MODELLING ULTRAFINE PARTICLE CONCENTRATIONS AT STREET-LEVEL SCALE FOR THE ENTIRE CITY OF ANTWERP

Hans Hooyberghs, Wouter Lefebvre, Felix Deutsch, Sandy Adriaenssens, Elke Trimpeneers, Frans Fierens, Stijn Janssen

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

INTERREG IVB

OVERVIEW

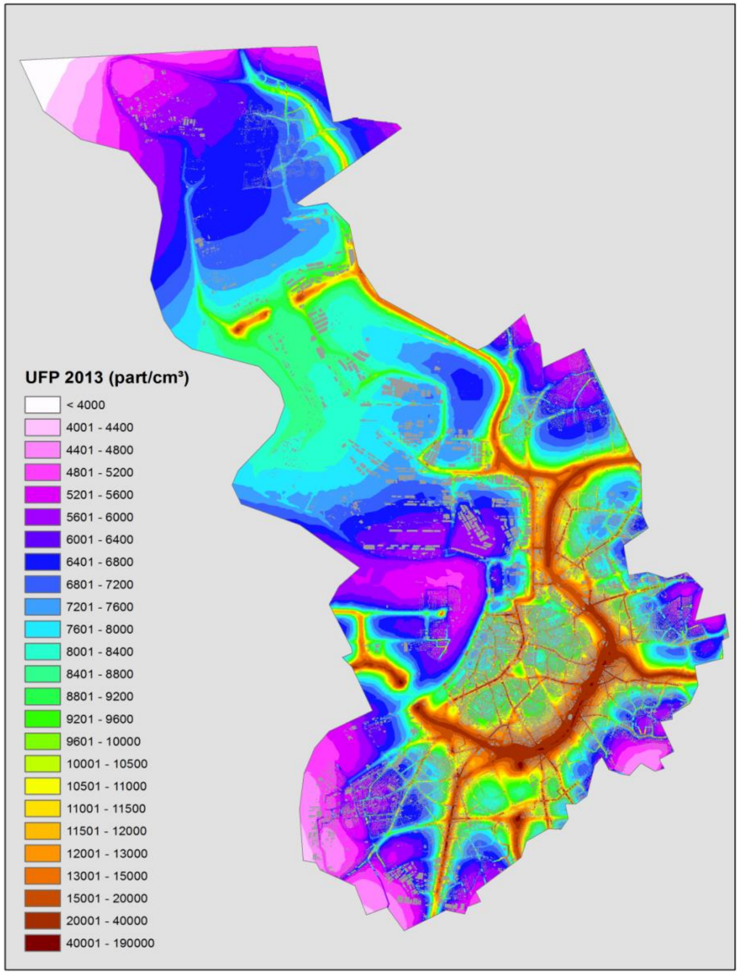
» Motivation

» Model chain
  » Basic description
  » Model input

» Model results for the city of Antwerp, Belgium

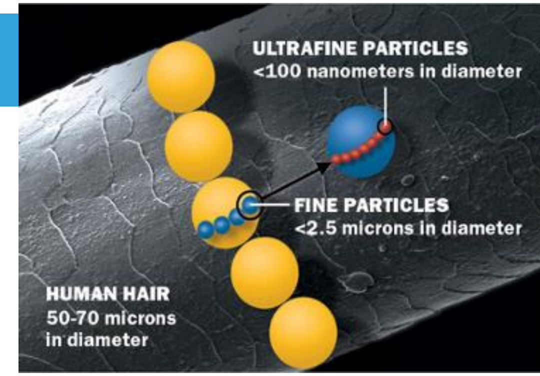
» Measurement campaign and validation

» Summary



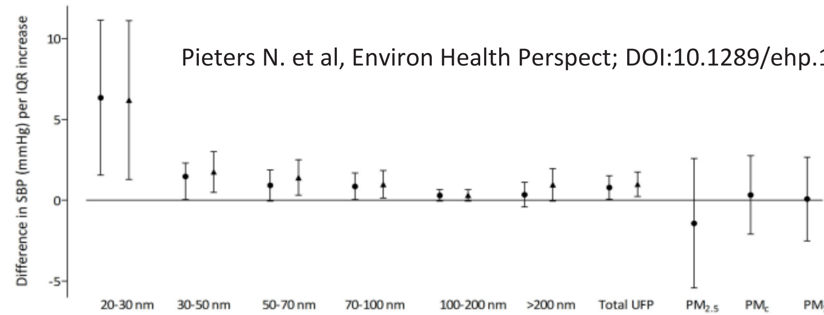
ULTRAFINE PARTICLES

Motivation



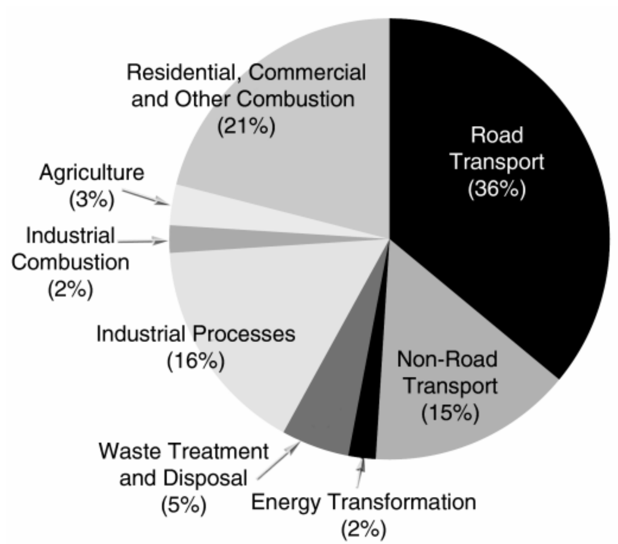
- Definition
  - Particles less than 100 nanometres in diameter
  - Interested in total particle number concentrations (TNC)

- Health effects
  - Possibility to be absorbed in bloodstream
  - Adverse health effects could differ from those of exposure to larger particles
  - Evidence for short term health effects F.i. linked to higher blood pressures



Pieters N. et al, Environ Health Perspect; DOI:10.1289/ehp.1408121

- Main emission sources: Road traffic and combustion



Sector contributions in 2005 to European particle number emissions < 300 nm

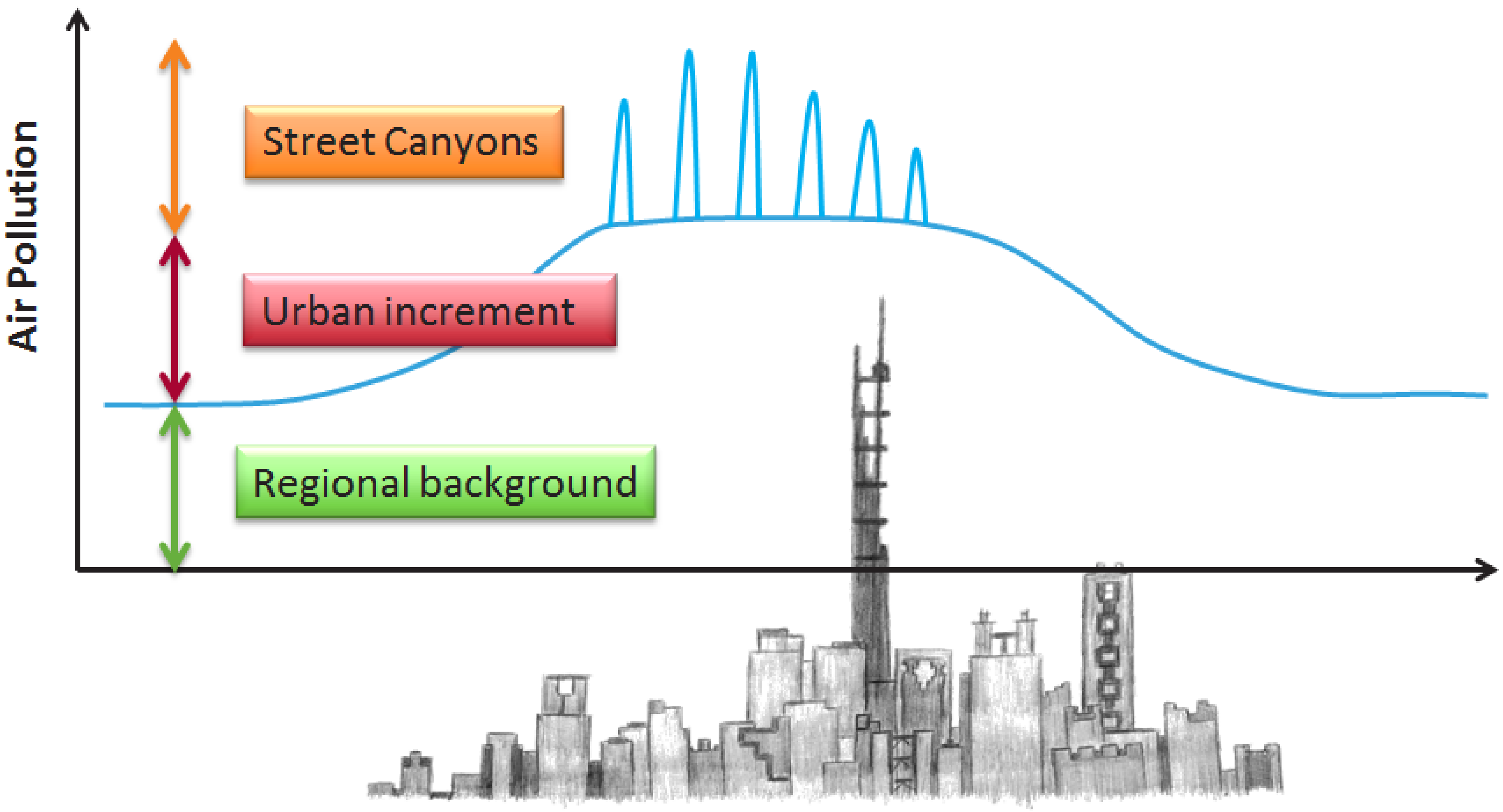
Denier van der Gon HAC, Visschedijk A, Johansson C, Ntziachristos L, Harrison R. 2010. Size-resolved pan-European anthropogenic particle number inventory. Abstract submitted to IAC, 2010, Helsinki, Finland

Basic description

IFDM – OSPM chain

Urban scale
rooftop concentrations

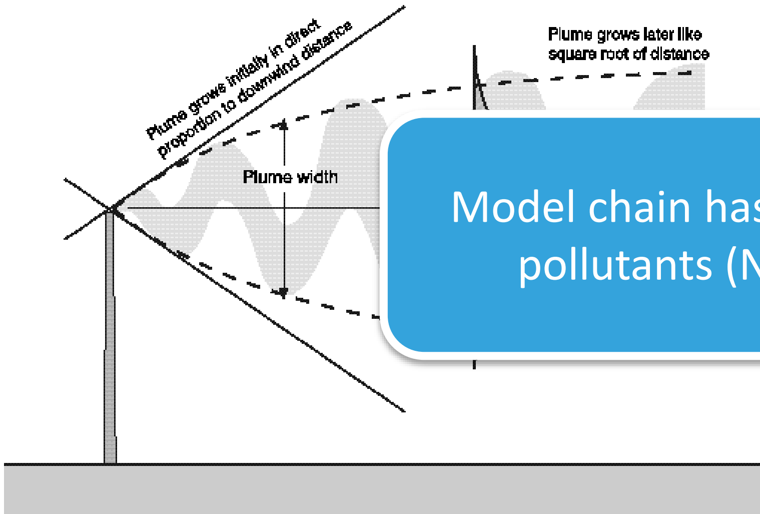
Street-canyon
module

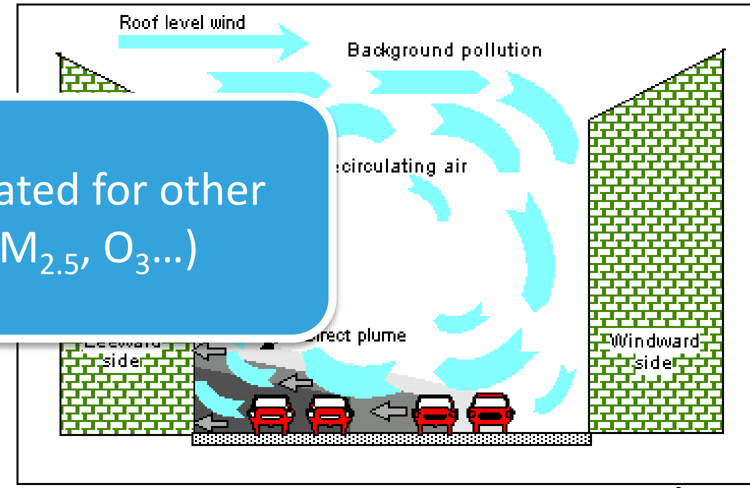


IFDM
Urban scale traffic

Double-counting procedure

OSPM
Street-canyon module





Model chain has been validated for other pollutants (NO_2, PM_{10}, $PM_{2.5}$, O_3…)

- Plume model
- Gaussion dispersion, taking into account the stability of the atmosphere using stability classes (based on meteorological input)
- Receptor model

- Box model for the recirculating part of the pollutants in the street canyon (resuspension)
- For simplicity: asymmetry of street canyon is neglected

Lefebvre, W. et al. (2011), Atm. Env., 45, p. 6705-6713

Berkowicz, R. (2000), Environmental Monitoring and Assessment, 65, pp. 323-331.

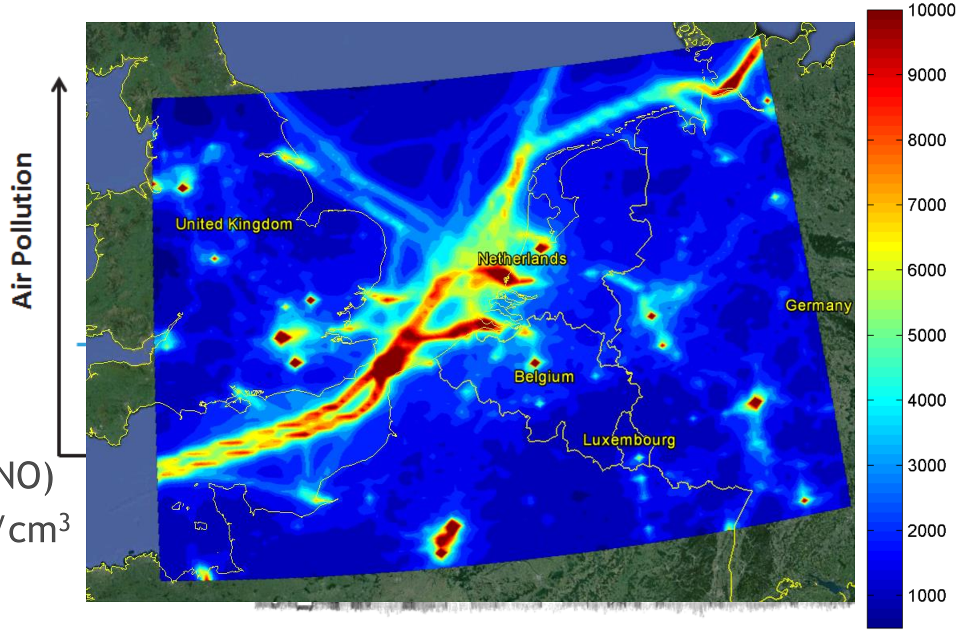
DYNAMICAL PROCESSES

Assumptions in local-scale modelling

- Dispersion
  - Taken into account (described by bigaussian modelling)
- Coagulation
  - Much longer time scale than dispersion => Neglected
- Deposition on surfaces
  - Unimportant for particle diameters between 10 nm and 2µm according to sensitivity tests using IFDM => Neglected
- Nucleation: formation of new particles
  - Effects of photochemical reactions are for Western European cities almost always negligible, especially at locations close to major emission sources

MODEL INPUT

General input for local scale-modelling



- Regional background: 2 choices
  - 2 choices:
    - Output of CTM (LOTOS-EUROS, TNO)
    - Constant value of 5000 particles/cm^3
  - Double counting procedure

- Meteorological input
  - Hourly local measurements of temperature and wind speed for 2013

- Emissions for local scale modelling
  - Major locatable source for UFP-emissions in Antwerp: Road traffic
    - Only traffic emissions are directly taken into account in the local modelling
    - All other emissions are taken into account in the background concentrations

MODEL INPUT

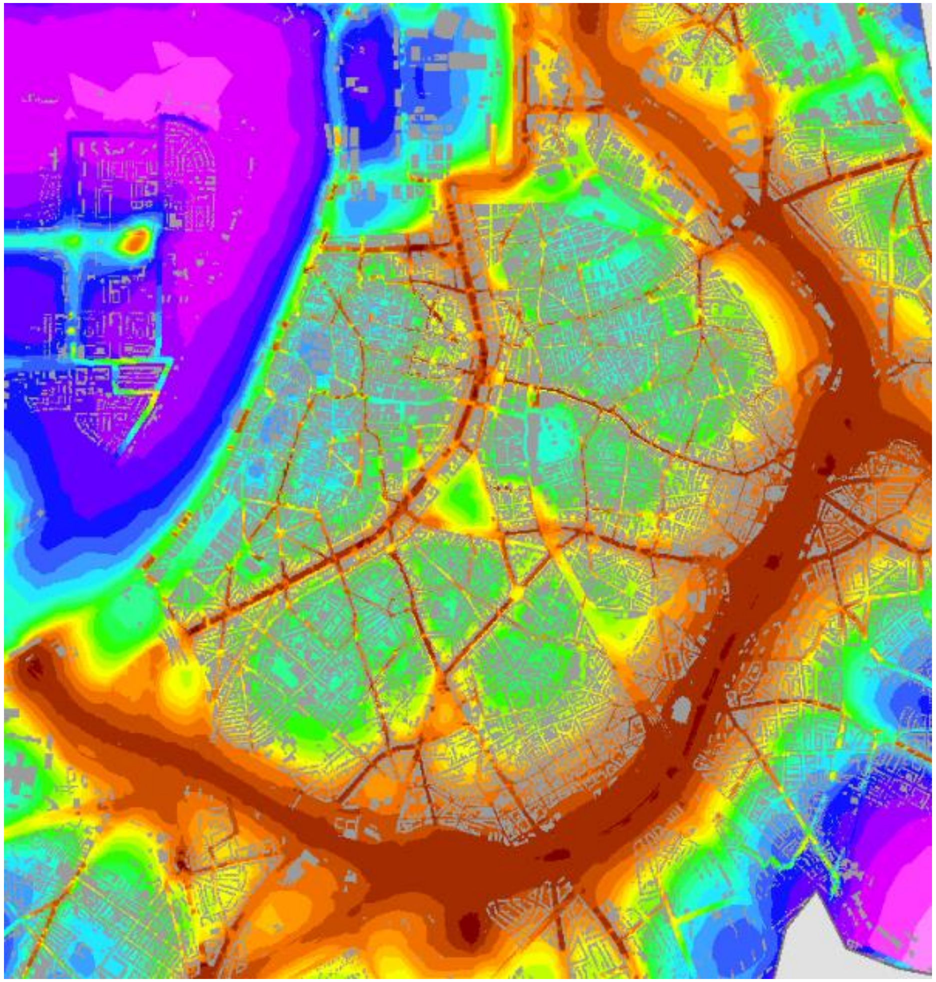
Traffic emissions

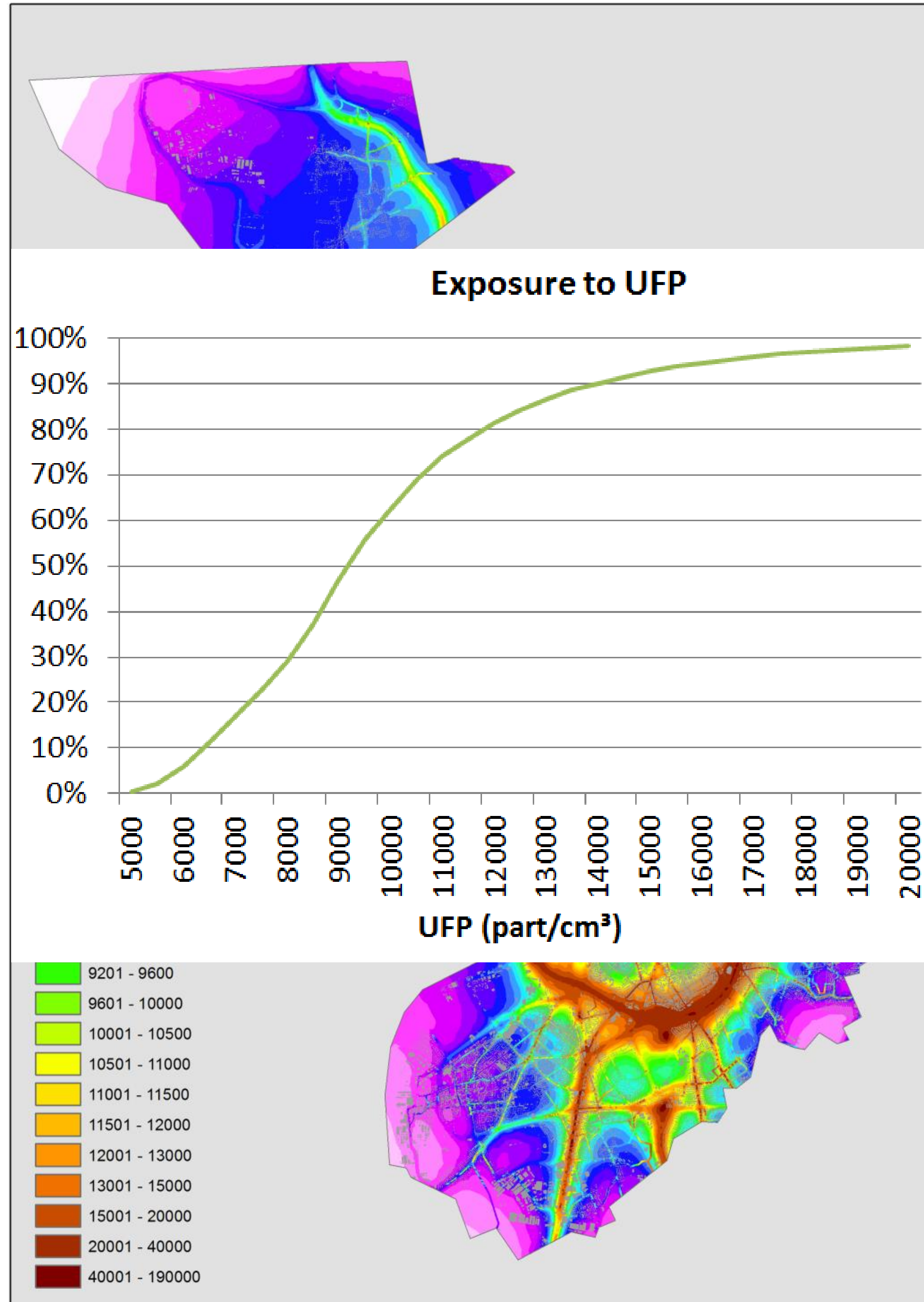
- Standard emission factors:
  - Hbefa
  - Resulting emissions are multiplied by factor 10
    - Underlying reasons:
      - Test cycle emissions do not correspond to real driving emissions
      - HBefa has a cutoff at 23 nm
    - Similar approach and factors have been applied before
      - Keuken et al. (2016) for Amsterdam
      - Nikolova et al. (2011)
- Emissions factors processed in traffic emissions model (MIMOSA)

M.P. Keuken, M. Moerman, M. Voogt, P. Zandveld, H. Verhagen, U. Stelwagen, D. Jonge de, Particle number concentration near road traffic in Amsterdam (the Netherlands): Comparison of standard and real-world emission factors, Atm. Env. 132,: 345-355 (2016), http://dx.doi.org/10.1016/j.atmosenv.2016.03.009.
Nikolova I., Janssen S., Vrancken K., Vos P., Mishra V., Berghmans P.. Size resolved ultrafine particles emission model – a continuous size distribution approach, STOTEN, 409, 6492-3499, (2016) doi:10.1016/j.scitotenv.2011.05.015

RESULT

Annual mean UFP-concentration in 2013



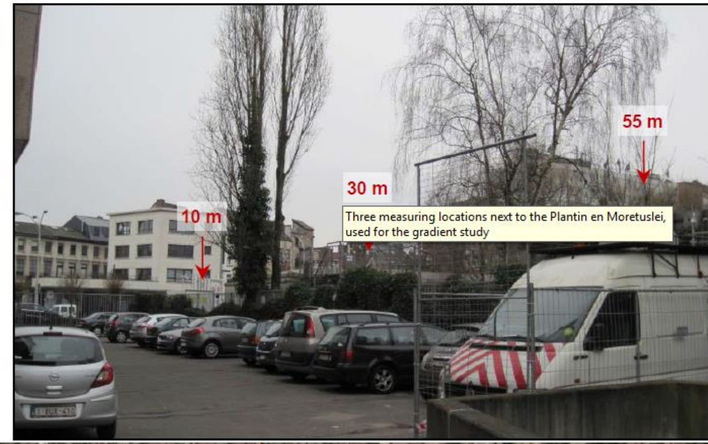


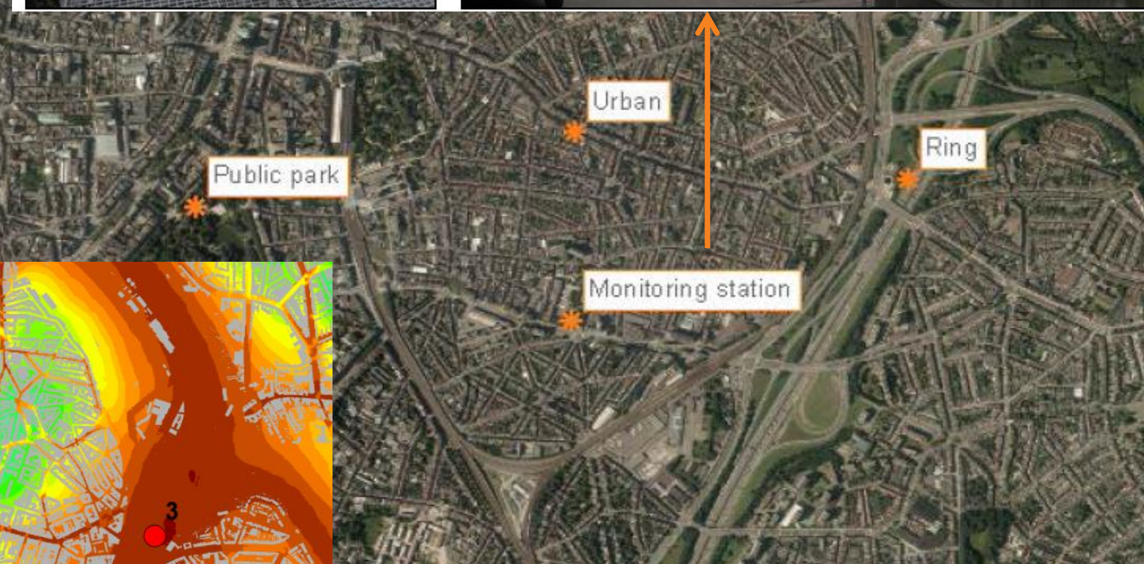
Hot-spots near major roads, in street canyons and close to tunnel exits lead to high exposure

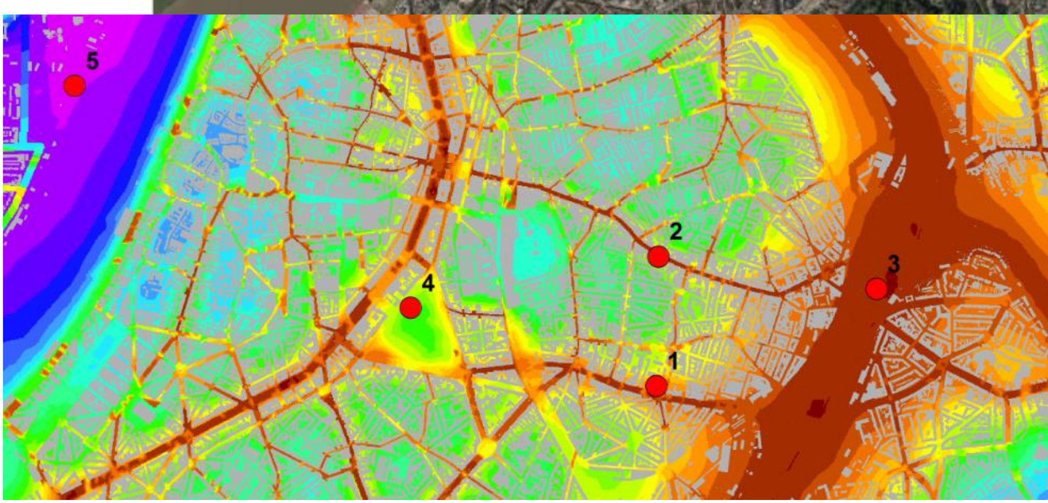
MEASUREMENT CAMPAIGN

Campaigns in February and October 2013

Gradient measurement

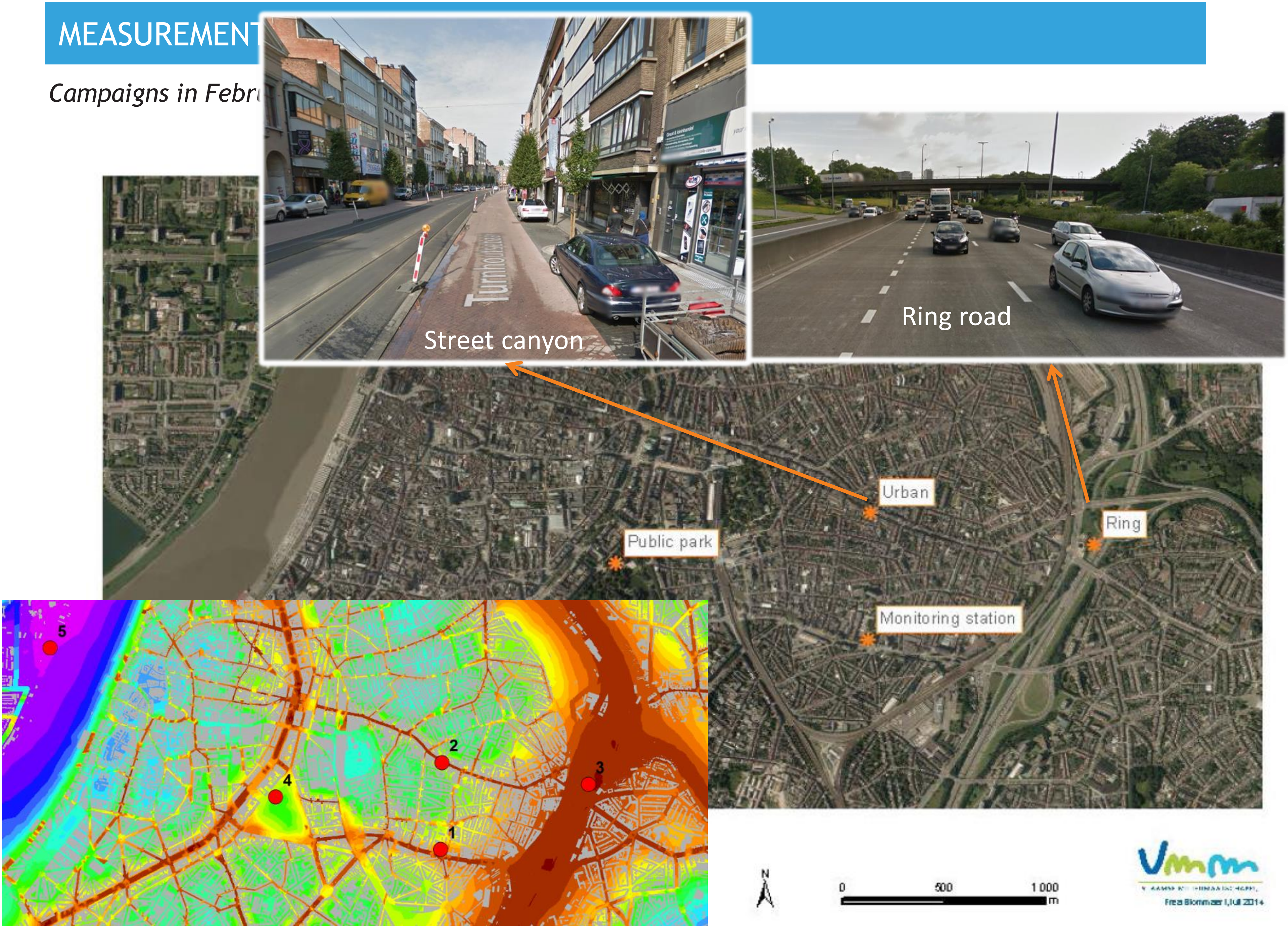






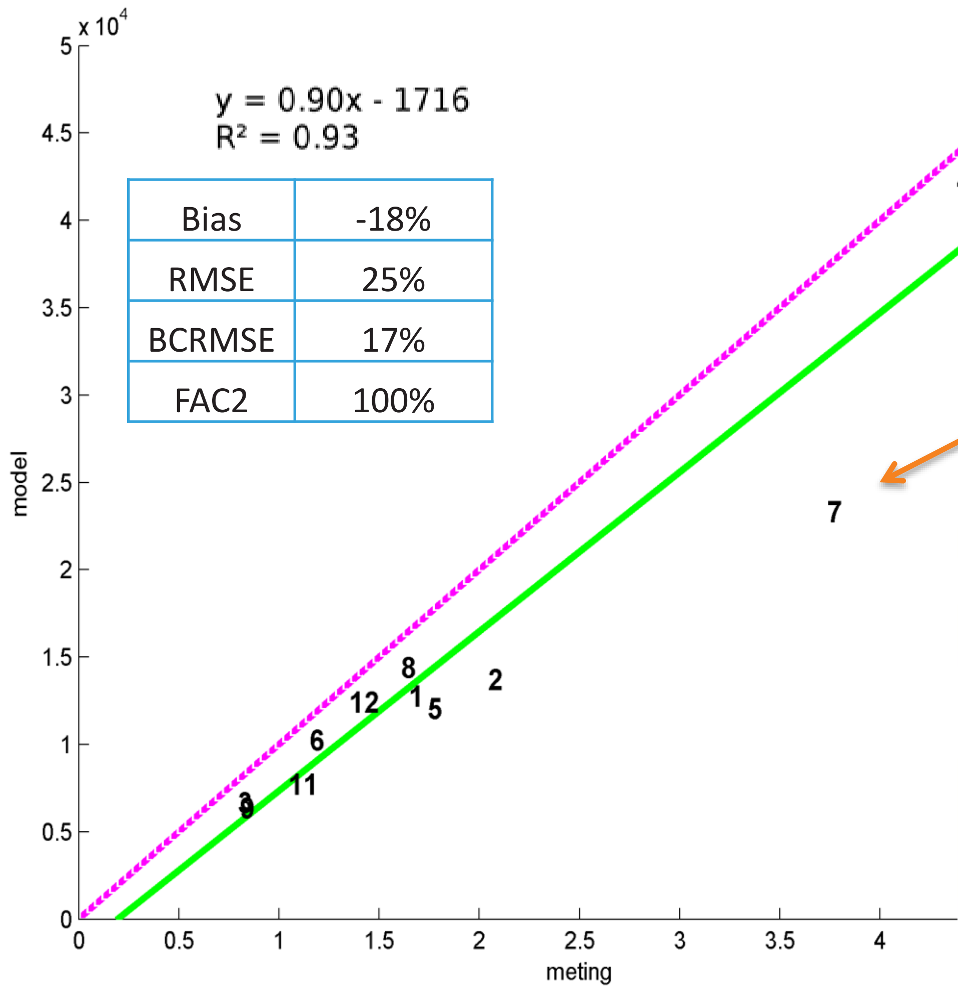
MEASUREMENT

Campaigns in Febr



SPATIAL VALIDATION

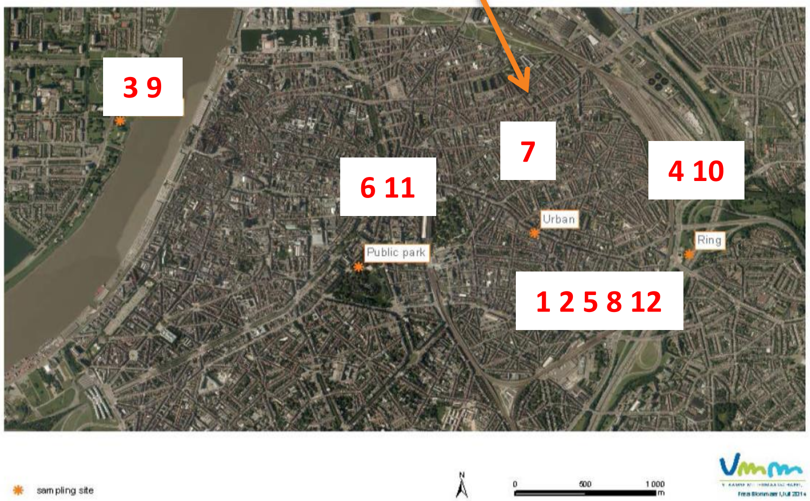
» UFP validation (spatial validation, several locations), average over measurement period



$y = 0.90x - 1716$
$R^2 = 0.93$

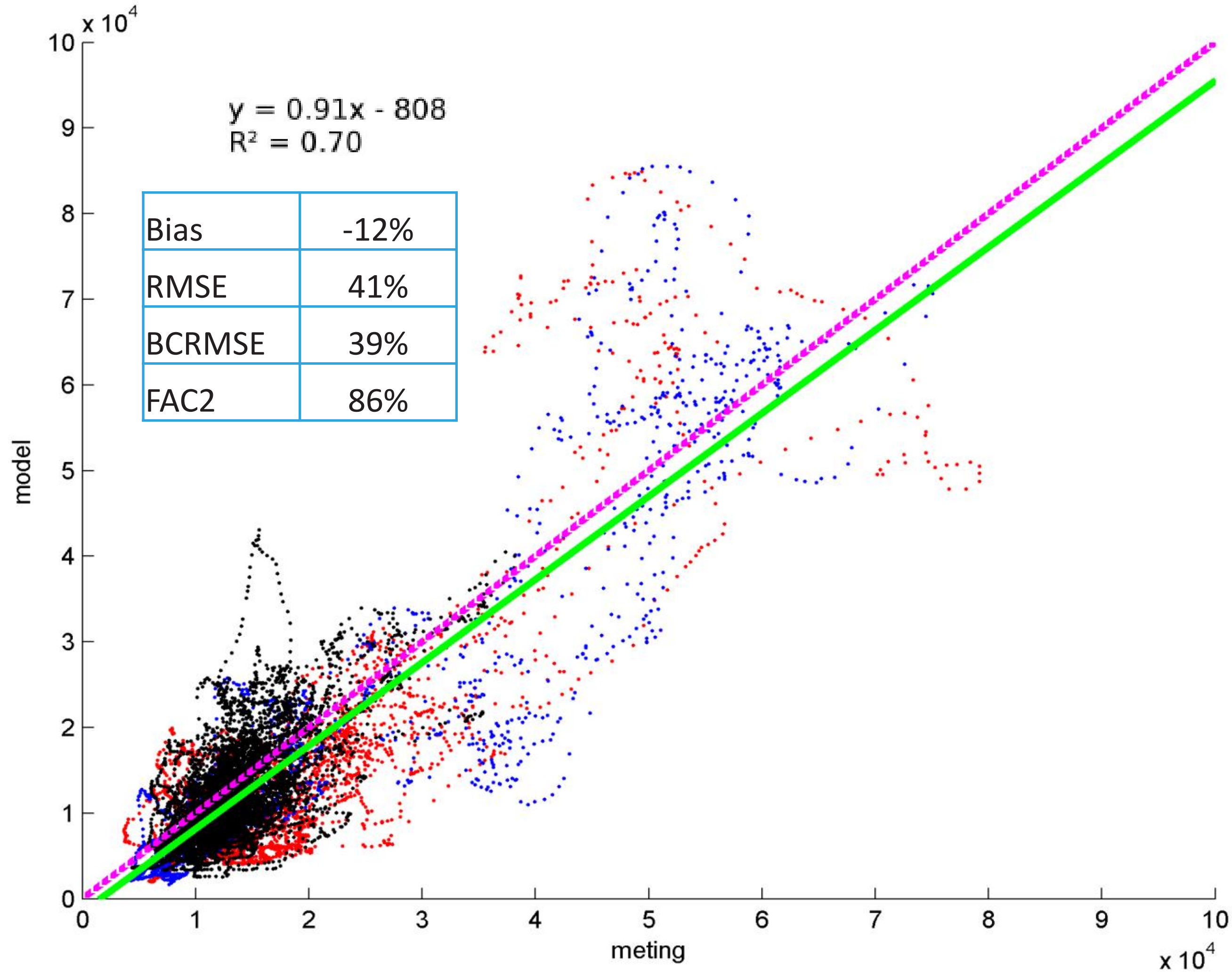
Bias	-18%
RMSE	25%
BCRMSE	17%
FAC2	100%

Missing buses in traffic data



SPATIO-TEMPORAL VALIDATION

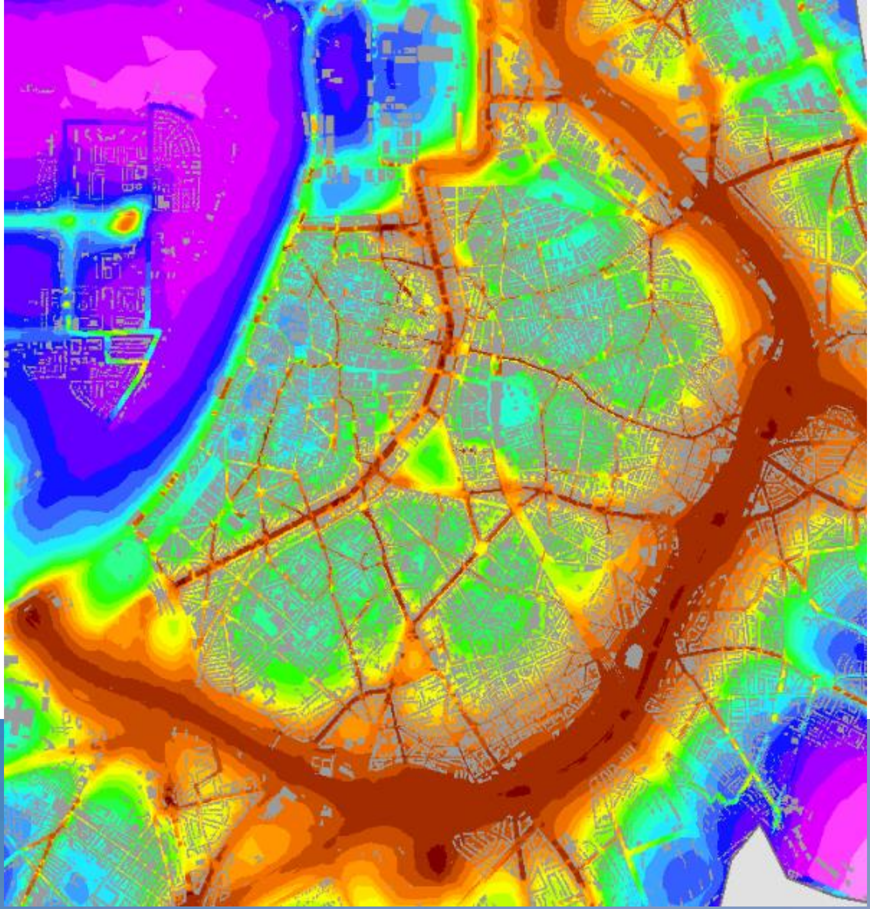
» UFP validation (spatio-temporal validation, several locations), 24h-sliding average measurements



Bias	-12%
RMSE	41%
BCRMSE	39%
FAC2	86%

CONCLUSIONS

- IFDM-OSPM model chain describing dispersion of UFP particles and neglecting all other dynamical processes
- Maps for annual mean UFP-concentrations in the city of Antwerp for 2013 show hotspots near major roads and tunnel exits
- Very good spatio-temporal and temporal validation if factor is included in the emissions and decent validation of daily and weekly cycles
- All dynamical processes (except dispersion) are negligible for studies on an urban scale for Antwerp
- Importance of good emission and traffic data

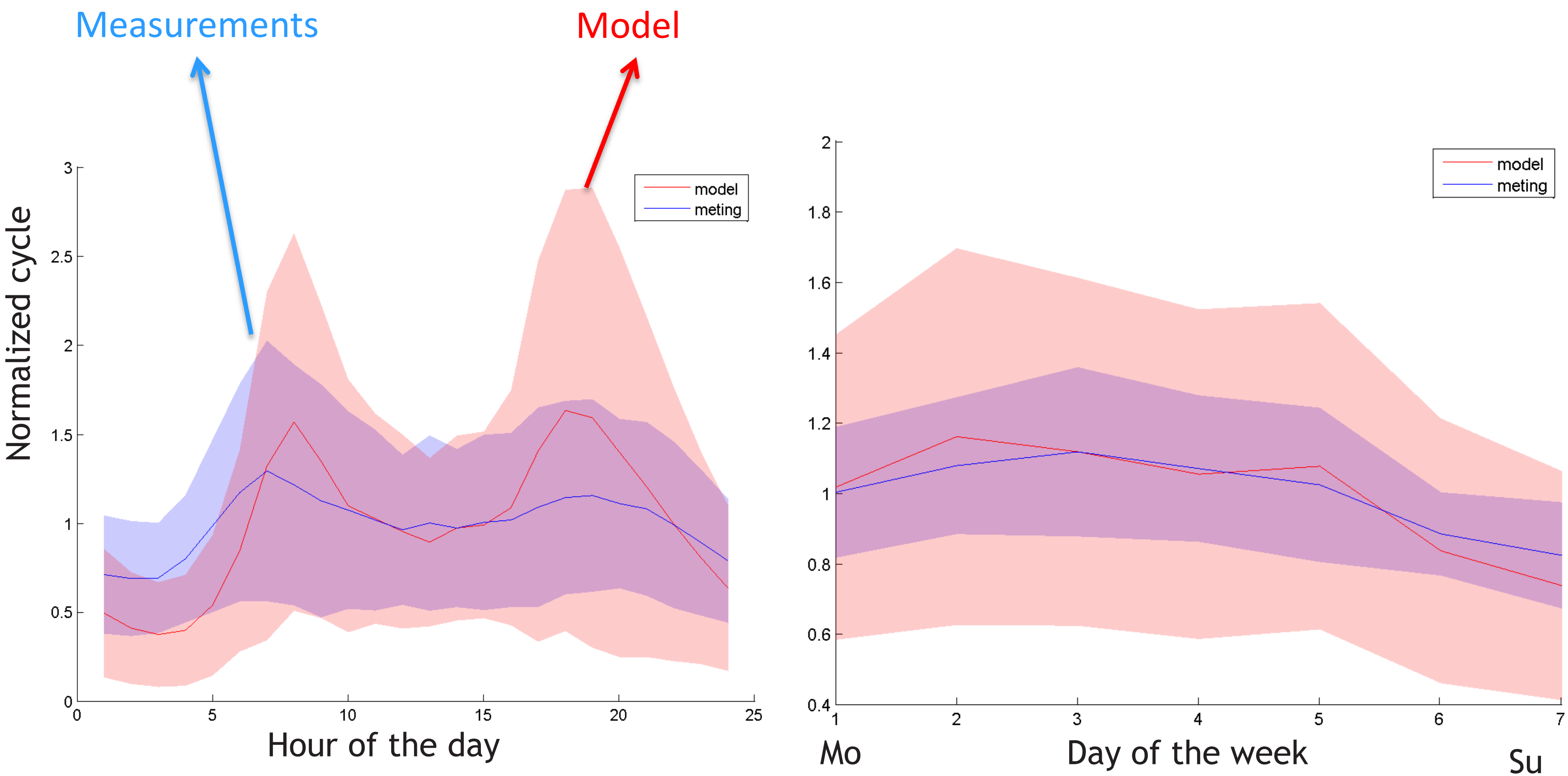


Köszönöm!

» Questions?

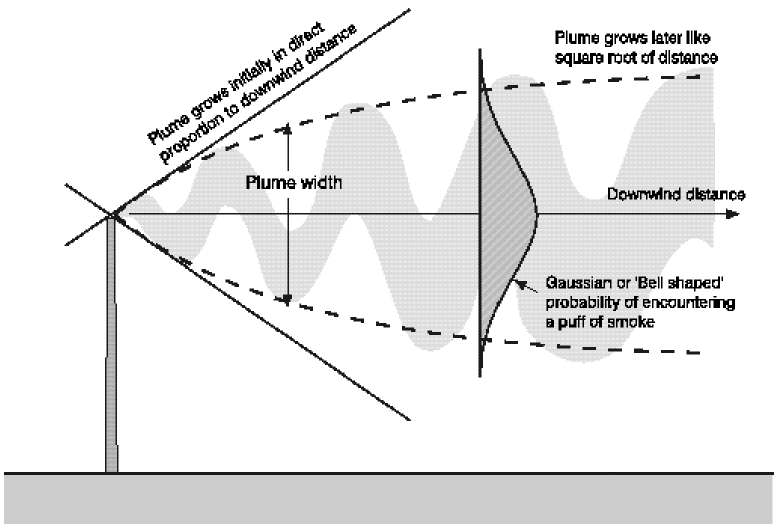
DAILY AND WEEKLY CYCLES

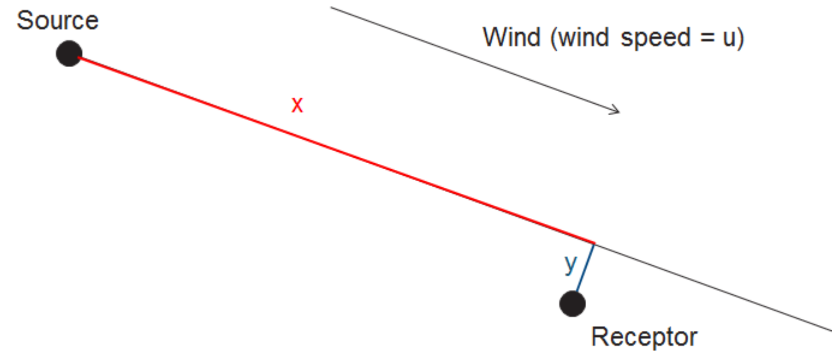
Validation for Borgerhout measurement station



Gaussian dispersion

» Plume disperses using Gaussian profile





$$C(x,y,z) = \frac{Q}{U}\,\frac{1}{2\,\pi\,\sigma_y\,\sigma_z}\,e^{\left(\frac{-y^2}{2\,\sigma_y^2}\right)}\left[e^{\left(\frac{-(z-H)^2}{2\,\sigma_z^2}\right)} + e^{\left(\frac{-(z+H)^2}{2\,\sigma_z^2}\right)}\right]$$

C = concentration (g/m^3)
Q = emission source (g/s)
H = h_e = effective plume height (m)
U = u_{he} = wind speed at h_e (m/s)
$\sigma_y(x)$ & $\sigma_z(x)$= horizontal & vertical dispersion parameters (m)
y = distance from plume centre line (m)

» Characteristics of the dispersion (plume width, plume rise, stability…) are determined by the stability of the atmosphere
  » Use of stability parameters

IFDM

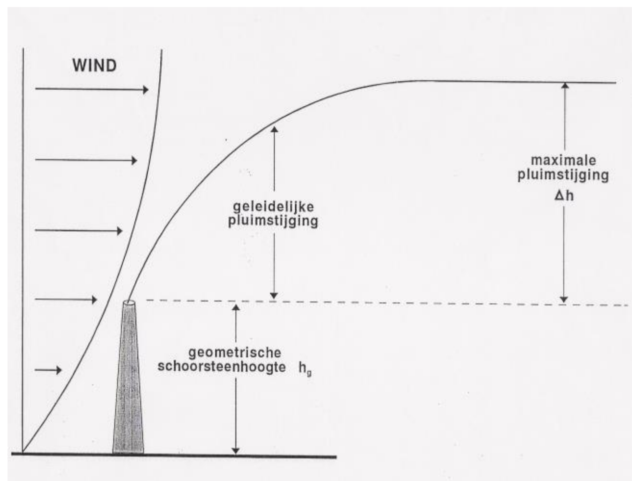
Gaussian dispersion

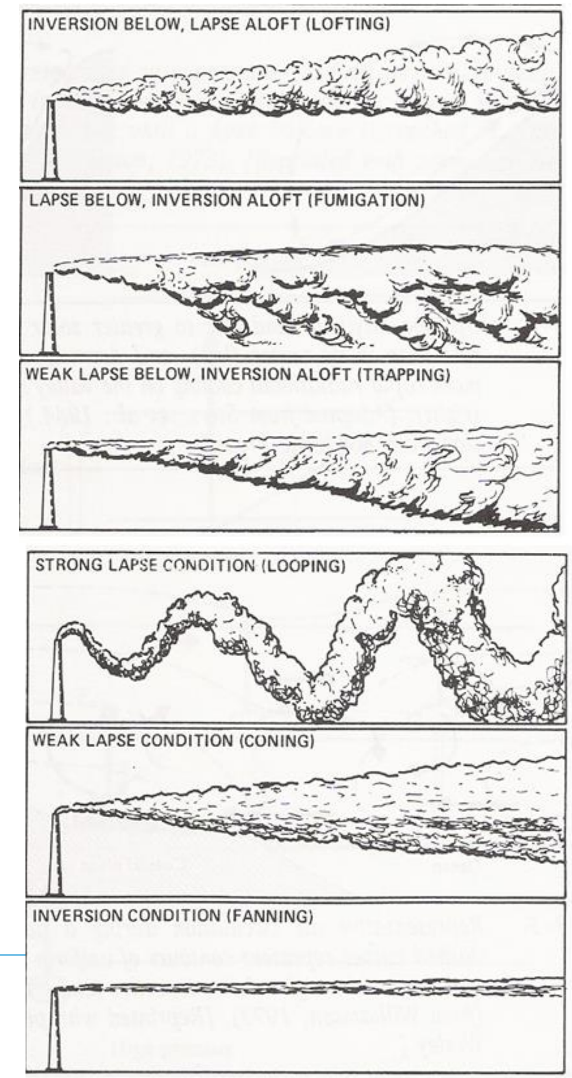
$$C(x,y,z) = \frac{Q}{U} \frac{1}{2\pi\sigma_y\sigma_z} e^{\left(\frac{-y^2}{2\sigma_y^2}\right)} \left[e^{\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)} + e^{\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)} \right]$$

- Plume disperses using Gaussian profile
- Characteristics of the dispersion (plume width, plume rise, stability…) are determined by the stability of the atmosphere
  - Use of Bultynk & Malet stability parameters

$$\sigma_y = A\,x^a \qquad \sigma_z = B\,x^b$$

Stability class	A	a	B	b
E1	0.235	0.796	0.311	0.711
E2	0.297	0.796	0.382	0.711
E3	0.418	0.796	0.520	0.711
E4	0.586	0.796	0.700	0.711
E5	0.826	0.796	0.950	0.711
E6	0.946	0.796	1.321	0.711
E7	1.043	0.698	0.819	0.669





vito

Bultynck H., Malet L.M. 1972. Tellus 24: 455–472.

IFDM

Gaussian dispersion

$$C(x,y,z) = \frac{Q}{U}\frac{1}{2\pi\sigma_y\sigma_z} e^{\left(\frac{-y^2}{2\sigma_y^2}\right)} \left[e^{\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)} + e^{\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)} \right]$$

» Plume disperses using Gaussian profile

» Characteristics of the dispersion (plume width, plume rise, stability…) are determined by the stability of the atmosphere

  » Use of Bultynk & Malet stability parameters

  » Stability classes are dependent on wind speed and temperature

Stability class	A	a	B	b
E1	0.235	0.796	0.311	0.711
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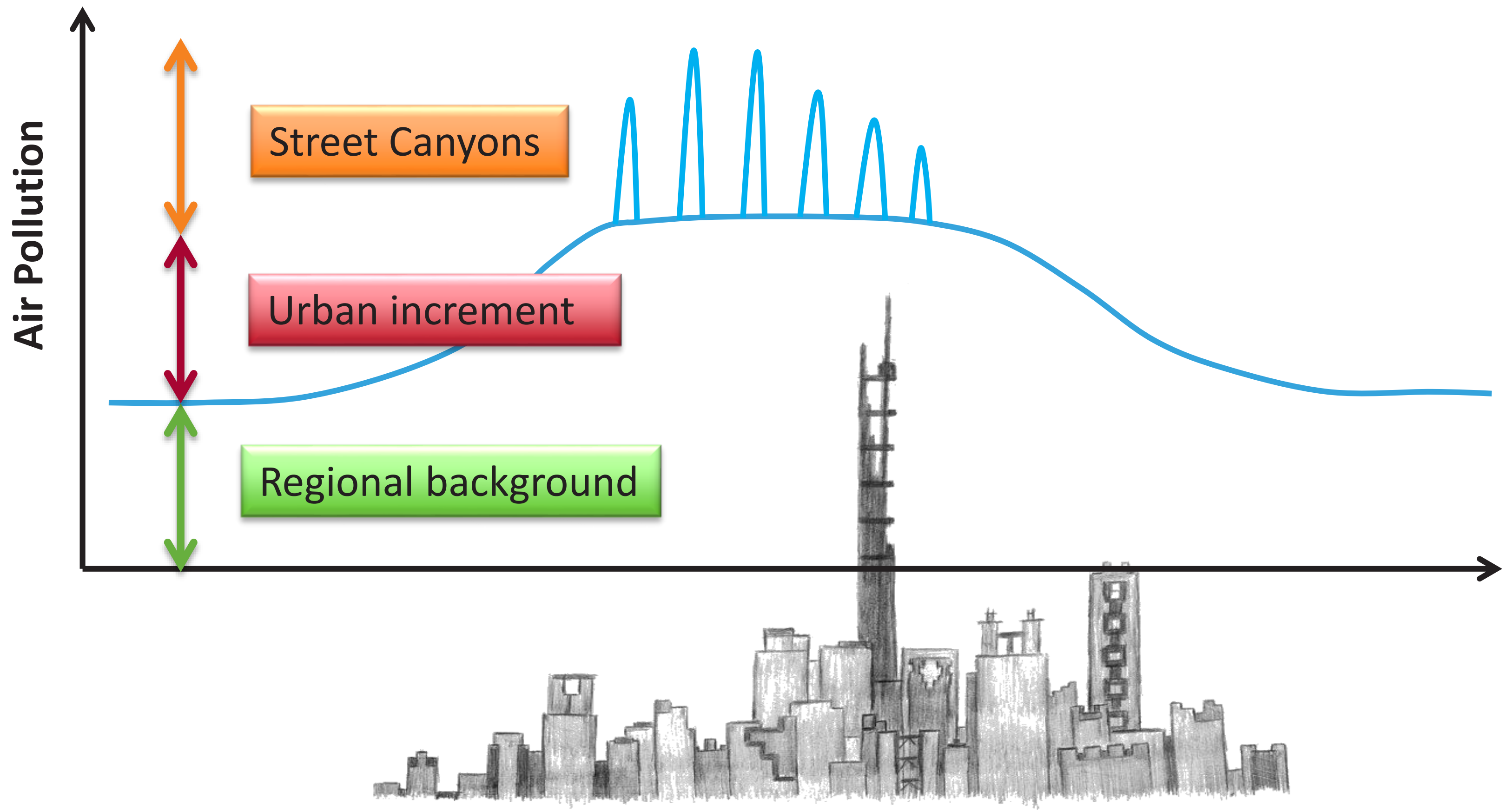
$$\sigma_y = A\,x^a \qquad \sigma_z = B\,x^b$$

Minimal requirements on meteorological input data

» Temperature

» Wind speed

Bultynck H., Malet L.M. 1972. Tellus 24: 455–472.


Air Pollution
Street Canyons
Urban increment
Regional background