STREET CANYON MODEL INTERCOMPARISON EXERCISE AND VALIDATION STUDY

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Street Canyon Model Intercomparison Exercise - Concept

Objectives

(i) Assess air pollution from traffic via the application of OSPM (Hertel and Berkowicz, 1990), SEP-SCAM (Papathanassiou et al., 2005) and MIMO (Ehrhard et al., 2000) to specific street canyons in three European cities.

(ii) Evaluate the results using data from monitoring stations located in the considered domains in order to asses the effectiveness of the models in street canyon applications.

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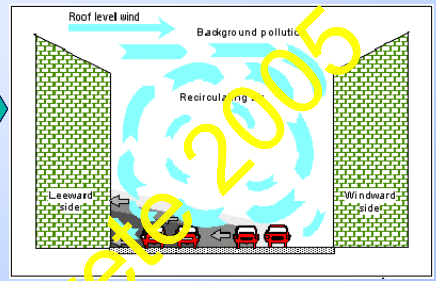
The Operational Street Pollution Model (OSPM) - Short Description

- OSPM is based on similar principles as the CPB model (Yamartino and Wiegand, 1986) and makes use of a simplified flow and dispersion parameterization in a street canyon.
- Concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculation part of the pollutants in the street.

Illustration of the basic concepts in the model



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The Operational Street Pollution Model (OSPM) – Basic assumptions

- The emission field is treated as a number of infinitesimal line sources aligned perpendicular to the wind direction at street level.
- The direct contribution is computed by the integration of the Gaussian plume equation along the wind path at street level.
- The ventilation takes place through the edges of the canyon vortex which considered to have the shape of a trapeze.
- For the recirculation contribution the inflow rate of the pollutants into the recirculation vortex is considered to be equal to the outflow rate.
- The total concentration is made up of the direct and recirculation contributions.

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The Semi-Empirical Parameterized Street Canyon Model (SEP-SCAM) - Short Description

- SEP-SCAM is based on concepts and techniques previously used for the development of the OSPM, CPB and STREET (Johnson et al, 1973) models.
- The model produces information on two-dimensional horizontal distribution of concentrations in street canyons based on new empirically derived concepts and techniques.
- For the direct contribution the model makes use of a combination of a plume model and a a revised empirical algorithm (Johnson et al, 1971).
- For the recirculation part of the pollutants in the street a simple box model is used.

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The Semi-Empirical Parameterized Street Canyon Model (SEP-SCAM) - Short Description

- The distribution of concentrations when an intersection is present is computed applying an empirical formula.
- The total concentration at each point along both sides of the canyon is made up of the direct and recirculation contributions.
- The concentrations across street canyon are calculated with an algorithm based on a very simplified parameterization of flow and dispersion conditions.
- Only the fastest chemical reactions of nitrogen oxides (NO_x) are taken into consideration due to the relatively short time scale of the street canyon.

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SEP-SCAM - Direct contribution

- The emission field is primary treated following a concept similar to OSPM. Then the contribution is computed by the integration of the Gaussian plume equation as it was previously mentioned.
- Alternatively the emission field can be considered as a specific number of line sources (traffic lanes) at street level aligned along the canyon axis.
- An empirical algorithm is applied in order to estimate an additional portion of concentration with respect to the distance, x_i, from each traffic lane.
- All the related dispersion parameters are extracted considering the wind speed and direction at street level, the traffic produced turbulence and the vertical turbulent velocity fluctuation.

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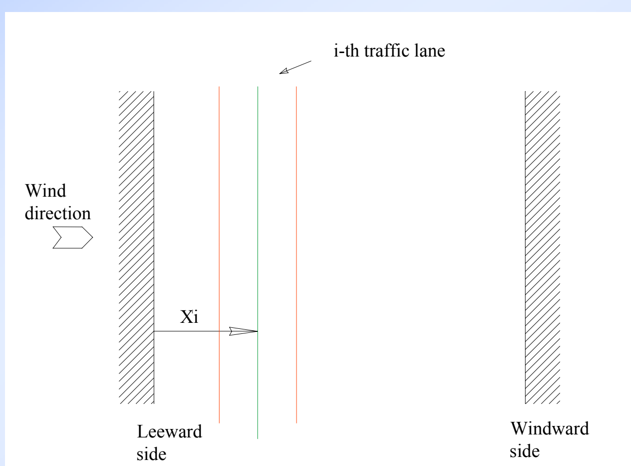
SEP-SCAM - Direct contribution

Illustration of traffic emissions distribution in a street canyon considering each traffic lane as a discrete line source



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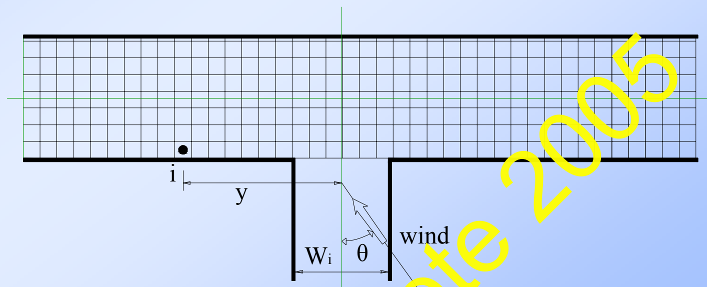
SEP-SCAM - Intersection parameterization

- In the presence of an intersection a novel approach is considered by which the extension of the recirculation zone is weighted along the leeward side by a factor calculated by an empirical formula.

- The aforementioned factor depends on speed and orientation, θ, of the wind, the distance, y, from the middle of the intersection and the geometrical characteristics of the intersection.



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SEP-SCAM - Distribution across the canyon

- The distribution of concentrations across the street canyon is approximated by a simplified formula which consists of an aggregation of two terms.

- The first term accounts for the case that a well established vortex flow regime governs the concentrations distribution while the second term holds when this distribution is governed by a non vortex flow regime.

- Both terms are computed across the canyon depending on:

  - the geometry of the canyon, the wind speed and direction at roof level and the vertical turbulent velocity fluctuation at street level.

  - the fraction of recirculated pollutants and the residence time of pollutants within the canyon.

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MIMO : general description

- MIMO is a 3D Reynolds Averaged Navier-Stokes (RANS) CFD model for street canyon applications.
- Simulates wind field and dispersion of pollutants in and around complex urban geometries (Street canyons, rows of buildings and streets).
- Solves the equations for mass continuity, momentum and energy.
- Ability to simulate the effects of heat transfer on the developing flow and the corresponding dispersion fields.
- Options for various turbulence models including κ-ω.
- It makes use of non-equidistant structured grid (hexa).

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MIMO : general description

MIMO has been evaluated & validated during numerous projects like the EU project "TRAPOS":

- By intercomparison of numerical results obtained with other models for a square street canyon (W/H = 1).
- By intercomparison of numerical results for the flow field around a single cube approximating an isolated building, obtained with other models.
- Comparison with filed measurements from a real street in Hanover, Germany (Göttinger Strasse).

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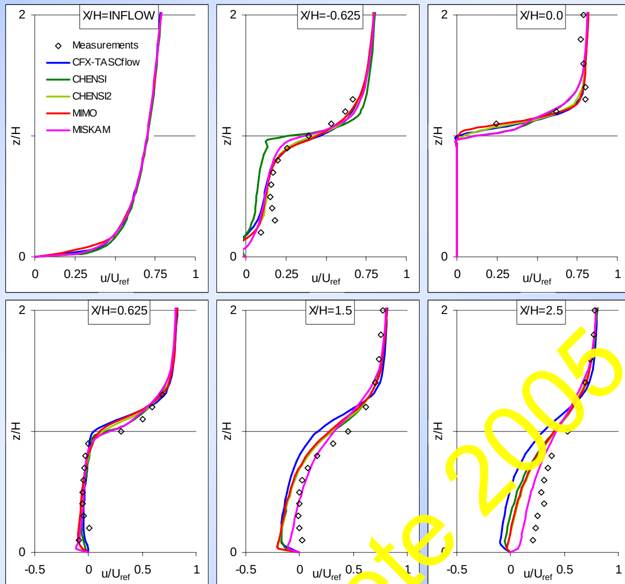
MIMO : general description

Example: Flow around a wall mounted cube



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Models applications

- Models were applied to specific street canyons in three European cities:
  - Berlin (Frankfurter Allee) for the year 2002
  - Stockholm (Hornsgatan) for the year 2000
  - London (Marylebone Rd) for the year 2000
- Emission input data computed with COPERT III and the local traffic data.
- The meteorological and concentration data were available from stations located within the considered domain or nearby locations.
- Simulation results for street level concentrations of NO_x, $PM_{2.5}$ and PM_{10}. extracted
- Technique followed with MIMO from Ketzel et al.

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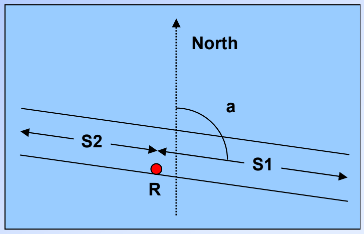
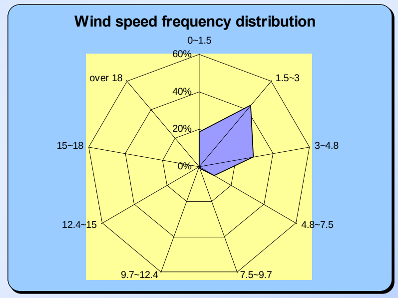
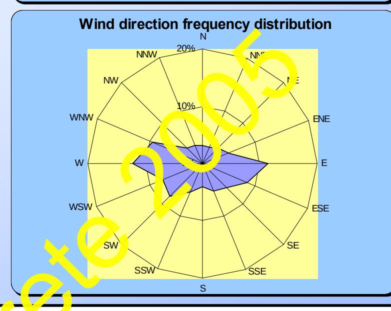
Street canyon configuration – Meteorological data analysis for the case of Berlin



CANYON CHARACTERISTICS	
Height of the canyon	21 m
Width of the canyon	41.6 m
Aspect ratio	0.51
Angle a	98º
Distance S1	47 m
Distance S2	33 m
Height of the Receptor	3.8 m
Number of traffic lanes	6





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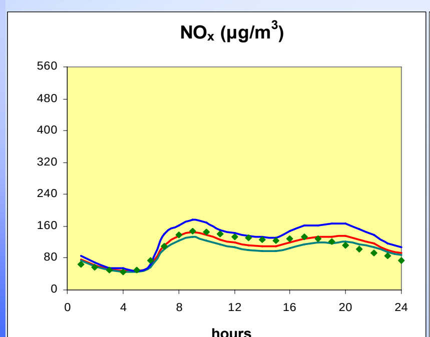
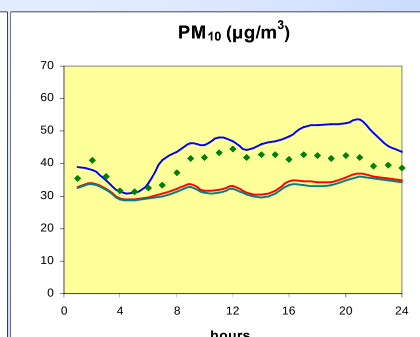
Simulation results of models application for the case of Berlin

Diurnal variation of one-hour annual averaged street level concentrations computed with OSPM(▬), SEP-SCAM (▬) and MIMO (▬) compared to observed street level concentrations (♦).





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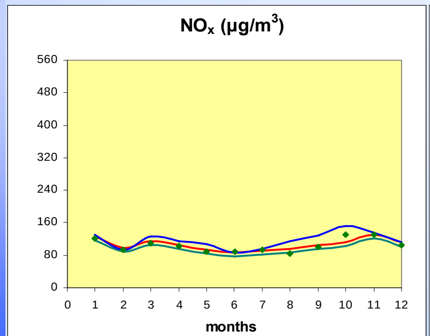
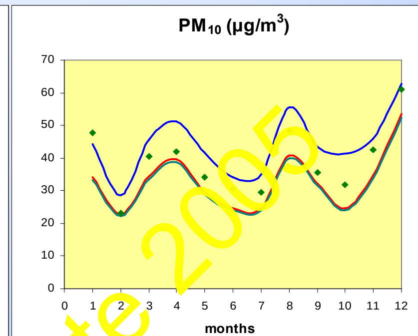
Annual variation of monthly averaged street level concentrations computed with OSPM(▬), SEP-SCAM (▬) and MIMO (▬) compared to observed street level concentrations (♦).





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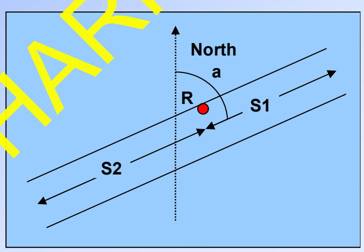
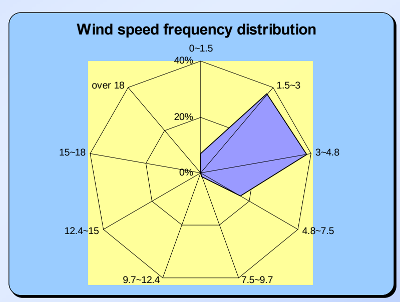
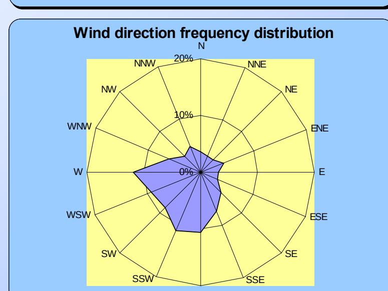
Street canyon configuration – Meteorological data analysis for the case of Stockholm



CANYON CHARACTERISTICS	
Height of the canyon	25 m
Width of the canyon	24 m
Aspect ratio	1.04
Angle a	66°
Distance S1	70 m
Distance S2	90 m
Height of the Receptor	3 m
Number of traffic lanes	4





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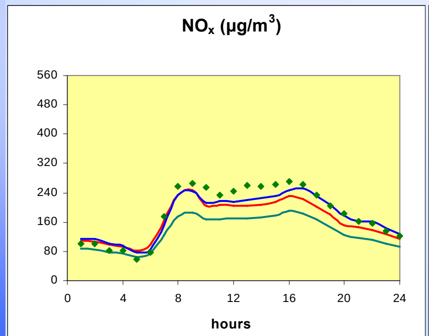

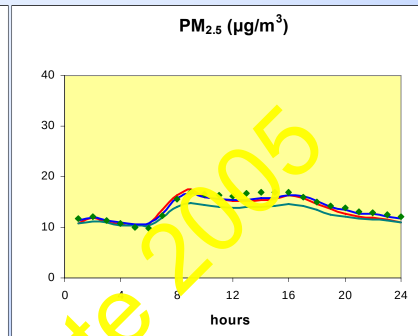

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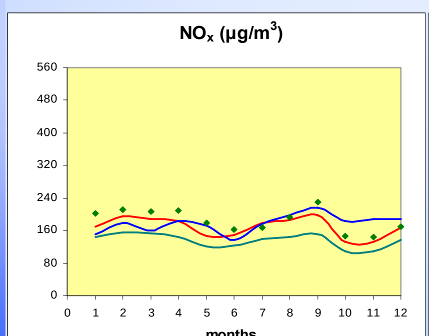

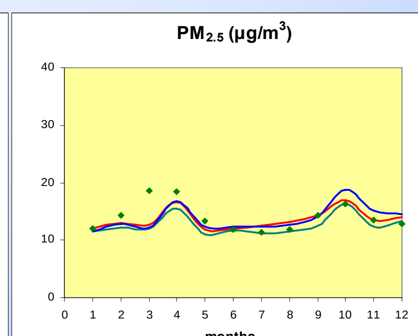

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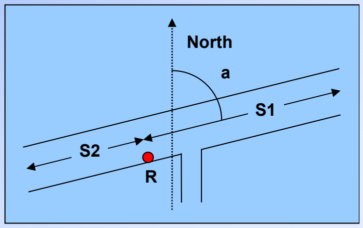
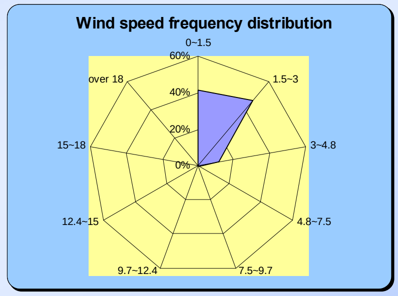
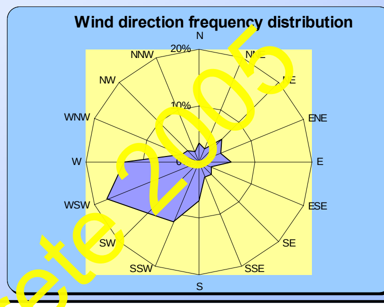


CANYON CHARACTERISTICS	
Height of the canyon	22 m
Width of the canyon	35 m
Aspect ratio	0.63
Angle a	76°
Distance S1	84 m
Distance S2	51 m
Height of the Receptor	3.5 m
Number of traffic lanes	6





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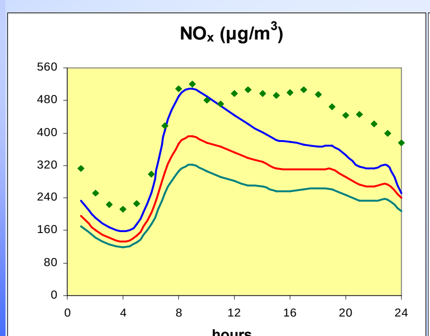

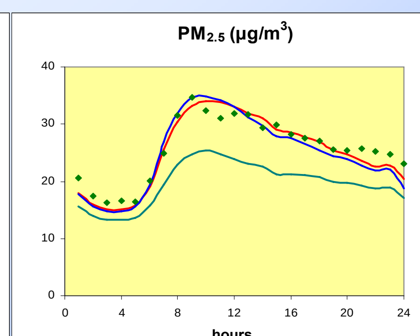

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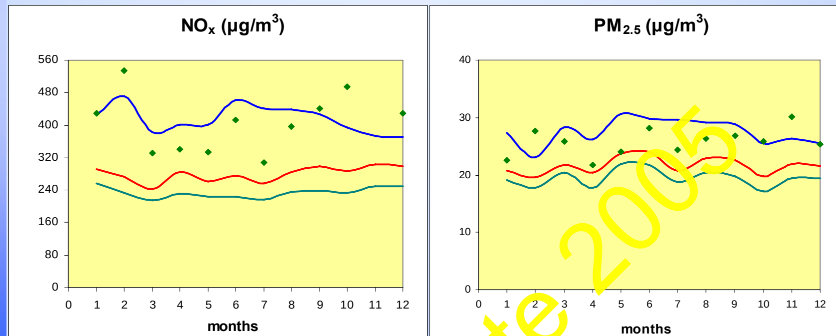

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Statistical results of models applications

Statistical index		Mean Annual street level concentration (µg/m^3)			
Models		OBSERVATIONS	OSPM	SEP-SCAM	MIMO
Berlin	NO_x	104.91	96.23	105.84	126.69
	PM_{10}	39.47	32.19	32.91	44.36
Stockholm	NO_x	185.06	133.74	166.29	176.76
	$PM_{2.5}$	14.03	12.59	13.54	13.78
London	NO_x	415.37	233.81	279.58	342.67
	$PM_{2.5}$	25.73	19.59	25.14	24.80

Statistical indices		BIAS			Correlation Coefficient		
Models		OSPM	SEP-SCAM	MIMO	OSPM	SEP-SCAM	MIMO
Berlin	NO_x	-8.69	0.92	21.77	0.905	0.918	0.917
	PM_{10}	-7.28	-6.56	4.89	0.486	0.552	0.835
Stockholm	NO_x	-51.32	-18.77	-8.29	0.995	0.985	0.988
	$PM_{2.5}$	-1.44	-0.49	-0.25	0.980	0.951	0.983
London	NO_x	-181.56	-135.79	-72.70	0.962	0.956	0.915
	$PM_{2.5}$	-6.15	-0.59	-0.93	0.986	0.980	0.970

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Conclusions (1/2)

- All three models lead to realistic estimates of street scale pollution levels.
- MIMO is found to be generally closest to observed data.
- The newly developed SEP-SCAM model is promising.
- It can be an effective tool for the assessment of the air quality at different levels within a specific street.
- The semi-empirical OSPM and SEP-SCAM models can actually allow authorities to assess air pollution from traffic in urban streets in a fast, simple and reliable way.

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Conclusions (1/2)

- MIMO is a very accurate tool for addressing the issues raised by the complex effect of street canyon configuration to the urban air quality.
- As a CFD code however, it requires availability of adequate computing power.