# A Model Evaluation Protocol for Urban Scale Flow and Dispersion Models

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COST Action 732
Quality Assurance of Micro-Scale Meteorological Models

INTRODUCTION

- METEOROLOGY
- ACTIVITIES INFLUENCED BY METEOROLOGY, PARTICULARLY DISPERSION IN URBAN AND BUILT UP ENVIRONMENTS
- MODELS AND THEIR FORMALISED EVALUATION BY ADOPTING THE “FIT-FOR PURPOSE” CRITERION
- FOCUS ON CFD MODELS WITH THE INCLUSION OF “NON-CFD” MODELS IN ORDER TO:
  - BUILD A CONSENSUS WITHIN THE SCIENTIFIC AND USER COMMUNITY
  - STIMULATE A WIDESPREAD APPLICATION OF THE PROCEDURE AND THE PREPARATION OF QUALITY ASSURANCE PROTOCOLS
  - GIVE RECOMMENDATIONS FOR THE IMPROVEMENT OF PRESENT MODELS
Best Practice Guideline for the CFD simulation of flows in the urban environment (Vers. 1 May 2007) - based on published guidelines and recommendations, which mainly deal with the prediction of the statistically steady mean flow and turbulence in the built environment for situations with neutral stratification (J. Franke, A. Hellsten, H. Schlünzen and B. Carissimo, in press. The COST 732 best practice guideline for CFD simulation of flows in the urban enviroment - A summary. Int. J. of Environment and Pollution)

Model evaluation guidance and protocol document (Vers. 1 May 2007) - a stand alone document to assist the setting up and executing of a model evaluation exercise

Background and justification document to support the model evaluation guidance and protocol (Vers. 1 May 2007) (M. Schatzmann and R. Britter, in press. Quality assurance and improvement of micro-scale meteorological models. Int. J. of Environment and Pollution)

Available on line at http://www.mi.uni-hamburg.de/Official-Documents.5849.0.html

- The MUST wind tunnel exercise: Validation methods and results (in progress) - guidance to interpretation of graphs and metrics. Protocol for the case of MUST experiment, as simulated in the Hamburg wind tunnel. Results from the various models in the form of graphs and metrics.
Phases of modelling and simulation and the role of Verification and Validation (Schlesinger, 1979). Taken from Oberkampf et al. (2004).


Scientific Evaluation Process

Verification Process

Provision of “evaluated” (appropriate and quality assured) Data Sets (this includes statements on the nature of the data – from controlled laboratory experiments or/and from field measurements (routinely available or “controlled” measurement campaigns)

Model Validation Process

Operational Evaluation Process
Based on a questionnaire

• Specify clearly the model purpose(s)
• Produce a consensus of what “science” is required for this model and its applications
• Determine whether the “science” is present adequately
• Give proof and clear evidence on the above
MODEL VALIDATION

- Processing of the experimental data
- What variables to compare?
- How should the variables be compared?
- How should the model be run and the results interpreted? (modelling inputs, set-up, post-treatment of outputs ...)

- Exploratory data analysis (Olesen et al.)
- Metrics for a Model Validation (Franke et al.)
- Quality acceptance criteria
- Baseline approach to model validation
Wind tunnel measurements at the Environmental Wind Tunnel Laboratory at Hamburg University

- scaled model of the MUST configuration (1:75)
- approaching flow cases: 0°, -30°, -45°, -60°, -90°
- flow and dispersion measurements: vertical and horizontal profiles

extensive field test carried out on a test site of the US Army in the Great Basin Desert in 2001
- flow and dispersion data measured within an idealized urban roughness
- 120 standard size shipping containers (regular array of 10 by 12 obstacles)
Schematic view of the MUST building array and cases considered. The point source is positioned along the axis of the first street canyons line.

Wind tunnel measurements: vertical profiles

Wind tunnel measurements: horizontal profiles
Models can be thought for general OR SPECIFIC applications, it is important to check their fitness for purpose when we use them for solving a problem or for a new application...

### Computational Fluid Dynamics (CFD) models
- MISKAM
- FLUENT
- ADREA
- STAR-CD
- FINFLO
- CFX
- MITRAS
- TSU/M2UE
- VADIS
- CODE_SATURNE

### Non-CFD models
- LASAT
- ADMS-URBAN
- RAMS
- OML
- ESCAPE
- CALPUFF

#### 15 GROUPS INVOLVED
- **0° case**: about 40 model flow results
- **-45° case**: about 30 model flow results
- **-45° case**: about 20 model dispersion results

#### 7 GROUPS INVOLVED
- **-45° case**: about 10 model dispersion results
Physical parameters of simulations of the MUST wind tunnel case with -45° approach flow direction

Please give all required information if available. In case of non-CFD model, many questions may be irrelevant. Answer those questions that you find meaningful.

If different codes were used or one code with different turbulence models, then use a separate questionnaire for each computation.

1. Contact person
   - Name: SILVANA DI SABATINO
     RICCARDO BUCCOLIERI
   - Institution: DIPARTIMENTO DI SCIENZA DEI MATERIALI, UNIVERSITY OF SALENTO, LECCE (IT)

2. Computer Code
   - Name, version and precision: FLUENT 6.2.16, single precision
   - CFD or non CFD: CFD
   - If non CFD, describe the model briefly (obstacle mapping or not, etc.)
   - Primary variables (i.e. variables solved from differential equations): $\mathbf{u}, \mathbf{v}, \mathbf{w}$, $T$, $\kappa$, $\epsilon$, concentration

3. Reynolds number
   - Value: $10 \times 10^5$
   - What length scale is used in the above given Reynolds number (for instance container height)? Container height H=2.54m
   - What velocity scale is used in the above given Reynolds number (for instance inflow reference velocity at $z=2.0$ m)? Inflow reference velocity $u=5.5$m/s

4. Turbulence model
   - Model class (linear 2-equation model, nonlinear 2-equation model, RSM, other)? Linear 2-equation model

- Wall treatment (wall functions or solution up to the wall)? Standard wall function
- The velocity scale-determining variable if not turbulent kinetic energy?
- The length scale-determining variable (epsilon, omega other)?
- Model version name or developer's name (for instance: std. k-epsilon, Launder-Sharma k-epsilon, Launder-Reece-Gibbs RSM, give also a literature reference if the model is not widely known)? Std-k-epsilon
- Nonstandard coefficient values if used?
- Nonstandard correction terms if used?
- Nonstandard damping, mixing or other functions if used?
- Other nonstandard features if used?
- Other information? gradient diffusion model, $Sc=0.7$
**WHAT VARIABLES? AND EXPLORATORY DATA ANALYSIS**

- Contours of $u/U_{ref}$ - TKE/$U_{ref}^2$ - Turbulent fluxes ($u'w'$ **Qualitative**)
- Profiles of $u/U_{ref}$
- Profiles of $w/U_{ref}$
- Profiles of dimensionless concentration $K$ (or $C^*$)

**METRICS (some example of statistical parameters)**

**Hit Rate Test**

(the fraction of model results which differs within an allowed range $D$ from the experimental data)

$$q = \frac{N}{n} = \frac{1}{n} \sum_{i=1}^{n} N_i$$

VDI, 2005

$N_i = \begin{cases} 1 & \text{if } |P_i - O_i| \leq D \text{ or } |P_i - O_i| \leq W \\ 0 & \text{else} \end{cases}$

- $N$: number of measurement positions
- $D$: allowed relative difference, $D = 0.25$
- $W$: allowed absolute difference (based on error due to interpolation and exp. uncertainty due to repeatability)

**Normalised mean square error**

(normalised discrepancies between computed and experimental values)

$$NMSE = \frac{(C_o - C_p)^2}{C_o \cdot C_p}$$

**Fractional BIAS**

(over- or under-estimation)

$$FB = \frac{(\overline{C_o} - \overline{C_p})}{0.5 \left( \overline{C_o} + \overline{C_p} \right)}$$

**Factor2**

$$FAC2 = \text{fraction of data that satisfy } 0.5 \leq \frac{C_p}{C_o} \leq 2.0$$

Chang and Hanna, 2004
Hit Rate Test

\[ q = \frac{N}{n} = \frac{1}{n} \sum_{i=1}^{n} N_i \]
\[ N_i = \begin{cases} 1 & \text{if } \left| \frac{P_i - O_i}{O_i} \right| \leq \epsilon \text{ or } |P_i - O_i| \leq \nu \text{ or both} \\ 0 & \text{else} \end{cases} \]

Threshold values for Hit Rate and FAC2

<table>
<thead>
<tr>
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<th>Allowed absolute deviation W, referring to Hit rate. The same value is used as threshold when FAC2 is determined.</th>
<th>Allowed fractional deviation D, referring to Hit rate</th>
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<tbody>
<tr>
<td>( \frac{u}{u_{ref}} ) (velocity component)</td>
<td>0.008</td>
<td>0.25</td>
</tr>
<tr>
<td>( \frac{v}{u_{ref}} ) (velocity component)</td>
<td>0.007</td>
<td>0.25</td>
</tr>
<tr>
<td>( \frac{w}{u_{ref}} ) (velocity component)</td>
<td>0.007</td>
<td>0.25</td>
</tr>
<tr>
<td>TKE/(u_{ref}^2)</td>
<td>0.005</td>
<td>0.25</td>
</tr>
<tr>
<td>( c^* ) (concentration)</td>
<td>0.003</td>
<td>0.25</td>
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 variables (what variable?)

 definition (some of the above mentioned statistical parameters do not make sense for some variables)

 implementation (interpolation or closest point?)

 treatment of zero values

 measurement errors
Fractional bias (FB) and Normalised Mean Square Error (NMSE) make no sense for parameters that can take both negative and positive values, such as velocity components.

FB is meant to be bounded within the range -2 to +2. It is -2 for extreme over-prediction, and +2 for extreme under-prediction. An over-prediction by a factor of two gives a value of FB = -0.67.

In the MUST, for TKE, it is formally OK to compute FB and NMSE, but it should be kept in mind that the observed TKE is an artefact and cannot be directly compared to modelled values.
Example of the Excel spreadsheet (Olesen et al. 2008) including a macro tool which allows easy graphical inter-comparisons.
-45° approach flow case - concentrations

Example of the Excel spreadsheet including a macro tool which allows easy graphical inter-comparisons
EXPLORATORY DATA ANALYSIS

0° approach flow case - flow

Examples

FLUENT_1

FLUENT_2

MISKAM_1

MISKAM_2
-45° approach flow case - flow

Examples

STAR-CD_1

FLUENT_1

STAR-CD_2

FLUENT_2
EXPLORATORY DATA ANALYSIS

-45° approach flow case

concentrations

\[
K = \frac{CU_{\text{ref}} H_{\text{ref}}^2}{Q}
\]

\(C\) measured or calculated concentration
\(U_{\text{ref}}\) reference wind speed
(undisturbed flow)
\(H_{\text{ref}}\) building height
\(Q\) emission rate

Source (ground level)

Distance from the source: 35m

Profiles at \(z=0.5H\)

MISKAM_3

FLUENT_3

FINFLO

STAR-CD_2

\[
\text{Conc - nondim}
\]

\[
\begin{array}{l}
\text{model} \quad \text{wind tunnel}
\end{array}
\]
-45° approach flow case
concentrations

\[ K = \frac{C U_{\text{ref}} H_{\text{ref}}^2}{Q} \]

- measured or calculated concentration
- \( U_{\text{ref}} \) reference wind speed (undisturbed flow)
- \( H_{\text{ref}} \) building height
- \( Q \) emission rate

Distance from the source: 102m
Profiles at \( z=0.5H \)
-45° approach flow case

concentrations

\[ K = \frac{C U_{\text{ref}} H_{\text{ref}}^2}{Q} \]

- measured or calculated concentration
- \( U_{\text{ref}} \) reference wind speed (undisturbed flow)
- \( H_{\text{ref}} \) building height
- \( Q \) emission rate

Distance from the source: 170m

Profiles at \( z=0.5H \)
EXAMPLES FOR NON-CFD MODELS
THE PROTOCOL IMPLEMENTATION TO THE MUST EXPERIMENTS HAS ALLOWED US TO FIND OUT WHAT CAN BE EXPECTED BY STATE OF ART MODELS (AS MANY MODELS ARE INVOLVED WHICH ARE WIDELY APPLIED IN EUROPE)

THE DEVELOPMENT OF A GRAPHICAL TOOL (MADE AVAILABLE TO ALL PARTICIPANTS) ALLOWS IN DEPTH ANALYSES OF MODEL PERFORMANCE IN AN ENVIRONMENT WHERE THE DIFFERENCES ARE NOT OBSCURED BY DIFFERENCES IN PRESENTATIONS

THIS IS A UNIQUE OPPORTUNITY OF SHARING EXPERIENCE NECESSARY TO FORM A GENERAL VIEW ABOUT MODEL EVALUATION (THIS MAY DIFFER ACCORDING TO EXPERIENCE AND APPLICATION INTERESTS)
THE IMPLEMENTATION OF THE PROTOCOL HAVE ALLOWED US TO:

• DEVELOP A COHERENT AND STRUCTURED QUALITY ASSURANCE PROCEDURE FOR THESE TYPES OF MODELS THAT GIVES CLEAR GUIDANCE TO DEVELOPERS AND USERS OF SUCH MODELS AS TO HOW TO PROPERLY ASSURE THEIR QUALITY AND THEIR PROPER APPLICATION

• PROVIDE A SYSTEMATICALLY COMPILED SET OF APPROPRIATE AND SUFFICIENTLY DETAILED DATA FOR MODEL VALIDATION WORK IN A CONVENIENT AND GENERALLY ACCESSIBLE FORM

THOSE STEPS ARE BELIEVED TO BE CRUCIAL TO BUILD A CONSENSUS (AT LEAST AT EUROPEAN LEVEL) ABOUT MODEL EVALUATION
THANK YOU!