Statistics for street pollution modelling: Lab experiments and calibration of computer models

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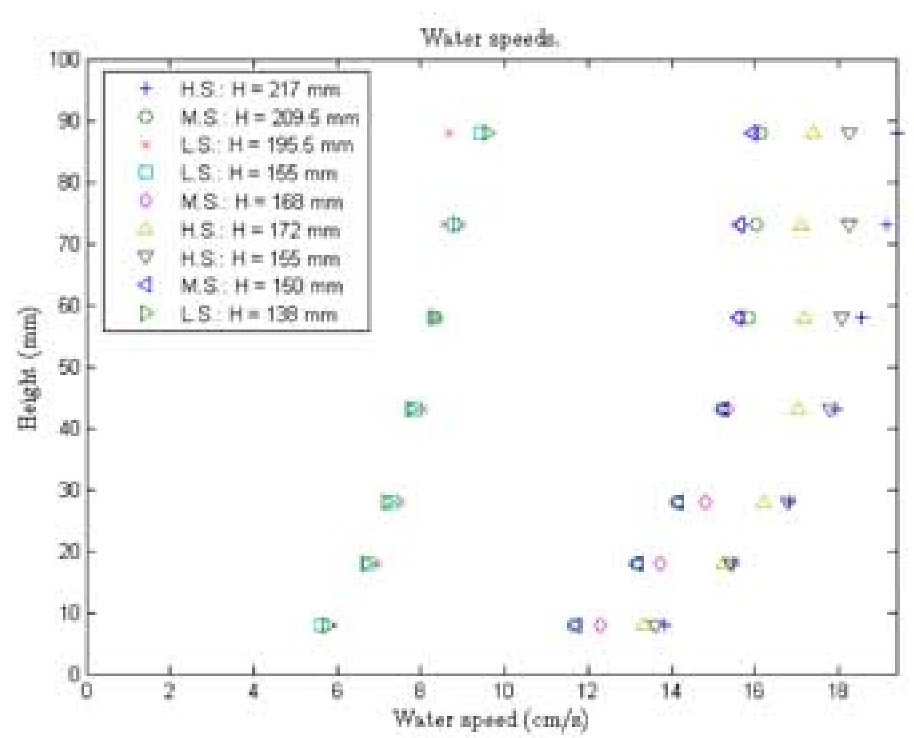
Summary

The aim of this work is to understand the pollution in street canyons when cars are present. In the first stage, we carried out a series of lab experiments in a water tunnel. We placed a car in the tunnel and observed the speed flows. We placed the speed meters according to a design that reflects the variability of the flow. We validate this design by a leave-one-out diagnostic.
In a second stage, we produce simulations of the speed flow under the conditions of the lab experiment. We use Computer Fluid Dynamics (CFD) for that purpose. Three unknown input parameters that influence the results are being investigated: inlet speed, eddy length scale and turbulence. The goal is to calibrate the model, i.e. to find the optimal parameters that enable accurate CFD simulations.

Lab experiments

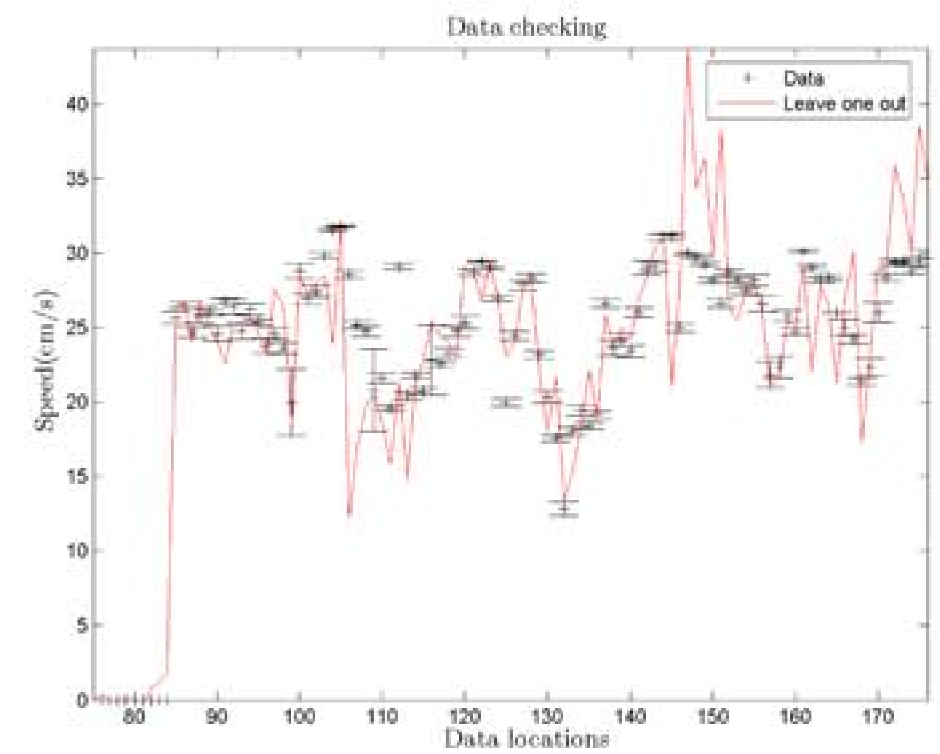


Speed vertical profiles along the water tunnel initially considered. High speed was selected.

Validation of the choice of measurement locations

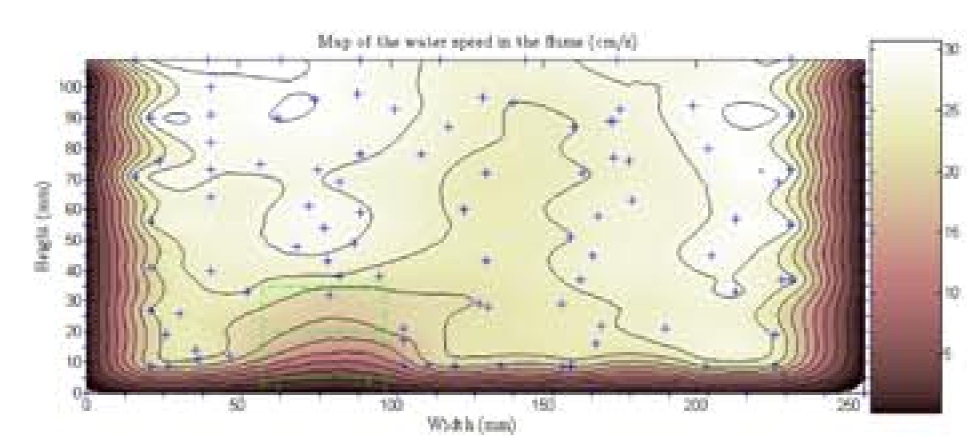
To investigate the approximation of the entire surface of speed flows retrieved from the speed meters at specific locations, we:

1. remove a speed flow meter location
2. statistically predict at that location the speed flow using all the other values measured by speed flow meters at all the other locations. The statistical method used is kriging.
3. compare the predictions with the original data.

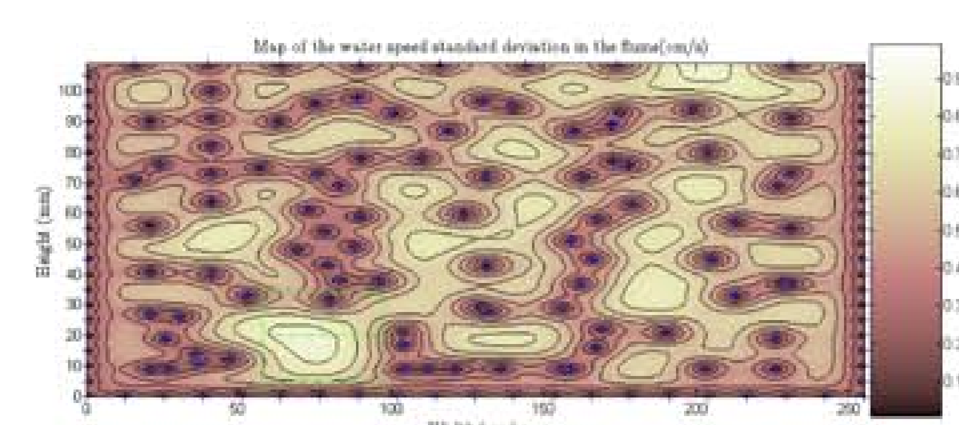


Comparison of leave-one-out predictions and observations over all sites (zeros correspond to boundary conditions)

Map the speed flows and corresponding uncertainties, using kriging:



Speed flows



Speed flows standard errors

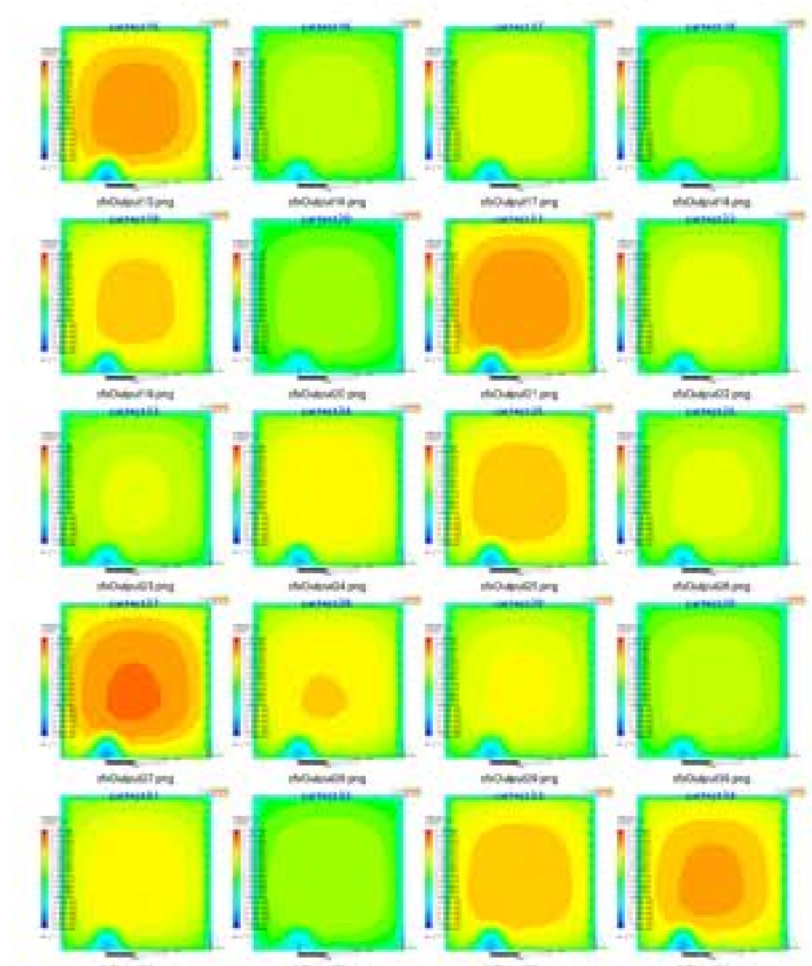
Calibration of CFD computer model

Find optimal tuning parameters that give best model outputs. Denote input parameters $z = (x, u)$. Two categories:

- known parameters (controllable parameters x): geometry of the street cayon, size of car, temperature,..
- unknown parameters (calibration parameters u): inlet speed, eddy length scale and turbulence.

Data sampling and computer model representation:

1. Computer experiments are expensive and time consuming..so small subset of the parameters: design.
2. In between, emulate the computer model by a Gaussian process response-surface (Sacks et al. 1989, Welch et al. 1992, Morris et al. 1993).



Representations of model bias and uncertainty: Kennedy and O'Hagan (2001) y^R is reality, y^M model output, y^F field data.

bias $b_u(x)$ and observation error ε:

$$y^R(x) = y^M(x, u) + b_u(x) \quad (1)$$

$$y^F(x) = y^R(x) + \varepsilon \quad (2)$$

Calibration procedure:
fully Bayesian procedure, MCMC approach with Metropolis-Hastings algorithm to draw realizations from the posterior distribution.

Conclusion and future work

- Accurate measurements, but only one slice, enhanced measurements necessary to understand the flow
- Computational cost of CFD huge! Use of CFX on parralel cluster: Legion at UCL
- improved choice of parameters for the numerical model