GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

REPRESENTATIVENESS OF URBAN MONITORING STATIONS

JL Santiago, F Martín, A Martilli
Atmospheric Pollution Division,
Environmental Department,
CIEMAT,
Spain
jl.santiago@ciemat.es
fernando.martin@ciemat.es
alberto.martilli@ciemat.es

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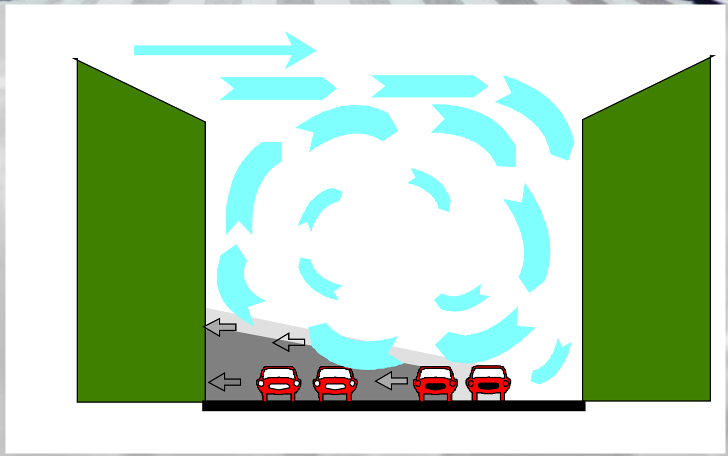
- Objective
- Methodology
- Application to real cases:
  - A traffic monitoring station inside a square in Pamplona (Spain)
  - A traffic monitoring station close to an urban park in Madrid (Spain)
- Conclusions

Introduction

- Urban air quality assessment is an important part of urban air quality management.
- Usually based on a network of urban monitoring stations.
- Urban morphology with atmospheric processes:
  - complex flow field
  - strong spatial heterogeneities of pollutant concentration patterns
- Spatial representativeness of point measurements is very limited.
- Very difficult to catch this heterogeneity.
- Increase the number of stations:
  - very expensive
  - often not possible in practice.



Objective

- **To estimate the spatial representativeness of the urban air quality stations.**
  - Maps of areas of similar concentration to that measured in the AQ station.
- How? ➔ Using the RANS-CFD models.
  - Disadvantage ➔ computational time that prevents unsteady simulations for large time periods.
- Other option? ➔ Steady-state simulations of representative cases and averaging the results.
  - Less computationally expensive.

Description of Methodology

- Steady simulations for meteorological scenarios: every wind direction (16 wind directions: N, NNE, NE, …) with a passive tracer emitted from each street. (*Parra et al., 2010, Atmospheric Environment*).
- Due to the linearity of the conservation equation of the passive scalar, the concentration at every hour is

$$C(t) = \sum_i C_i(sector(t))A\frac{N_i}{v_{in}(t)}$$

$$A = f\left(car_{speed}, car_{emission}, L_{street}, V_{source}\right)$$

Where N_i is the number of cars passing in road i, and $v_{in}(t)$ is the inlet wind speed at that hour.

- $C(t)$ computed is proportional to real concentration, a normalization with monitoring station value is made.
- Averaged tracer concentration maps computed by applying weighted average of steady simulations taking into account how frequent are the scenarios.

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Methodology: Assumptions

- Pollutants must be non-reactive or at least for the time period studied pollutants should be little influenced by atmospheric chemistry
- Thermal effects negligible in comparison with dynamical effects.
- Emissions inside each street at a selected hour proportional to traffic intensity at that hour.
- Emissions modelled as a line source inside each street and several tracers (one for type of street).
- Tracer concentration at certain hour only depending on emissions and meteorological conditions at that hour.

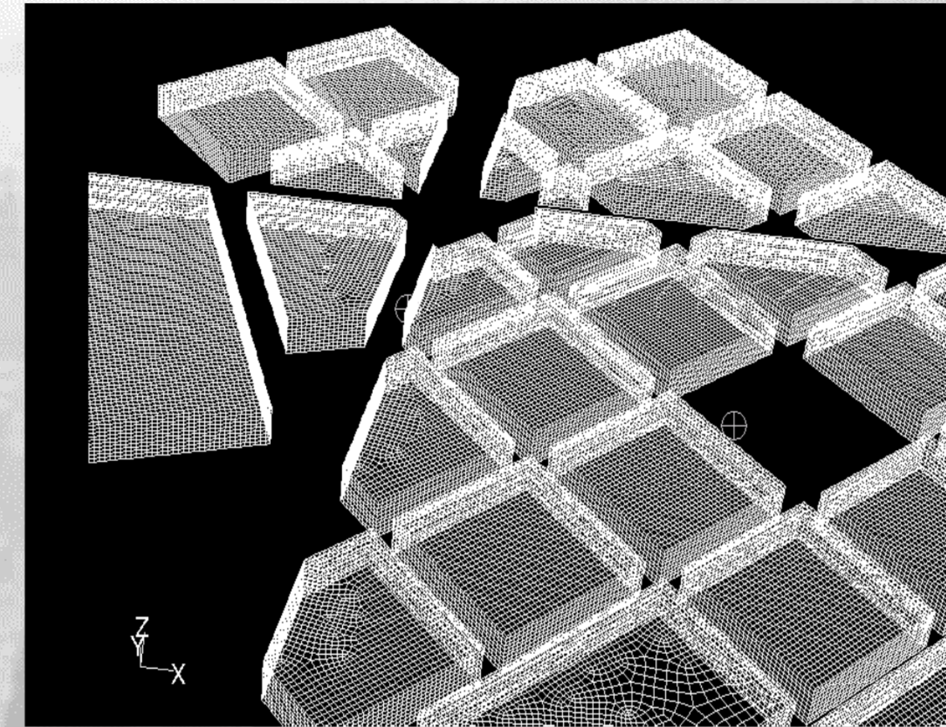
APLICATION TO REAL CASES

Case 1. A traffic monitoring station inside a square in Pamplona (Spain)

Case 2. A traffic monitoring station close to an urban park in Madrid (Spain)

Traffic station - square - Pamplona

- Medium-size city of Northern Spain

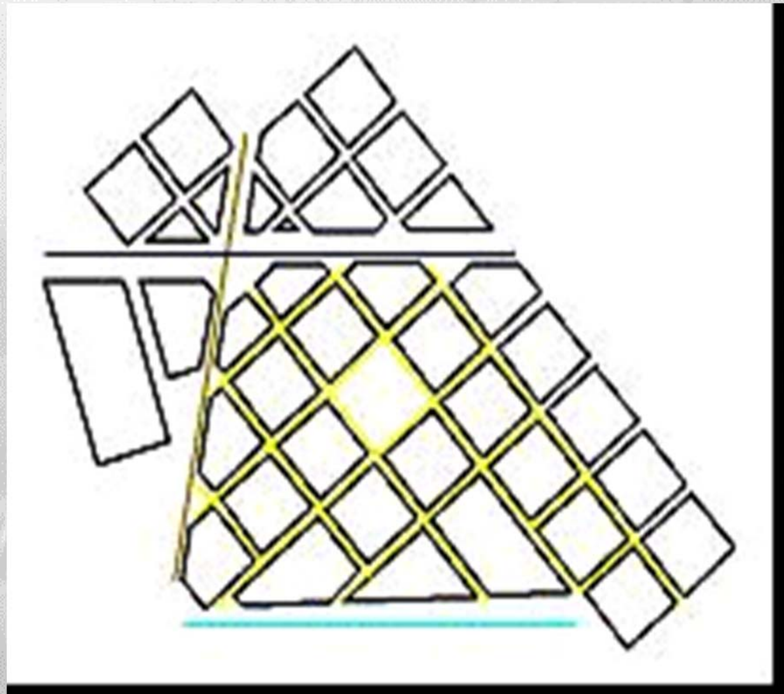


15 m-high buildings

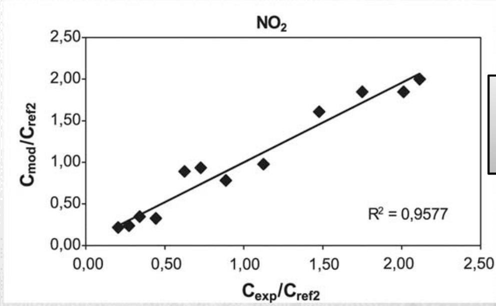
Traffic station - square - Pamplona

Modelling setup:

- CFD – RANS with standard *k*-ε turbulent.
- Tracers simulated with a transport equation for passive scalar
- $3.5 \cdot 10^6$ cells approximately. Cell size smaller close to buildings:
  - 2 m in X- and Y-direction
  - 1.5 m in Z-direction.
- Symmetry boundary conditions at the top and standard wall functions at solid boundaries (buildings and ground).
- Four passive tracers.
- Simulations for 16 wind directions.
- Time period of January and February 2007 (from 8h to 20h of each day).



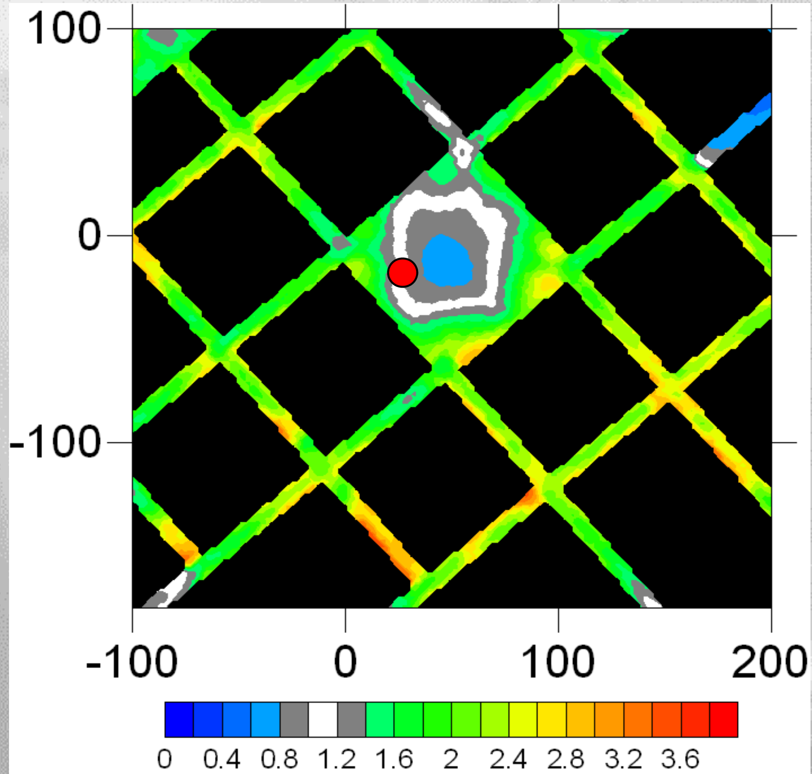
Traffic station - square - Pamplona



r=0.96

Results:

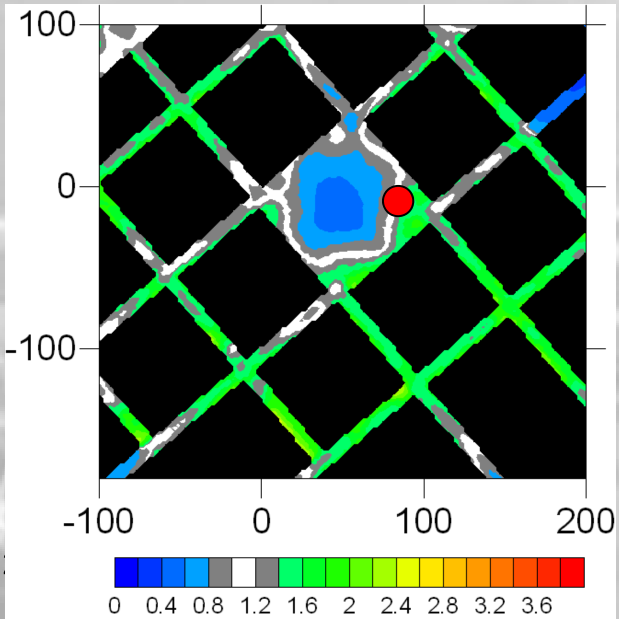
- Former studies ((*Parra et al., 2010, Atmospheric Environment*) demonstrate good performance of model respect measurements.
- Computed mean concentration (normalized by concentration at station location) in the square.
  - White and grey colours represent ±20% of the concentration at the monitoring station (representativeness area – RA -) of urban air quality station
  - Strong spatial variability in the pollutant concentration
  - Differences larger than a factor 3.

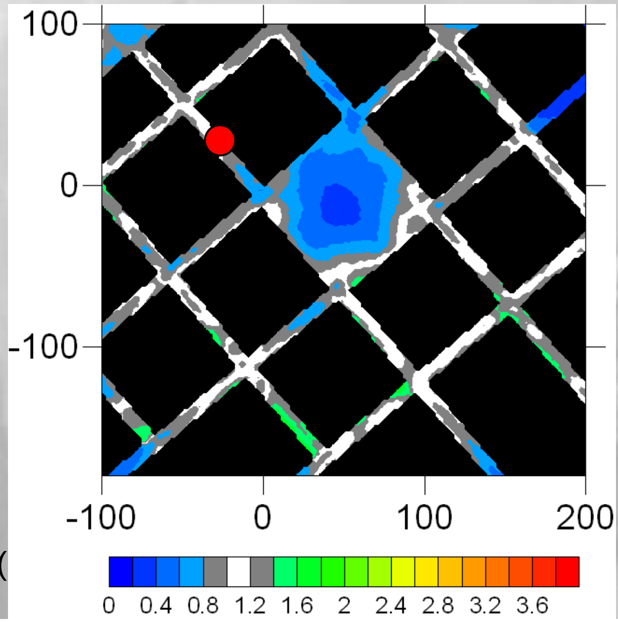


Traffic station - square - Pamplona

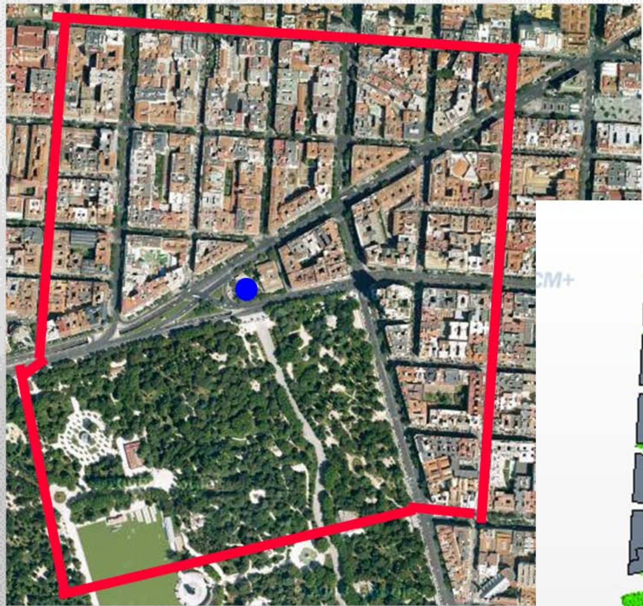
Results

- Hypothetical locations of the new monitoring stations were evaluated
  - another location in the square
  - in a nearby street
- Spatial extension of the RA is strongly dependent on the position of the station.
  - Location in the street seems to be more representative.
  - Concentration in the streets is quite homogeneous, while largest gradients are present in the square.

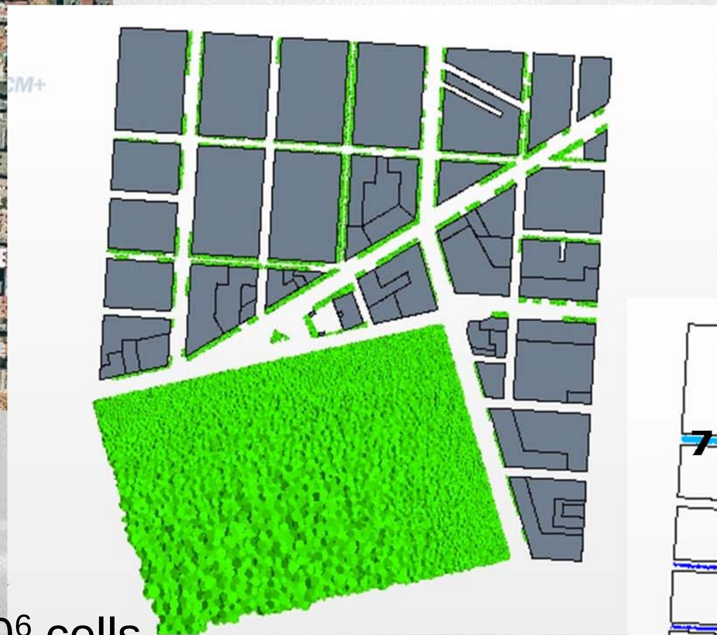




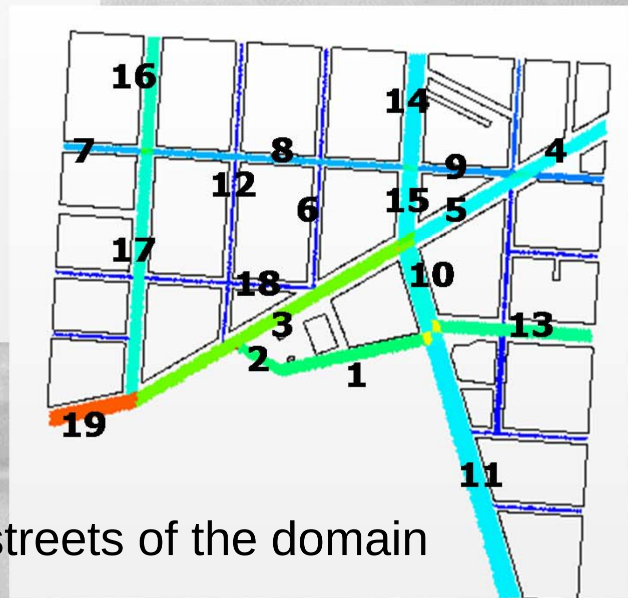
Traffic station - close to an urban park - Madrid



Max high buildings = 90 m
Most between 18-24 m
Size of simulated area 700x800 m^2



Irregular mesh of $3{\cdot}10^6$ cells
resolution of about 1m-3m close to the buildings



Relative traffic intensity in the main streets of the domain

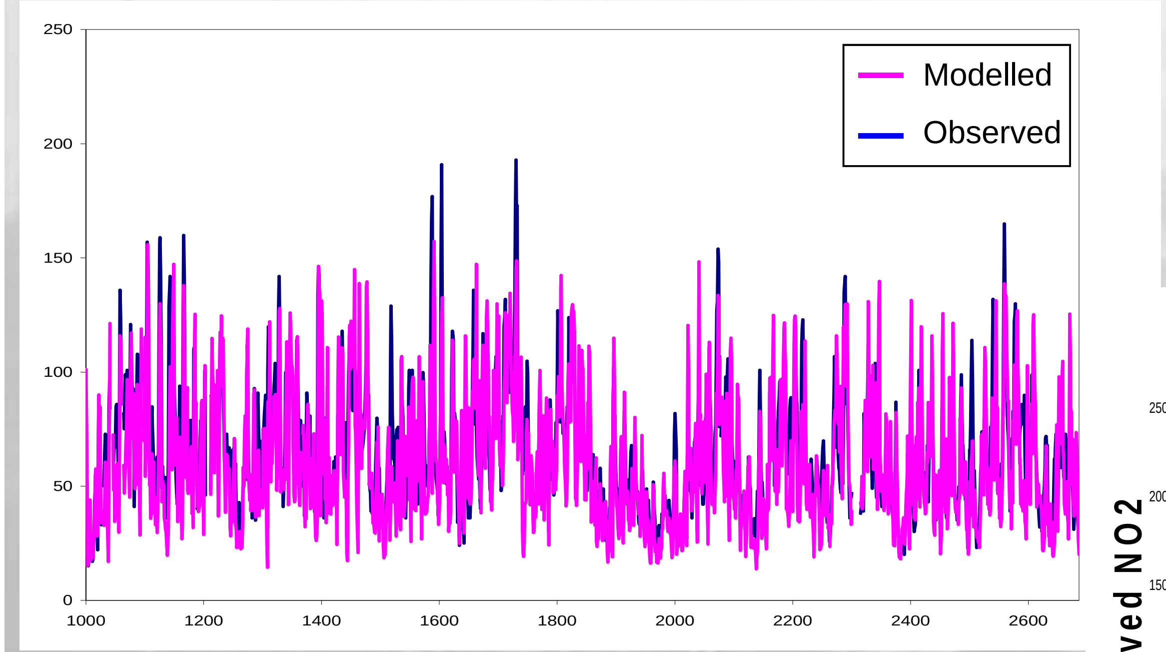
Traffic station - close to an urban park - Madrid

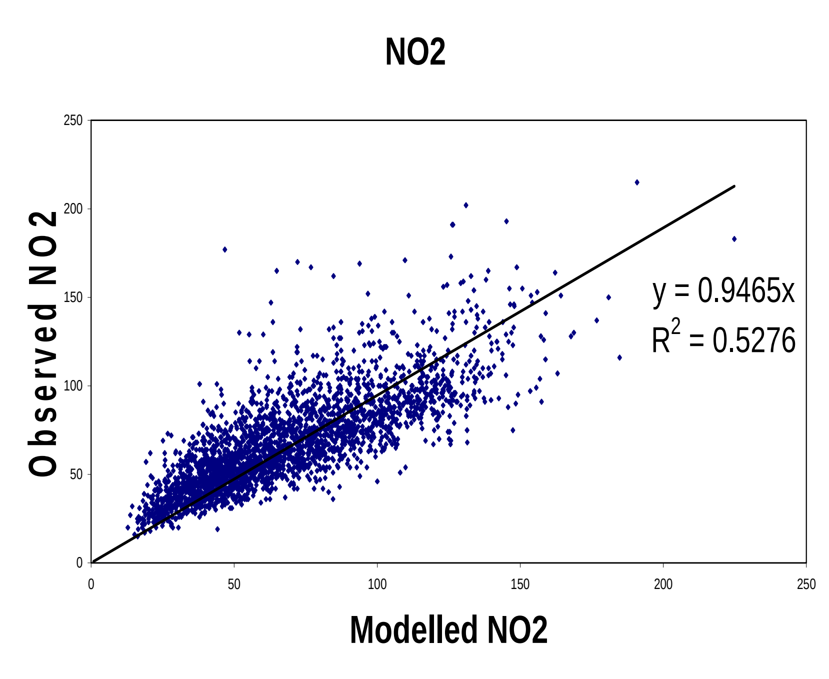
Additional considerations taken respect to the Pamplona case:

- Dynamic effects of vegetation included assuming trees as a porous medium.
- Concentrations from urban background stations were added to the results of the simulations as they only represent the local traffic impact.
- For weak winds ($V < 2$ m s^{-1}) we found that thermal effects are not negligible in this case. Therefore:
  - If **$V > 2$ m s^{-1}**, 16 wind sector cases with were simulated (Similar to Pamplona case).
  - If **$V < 2$ m s^{-1}**, pollutant concentration mostly depends on traffic intensity and mixing height (a simple parameterization is considered). In future works these cases have to be investigated in depth.
- Days with Saharan dust outbreak episodes removed in the computation of PM10 concentration.
- Weighted average concentrations were computed taking into account wind direction sector and wind speed cases.

Traffic station - close to an urban park - Madrid

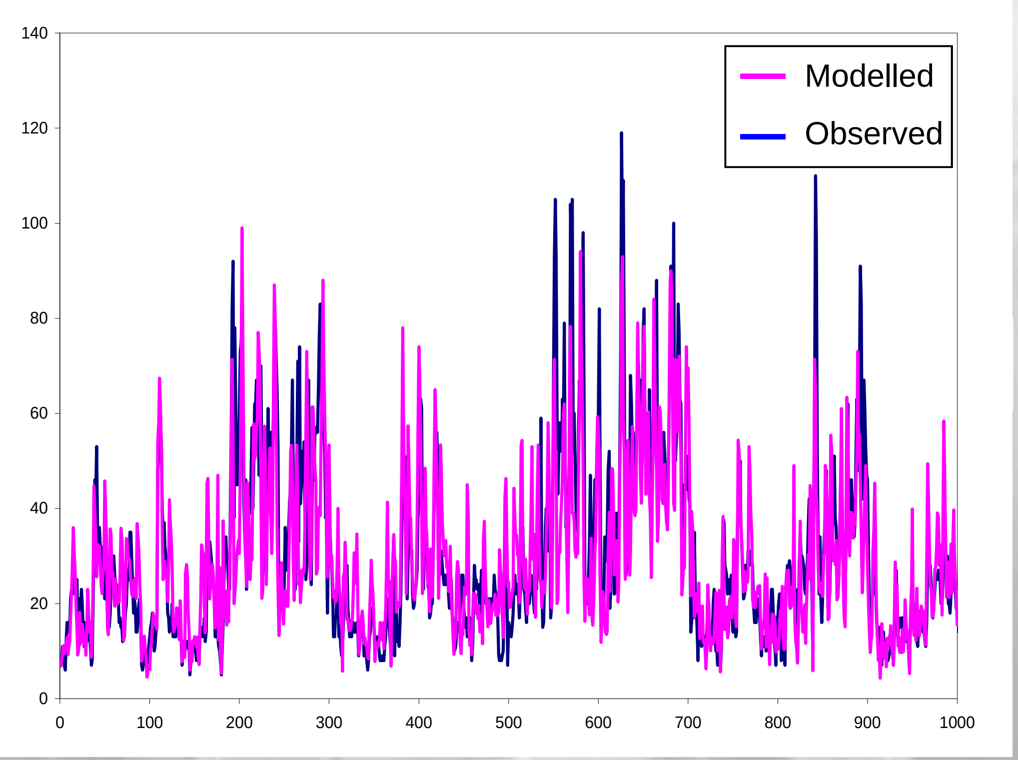
- The simulated period was January-May 2011.
- Comparison with observed data for hourly data for NO_2.

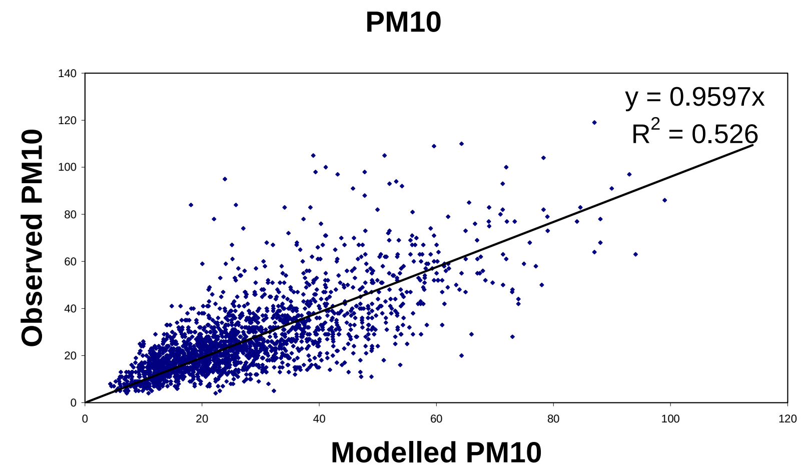


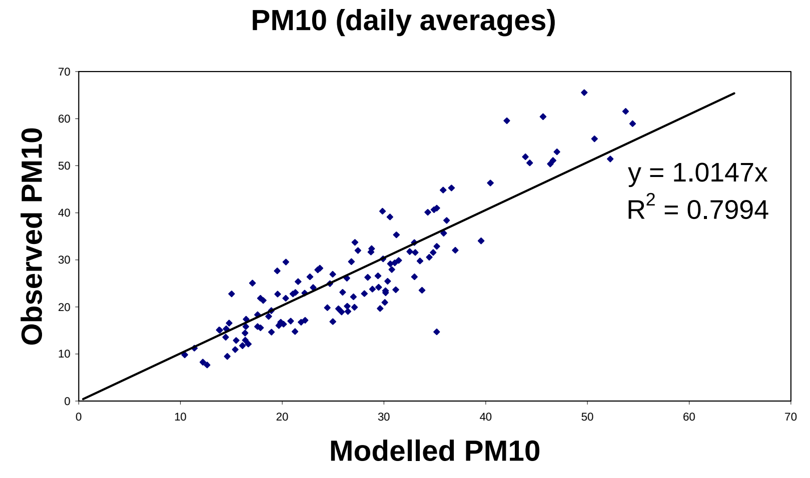


Traffic station - close to an urban park - Madrid

- The simulated period was January-May 2011.
- Comparison with observed data for hourly and daily mean data for PM10.



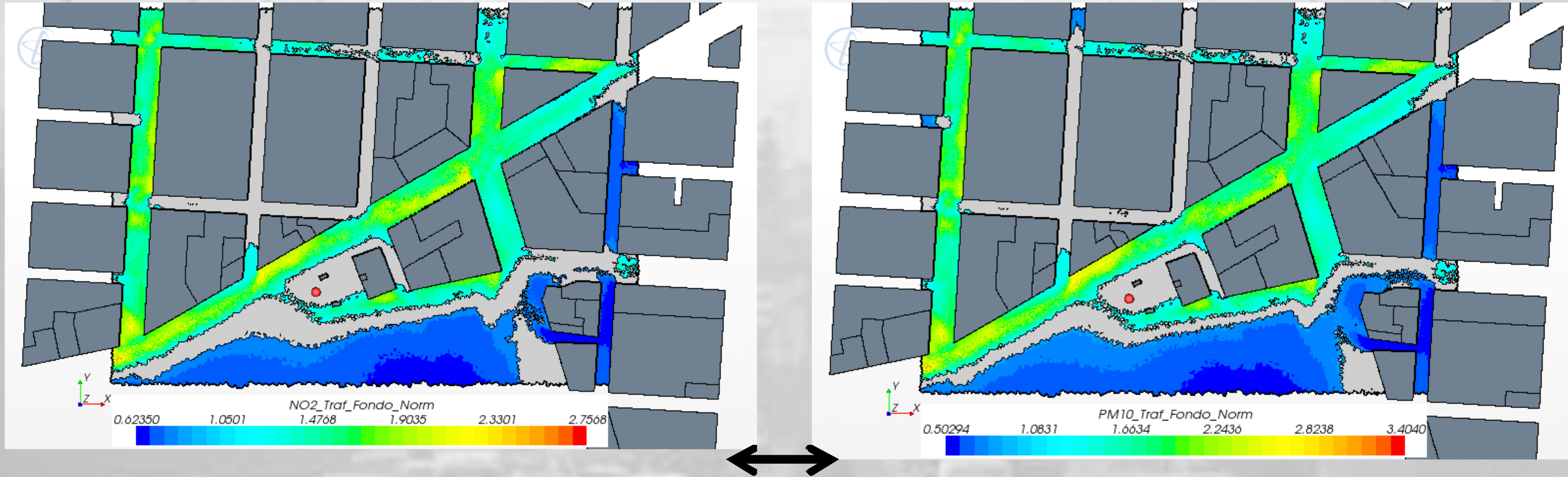




Traffic station - close to an urban park - Madrid

Results related to average concentrations January-May 2011:

- Averaged NO_2 and PM10 concentration maps



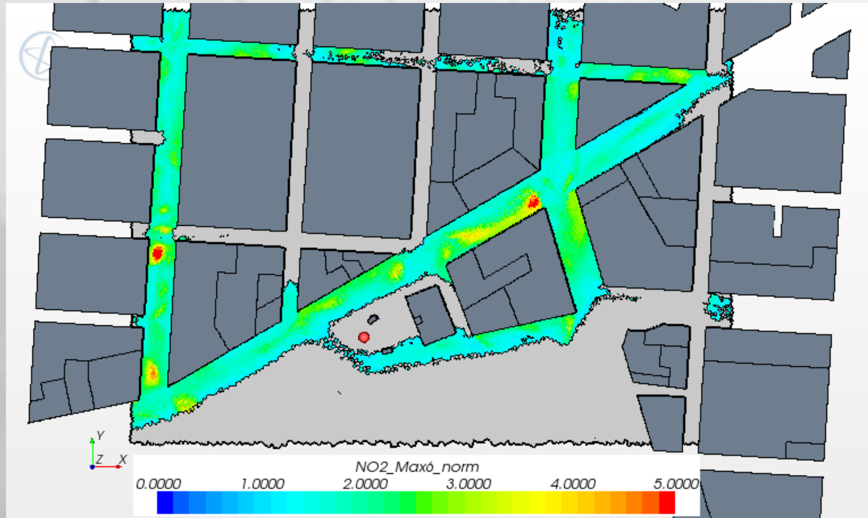
Scale: 100 m

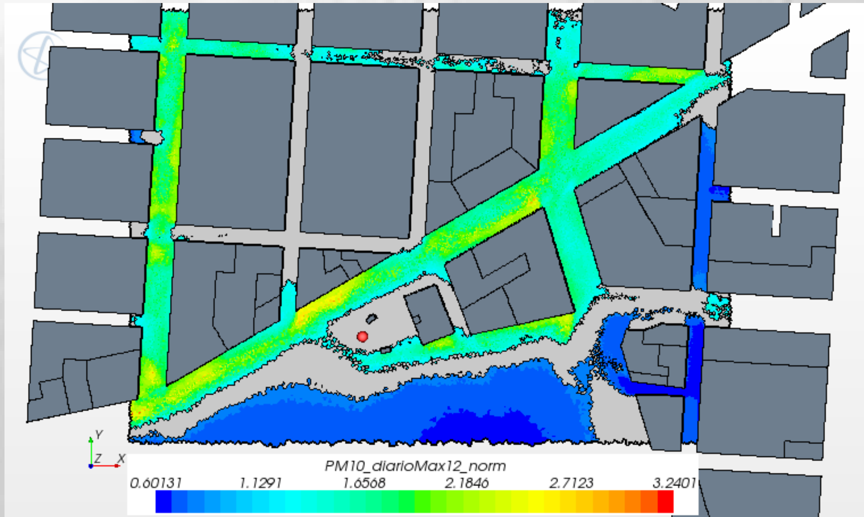
Mean concentration map normalized by concentration at station location (red dot) for NO2 (left) and PM10 (right). Grey shows the area with concentrations into ±20% around the station concentration.

Traffic station - close to an urban park - Madrid

Results related to probability of exceed limit values January-May 2011 :

- Percentile 99.8 hourly NO_2 and 90.4 daily PM10 concentration maps





Scale: 100 m

Concentration map normalized by concentration at station location (red dot) for 99.8 percentile of hourly data of NO2 (left) and 90.4 percentile of daily data of PM10 (right). Grey shows the area with concentrations into ±20% around the station concentration.

Conclusions

1. **Good performance of CFD-RANS** simulations compared with observations
2. **CFD-RANS reliable** to estimate distribution of pollutants in streets near the AQ stations and then, **to estimate spatial representativeness**.
3. Both cases show **strong spatial variability in distribution of pollutants** over long periods because complex flow over the streets.
4. **Spatial representativeness of two stations of two Spanish cities** demonstrate that they seem to **not meet completely requirements of Air Quality Directive (EC/2008/50) stating:**

   "…a sampling point must be sited in such a way that the air sampled is representative of air quality for a street segment no less than 100 m length at traffic-orientated sites…".
5. **Almost impossible to find measurements location fulfilling Directive's requirement.**
6. In our opinion, the **simple rule stated in the Directive must be revised**:
   - Better definition of representativeness (should be based only on spatial extension or also on people density?),
   - Recommendation of using CFD models to decide the best location.

Thank you for your attention