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SMALL SCALE PM DISPERSION MODELING IN THE INNER PART OF AN URBAN AREA

Jiri Pospisil[1], Miroslav Jicha[1], Vladimir Adamec[2], Marcela Sucmanova[2]

[1]Brno University of Technology, Faculty of Mechanical Engineering, Brno, Czech Republic

[2] Transport Research Center, Brno, Czech Republic

INTRODUCTION

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MAIN OBJECTIVE

- Modeling of PM dispersion in urban areas
- Focus on PM dispersion in vicinity of a street canyon with intensive traffic
- Detail involving of moving cars

Small scale modeling → Utilizing of CFD (StarCD) → Detail air velocity field

Input parameters:

- Geometry of the area
- Traffic related parameters
- Meteorological conditions

Traffic related parameters → PM production, additional turbulence, additional momentum

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THE EXPERIMENTAL URBAN AREA

•The studied street canyon is surrounded by urban area.

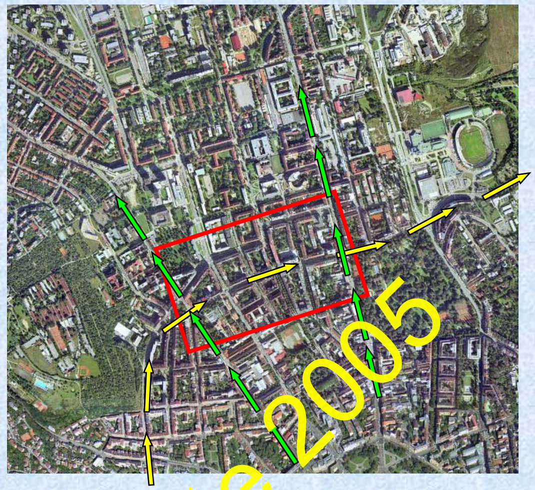
•Tree main city traffic paths are crossing at this area.

Intensive traffic

•Fleet:
cars, buses, trolley-buses

•Traffic: 7:30 – 9:00 AM
3:00 – 5:00 PM

•Two-way traffic runs at all major traffic path at this area.



main traffic paths

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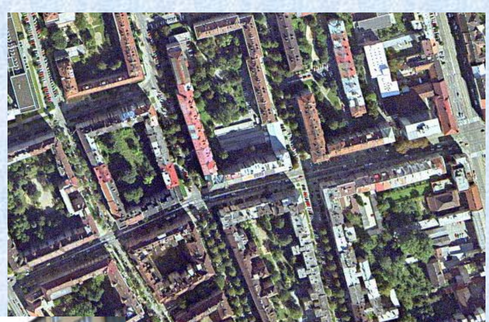
CLOSE LOOK AT THE STREET CANYON

• Six story buildings form street canyon with aspect ratio (H/W) 1.16

• 20 000 cars pass through the street Kotlarska per day

• Intersections controlled by traffic lights

•Two-way traffic in total 4 traffic lanes



CALCULATED DOMAIN

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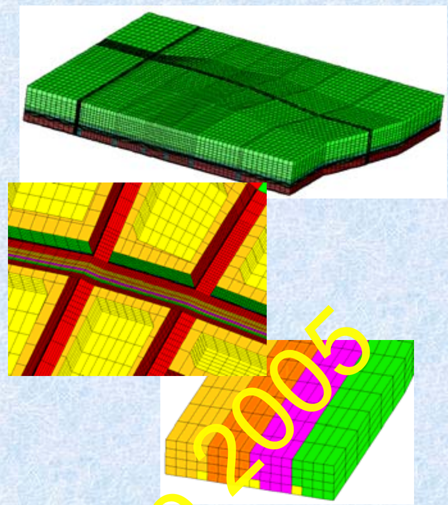
NUMERICAL MODEL

- CFD code StarCD
- The numerical model consist of 1 mil control volumes
- Fine mesh is used at bottom part of the model
- 200m high air layer is modeled above building roofs
- The perpendicular street canyons are modeled without traffic
- Four traffic lanes are modeled on the road surface.
- Size of control volumes passed by cars is 0.5x0.5x1m



MODELING

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CALCULATION SETTING

PARTICLES
- PASSIVE SCALAR APPROACH
- EULERIAN – LAGRANGIAN APPROACH

TRAFFIC
- MOVING CARS TAKEN INTO ACCOUNT
- WITHOUT MOVING CARS

BOUNDARY CONDITIONS
- VELOCITY LAYER
- VELOCITY PROFILE

MODEL OF TURBULENCE
- k-ε RNG
- LES

- TEMPERATURE
- HUMIDITY

EULERIAN – LAGRANGIAN APPROACH:

- TURBULENT DISPERSION: ON / OFF
- PARTICLE-WALL INTERACTION: REBOUND / DEPOSITION
- PARTICLE LIFETIME: 3600s / 1200s / 600s
- PARTICLE SHAPE: SPHERE / FIBRE
- PARTICLE DENSITY: 300 kg/m^3
- PARTICLE SIZE: PM10

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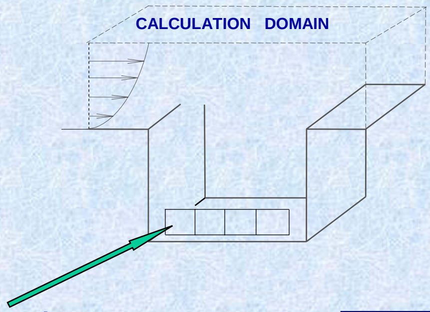
MATHEMATIC DESCRIPTION

INFLUENCE OF CAR MOTION



A model based on Eulerian-Lagrangian approach to moving objects has been developed and integrated into commercial CFD code StarCD.

Additional momentum

Drag force taken into account

$$m_p \frac{d\vec{U}_p}{dt} = \frac{1}{2}\rho_\infty C_D A_p \left|\vec{U}_\infty - \vec{U}_p\right| \left(\vec{U}_\infty - \vec{U}_p\right)$$

Additional turbulence

k-ε RNG model of turbulence with additional source term to k-equation

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho u_i k) = \frac{\partial}{\partial x_i}\left(\frac{\mu_{ef}}{\sigma_k}\frac{\partial k}{\partial x_i}\right) + \mu_t P - \rho\varepsilon + S_k$$

$$S_k = C_c \rho (U_{car} - U)^2 Q_{car}$$

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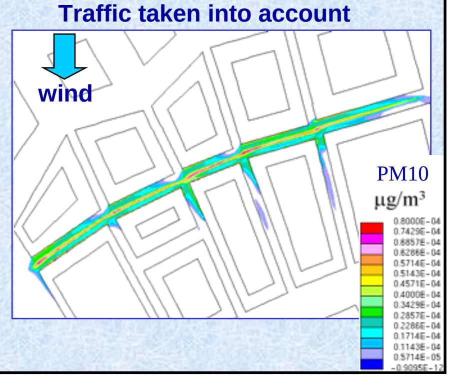
RESULTS

CAR MOTION INFLUENCE ON PM CONCENTRATION FIELDS

- Sections led 1.5m above road surface
- Turbulent dispersion ON
- Wind direction: north
- Wind velocity: 3.9 m/s
- k-ε RNG model of turbulence
- Particle lifetime 300 s
- Eulerian–Lagrangian approach

Without inclusion of traffic

Traffic taken into account



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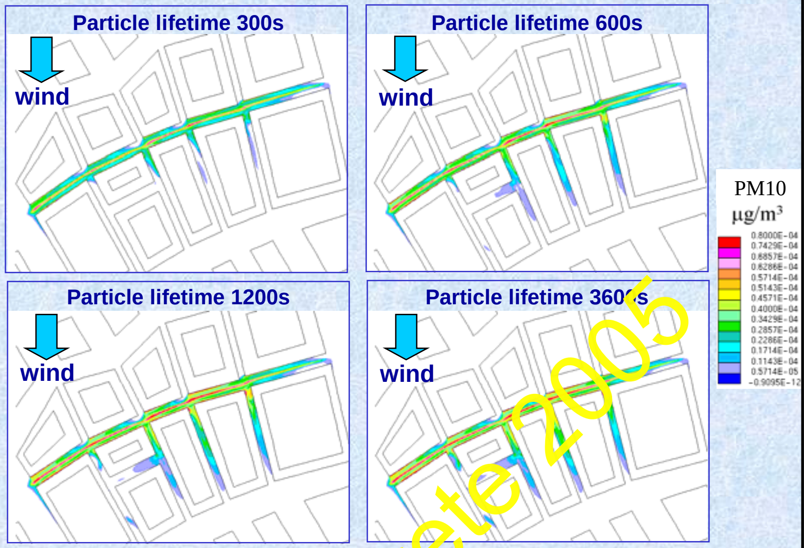
INFLUENCE OF "PARTICLE LIFETIME"

- Sections led 1.5m above road surface
- Influence of moving cars taken into account



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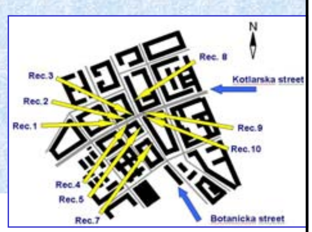
INFLUENCE OF "PARTICLE LIFETIME"

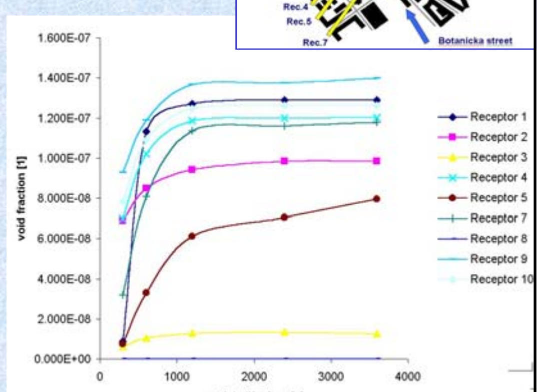
$$\text{void fraction} = \frac{\text{volume of particles in the control volume}}{\text{volume of the control volume}}$$



Void fraction values intensively rise up to particle lifetime 1200s.

Another increasing of the particle lifetime parameter doesn't change significantly void fraction values.

Following calculations were carried out for particle lifetime 3600s.



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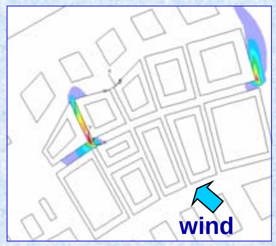
Assessment of PM10 sources

Total PM concentration = cars + local sources + local background

Contribution related with traffic

Contribution from large intersections



Local background concentration

- Sections led 1.5m above road surface
- Influence of moving cars taken into account

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Assessment of PM10 sources

PM10 concentration = cars + local sources + local background

car exhaust + other related with car

PM10 produced from car exhaust pipes – as function of car speed, type of car, road inclination, …

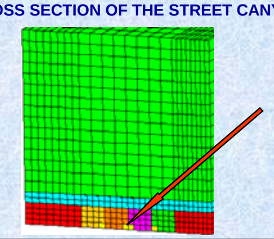
Diesel engine ……….1/3 of car fleet

This PM10 contribution is presumed at same production rate as the car exhaust pipes production obtained for horizontal road

The numerical model doesn't involve deposition of particles.

We presumed an ideal rebound of particles on all walls.

CROSS SECTION OF THE STREET CANYON



Sources of PM10 set as a line source between inner traffic lanes, 0.5m above road surface.

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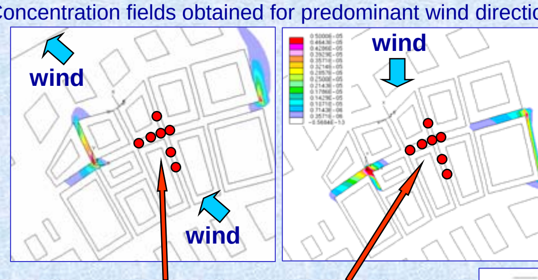
Assessment of PM10 sources

PM10 concentration = cars + **local sources** + local background

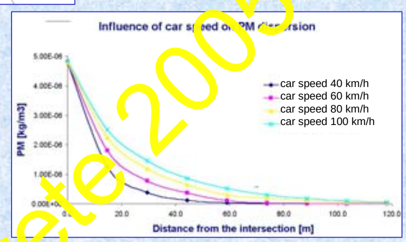
• influence of large intersections

Concentration fields obtained for predominant wind directions



Positions of measurement

The intersections don't influence PM concentration at positions of measurement for predominant wind directions.



The influence of the local source is generally limited by the first street canyon interruption.

Intensity of washing out process depends on the wind direction and the local geometry of the area.

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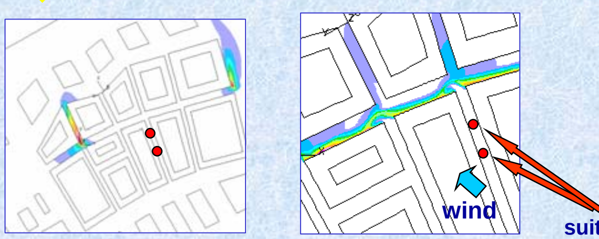
Assessment of PM10 sources

PM10 concentration = cars + local sources + **local background**

• Local background concentration of PM10 was obtained from measurement



suitable measuring points

The measurement carried out at positions:

- **at close vicinity of the studied street canyon**
- **no affected by PM originating from the studied street canyon**
- **no affected by local sources**

NUMERICAL PREDICTION INPUT PARAMETERS

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Parameters used for numerical prediction

Date	Traffic rate [cars/hour.lane]	Sum of PM contributions [µg/m.s]	Wind direction [°]	Wind velocity at height 25m [m/s]
11 October 2004	383	52.7	0	3.38
12 October 2004	380	53.1	67	6.01
13 October 2004	384	42.1	132	5.95
13 October 2004 NIGHT	26	2.4	136	5.44
14 October 2004	362	38.1	143	5.82

RESULTS

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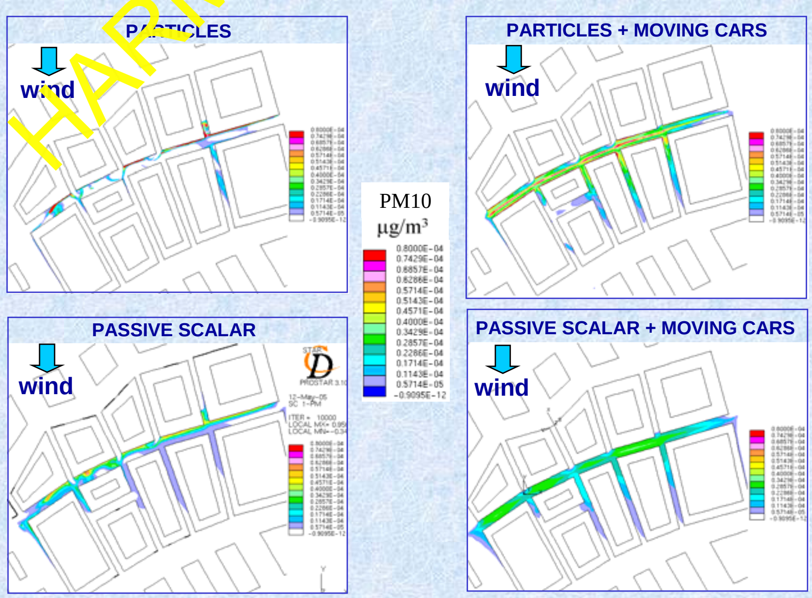
11th October 2004



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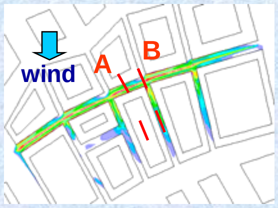
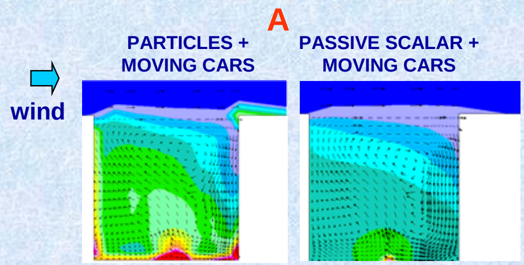
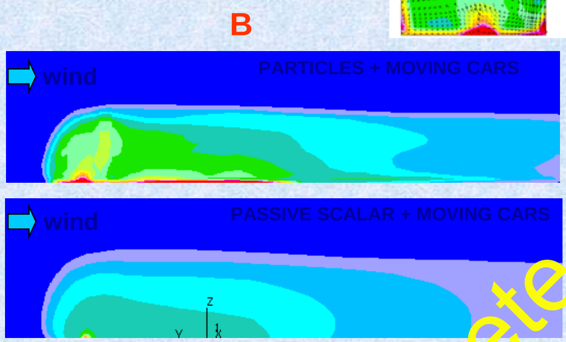
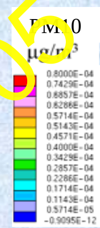
RESULTS

COMPARISON OF PASSIVE SCALAR APPROACH AND EULERIAN – LAGRANGIAN APPROACH









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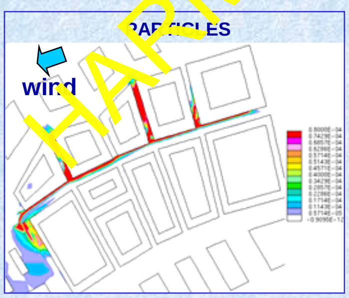
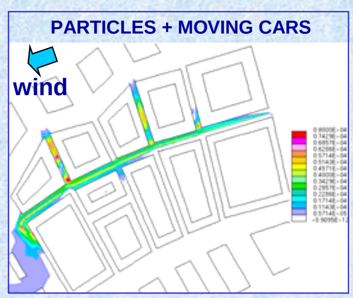
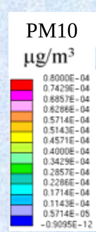
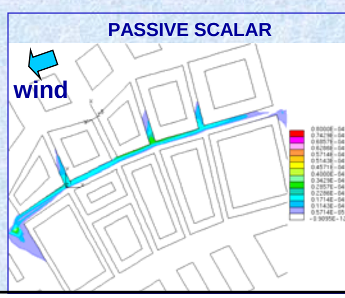
RESULTS

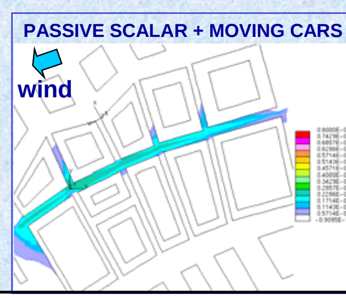
12th October 2004











RESULTS

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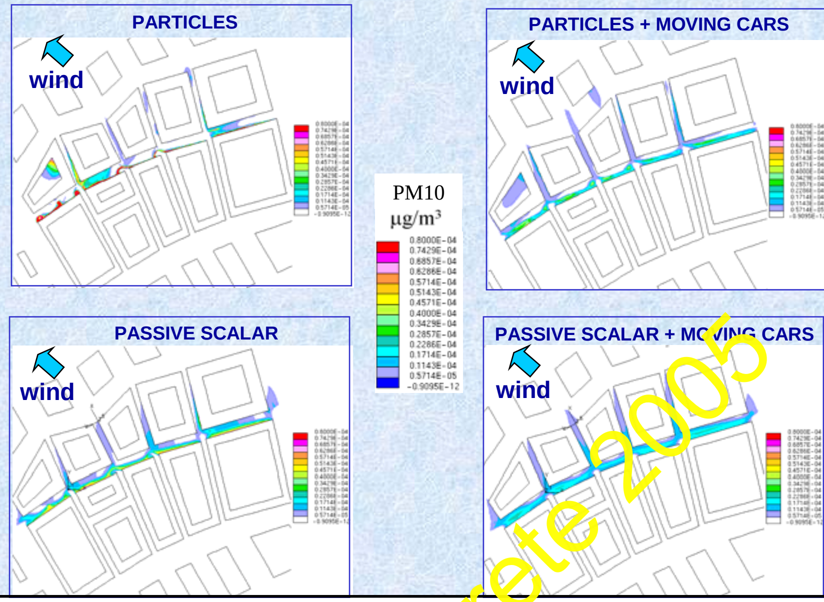
13th October 2004



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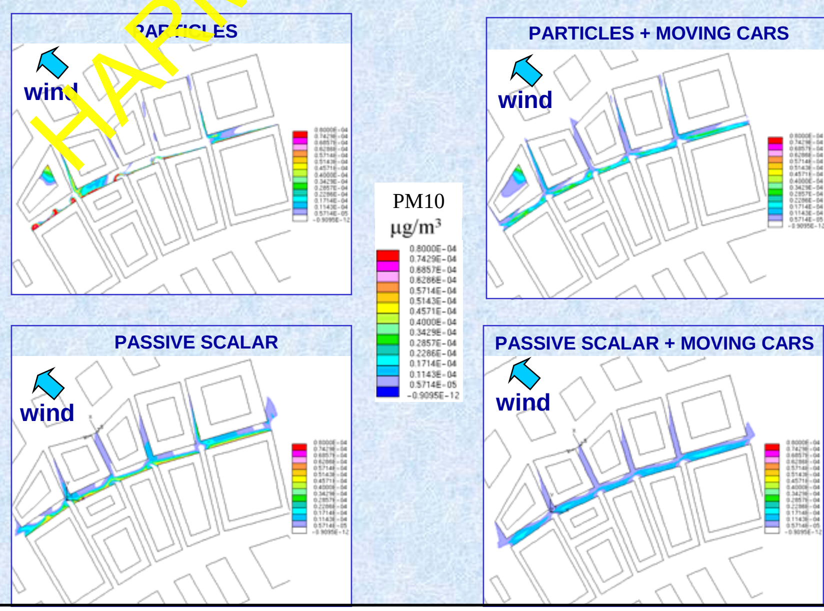
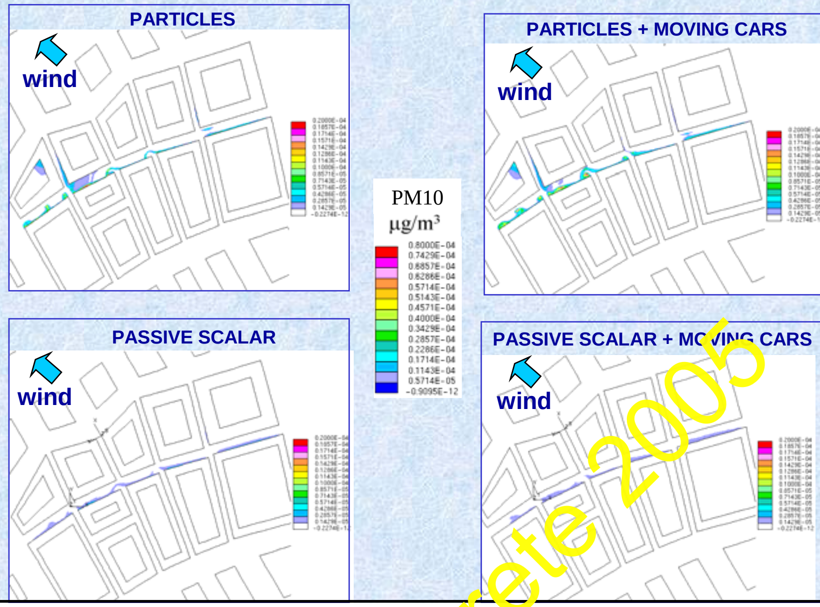
14th October 2004



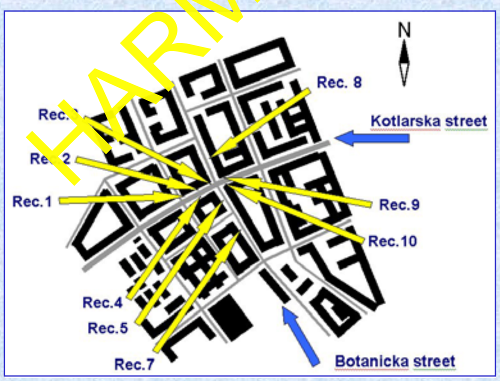
RESULTS

13th October 2004 - NIGHT



MEASUREMENT

RECEPTORS CONFIGURATION



- Ten receptors were used for comparison of CFD prediction with measurement.
- The receptors were located along the main street and in perpendicular street canyons.

- Receptor locations are 1.5 m above road surfaces.
- Measurement carried out during four working days in October 2004.
- Concentrations of PM10 were measured at terms 7:00-8:00, 8:00-9:00, 9:00-10:00, 15:00-17:00.
- Measuring periods correspond with top traffic periods.

PREDICTION AND MEASUREMENT

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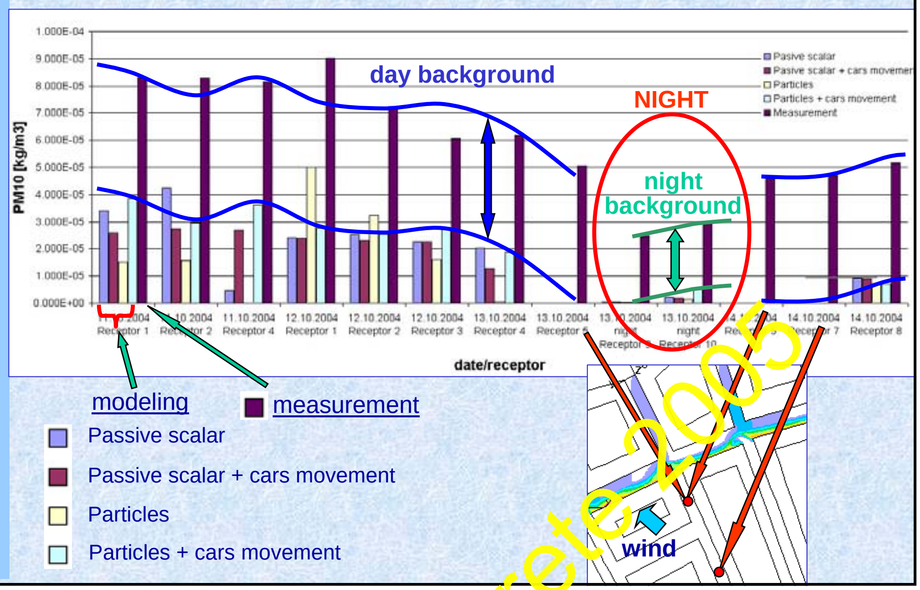
Comparison of prediction with measurement



PREDICTION AND MEASUREMENT

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CONCLUSIONS

In this paper authors compared two different ways of PM dispersion modeling in urban areas, namely Eulerian – Lagrangian approach and Passive scalar approach.

Eulerian – Lagrangian approach is more realistic and enables a more accurate description of the interaction between continuous phase and particles.

Passive scalar approach uses more simplifications but calculation is faster in comparison with Eulerian – Lagrangian approach.

The obtained results show significant influence of traffic dynamic on predicted PM concentration fields.