Effects of Traffic Emission Resolution on NOx Concentration Obtained by CFD-RANS Modelling Over a Real Urban Area in Madrid (Spain)

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Outline

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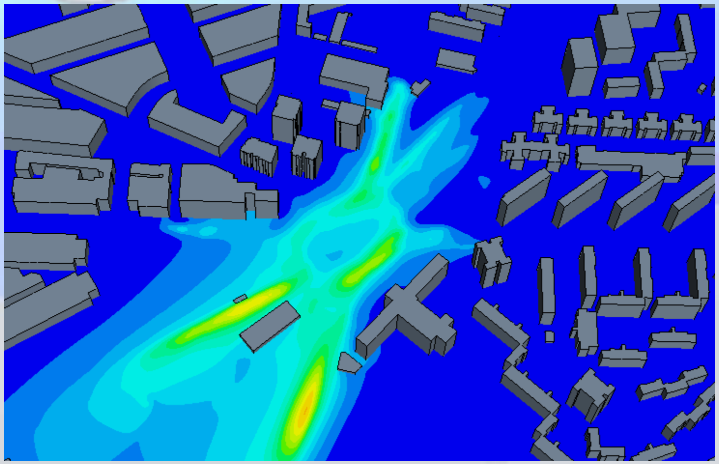
- Objective
- Experimental campaign
- CFD Model
- Traffic Emission Approaches
- Methodology
- Results
- Conclusions

Introduction

- 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

- Influence of details of traffic emission distribution on concentration maps?



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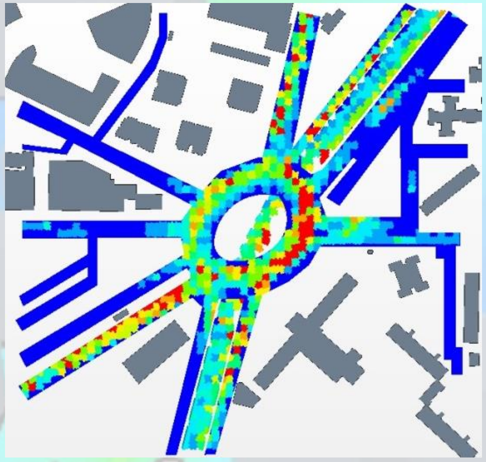
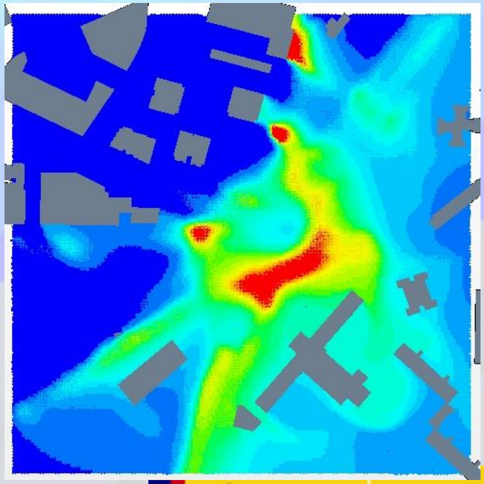
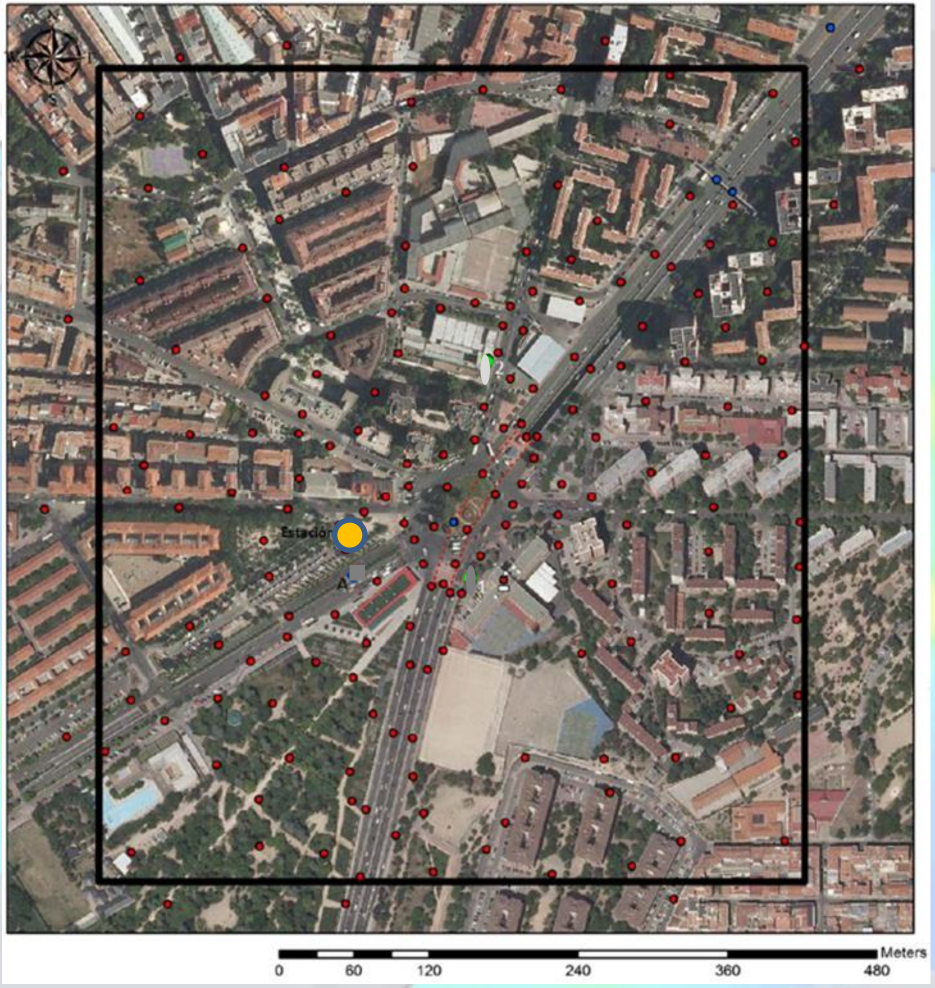
Objective

- To better understand the effect of traffic emission distribution on pollutant concentration maps in a real urban area.
- For this purpose:
  - CFD simulations using different traffic emission approaches.
  - Analysis of concentration distributions in the streets at pedestrian level.



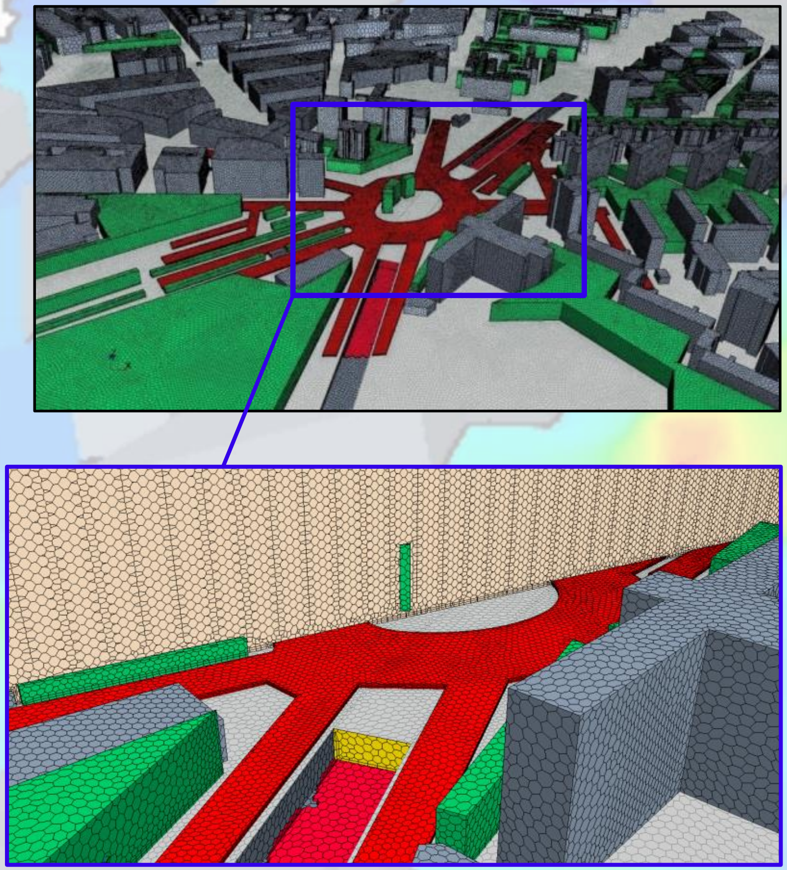


Experimental campaign



- Highly polluted zone in southern Madrid (Spain). Complex area: heavily trafficked roundabout, tunnel, vegetation, …
- Period: 9th – 27th February 2015.
- Air quality monitoring station (NO, NO_2, NO_x) (●). City Council network
- Passive samplers at 3 m height (period-averaged concentration of NO_2)

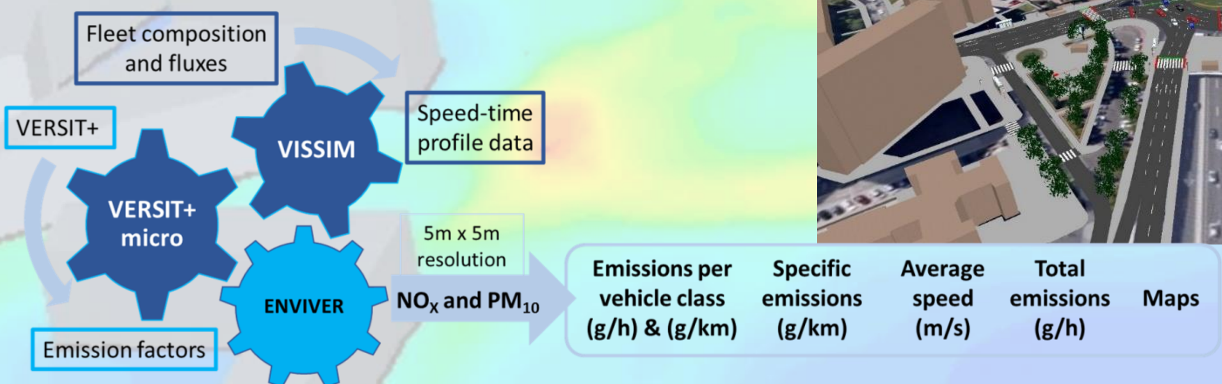
CFD modelling



- Steady state simulations with RANS with k-epsilon (model STAR-CCM+, CD-Adapco)
- Numerical domain: 1.3km x 1.3km
- Mesh: $8.5 \cdot 10^6$ polyhedral cells.
- Resolution 2 m in the studied zone with prism layer of 1m close to the surfaces.
- Inlet: neutral profiles (16 different wind directions)
- Dynamic effect of vegetation (momentum sink and turbulence sink/sources)
- Emissions located 300 m x 300 m around the square.

Traffic emission approaches

- Four alternative approaches to represent emissions in the modelling domain to understand the influence of this input on CDF modelling results
- All four approaches account for the same grand totals
  - **Case 1**: emissions from a detailed traffic emission model



  - **Case 2**: Uniform emissions within each street. The emissions given at each street for each scenario by Case 1 are uniformly distributed along the street
  - **Case 3**: Emissions at each scenario are distributed following traffic intensity.

$$\mathbf{Qstreet_a\,(S_i) = Qtotal(S_i) * Nstreet_a(S_i)/Ntotal(S_i)}$$

N : number of vehicles
Q: emissions

  - **Case 4**: Total Emissions are distributed following traffic intensity.

$$\mathbf{Qstreet_a\,(S_i) = Qtotal(week) * Nstreet_a\,(S_i)/Ntotal(week)}$$

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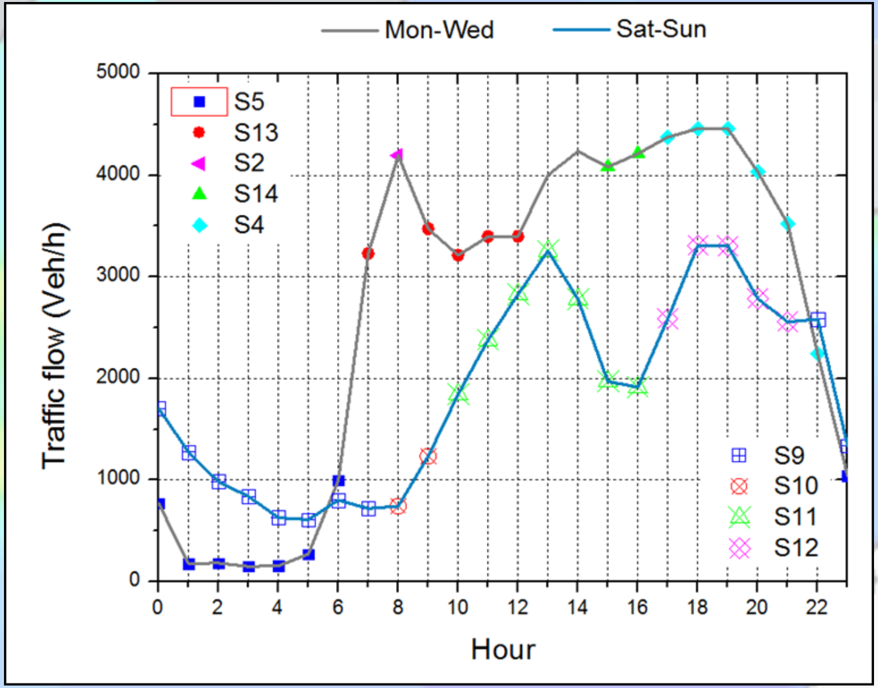
Traffic emission approaches

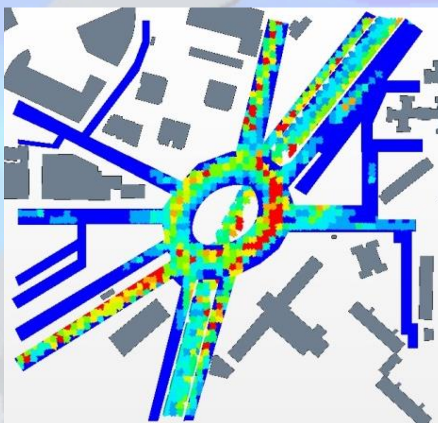
- **Case 1**: Detailed traffic emission model.
  - Emissions calculation: Microscale traffic model linked to a emissions model (Smit et al., 2007)
  - Spatial resolution: 5 m x 5m
  - 14 Emission scenarios in order to reproduce hourly emissions of one week.
  - At each scenario changes
    - Emission rate
    - Spatial distribution
  - More details in **Quaassdorff et al. (2016).** ***Science of The Total Environment.***



Day/Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
M	S5	S5	S5	S5	S5	S5	S5	S13	S2	S13	S13	S13	S13	S3	S3	S14	S14	S4	S4	S4	S4	S4	S4	S5
T	S5	S5	S5	S5	S5	S5	S5	S13	S2	S13	S13	S13	S13	S3	S3	S14	S14	S4	S4	S4	S4	S4	S4	S5
W	S5	S5	S5	S5	S5	S5	S5	S13	S2	S13	S13	S13	S13	S3	S3	S14	S14	S4	S4	S4	S4	S4	S4	S5
Th	S5	S5	S5	S5	S5	S5	S5	S13	S6	S13	S13	S13	S13	S7	S7	S14	S14	S14	S8	S4	S8	S8	S8	S5
F	S5	S5	S5	S5	S5	S5	S5	S13	S6	S13	S13	S13	S13	S7	S7	S14	S14	S14	S8	S8	S8	S8	S8	S5
Sat	S9	S9	S9	S9	S9	S9	S9	S9	S10	S10	S11	S11	S11	S11	S11	S11	S11	S12	S12	S12	S12	S12	S9	S9
Sun	S9	S9	S9	S9	S9	S9	S9	S9	S10	S10	S11	S11	S11	S11	S11	S11	S11	S12	S12	S12	S12	S12	S9	S9

Traffic emission approaches

- **Case 1**: Detailed traffic emission model.

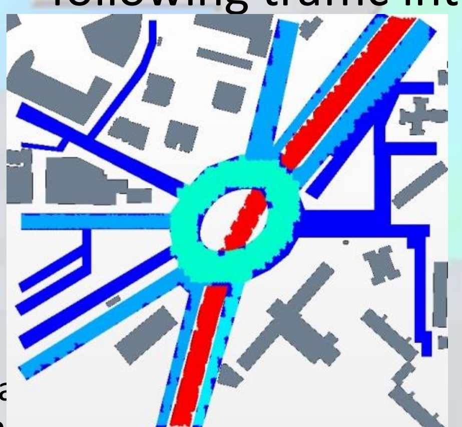


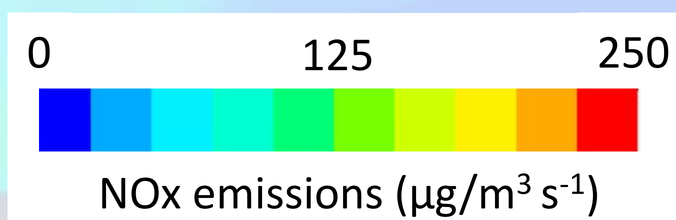
- **Case 2**: Uniform emissions within each street.

Example: S2

8h

- **Case 3**: Emissions at each scenario are distributed following traffic intensity.

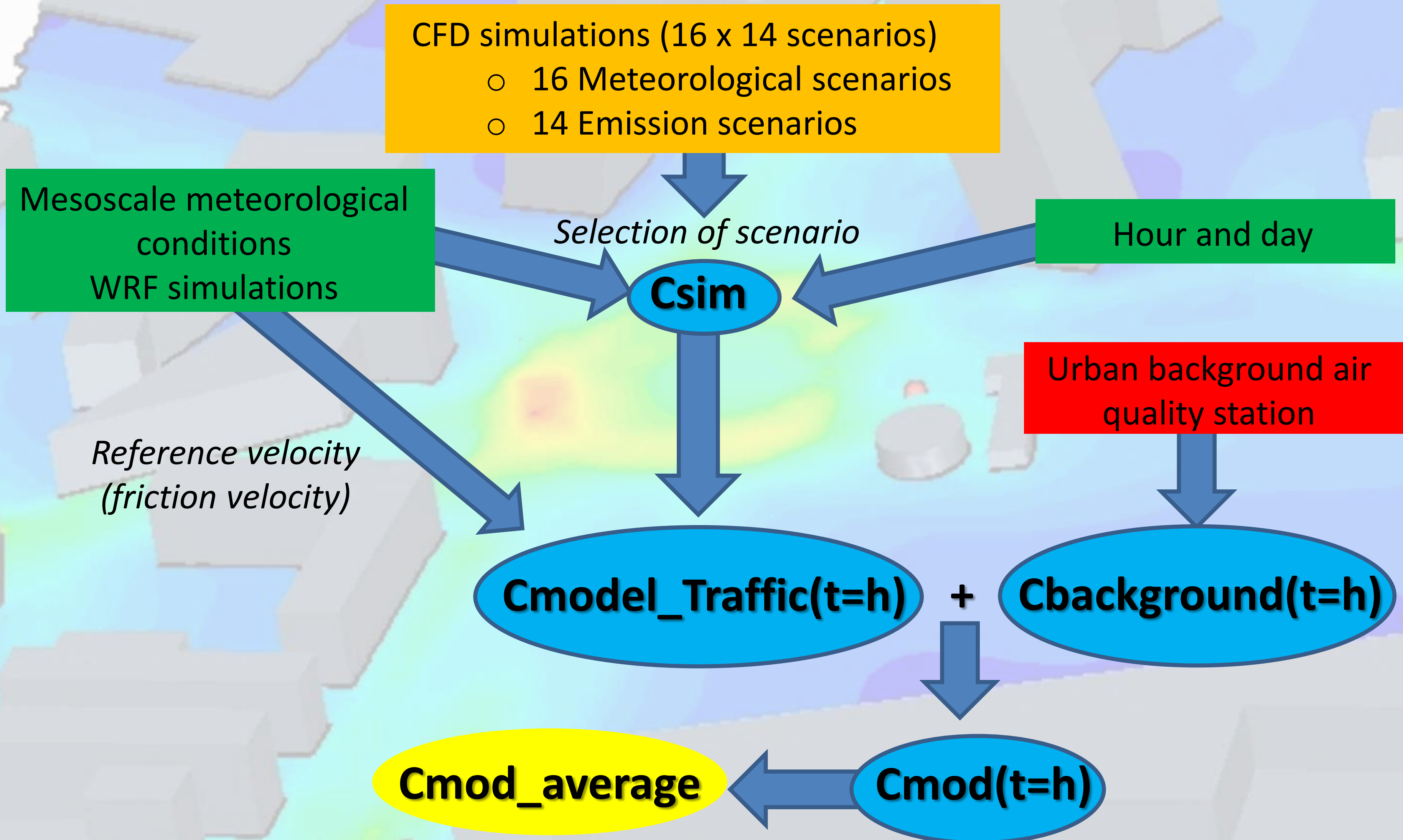




- **Case 4**: Total Emissions are distributed following traffic intensity.

CFD modelling methodology

- To compute average concentration over large period of time using CFD.



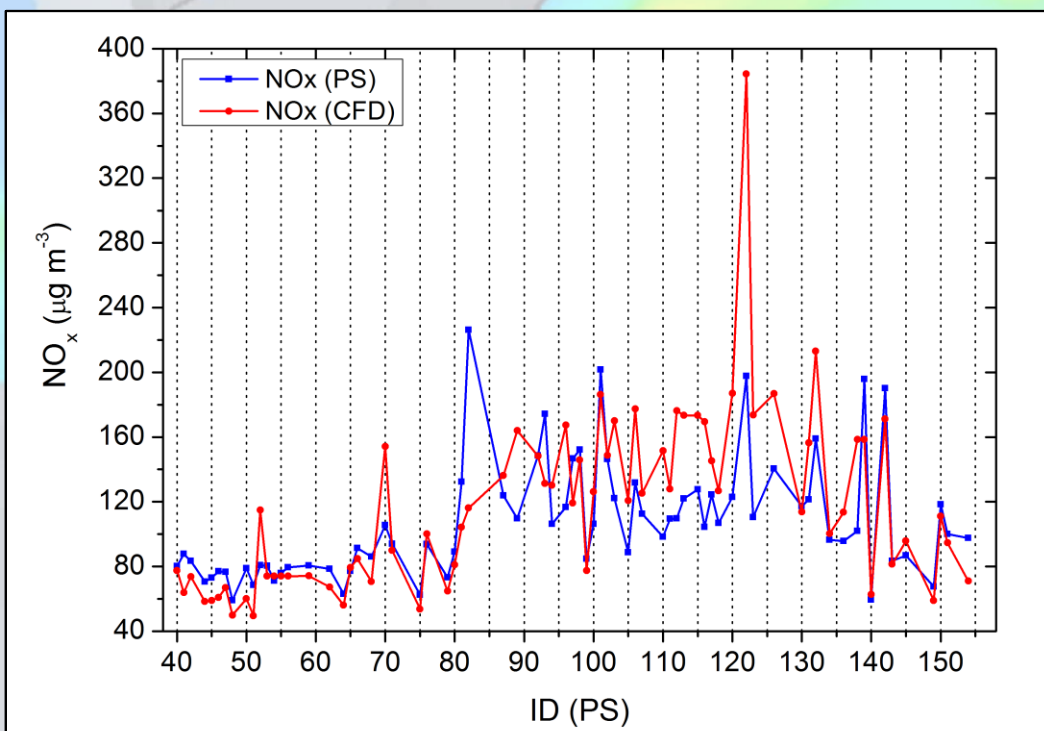
Results: Comparison with Passive Samplers

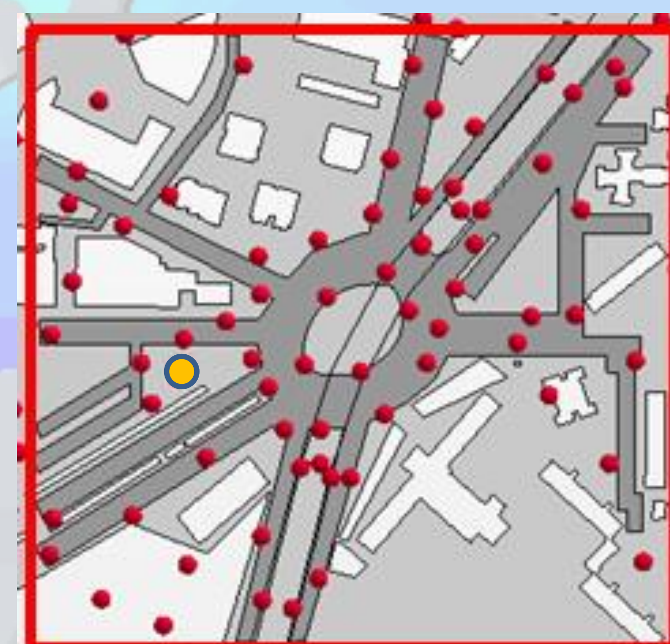
- Zoom 300 m x 300 m → 72 passive samplers
- Passive samplers: NO_2 averaged concentration over 444 h at 3 m. NO_2 is transformed into NO_x using the time average of the ratio at AQ station

$$[\mathrm{NO_x}] = \left.\frac{[\mathrm{NO_x}]}{[\mathrm{NO_2}]}\right)_{AQ\ Station} [\mathrm{NO_2}]$$

- NO_x averaged concentration over 444 h is modelled.

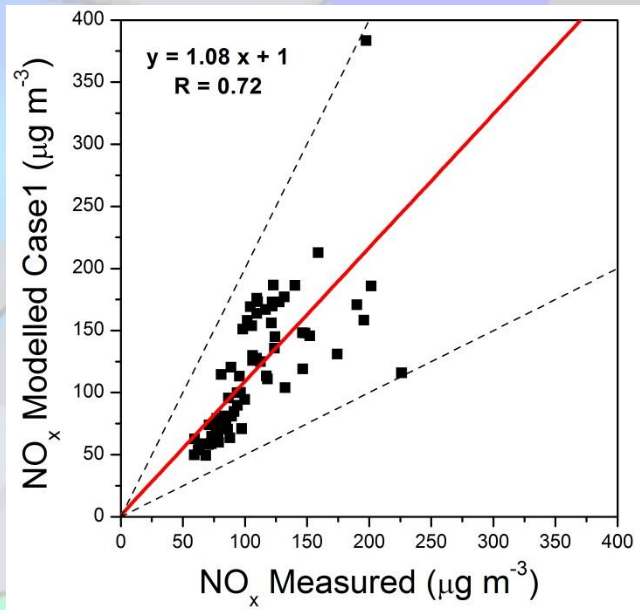
<u>Case 1: Detailed traffic emission model.</u>

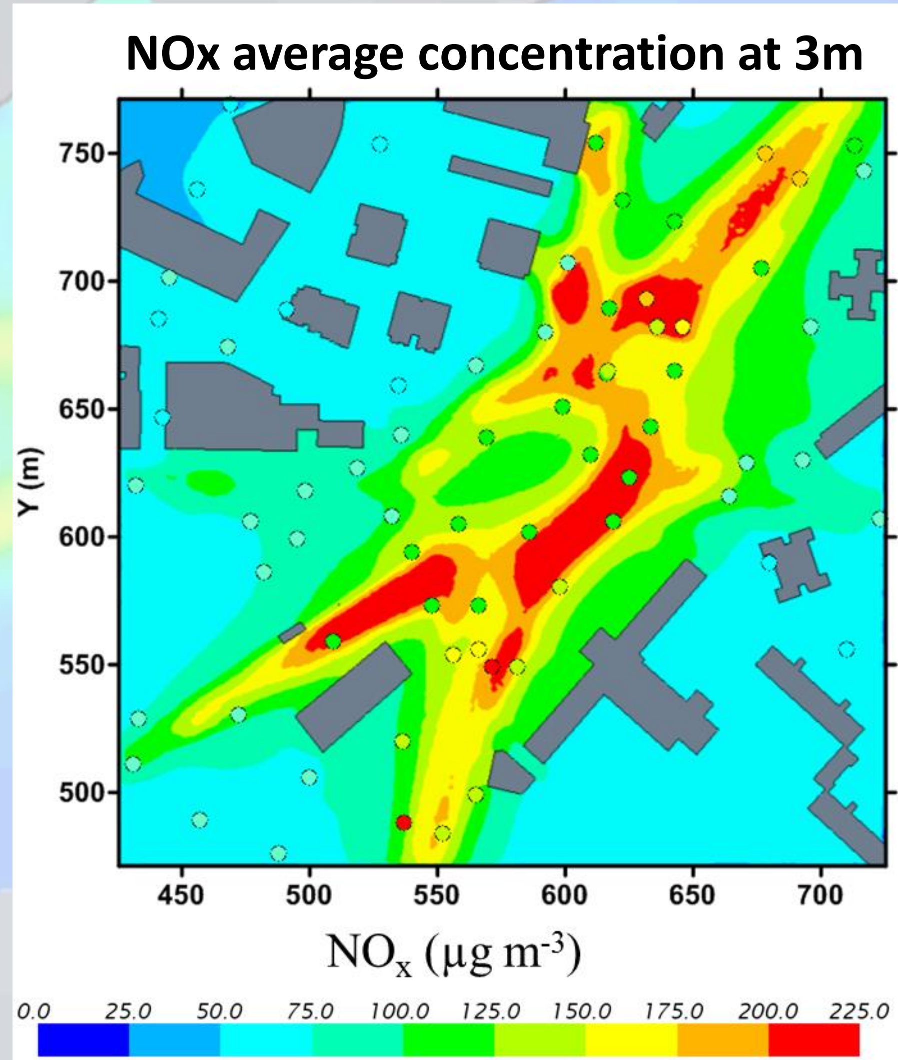




Results: Comparison with Passive Samplers

Case 1: Detailed traffic emission model.



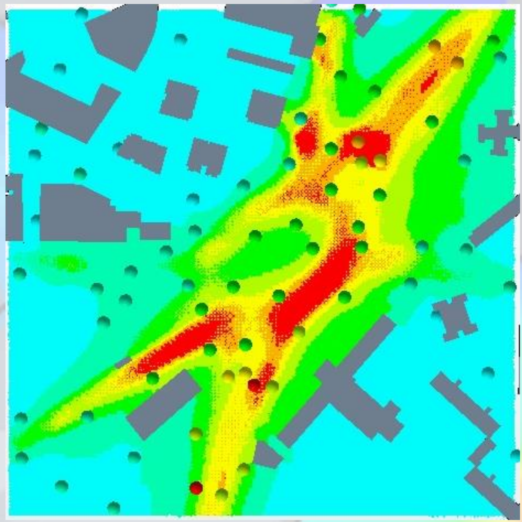


- Slight overestimation

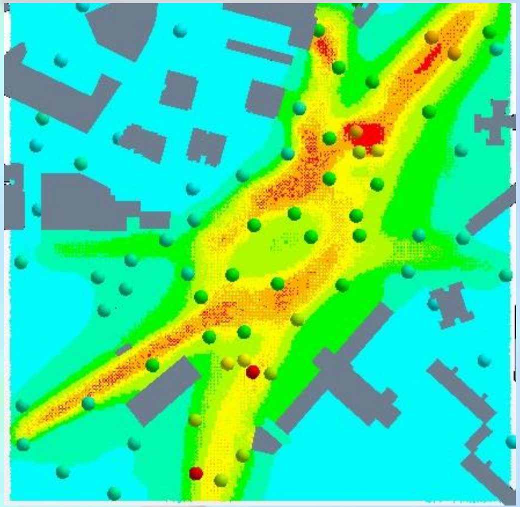
	$C_{mod}[u_*]$	Acceptance Criteria (Goricsan et al., 2011 and Chang et al., 2005)	
NMSE	0.11	<1.5	Good
FB	-0.09	-0.3 <0 <0.3	Good
R	0.72	0.5<R<0.8	Fair

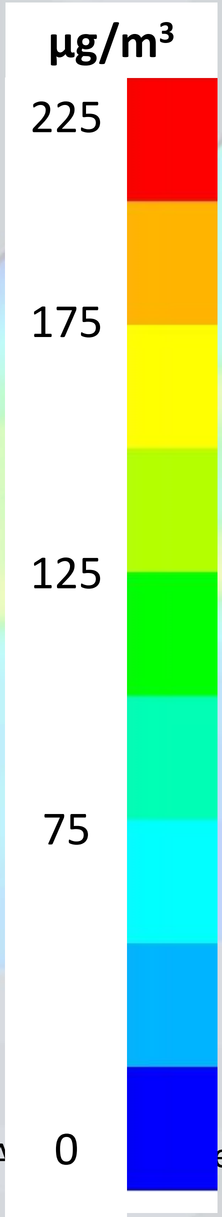
Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

Case 1: Detailed traffic emission model

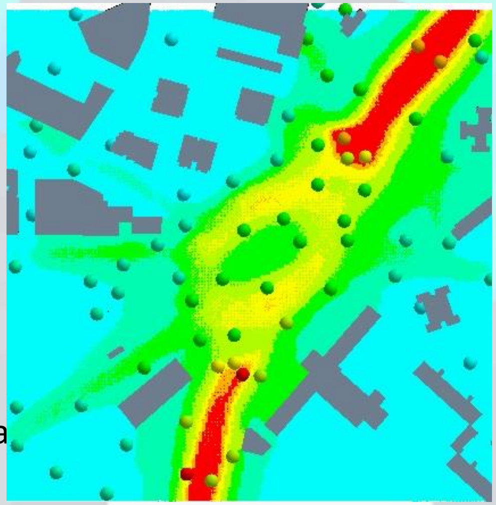


Case 2: Uniform emissions within street

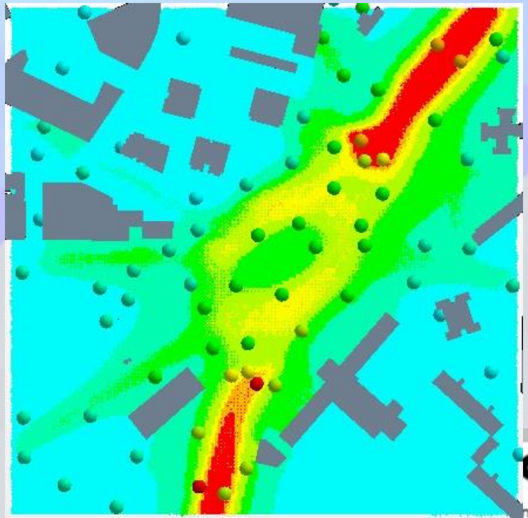




Case 3: Distribution for each scenario using vehicle number

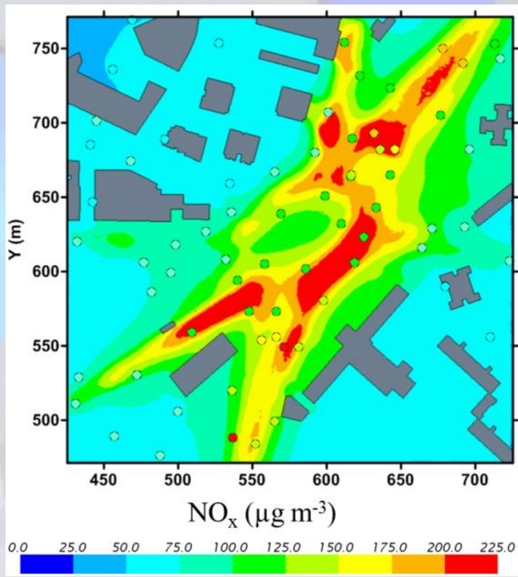


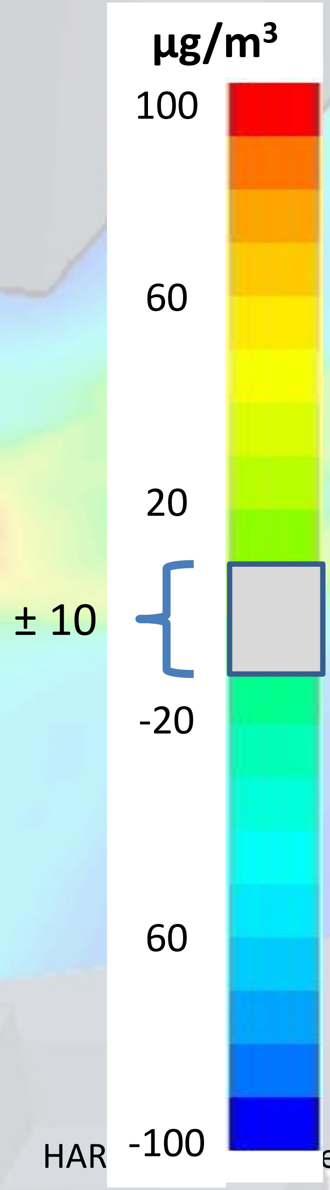
Case 4: Distribution using vehicle number



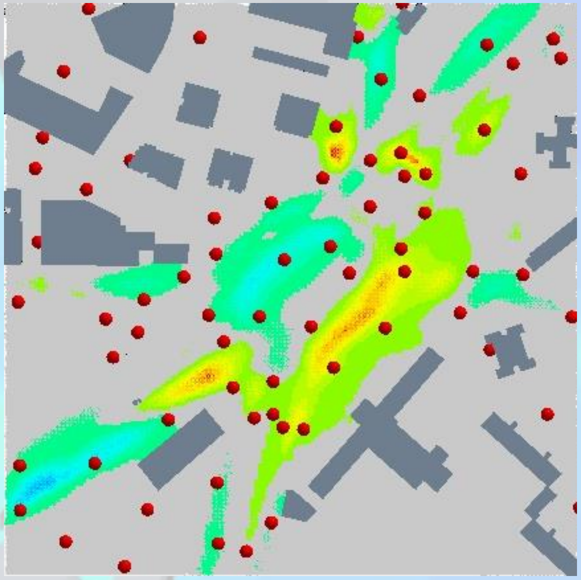
Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

Case 1:

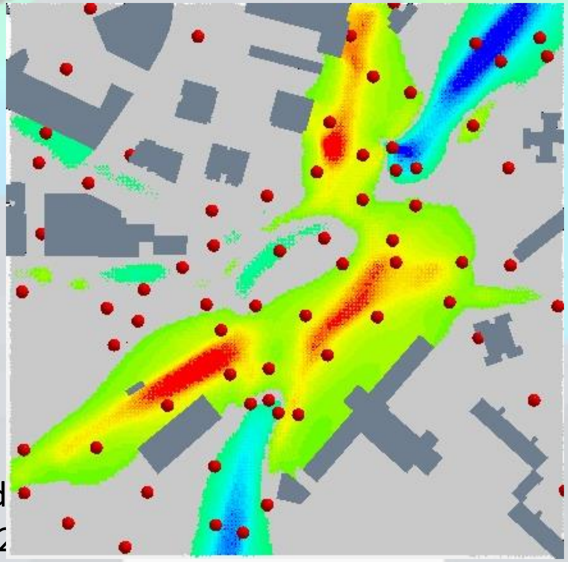




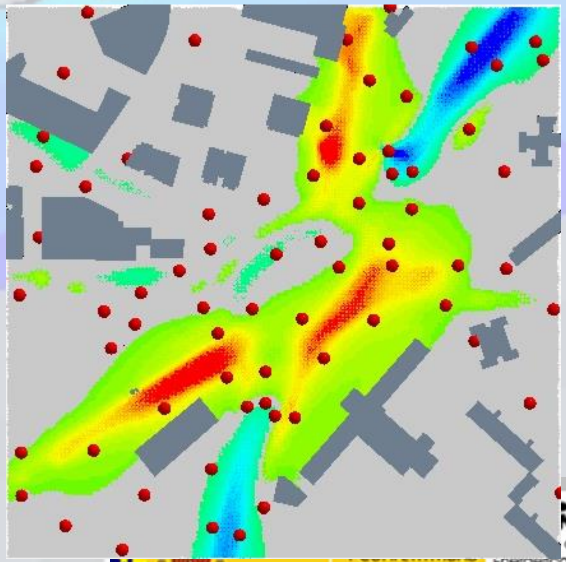
Case 1 – Case2:



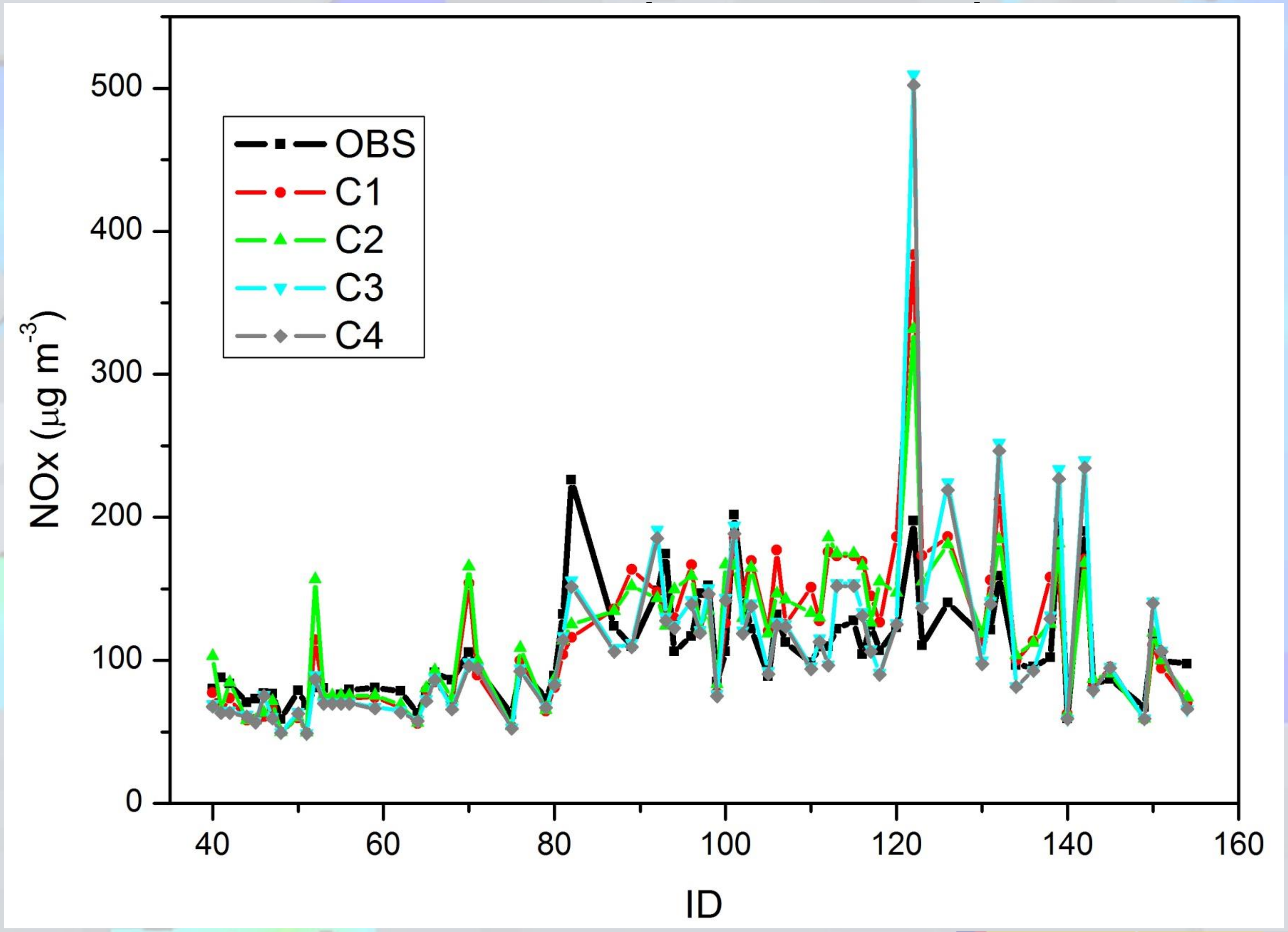
Case 1 - Case3



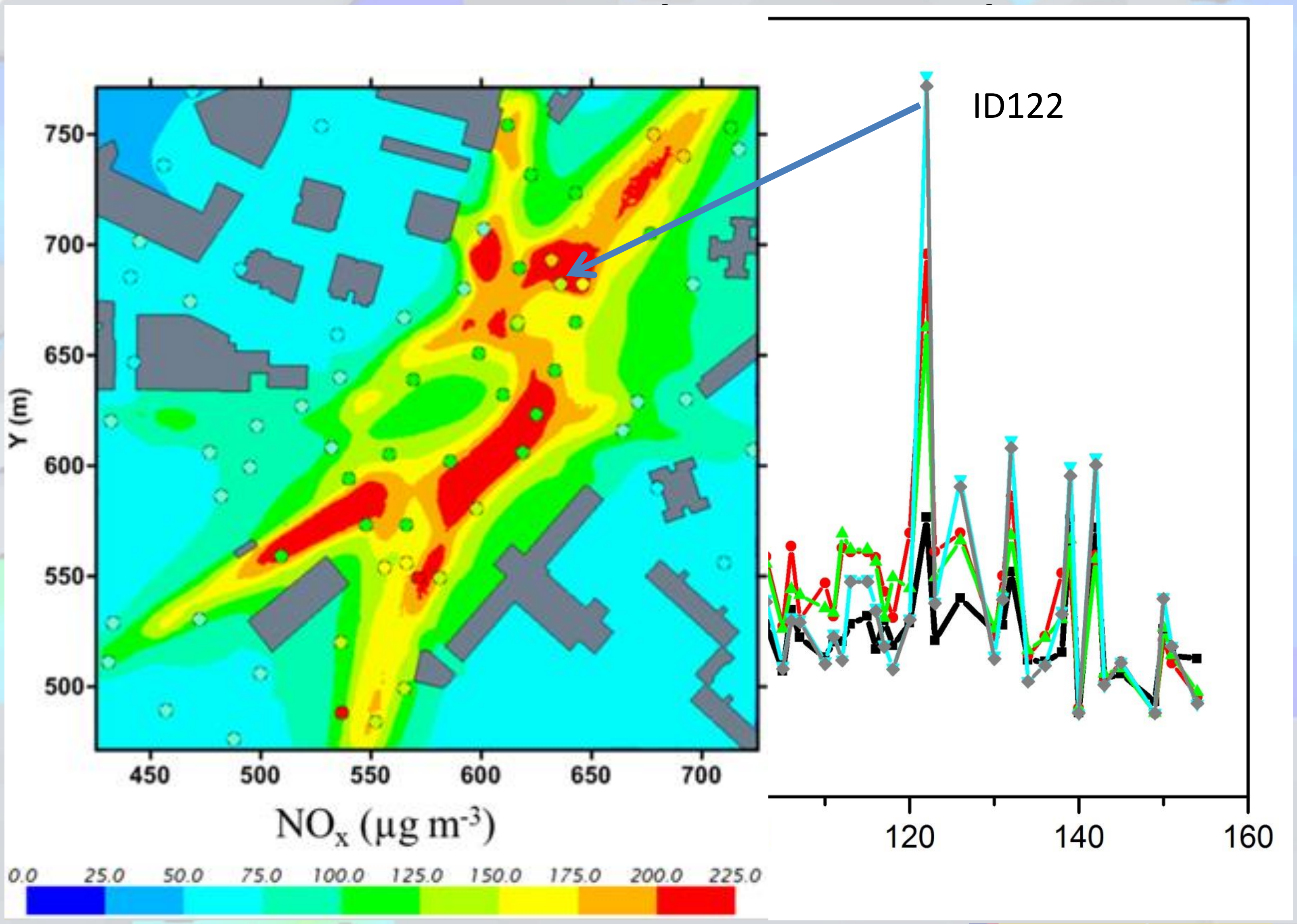
Case 1 – Case4



Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

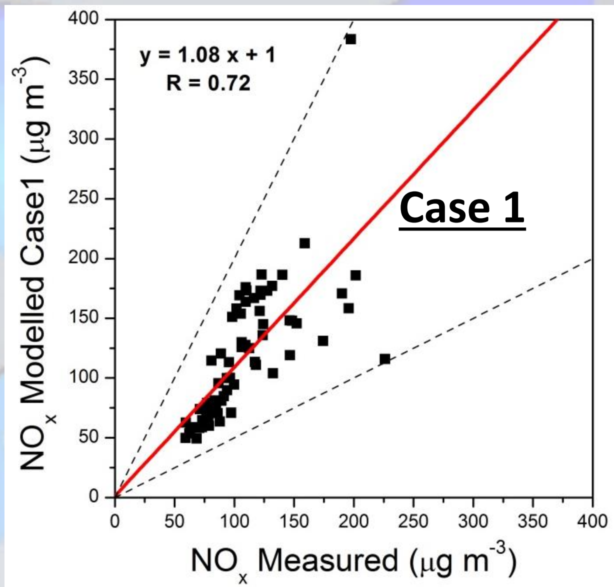


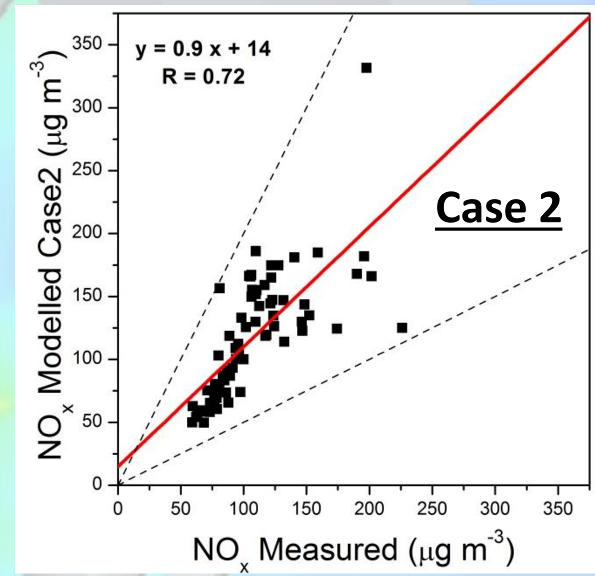
Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

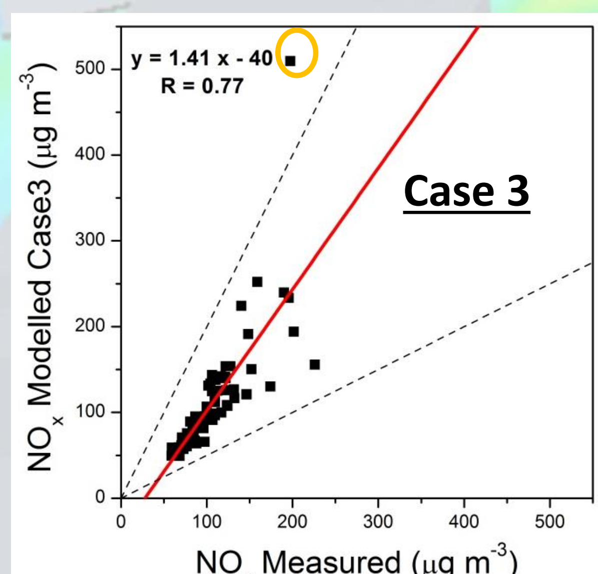


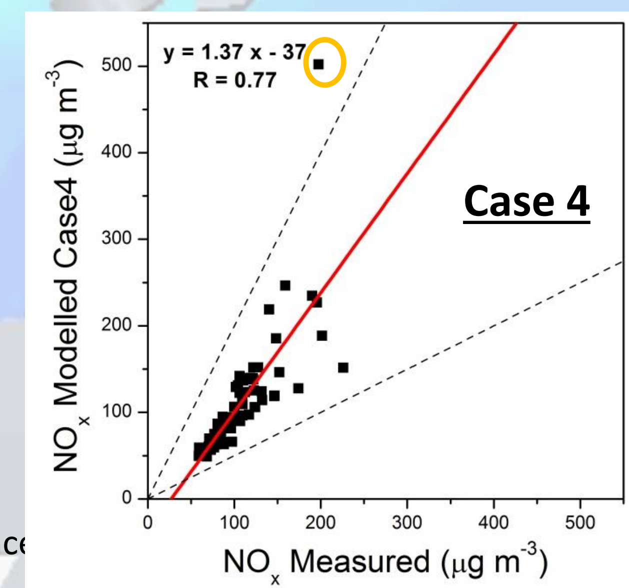
Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

Comparison with passive samplers:



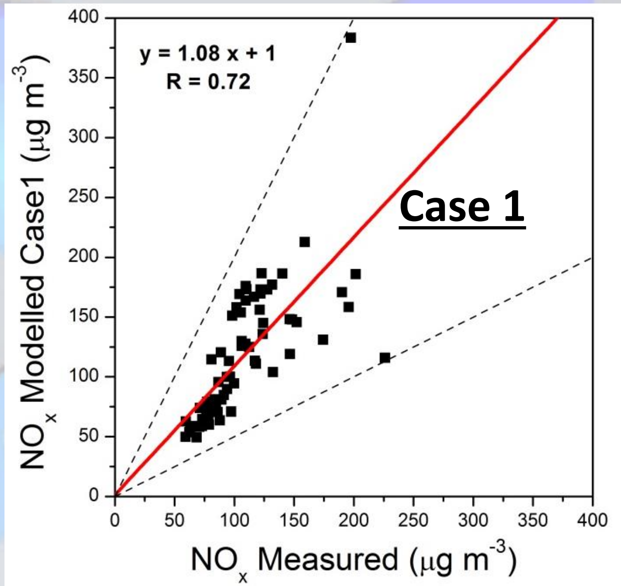


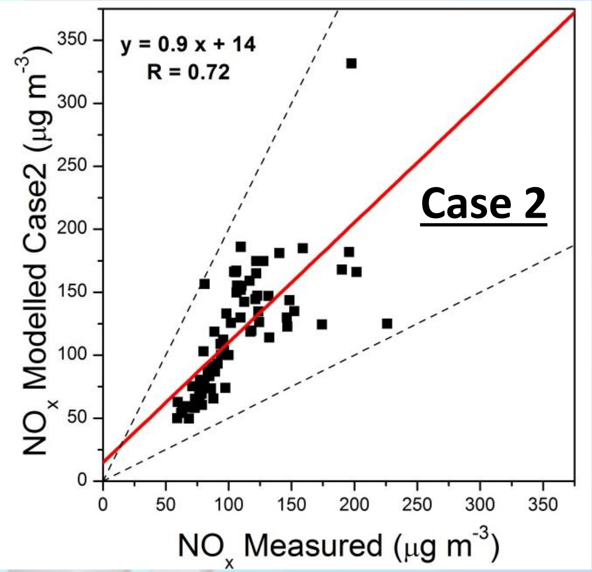


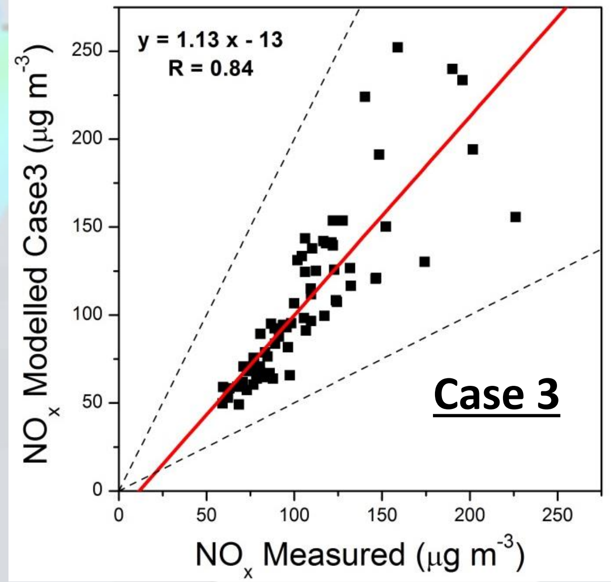


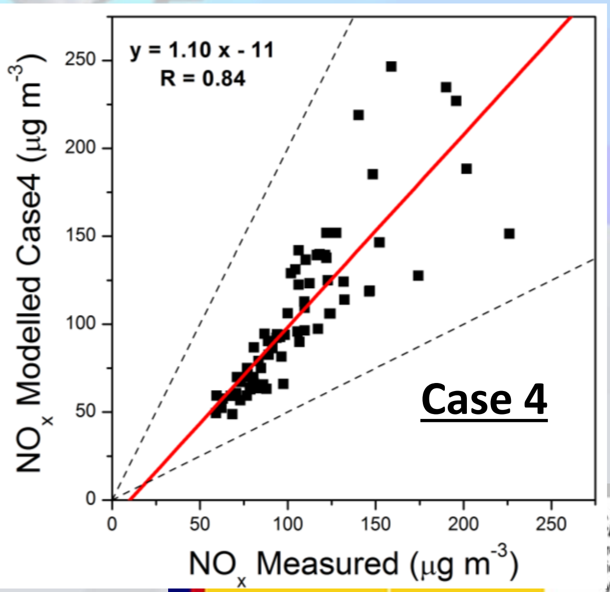
Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

Comparison with passive samplers:









Results: Influence of traffic emission approach on simulated NOx average concentration at 3m

Comparison with passive samplers:

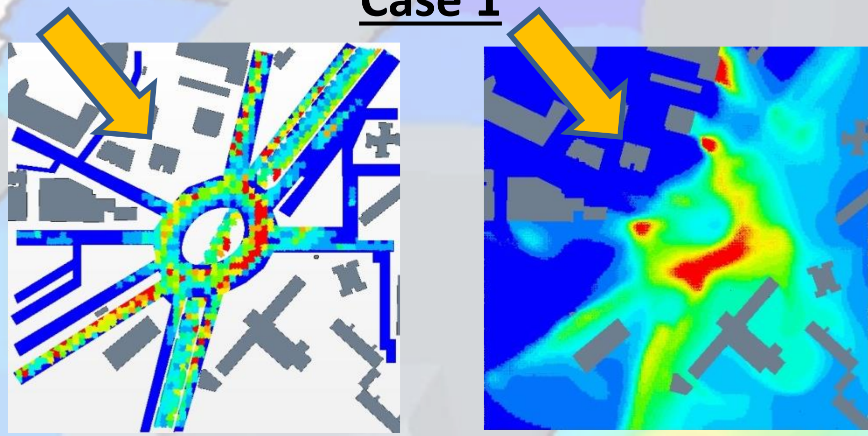
	Case 1	Case 2	Case 3	Case 4	Acceptance Criteria (Goricsan et al., 2011 and Chang et al., 2005)	
NMSE	0.11	0.09	0.14	0.14	<1.5	Good
FB	-0.09	-0.09	-0.05	-0.03	-0.3 <0 <0.3	Good
R	0.72	0.72	0.77	0.77	0.5<R<0.8	Fair

- Similar good agreement and higher differences between cases close to emission zones.
- Turbulence induced by traffic not considered can be responsible of an overestimation in case of detailed emissions. And the re-distribution of these emissions along the street (cases 2, 3 and 4) induces an decrease of this overestimation. Initial dispersion.
- Potential overestimation of emissions due to acceleration and braking of vehicles. Taking into account the measurements from passive samplers, it does not seem that the gradient in the emissions within the same street have to be so strong.
- Cases 3 and 4, in tunnel there is an overestimation of emissions. Emissions proportional to number of vehicles is considered (high number of vehicles but with higher speed in comparison with ones in the roundabout).

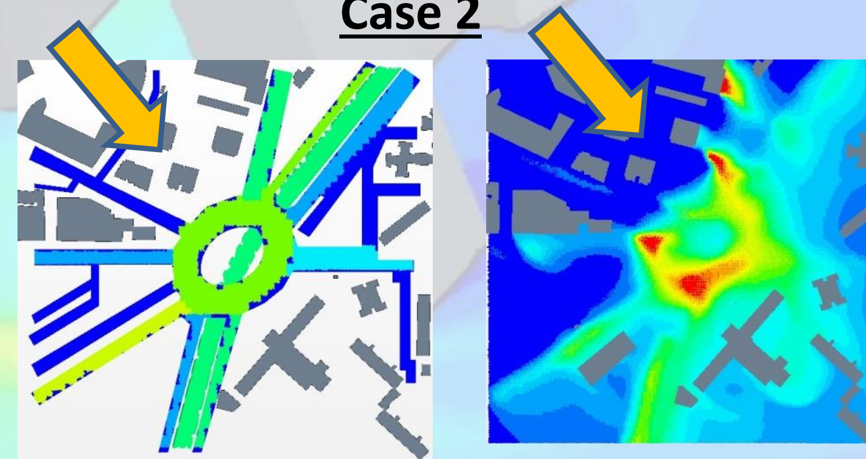
Results: Influence of traffic emission approach on simulated NOx in specific scenarios

Peak Traffic scenarios S2 (8h). Meteorology NW:

Case 1

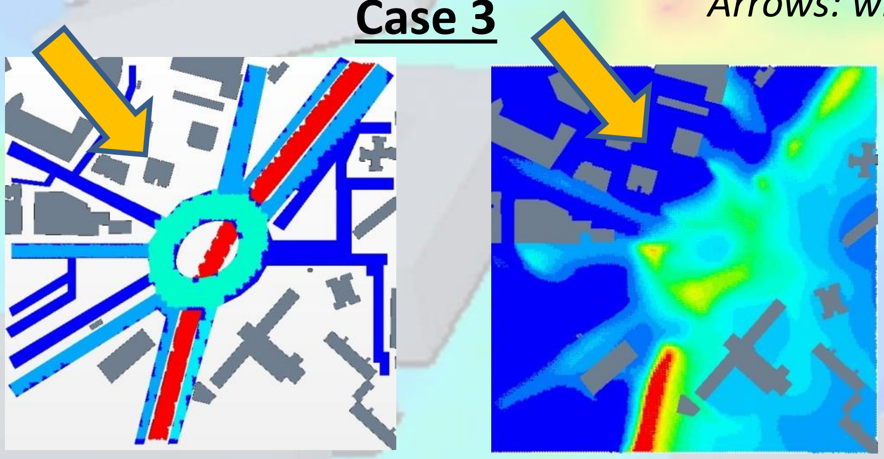


Case 2

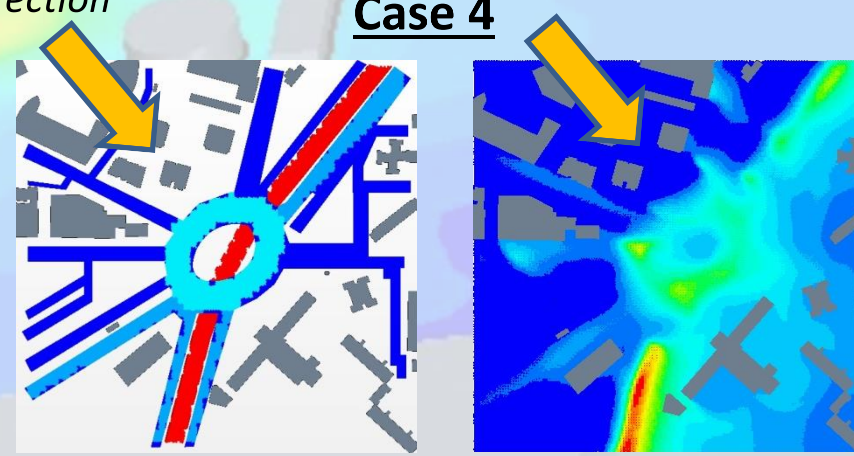


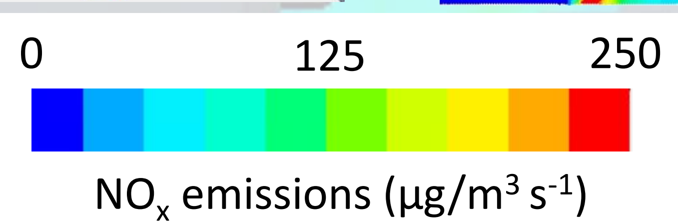
Arrows: wind direction

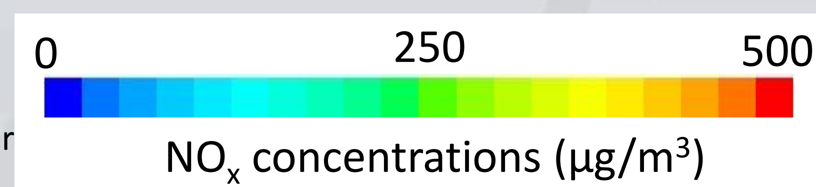
Case 3



Case 4



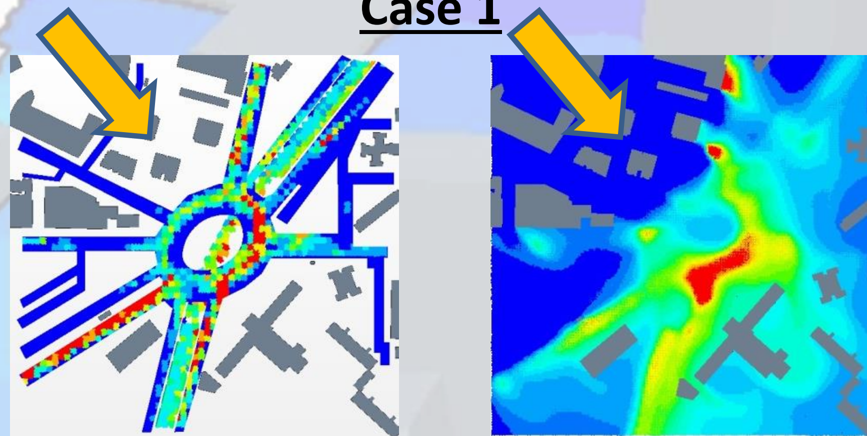




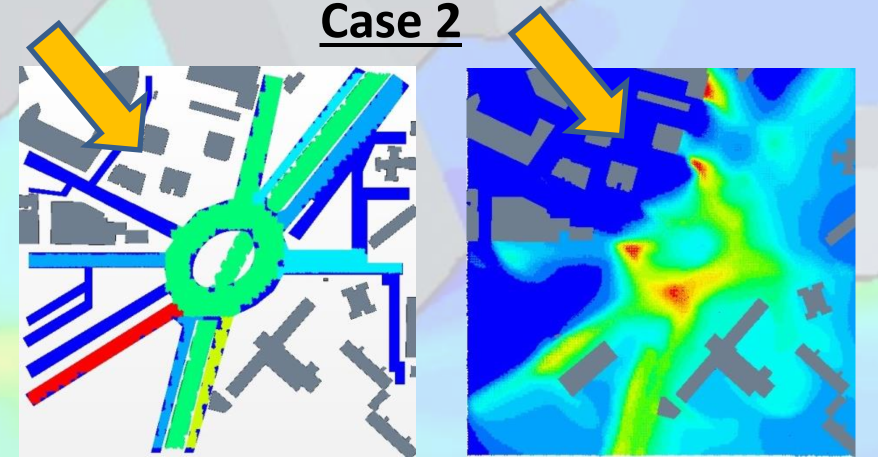
Results: Influence of traffic emission approach on simulated NOx in specific scenarios

Peak Traffic scenarios S3 (14h). Meteorology NW:

Case 1

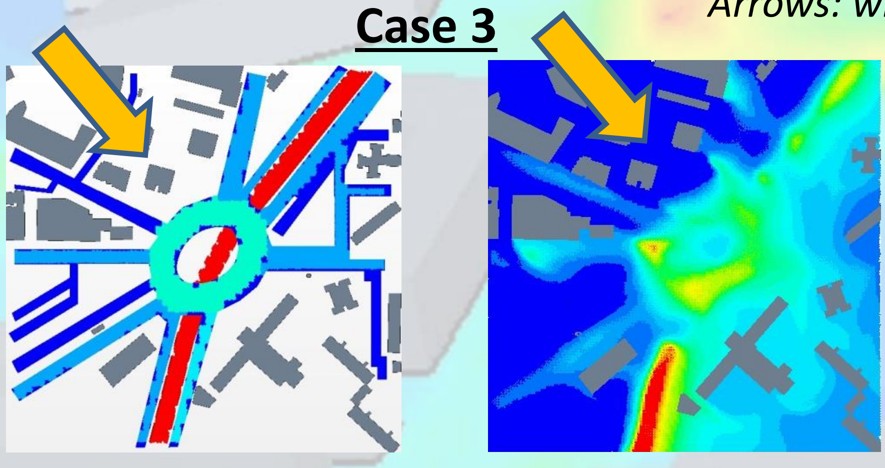


Case 2

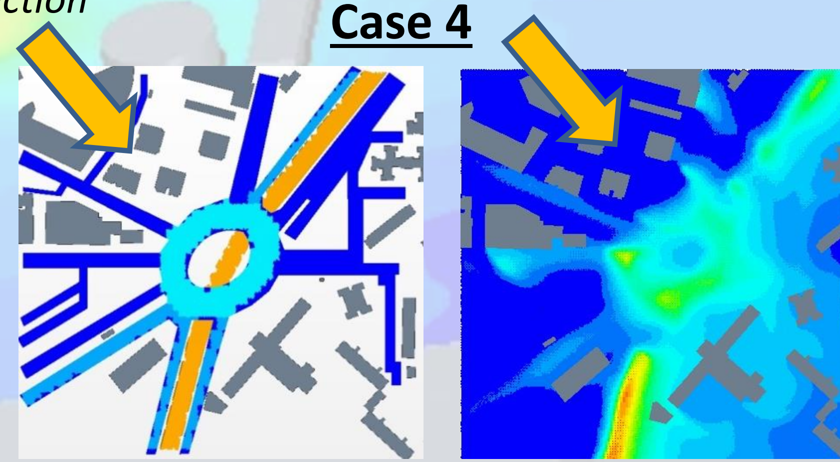


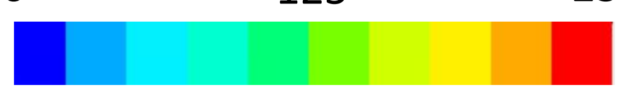
Arrows: wind direction

Case 3



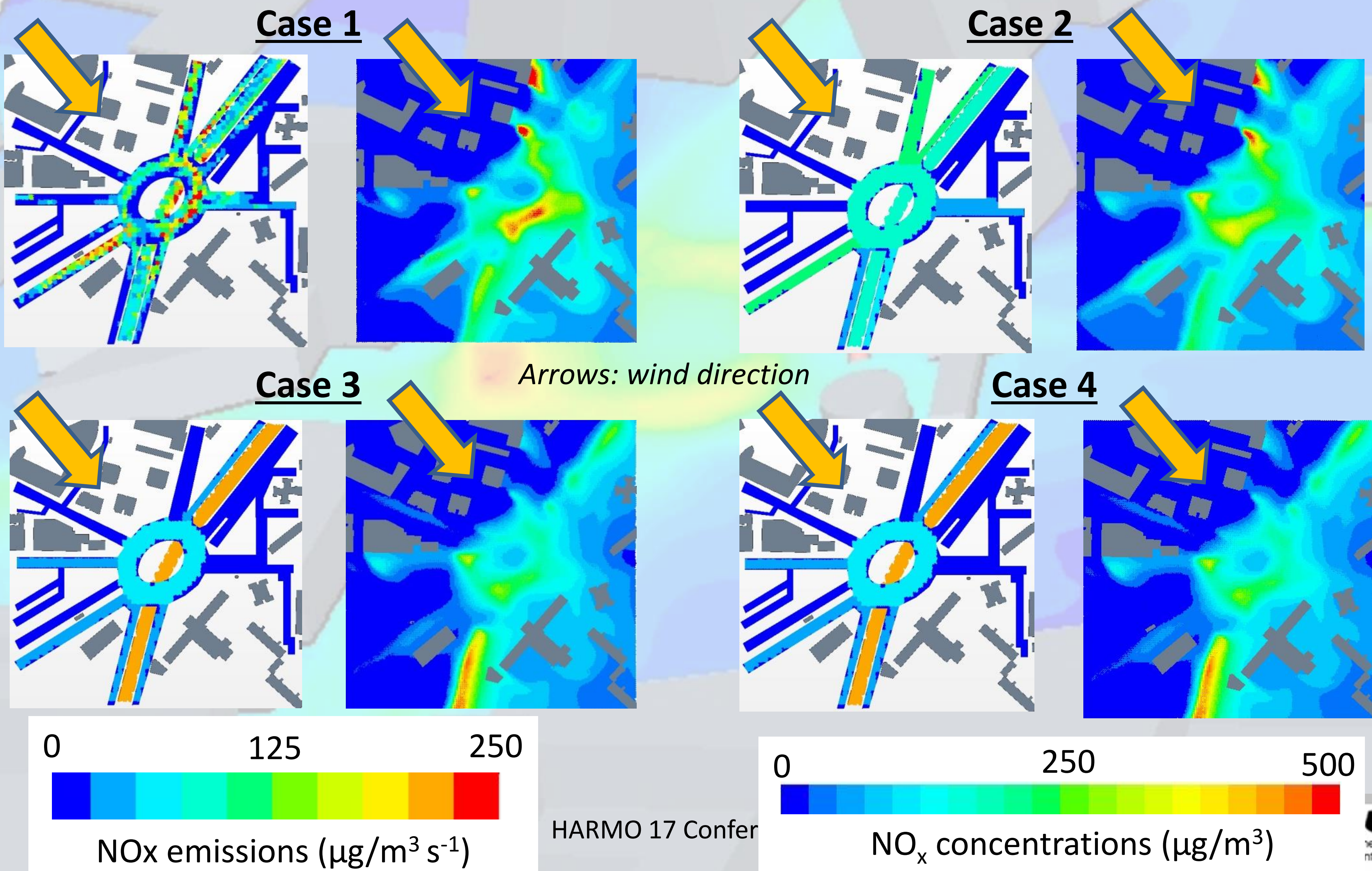
Case 4





Results: Influence of traffic emission approach on simulated NOx in specific scenarios

Peak Traffic scenarios S4 (20h). Meteorology NW:



Conclusions

- The use of different traffic emission approaches can induce strong differences in NOx concentrations in certain zones (specially in the road). But there similarities in the maps due to wind flow.
- Modelling approach is appropriate to obtain high resolution distribution of pollutant concentration within urban areas. General **good agreement with experimental average concentration over 19 days** in **the 4 cases** due to passive samplers are located outside of road (sidewalks, buildings, garden,…)
- Using **detailed traffic emission model**, a slight overestimation in some locations is found:
  - Turbulence induced by vehicles are not taken into account in the CFD (helps to the initial dispersion)
  - Potential overestimation of emissions
- **Case 2, 3 and 4** redistributes the emissions reducing the pollutant released in some zones (and increase in others). The agreement with experimental data is slightly better:
  - Or the dispersion simulated by the CFD is underestimated because some effects have not been taken into account as turbulence due to traffic or thermal effects. And the redistribution uniformly can be considered as a initial dispersion.
  - Or differences in the emissions within the same street are overestimated.
- **Cases 3 and 4**, in tunnel there is an overestimation of concentrations. Emissions proportional to the number of vehicles is considered (high number of vehicles but with higher speed in comparison with ones in the roundabout). Bad agreement close to tunnel but the reduction of emissions in the other streets induces a better fit there.

Thank you for your attention

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