CFD MODELLING OF PARTICLE MATTER DISPERSION IN A REAL HOT-SPOT

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Introduction

- Urban air quality → largest environmental health risk in Europe
- Interaction atmosphere with urban surfaces (buildings, trees, ...)
  linked with traffic emissions induces complex distribution of pollutant in the streets.
- Traffic distribution
- Wind flow within streets
- High resolution is needed

Concentration maps
**Objective**

Main objective: To model high resolution maps of particulate matter concentration using a Computational Fluid Dynamics (CFD) model in a real hot-spot.

**Multiscale system of models**

Profiles from mesoscale model

Traffic emission model

Background monitoring station

CFD model
Highly polluted zone in southern Madrid (Spain). Complex area: heavily trafficked roundabout, tunnel, vegetation, ...

- Winter: 25\textsuperscript{th} February 2015.
- Summer: 6\textsuperscript{th} July 2015.

- Meteorological monitoring: 1 Meteorological station at roof (18 m) and 2 sonic anemometers (6 and 8 m)
- Particulate matter measurements: 1 Grimm and 1 portable TSI DustTrak\textsuperscript{TM} DRX (measurements in 10 points).
Model Descriptions and Set-Ups

Multiscale system of models

Profiles from mesoscale model

Traffic emission model

Background monitoring station

CFD model
Model Descriptions and Set-Ups

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Model Descriptions and Set-Ups

Meteorological mesoscale model

- Madrid urban atmosphere at mesoscale was simulated by means of WRF (Weather Research and Forecasting) model (Chen et al., 2001).

- A multilayer urban parameterization was used to simulate urban areas (BEP-BEM, Martilli et al. (2002) and Salamanca et al. (2010)).

- For winter campaign, four nested domains were simulated with the finest domain with a horizontal resolution of 1 km x 1 km. In vertical, the resolution of the lowest levels is 5 m (see details in Sanchez et al., 2017a).

- Similar configuration was used to simulate meteorological conditions of summer campaign but with a resolution of the finest domain of 500 m x 500 m.
Model Descriptions and Set-Ups

Multiscale system of models

Profiles from mesoscale model

Traffic emission model

Background monitoring station

CFD model
Traffic emission model

- Hourly emissions with resolution of 5 m x 5 m are computed by means of a combination of traffic and emissions micro-simulation models (Quaassdorff et al., 2016).

- PM2.5 and PM10 emissions from vehicle exhaust, particle resuspension, pavement abrasion and brake and tire wear are considered in a region of 300 m x 300 m around the square.
Model Descriptions and Set-Ups

Multiscale system of models

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CFD model

Bologna, Italy
9-12 October 2017
Model Descriptions and Set-Ups

CFD model

- Reynolds-Averaged Navier-Stokes (RANS) equations with a Realizable \( k-\varepsilon \) (model STAR-CCM+, Siemens).
- Buoyancy terms: Bousinesq’s approach and an equation for temperature is solved.
- Pollutant dispersion: Transport equations are solved for pollutants dispersion with a low Schmidt number (Sc = 0.3).
- Domain: 1300 m x 1300 m x 270 m.
- Mesh: \( 8.5 \times 10^6 \) polyhedral cells.
- Resolution 2 m in the studied zone with prism layer of 1m close to the surfaces. More details in Sanchez et al., 2017a.
- Dynamic effect of vegetation (momentum sink and turbulence sink/sources)
- Emissions located 300 m x 300 m around the square.
CFD model

- Unsteady CFD simulations are performed from 6UTC to 18UTC:
  - 25th February
  - 6th July

- Inlet: hourly vertical profiles from WRF
- Wind speed
- TKE
- Temperature

- Inlet wind direction from meteorological station at roof

- A radiation model is not implemented in the CFD model, however in order to analyze the effects of surface heat fluxes at different hours, two scenarios are simulated:
  1) considering adiabatic the ground and buildings (CFD)
  2) imposing at ground the surface heat flux computed at mesoscale in the whole domain by WRF at each hour (CFD+SHF) (Sanchez et al., 2017b; Poster H18-164).
Evaluation of meteorological results

- **25th February**: Unsteady CFD simulations are performed from 6LST-18LST

**Meteorological station (18 m AGL)**
- Wind speed underestimated → Wind speed imposed at inlet of microscale domain is underestimated → Impact on CFD results
Results

Evaluation of meteorological results

- 25th February: Unsteady CFD simulations are performed from 6LST-18LST

Sonic anemometers (6m and 8 m AGL)
- Slight underestimation of wind speed
- Underestimation of TKE. Better results as surface heat flux at ground (SHF) is considered

Bologna, Italy
9-12 October 2017
Evaluation of meteorological results

- **6th July**: Unsteady CFD simulations are performed from 6UTC-18UTC

* Meteorological station (18 m AGL)
  - Slight underestimation of wind speed.
  - Lower wind speed than 25th February
Evaluation of meteorological results

- **6th July**: Unsteady CFD simulations are performed from 6UTC-18UTC

  **Sonic anemometers (6m and 8 m AGL)**
  - Slight underestimation of wind speed
  - Underestimation of TKE. Better results as surface heat flux at ground (SHF) is considered.
  - Better agreement for 6th July.
Results

Evaluation of particulate matter concentrations

6th July
Results

Evaluation of particulate matter concentrations

6th July

PM10 (µg m⁻³)

7 LST

8 LST

9 LST

position

10

Position

0 1 2 3 4 5 6 7 8 9 10

0 20 40 60 80 >100

7 LST

8 LST

9 LST

PM10 (µg m⁻³)

150

130

110

90

70

50

30

10

0

EXP

CFD+SHF

EXP

CFD+SHF

EXP

CFD+SHF

100

80

60

40

20

0
Results

Evaluation of particulate matter concentrations

6th July

PM10 (µg m⁻³)

Point 1

Point 5

Point 9

Hour
Results

Evaluation of particulate matter concentrations

25th February

PM10 (µg m⁻³)

0 10 20 30 40 50 60 70 80

0 1 2 3 4 5 6 7 8 9 10 Position

0 1 2 3 4 5 6 7 8 9 10 Position

0 1 2 3 4 5 6 7 8 9 10 Position
Results

Evaluation of particulate matter concentrations

- 25th February

<table>
<thead>
<tr>
<th>Time</th>
<th>PM10 (CFD)</th>
<th>PM10 (CFD+SHF)</th>
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</thead>
<tbody>
<tr>
<td>WINTER+ SUMMER</td>
<td></td>
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<tr>
<td>NMSE</td>
<td>0.48</td>
<td>0.085</td>
</tr>
<tr>
<td>FB</td>
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<td>-0.15</td>
</tr>
<tr>
<td>FAC2</td>
<td>0.84</td>
<td>0.89</td>
</tr>
</tbody>
</table>

PM10 (µg m⁻³)

- Zero
- 20
- 40
- 60
- 80
- >100

Graphs showing PM10 concentrations at different times and positions.
Summary and Conclusions

- Multiscale system of models (meteorological mesoscale (WRF) model, traffic emission model and CFD model) has been satisfactorily applied to simulate particulate matter dispersion in a real hot-spot in a winter and a summer day.

- Meteorological evaluation
  - Uncertainties in inlet boundary conditions (WRF outputs) affect the performance in CFD simulation.
  - Overall wind speed is well predicted at sonic anemometer locations. Better agreement for summer results.
  - TKE is, in general, underestimated in the lower part of the canopy (sonics anemometers at 6 m and 8 m). Better agreement for summer results.
  - Inclusion of Surface Heat Flux (SHF) from WRF at ground in the CFD improves modelled wind speed and TKE at sonic locations (Sanchez et al. 2017. Poster H18-164).
Summary and Conclusions

- Evaluation of particulate matter concentration
  - Concentration maps computed by the CFD show strong gradients in the square.
  - General good agreement (slight underestimation) between modelled and experimental PM10 concentrations.
  - Better results as SHF from WRF at ground are considered in CFD simulation.
  - Schmidt number is important in the computation of concentration (low Schmidt number increase the dispersion). More detailed analysis is necessary.

- Uncertainties in CFD simulations:
  - Uncertainties in inlet boundary conditions (WRF outputs) affect the performance in CFD simulation, especially in conditions with low wind speed and TKE.
  - One inlet wind direction simulated each hour → Fluctuation of wind direction is not considered.
  - Background concentration from a background monitoring station.
  - Emission model → Average emission in one hour.
  - Turbulence induced by traffic → how can be applied to this square?
Thank you for your attention

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