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

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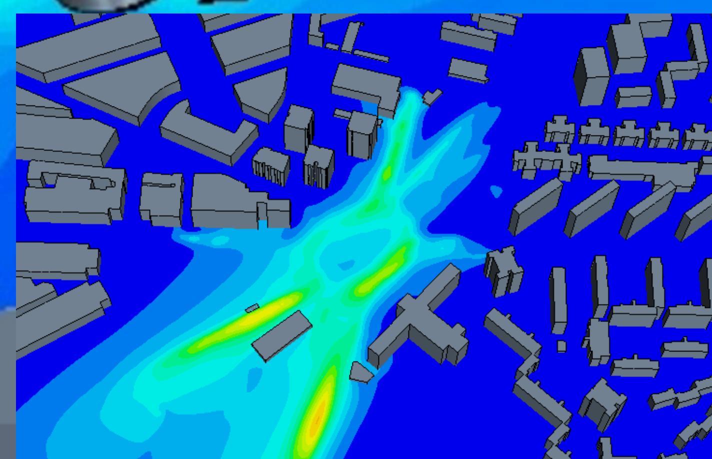
Introduction

- 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

} Concentration maps

- High resolution is needed

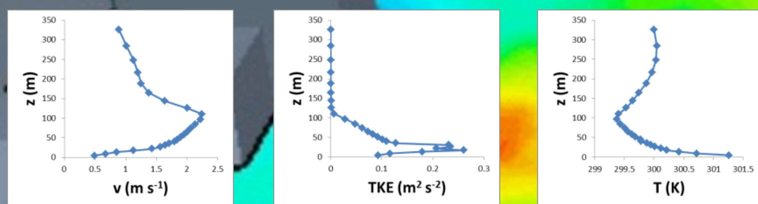


Objective

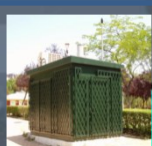
- **<u>Main objective</u>**: To model high resolution maps of particulate matter concentration using a Computational Fluid Dynamics (CFD) model in a real hot-spot.

Multiscale system of models

Profiles from mesoscale model

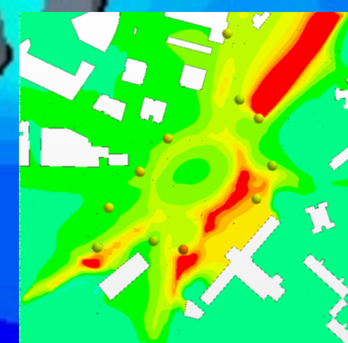


Traffic emission model



Background monitoring station

CFD model



Study Area and Experimental Campaigns

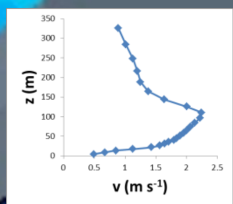
- Highly polluted zone in southern Madrid (Spain). Complex area: heavily trafficked roundabout, tunnel, vegetation, …
- Winter: 25th February 2015.
- Summer: 6th July 2015.

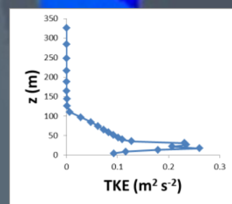
- Meteorological monitoring: 1 Meteorological station at roof (18 m) and 2 sonic anemometers (6 and 8 m)
- Particulate matter measurements: 1 Grimm and 1 portable TSI DustTrak™ DRX (measurements in 10 points).

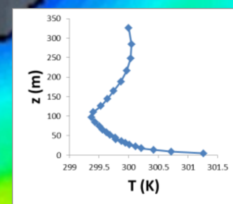
Model Descriptions and Set-Ups

Multiscale system of models

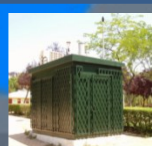
Profiles from **mesoscale model**





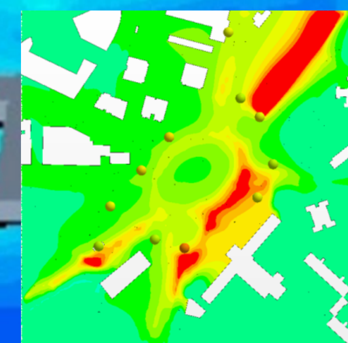


Traffic emission model



Background monitoring station

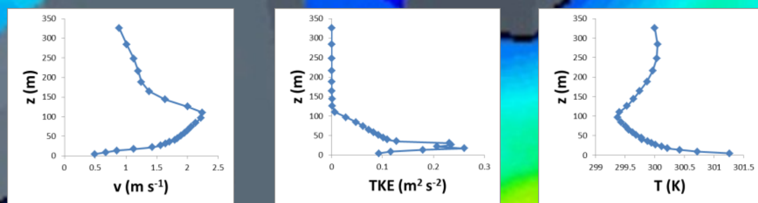
CFD model



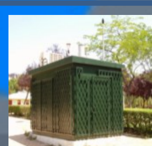
Model Descriptions and Set-Ups

Multiscale system of models

Profiles from **mesoscale model**

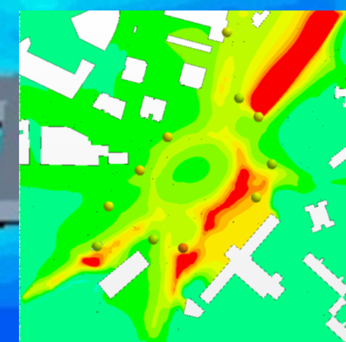


Traffic emission model



Background monitoring station

CED model



Model Descriptions and Set-Ups

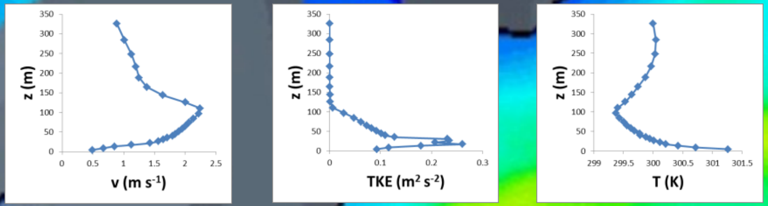
Meteorological mesoscale model

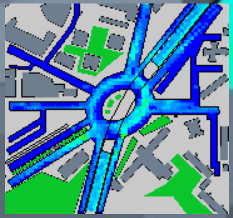
- Madrid urban atmosphere at mesoscale was simulated by means of **WRF** (Weather Research and Forecasting) model (Chen et al., 2001).
- A **multilayer urban parameterization** was used to simulate urban areas (**BEP-BEM**, Martilli et al. (2002) and Salamanca et al. (2010)).
- For winter campaign, four 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**

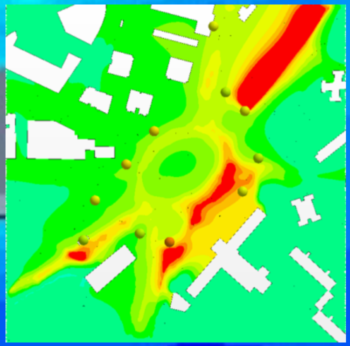




Traffic emission model

Background monitoring station

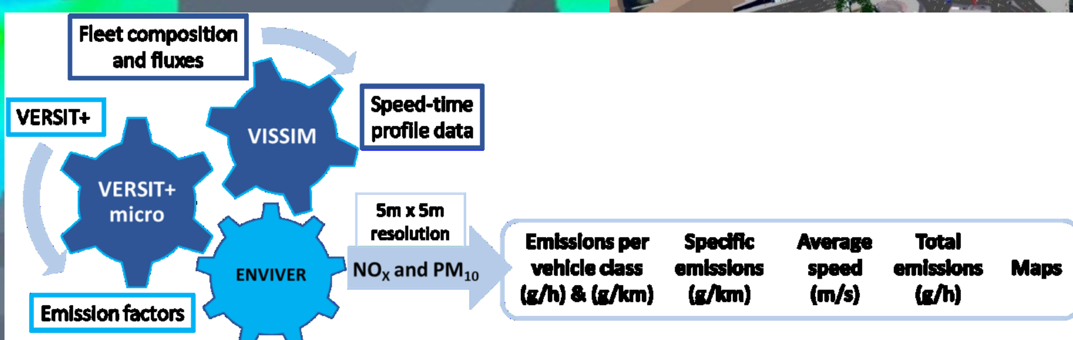
CFD model

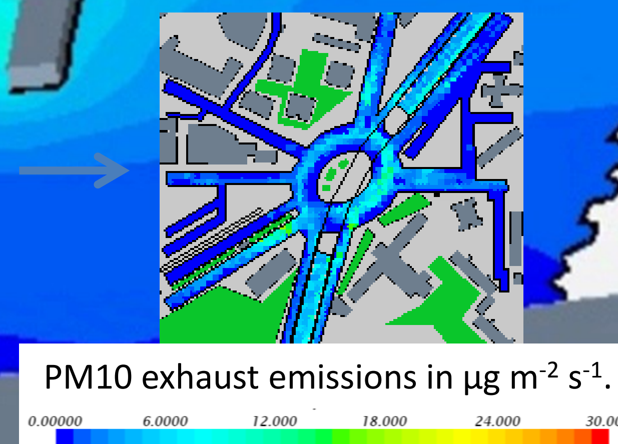


Model Descriptions and Set-Ups

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.



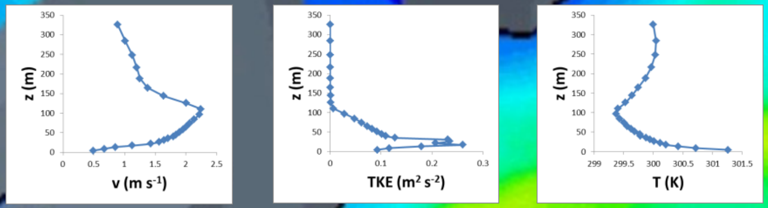


PM10 exhaust emissions in µg m^{-2} s^{-1}.

Model Descriptions and Set-Ups

Multiscale system of models

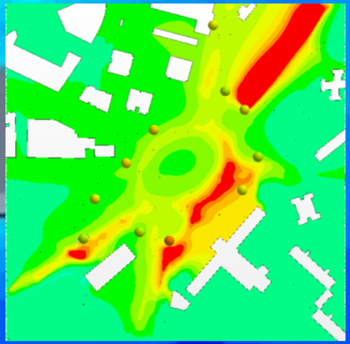
Profiles from **mesoscale model**



Traffic emission model

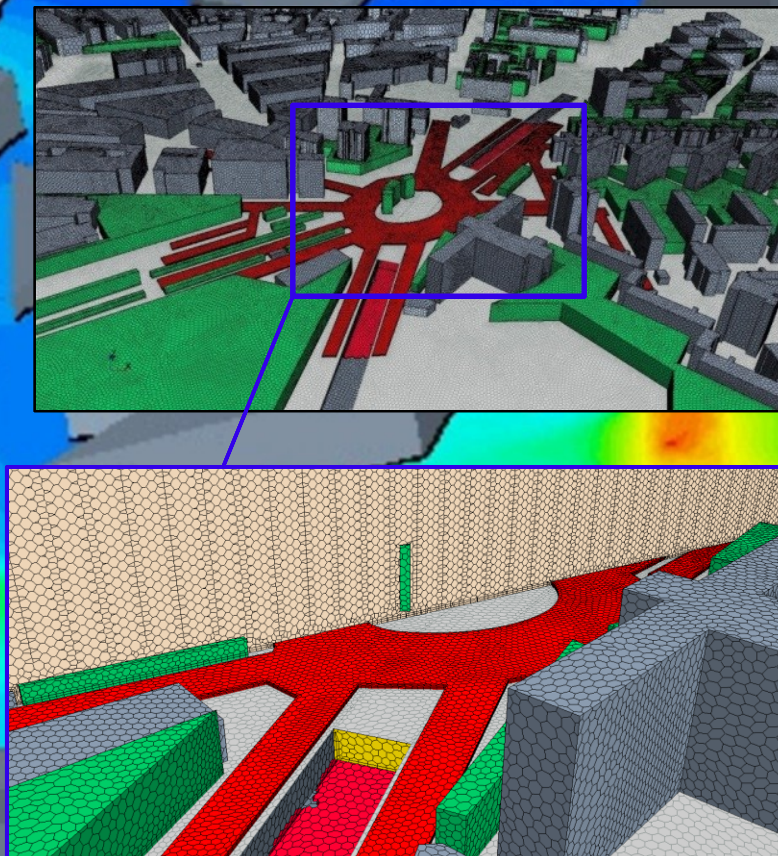
Background monitoring station

CFD model



Model Descriptions and Set-Ups

CFD model



- Reynolds-Averaged Navier-Stokes (**RANS**) equations with a **Realizable *k-ε*** (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**: $8.5 \cdot 10^6$ 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.

Model Descriptions and Set-Ups

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 }

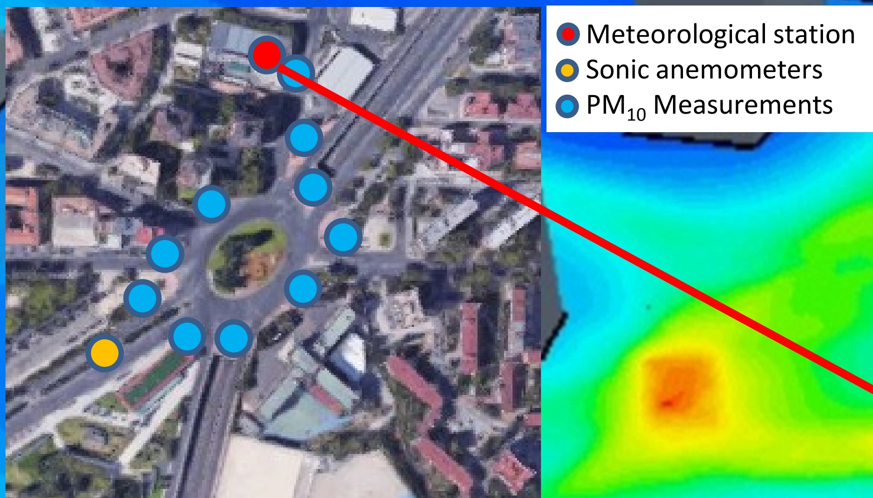
  ε is computed from TKE profile as, $\varepsilon_{in} = {C_\mu}^{3/4}\ {TKE_{in}}^{3/2}/(\kappa z)$
- Inlet wind direction from meteorological station at roof
- A radiation model is not implemented in the CFD model, however in order to analyze the effects of surface heat fluxes at different hours, two scenarios are simulated:

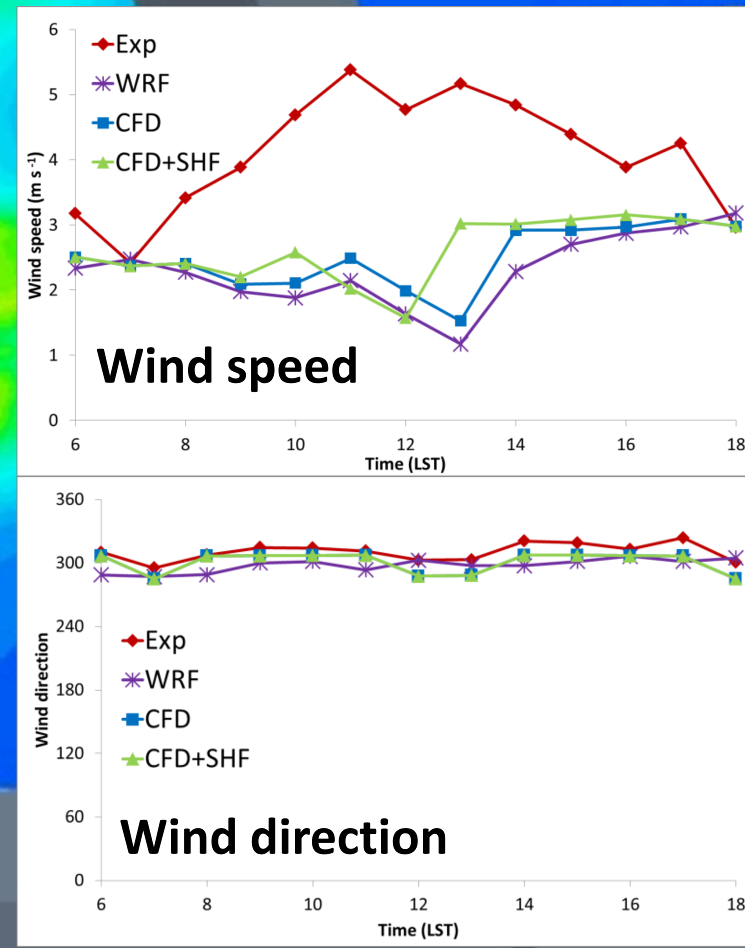
1) considering adiabatic the ground and buildings **(CFD)**
2) imposing at ground the surface heat flux computed at mesoscale in the whole domain by WRF at each hour (**CFD+SHF**) (Sanchez et al., 2017b; **Poster H18-164**).

Results

Evaluation of meteorological results

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





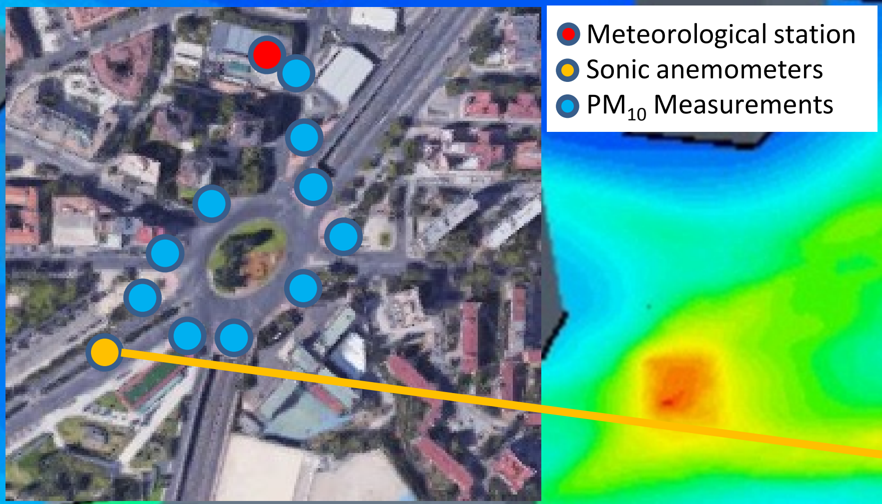
Meteorological station (18 m AGL)

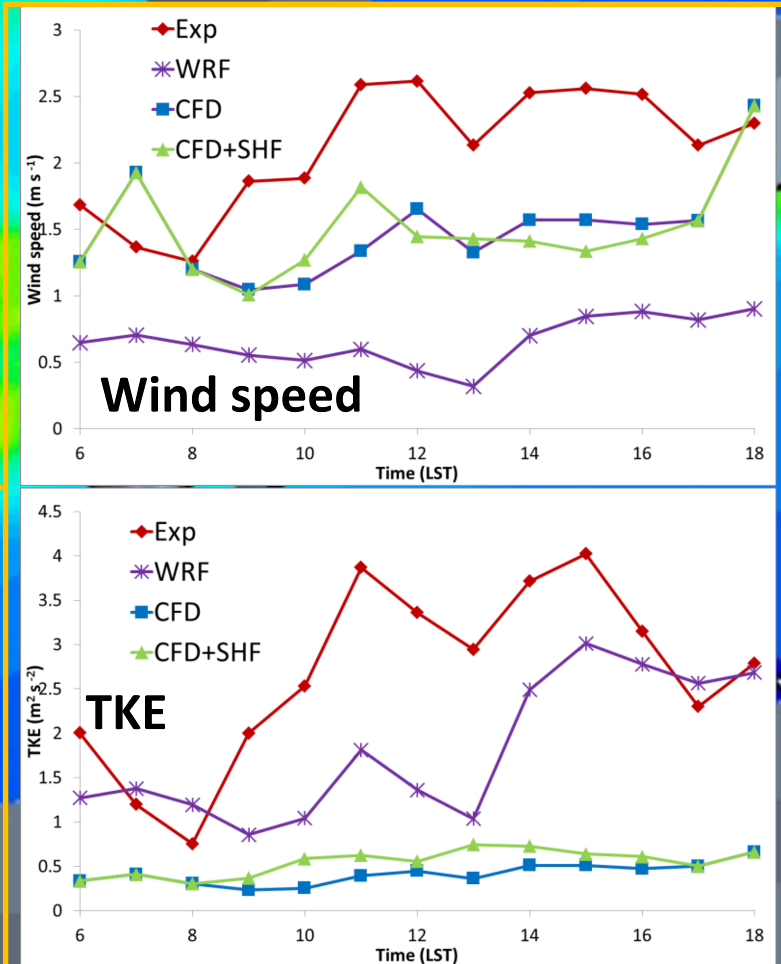
- Wind speed underestimated → Wind speed imposed at inlet of microscale domain is underestimated → Impact on CFD results

Results

Evaluation of meteorological results

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





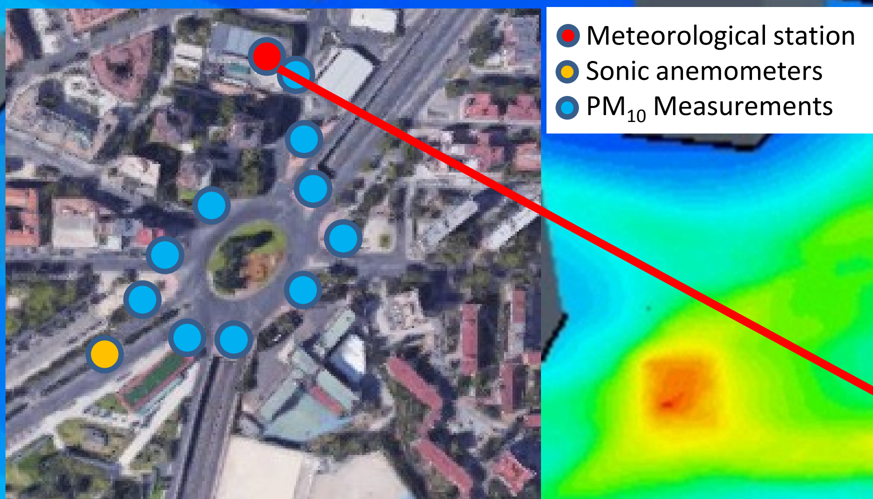
Sonic anemometers (6m and 8 m AGL)

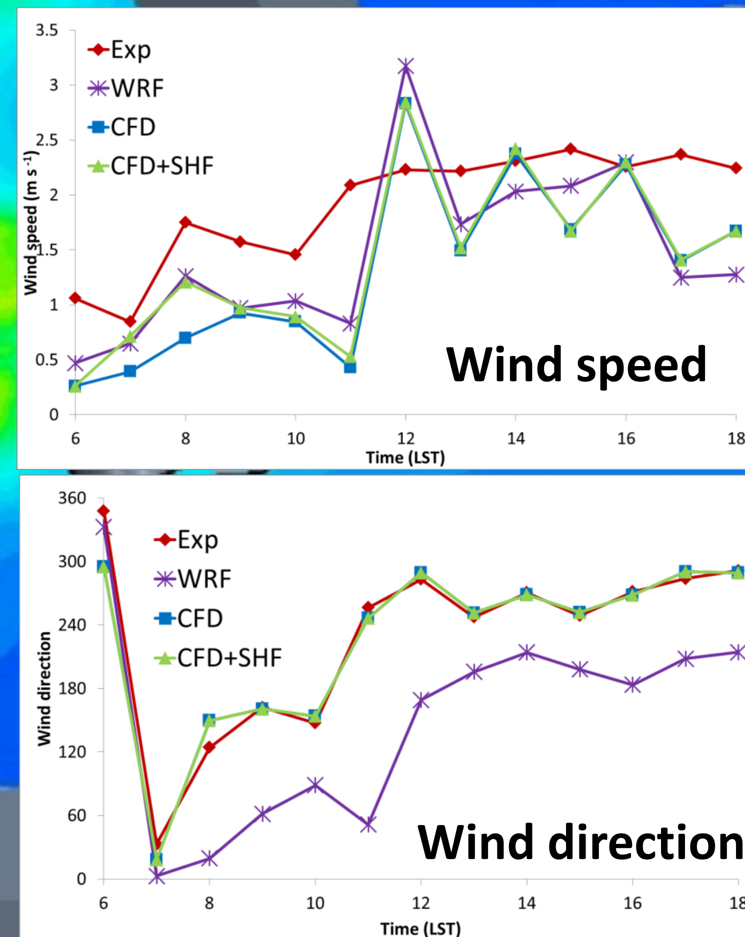
- Slight underestimation of wind speed
- Underestimation of TKE. Better results as surface heat flux at ground (SHF) is considered

Results

Evaluation of meteorological results

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





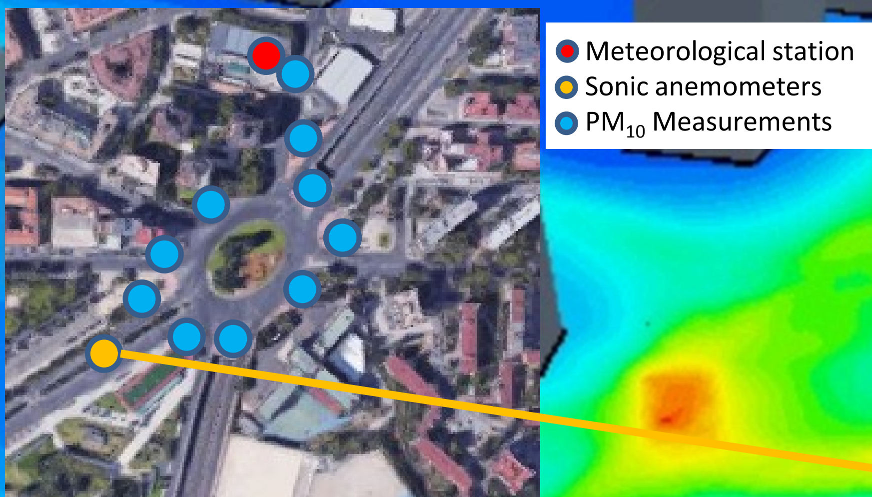
Meteorological station (18 m AGL)

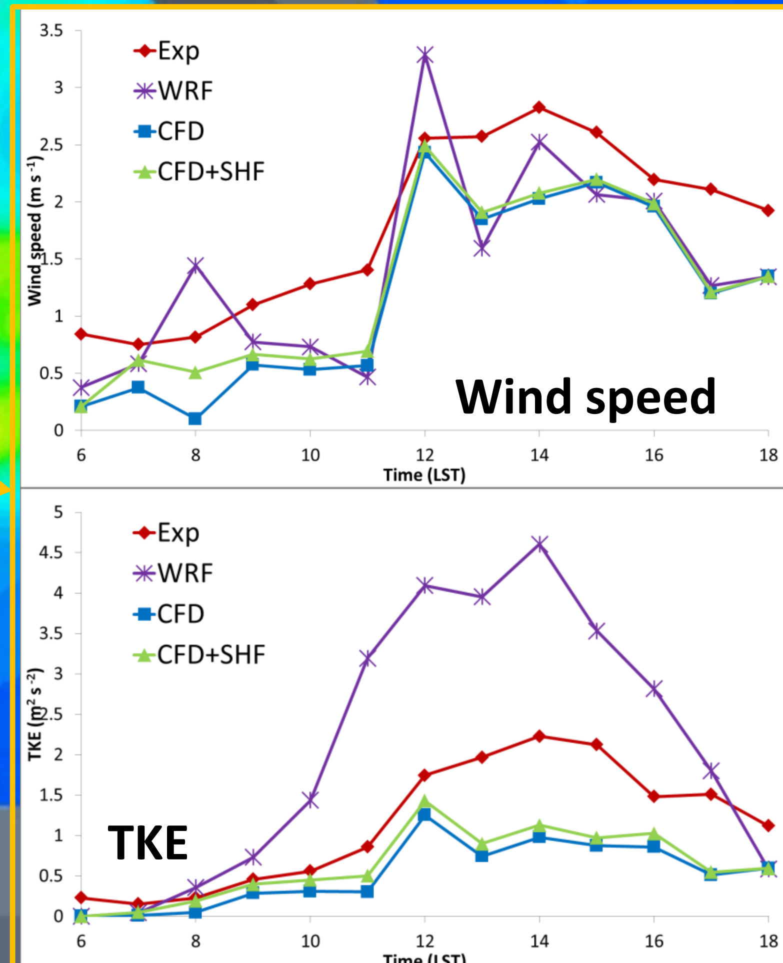
- Slight underestimation of wind speed.
- Lower wind speed than 25th February

Results

Evaluation of meteorological results

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





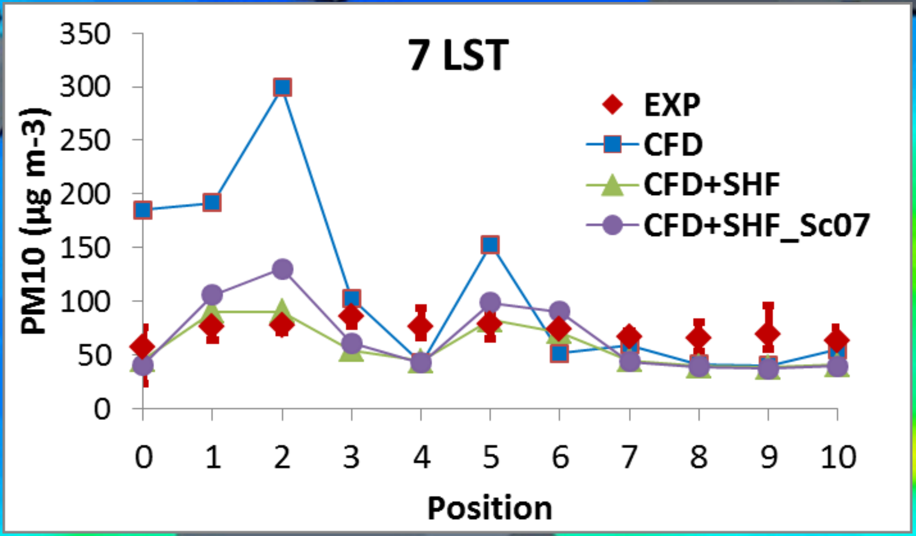
Sonic anemometers (6m and 8 m AGL)

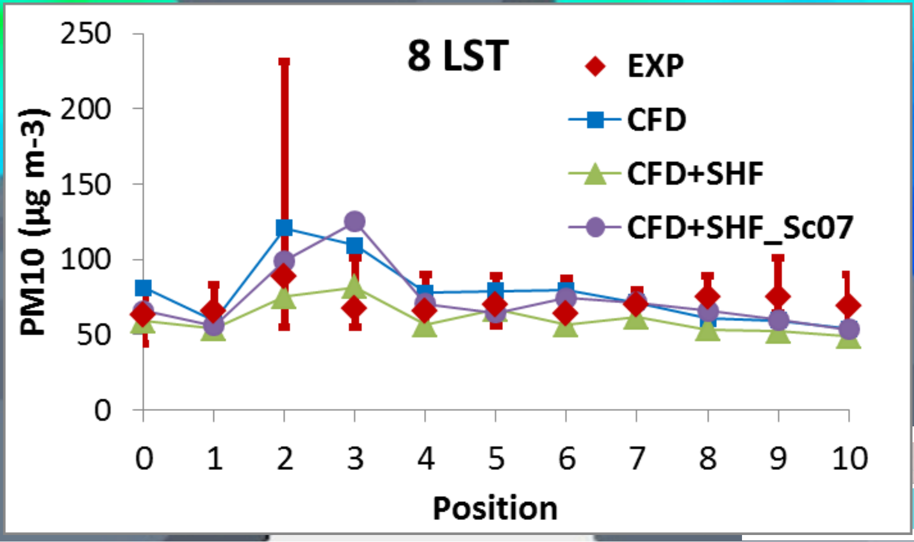
- Slight underestimation of wind speed
- Underestimation of TKE. Better results as surface heat flux at ground (SHF) is considered.
- Better agreement for 6th July.

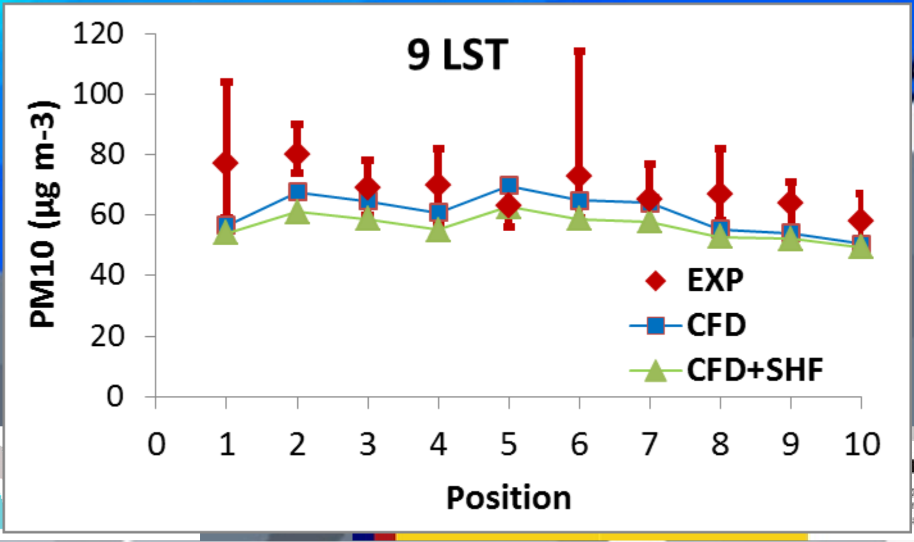
Results

Evaluation of particulate matter concentrations

- 6th July



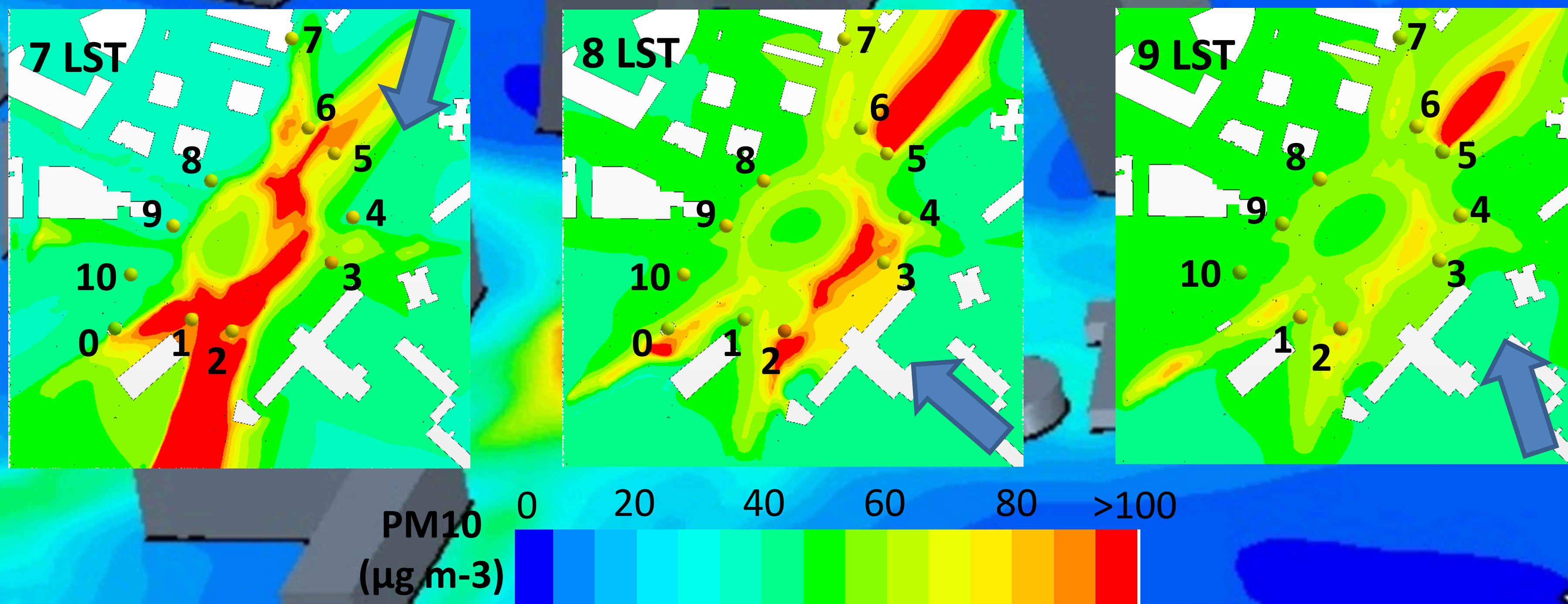


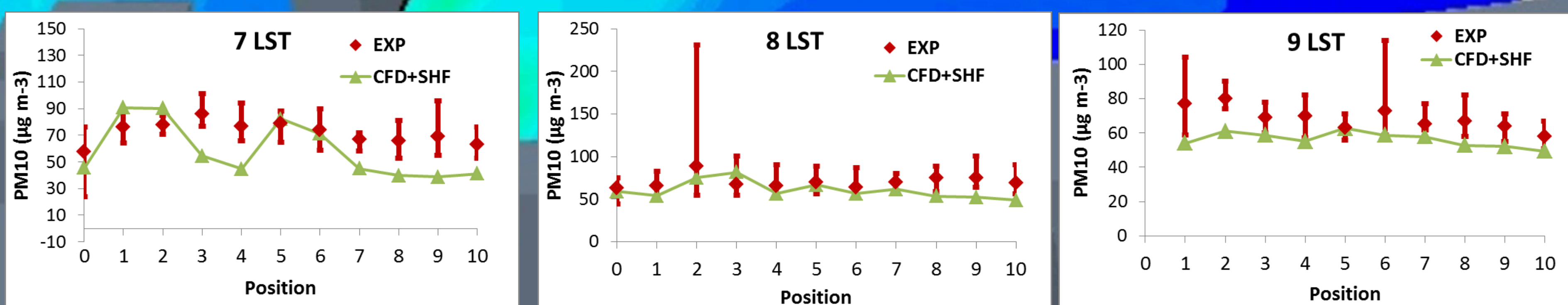


Results

Evaluation of particulate matter concentrations

- 6th July

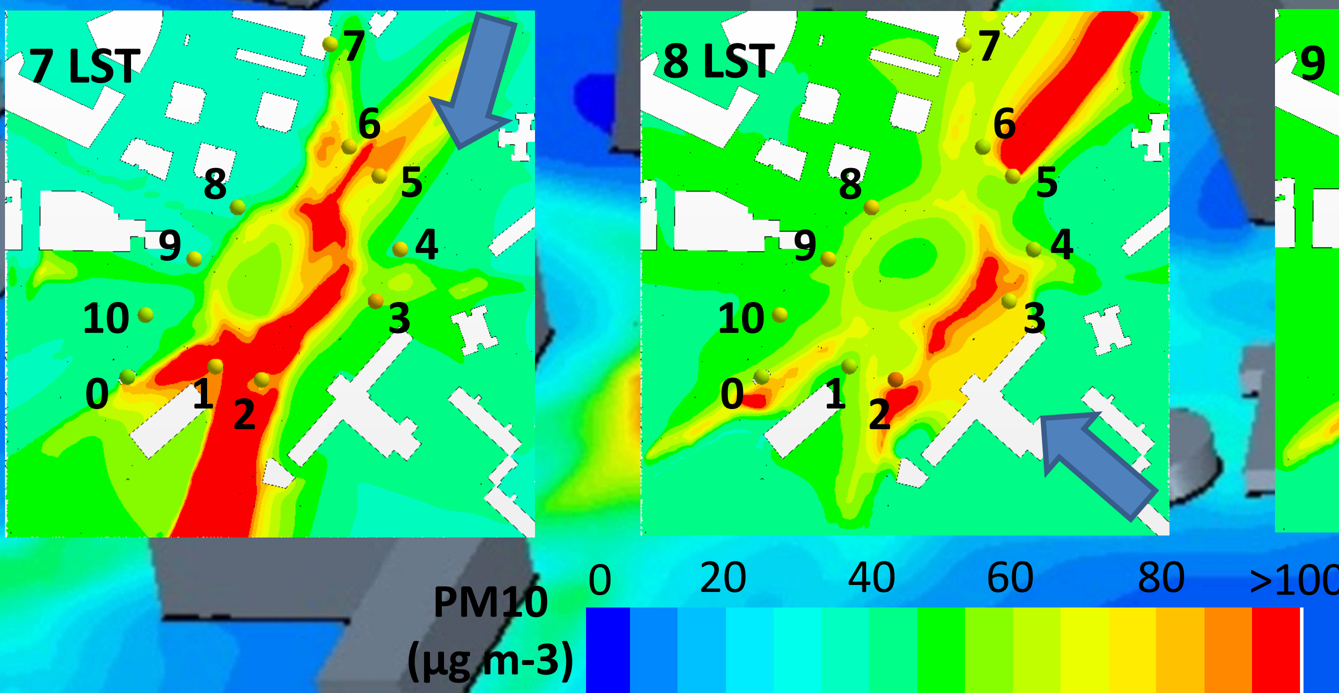


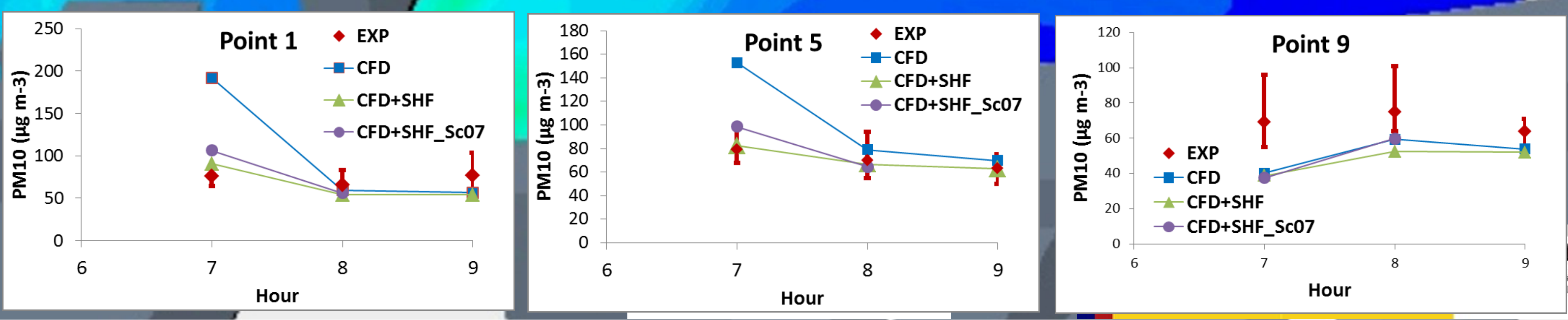


Results

Evaluation of particulate matter concentrations

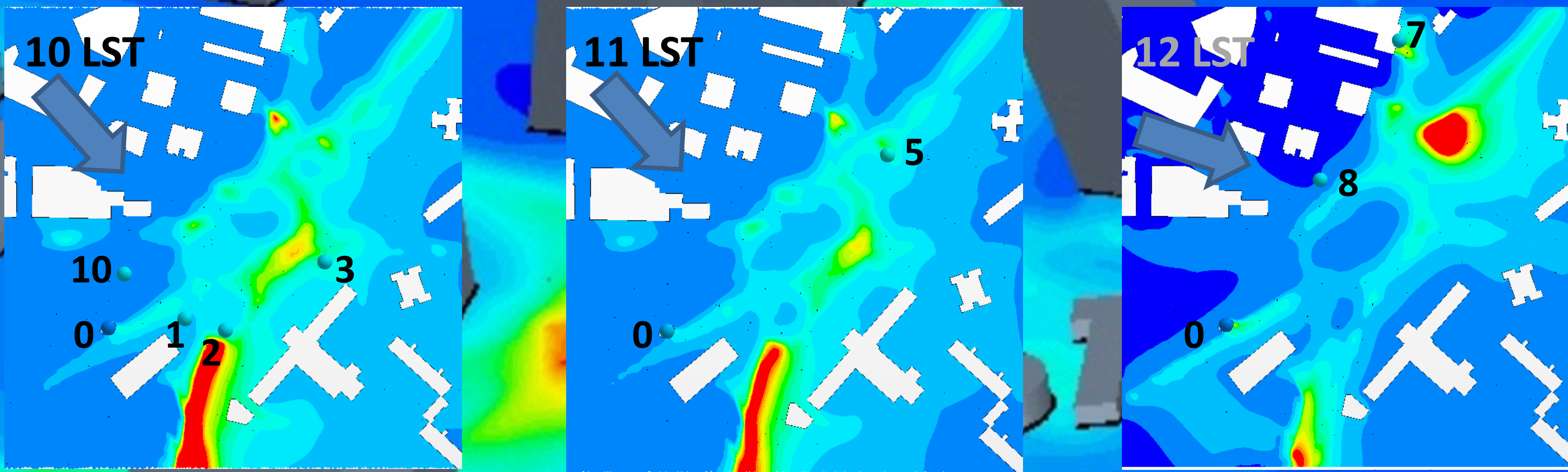
- 6th July

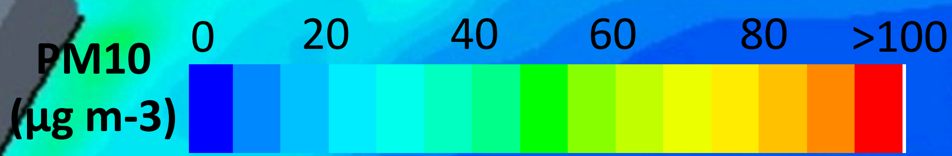


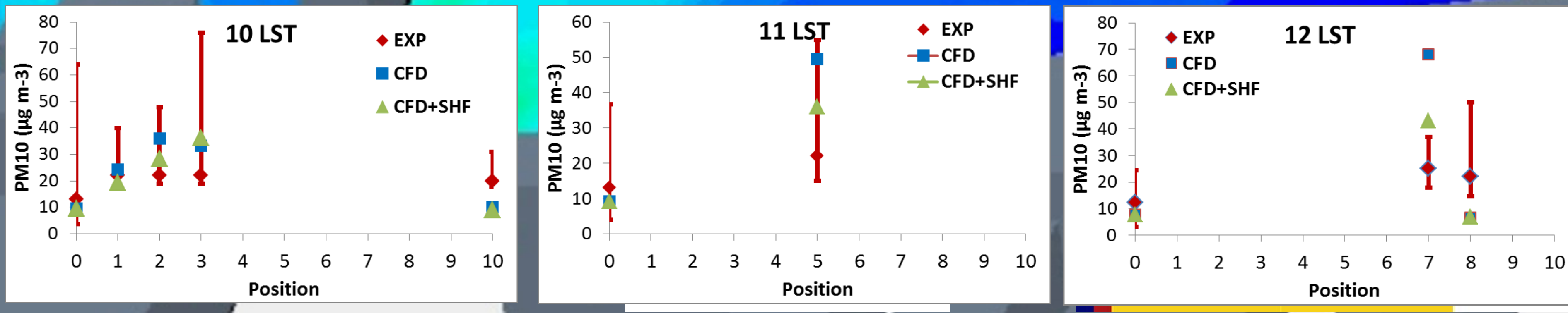


Evaluation of particulate matter concentrations

- 25th February



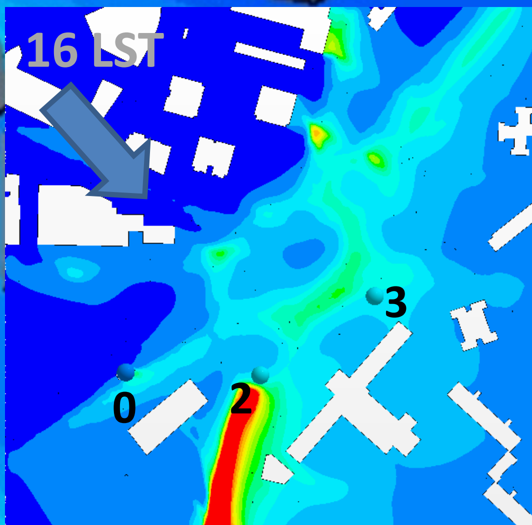


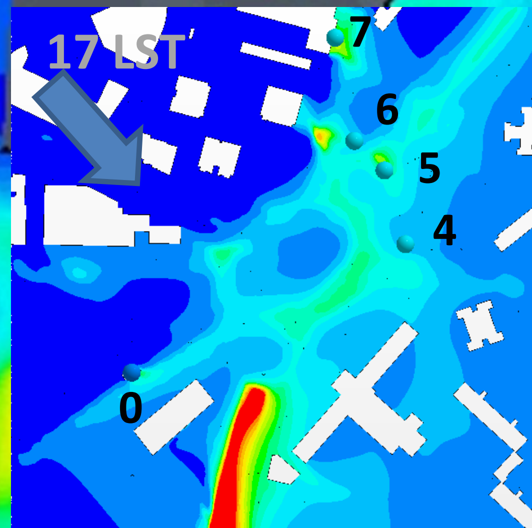


Results

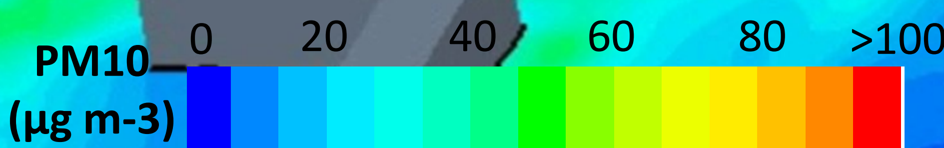
Evaluation of particulate matter concentrations

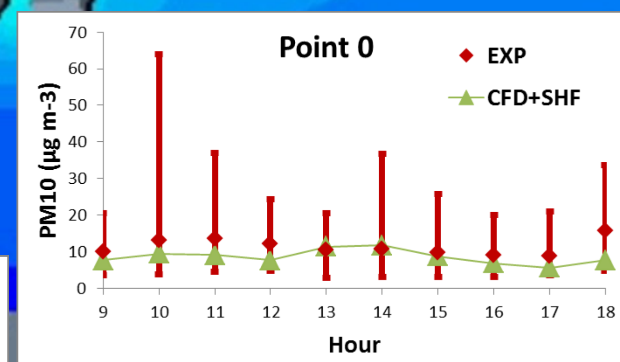
- 25th February

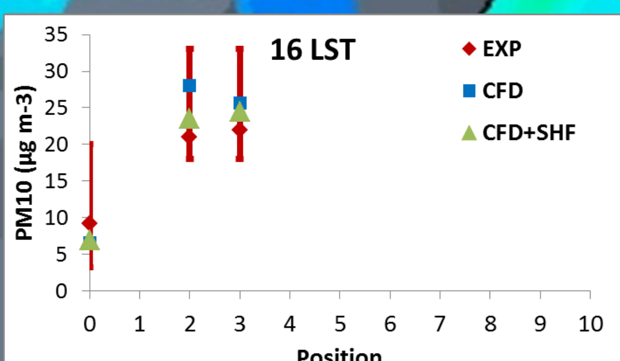


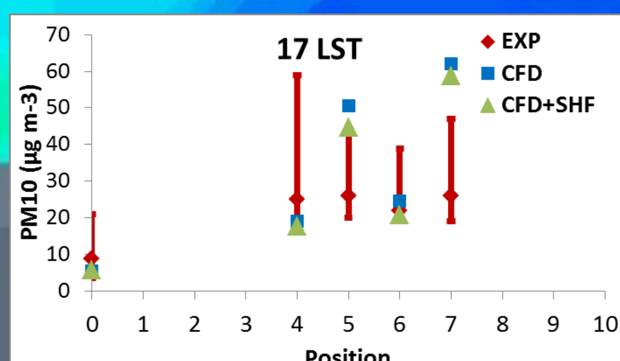


WINTER+ SUMMER	PM10 (CFD)	PM10 (CFD+SHF)
NMSE	0.48	0.085
FB	0.17	-0.15
FAC2	0.84	0.89









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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

- **Acknokledgements:**
  - This study has been supported by the **TECNAIRE-CM research project** (S2013/MAE-2972) funded by The Regional Government of Madrid.
  - Thanks to **Madrid City Council** for collaborating in the development of the project.
  - The authors are also grateful to Extremadura Research Center for Advanced Technologies (**CETA-CIEMAT**) by helping in using its computing facilities for the simulations.

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