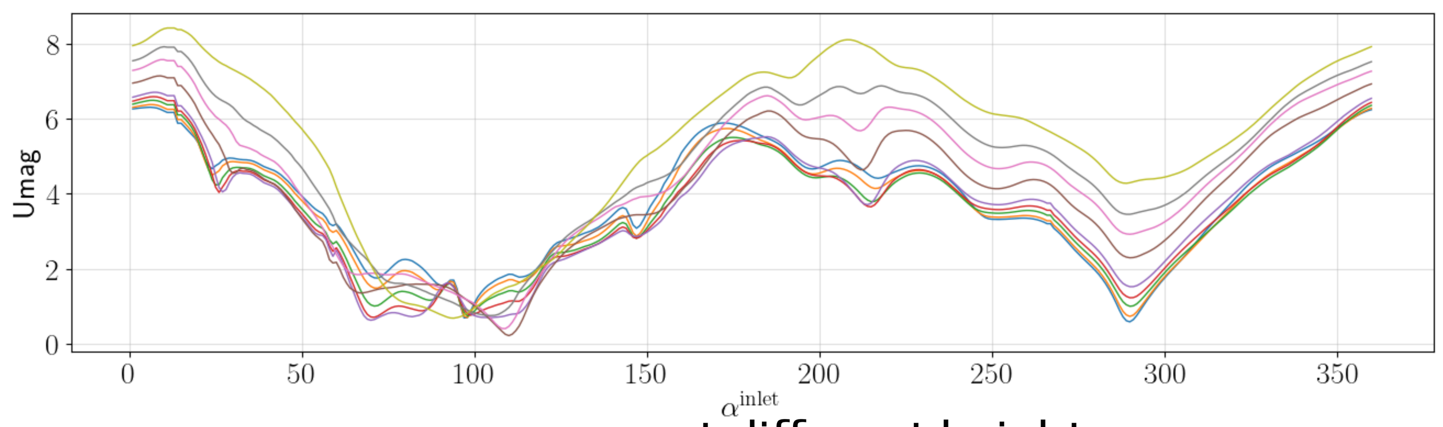
The local flow is driven by three main factors:
i) Reference velocity (scale)
ii) Inlet flow angle α_{inlet}
iii) Domain geometry



Sensor Placement

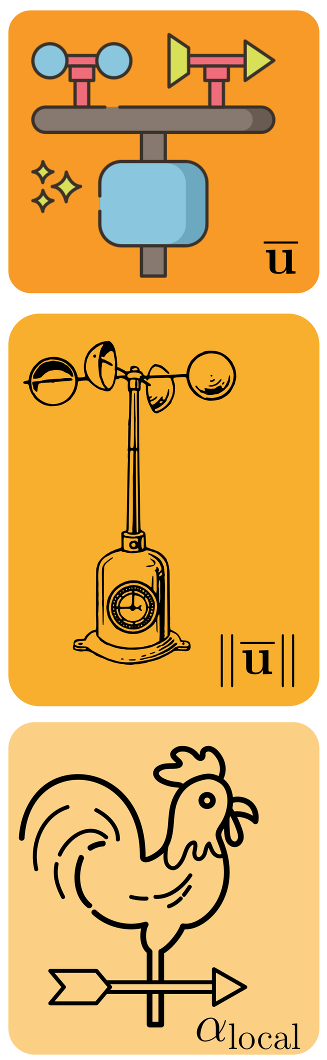
360° simulations





one sensor at different heights

Which value to observe?



Inflow Estimation

We use synthetic twin experiment first to validate the assimilation process. We use **Ensemble Smoothing (ES)** for the estimation

model

$\mathbf{y} = \mathcal{G}(\alpha_{\text{inlet}}) + \boldsymbol{\epsilon}$

$\mathbb{E}[\boldsymbol{\epsilon}] = 0,\ \mathbb{E}[\boldsymbol{\epsilon}\boldsymbol{\epsilon}^T] = \mathbf{C}_{\mathbf{dd}}$

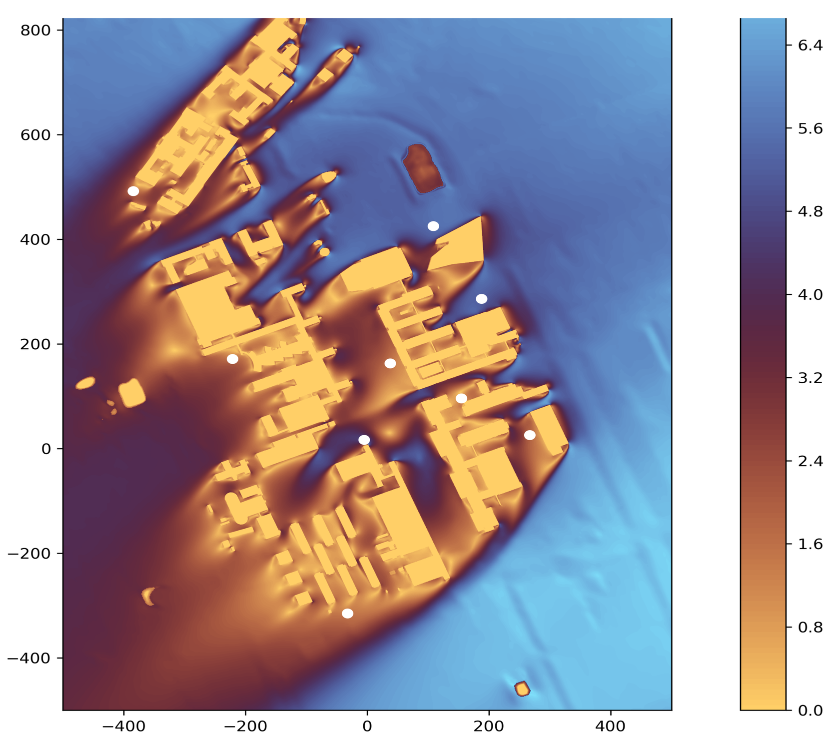
$\mathbf{y}$: value at different locations

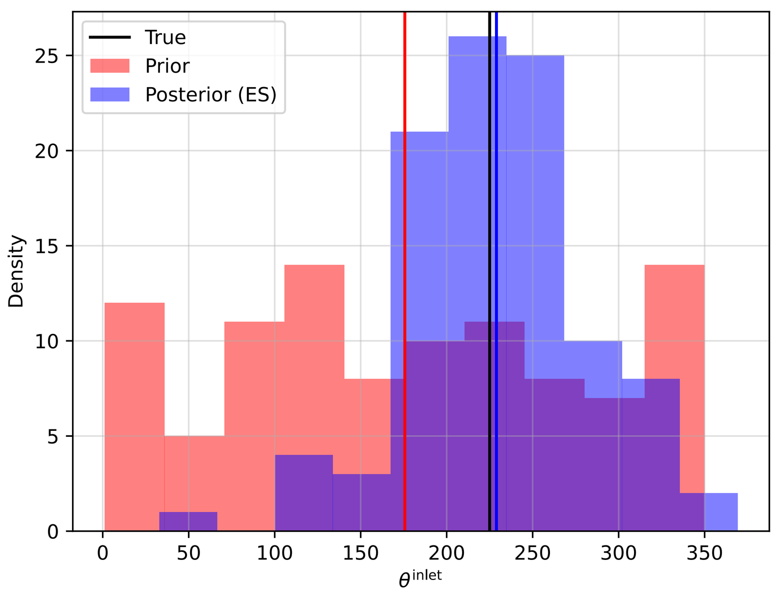
$\mathcal{G}$: RANS solver (OpenFOAM)

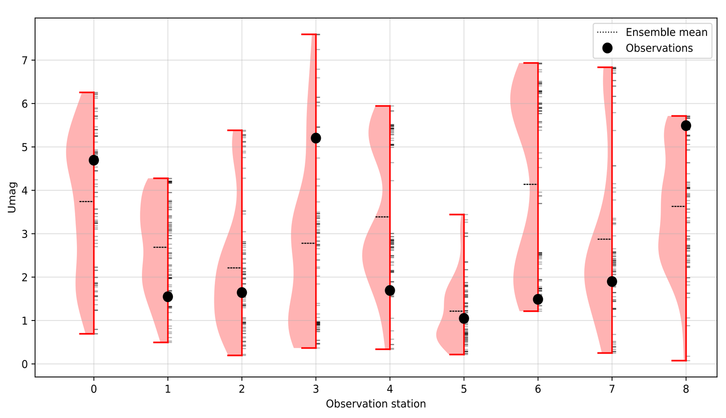
$$\alpha_j^a = \alpha_j^f + \mathbf{C}^e_{\alpha\mathbf{y}}\left(\mathbf{C}^e_{\mathbf{yy}} + \mathbf{C}_{\mathbf{dd}}\right)^{-1}\left(\mathbf{d}_j - \mathcal{G}\left(\alpha_j^f\right)\right)$$

$$\mathbf{y}_j^a = \mathcal{G}\left(\alpha_j^a\right)$$

$$\mathbf{d} = \operatorname{col}\left(\|\bar{\mathbf{u}}_{\text{station1}}\|, \ldots, \|\bar{\mathbf{u}}_{\text{stationK}}\|\right) \quad \mathbf{d}_j = \mathbf{d} + \boldsymbol{\epsilon}_j$$



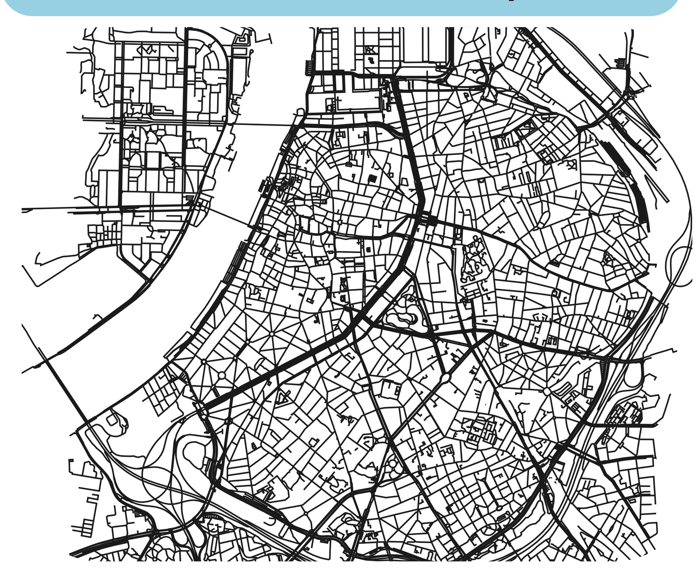




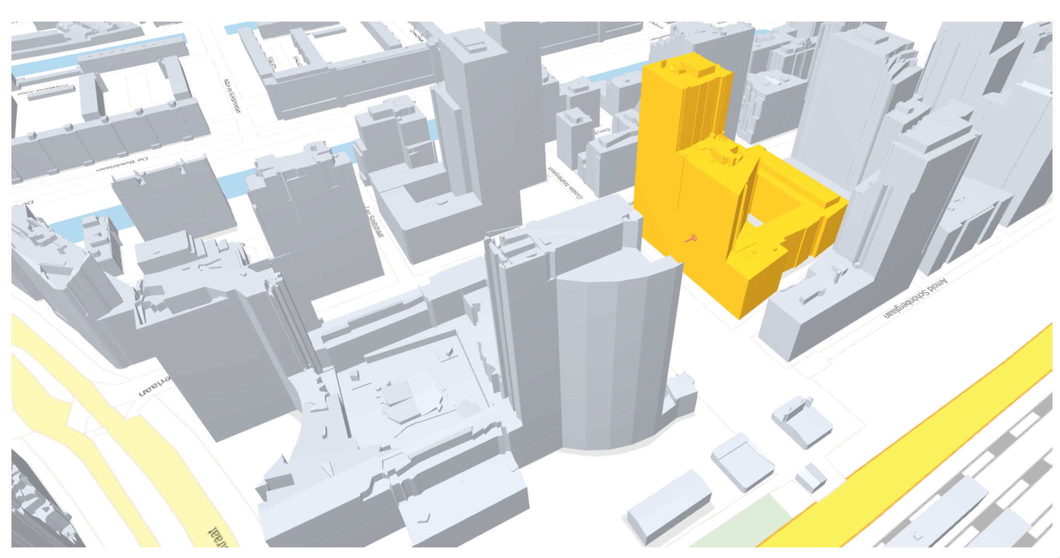
Outlook

Parameters | Boundary Climate | Initial Conditions | City Geometry | **DA in CFD** | Pollutant characterization | Physics/ Turbulence | Sensor Placement | State Estimation

Extend results to city scale



Study of urban morphology with DA



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