DEVELOPMENT OF A FAST TOOL FOR AIR QUALITY CFD MODELLING IN URBAN CANOPIES

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Introduction

- CFD models are a valuable tool for addressing air quality levels in urban environments and traffic congested street canopies within which maximum concentrations levels usually occur.
- Concentration hotspots within urban canopies are difficult to estimate or locate due to geometry and flow complexity.
- However, they are inherently slow and therefore, alternative approaches should be examined to speed up the modelling process on determined configurations.

Problem description

- Model simplified urban flow regimes that include roads, buildings and trees.
- More specifically, the selected tested case involves a line pollutant source, parallel to a long building. A series of experiments performed by TNO in wind tunnels.
- The measured concentration exhibits strong dependencies from the so-called direct contribution from the pollutant source and the recirculation in the wake of the buildings.
- The ADREA-HF CFD modelling system (Bartzis, 1991) is used incorporating the new k-ζ turbulence model proposed by Bartzis (2005).

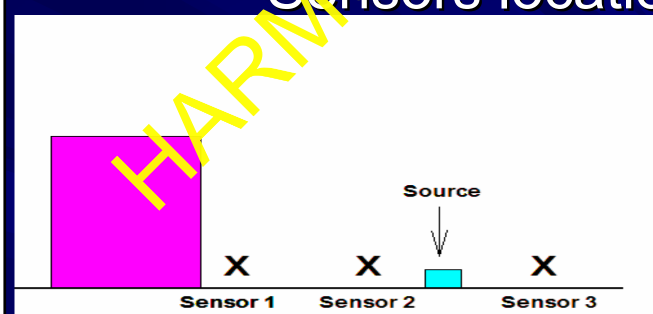
Problem description

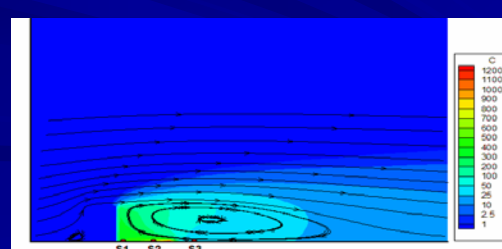
- An interpolation methodology was introduced to speed up the modelling process of the examined configuration.
- Concentration values on selected areas (sensor positions) were approximated with respect to wind direction, thus allowing the direct estimation of concentration levels on cases other than the examined ones.
- The applied interpolation method is the Adaptive Neuro-Fuzzy Inference System (Jang 1993).
- The strength of this tool lies in its ability to deal with few or incomplete data (fuzziness) and simulate in a non-linear manner any problem.

Experimental Configuration

- The experiments were performed in TNO wind tunnels.
- The atmospheric boundary layer was simulated on a scale of 1:250.
- The building models were in the examined case 15m high (H) and 10m wide.
- The centerline of the source was located at x/H=+1.03 from the downstream building edge.
- Three sensors were used located at x/H = +0.1, +0.7 and +1.5 from the source.

Sensors location





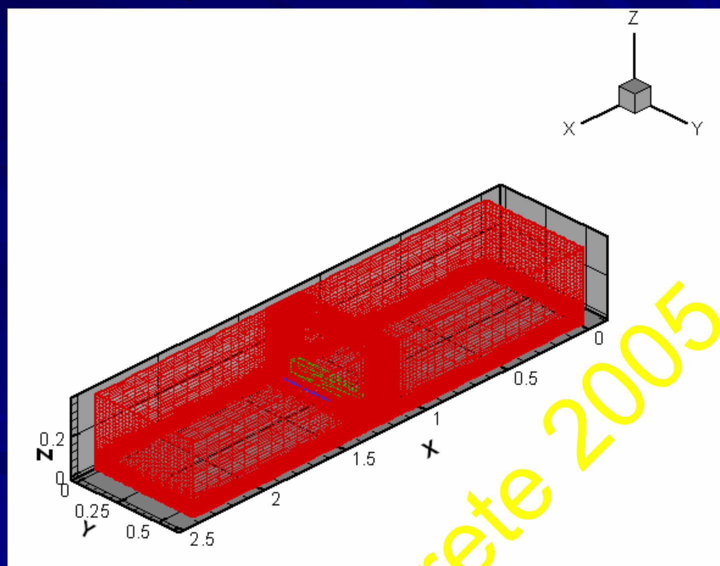
Modeling Approach

- The ADREA-HF CFD local scale computer code has been used to carry out the modelling (Bartzis, 1991).
- It is a finite volume transient, three-dimensional, fully compressible transport code, designed to be applied to vapour cloud dispersion predictions at local scale with emphasis on terrains of high complexity.
- The k-ζ turbulence model proposed by Bartzis (2005) was used.

Modeling Approach

- Inlet flow conditions have been derived by solving the corresponding 1-D boundary layer problem with top wind velocity which produces a wind speed velocity at 10m height the experimental value 2.2m/s.
- At the top boundary the vertical velocity is taken equal to zero.
- The 3D computation domain: $x/H = \pm 20$, $y/H = \pm 5$ and $z/H=6.5$.
- A non-uniform logarithmic grid 84x30x38 has been utilized for the x and z axes with minimum grid size near the obstacle maximum one near the domain boundaries.
- On the y axis uniform grid was selected.

Computational Domain



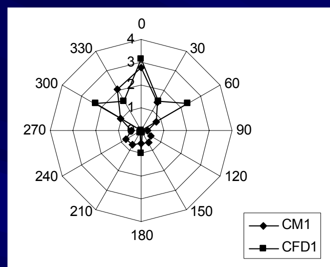
CFD Results
Mean concentration values

- Comparison of real to experimental adjusted concentration values
  - C* = C u10 / Q
  - Mean values over all directions

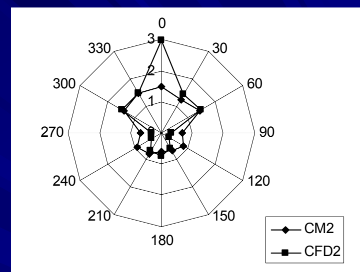
	Sensor 1	Sensor 2	Sensor 3
Measurements	112.71	677.24	177.08
CFD	116.99	218.08	34.84

- CFD modeling tool tends to underpredict measured concentration by a factor of 3 on sensor 2 and by a factor of 5 on sensor 3.
- Model derived concentration profiles match reasonably well with experimental ones.
- The majority of the data are within a factor of 2.

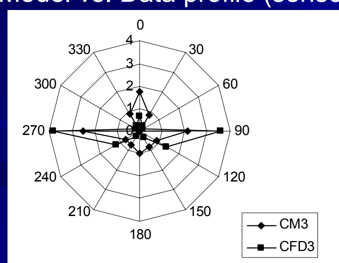
CFD Results
Normalized concentration distributions



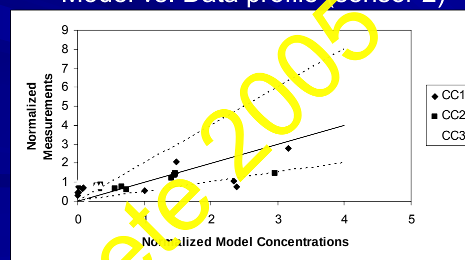
Model vs. Data profile (sensor 1)



Model vs. Data profile (sensor 2)



Model vs. Data profile (sensor 3)



Model Comparison

CFD Results - Discussion

- As expected profiles exhibit symmetric properties with respect to the North-South axis.
- The largest error of sensor 1 is observed for 60 deg and when the wind has a southern component where smaller concentrations than the actual are estimated.
- Sensor 2 profile matches better with experimental one but it exhibits an overestimate of the North wind.
- The highest discrepancy is observed on sensor 3; however, the data need to be looked further since experimental concentrations at certain directions are comparable to the concentrations very near the building.

Interpolation methodology - 1

- ANFIS: incorporate fuzzy if-then rules and also, provide fine-tuning of the membership function according to a desired input output data pair.
- A first order Sugeno fuzzy model is used as a means of modeling fuzzy rules into desired outputs.
  – if $X1 = A_i$ and $Xn = B_j$ then $f_i = p_i X1 + q_i Xn + r_i$
- A back-propagation training method is employed to find the optimum value for the parameters, in such a way as to minimize the error between the input and the output pairs.
- Also linear interpolation and cubic spline were tested for comparison

Interpolation methodology - 2

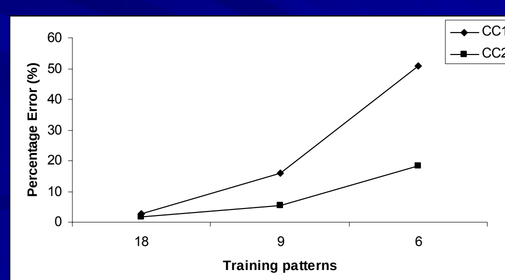
- Due to high symmetry of the experimental configuration and derived CFD results the interpolation analysis was conducted only using half of the data, from 0 to 180 degrees.
- Analysis was conducted only for the first two sensors.
- A “training set” was formed using CFD derived data every a specified range of degrees. (here10, 20 and 30 degrees tested).
- An “evaluation set” was set to contain CFD derived results for 45 and 135 angles. An additional “checking set” consisted of those data not used in the “training set” where applicable.
- These data sets were used to monitor the model performance and have not been included during the building of the neuro-fuzzy model or the interpolation methods.

Interpolation results
Percentage error

		Sensor 1		Sensor 2	
		Eval. Set	Ch. Set	Eval. Set	Ch. Set
10 deg	ANFIS	2.50	-	1.13	-
	Linear	4.01	-	2.96	-
	Spline	1.12	-	0.90	-
20 deg	ANFIS	9.27	55.27	1.45	15.81
	Linear	13.30	256.45	9.28	23.31
	Spline	41.29	198.77	2.73	18.21
30 deg	ANFIS	62.73	87.65	25.53	31.86
	Linear	37.40	107.03	28.33	19.88
	Spline	124.78	128.70	34.05	30.42

Interpolation results
Number of training data - percentage error

- Discontinuities in the values deteriorates model capabilities, especially in sensor 1.
- The curve describing Sensor 2 is smoother which is reflected in the lower values of both evaluation and checking set errors.
- As expected the more data are used for developing the interpolation schemes the lowest are the prediction errors. This can be used to specify the number of CFD runs required to achieve a desired percentage error.



Conclusions

- CFD modelling of simplified urban configurations representative of a road.
- The ADREA-HF code used incorporating the κ-ζ turbulence was introduced.
- The model produced mean concentrations over the entire wind rose were comparable to the experimental ones with the exception of Sensor 3.
- Several interpolation methodologies were examined in an attempt to produce fast modeling of concentration values with the least number of CFD runs.
- The nonlinear ANFIS approach gave best results, although further research is needed to further assess the proposed approach

References

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