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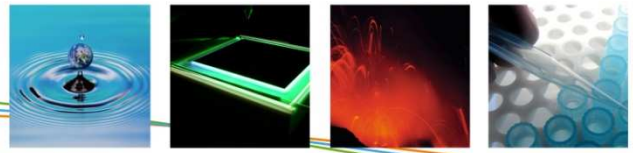


New approaches in outdoor air quality monitoring: mobile sensing, participatory sensing and sensor networks

8th AIAI Conference, 27 – 30 September, Halkidiki, Greece

Tutorial COST Action TD1105 EuNetAir

Presentation: Jan Theunis

Research team:

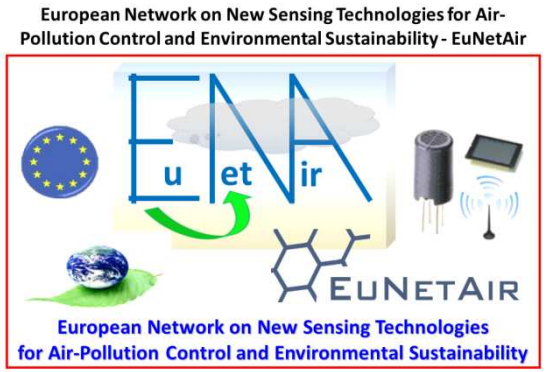
Matteo Reggente

Jan Peters

Martine Van Poppel

Evi Dons

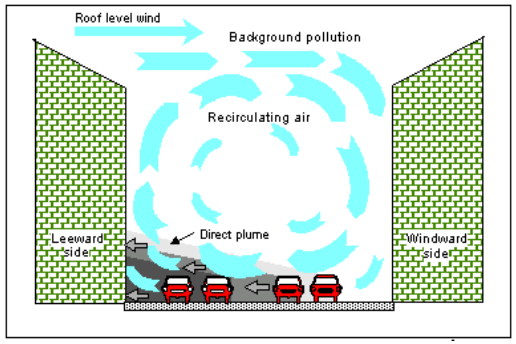
Joris Van den Bossche

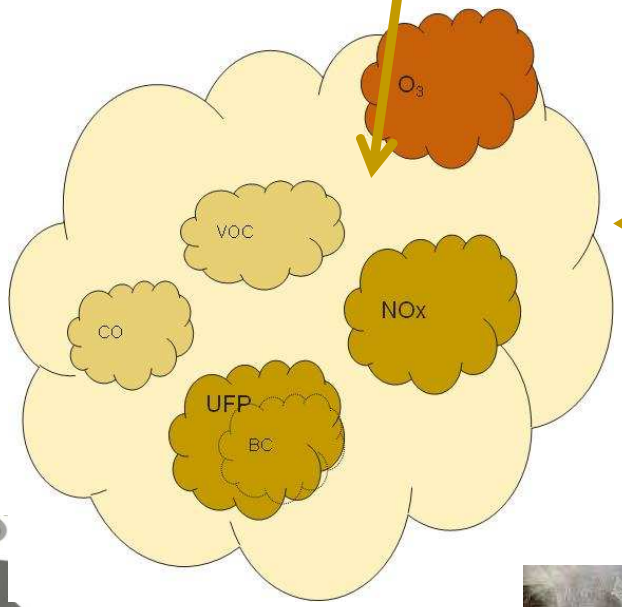


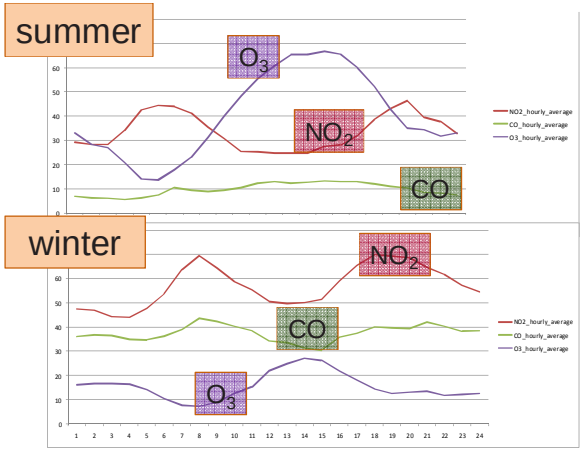
Outline

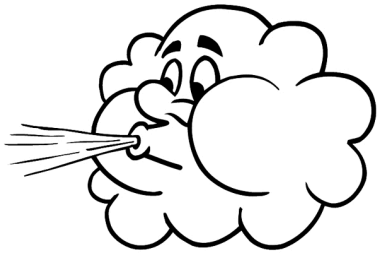
- Air quality monitoring
- New approaches: focus on exposure and health
- Sensor networks: concept, examples of statistical modelling
- Mobile monitoring: tools and methods
- Participatory monitoring: sesnor array

Urban air quality

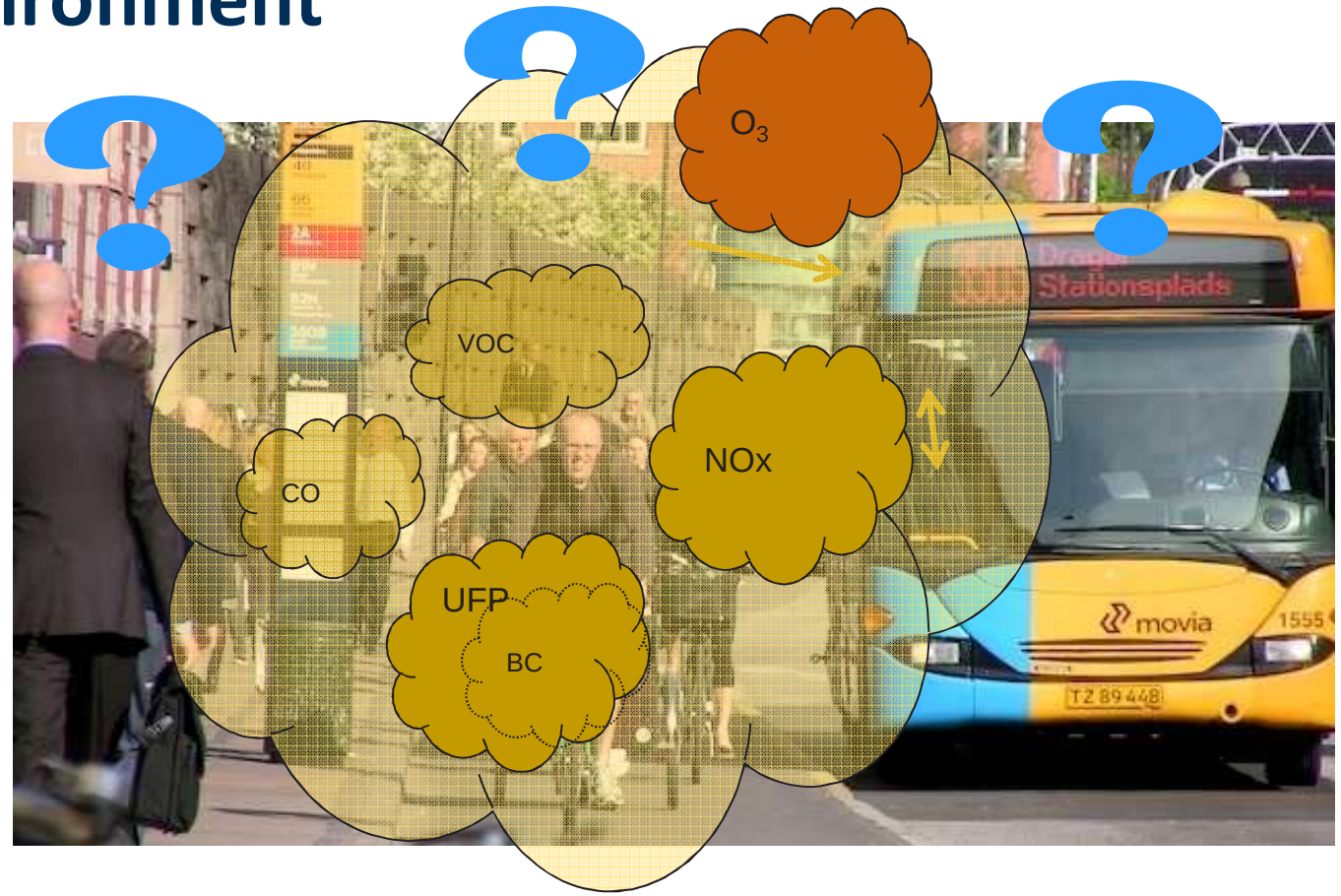








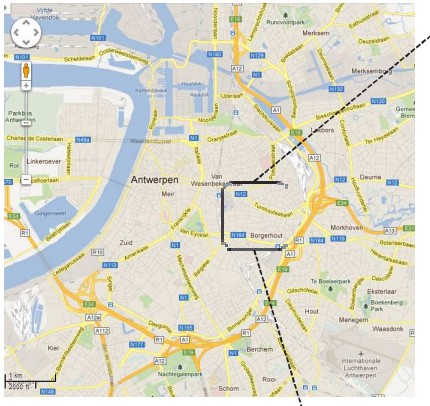
Exposure: people moving through the environment

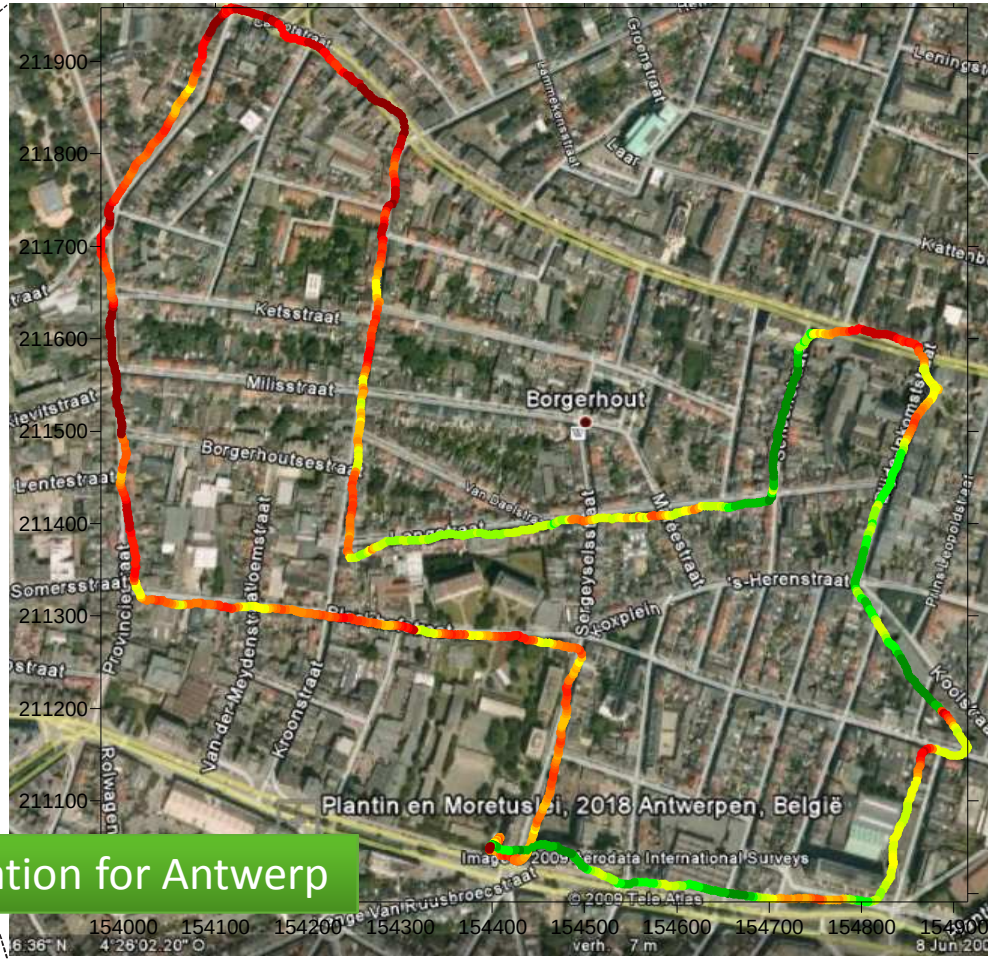


- Dynamic Exposure Assessment
- Need for detailed data with high spatial and temporal resolution

Air quality monitoring

- Conventional: Reference methods
  - Only regulated components
  - “Correct” but poor spatial coverage





1 Urban air quality station for Antwerp

Air quality is not homogeneous in urban environments!

New approaches: focus on exposure and health

- health-relevance versus regulation
- exposure in different micro-environments
- detailed data – high spatio-temporal resolution

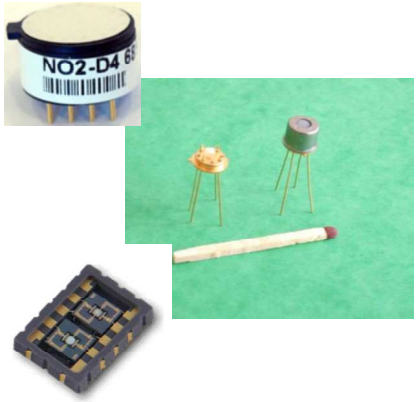
- Sensor networks : low cost sensors
- Mobile monitoring: high quality monitors – low cost sensors
- Participatory monitoring

- Challenges: sensor quality, data quality, mobile data, intelligent data processing

Sensor networks: concept

- Heterogeneous networks of low cost sensors and high performance instrumentation
- Lack of accuracy compensated by amount of data
- Making use of network intelligence (incl. learning capabilities) to guarantee overall quality
- Combined measurement of different agents, e.g. different air pollutants, noise, meteo, …
- Making sensors work closely together
  - UFP, NOx, CO, noise → “proxies”
- Data aggregation and mining

Sensor networks: low cost sensors



Basic sensors

- Electrochemical
- Semiconductor metaloxide
- 5 – 80 €

Sensor head

- temperature control
- calibration curve
- correcting for T, RH
- 200 - 300 €

Measuring device

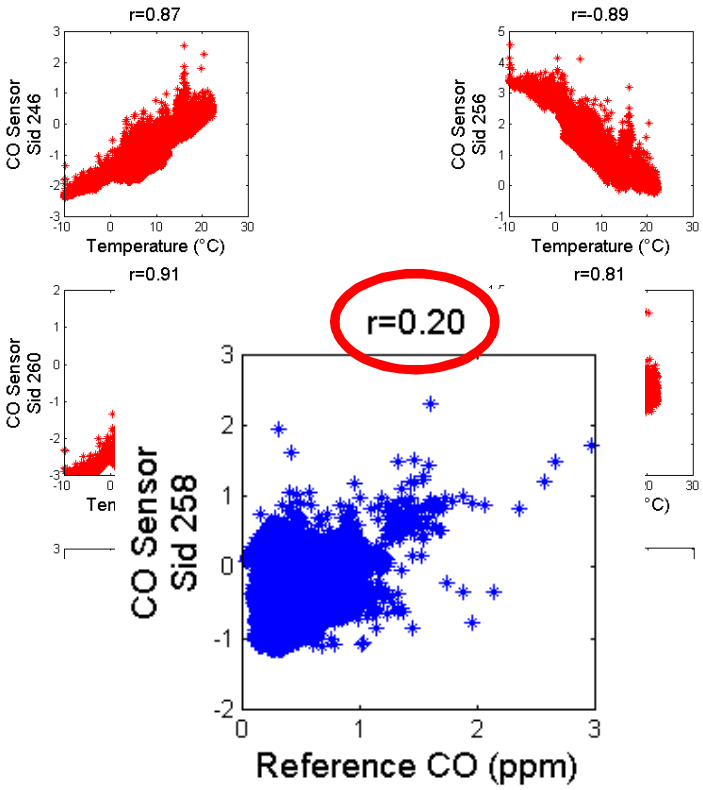
- 1000 - 2000 €

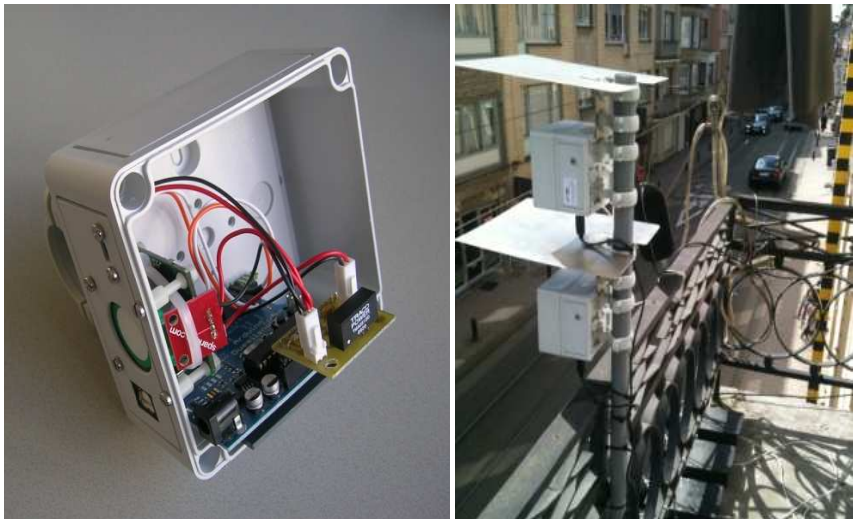
Not designed for / little experience in ppb range

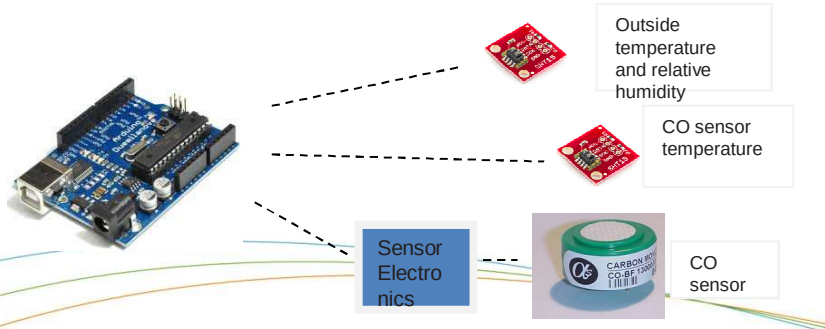
cross-interference, drift, T and Hum effects

Sensor networks: low cost sensors

- Sensor node with low-cost CO sensor:
- → Huge temperature dependence

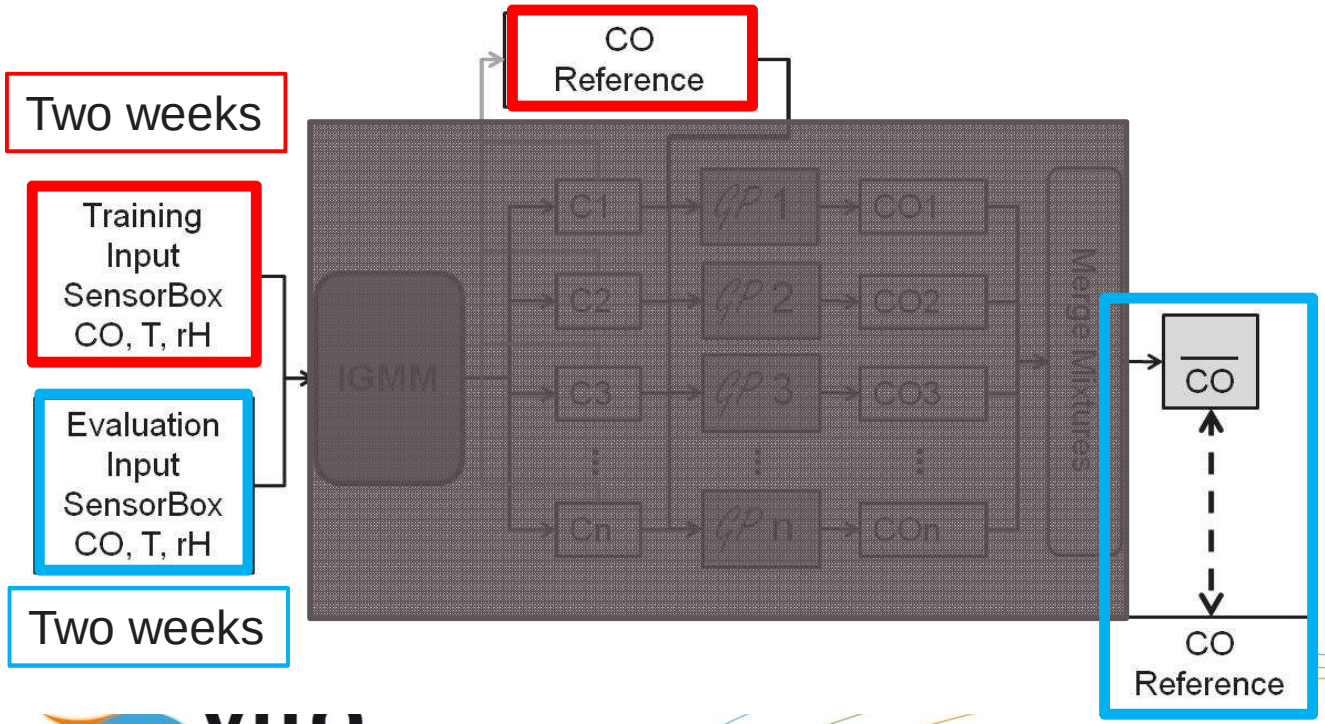






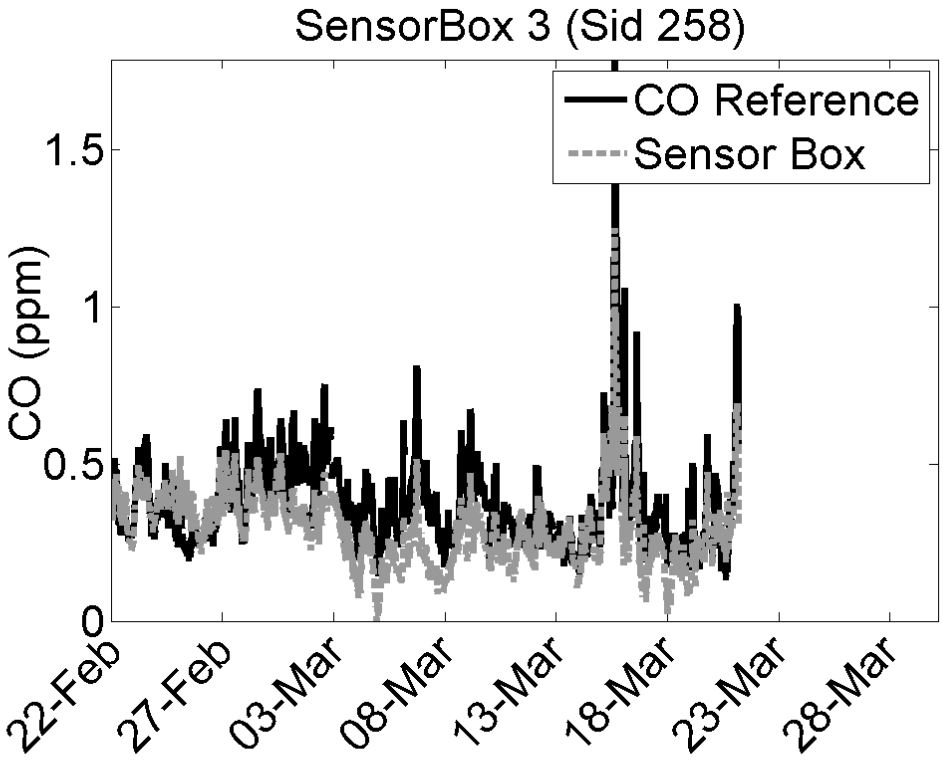
Sensor networks: low cost sensors

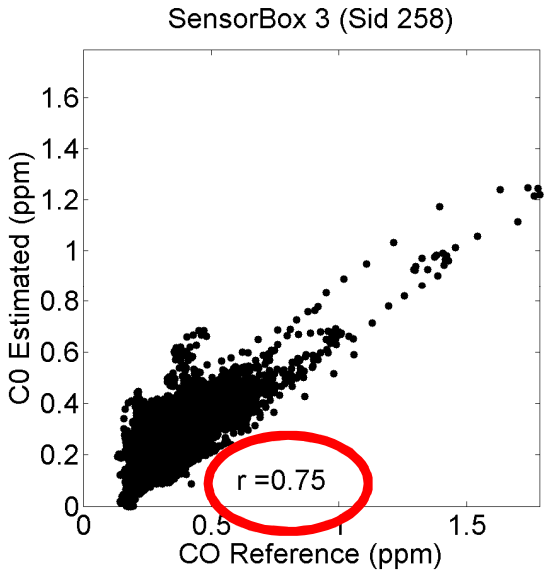
- Sensor node with low-cost CO sensor
  - » correcting interference of environmental factors
  - » Test set-up: sensors collocated with reference CO monitor
  - » Develop statistical model



Sensor networks: low cost sensors

- Sensor node with low-cost CO sensor
  - » correcting interference of environmental factors: result

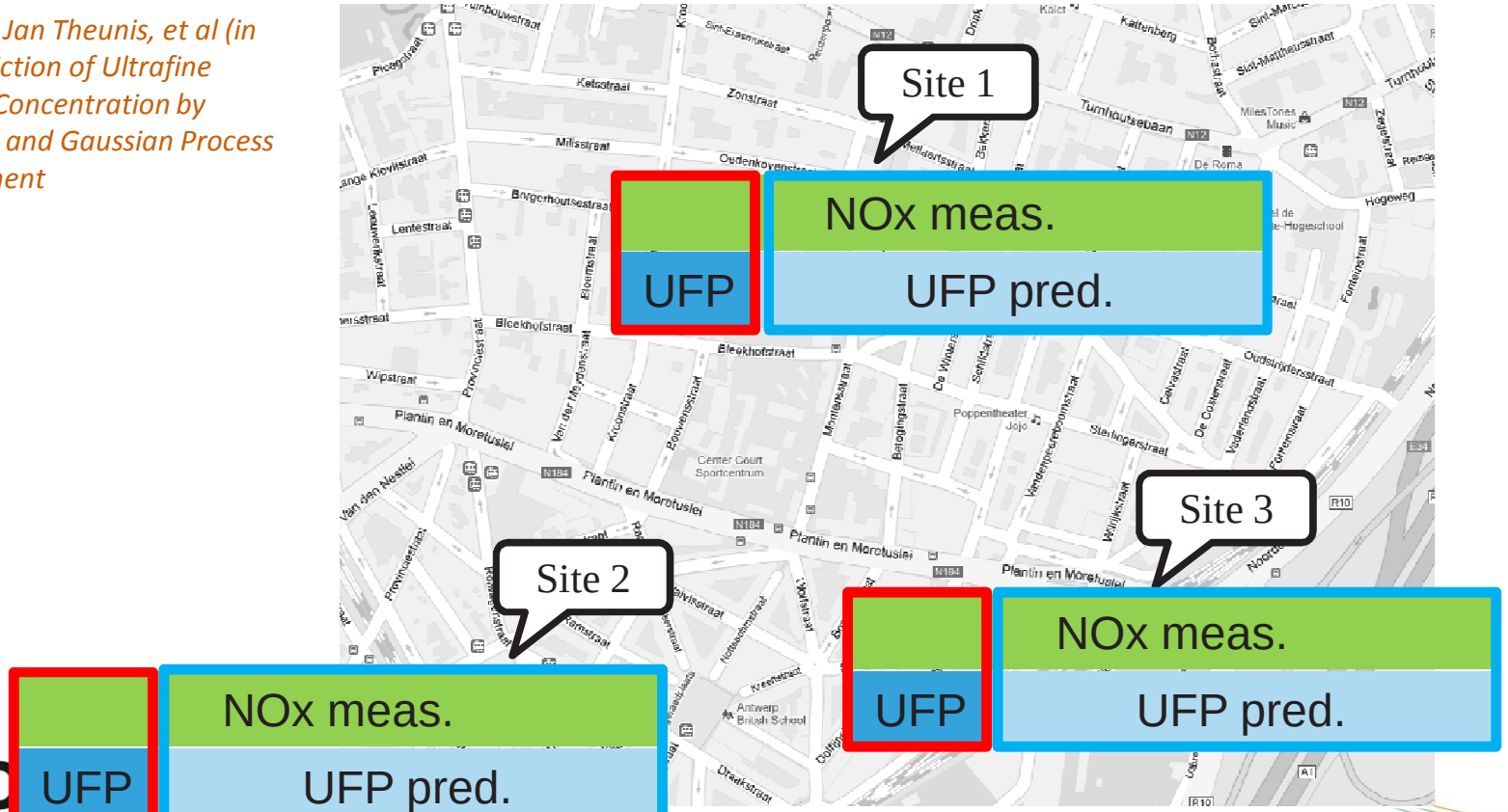




Sensor networks: sensors learning from each other

- Estimating UFP (ultrafine particles)
  - With the help of NO and NO_2 measurements

Matteo Reggente, Jan Theunis, et al (in preparation) Prediction of Ultrafine Particles Number Concentration by means of NO, NO_2 and Gaussian Process in Urban Environment

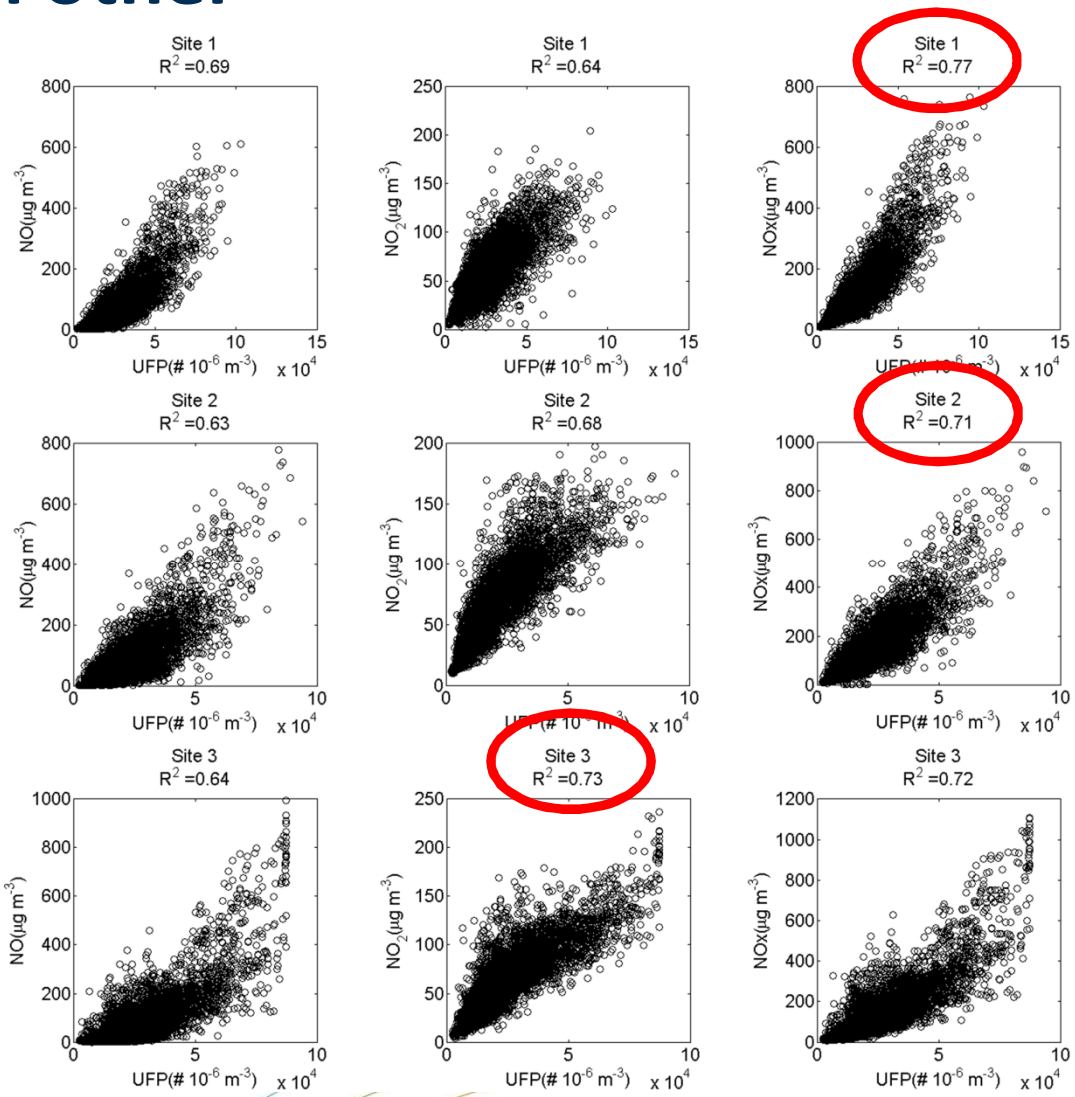


Sensor networks: sensors learning from each other: locations and measurements

AirPointer chemoluminiscence monitor → NO, NO_2
Grimm NanoCheck → UFP Concentrations (25-300nm)

Site	the distance from traffic (m)	Weekday traffic volume (veh $day^{-1)}$	Weekend traffic volume (veh $day^{-1)}$	Heavy duty fraction on weekday (and weekend) (%)
Site 3	20-30	37,000	25,000	7% (3%)
Site 1	3	5,000	4,000	5% (2%)
Site 2	2	4,000	3,000	4% (2%)

Sensor networks: sensors learning from each other



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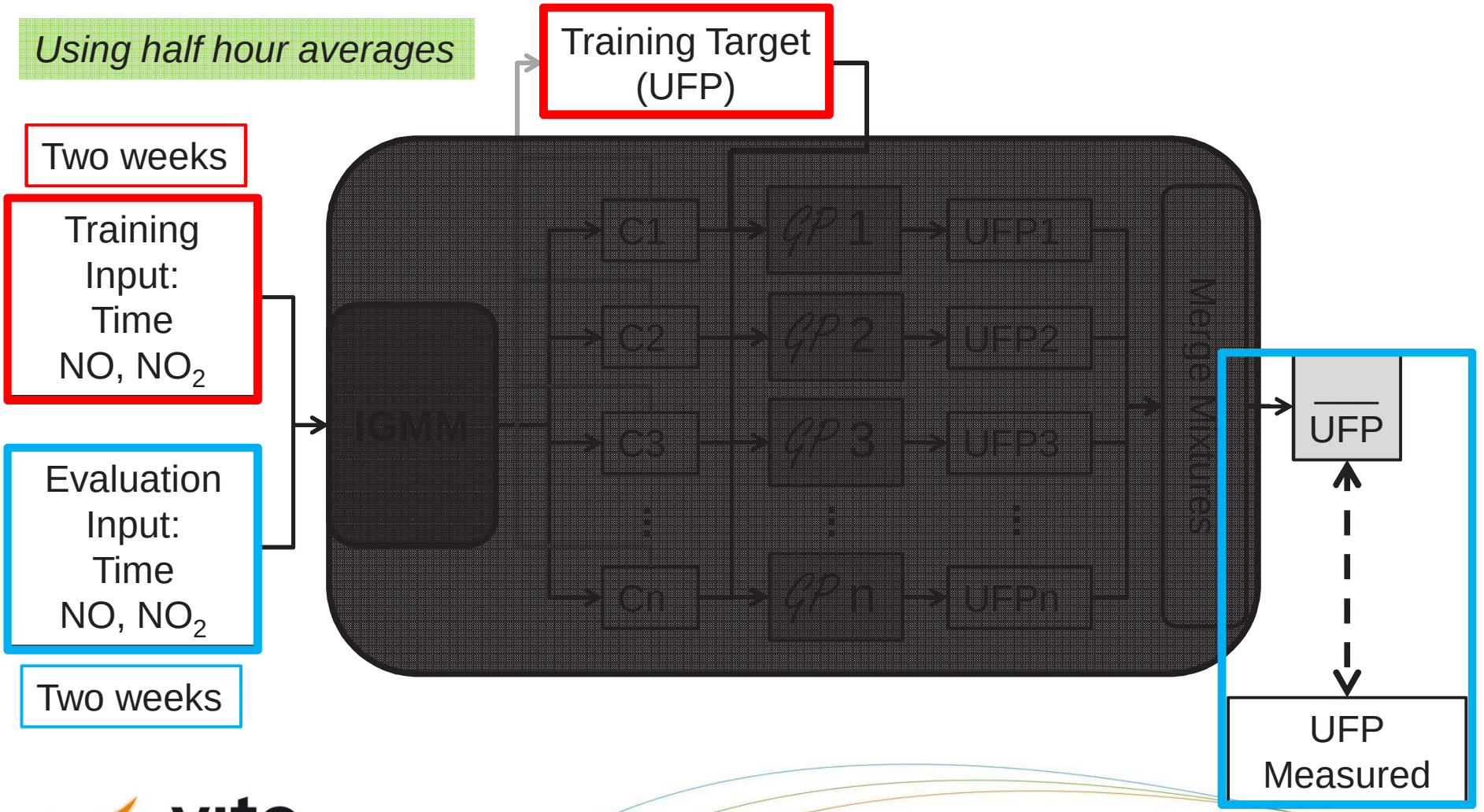
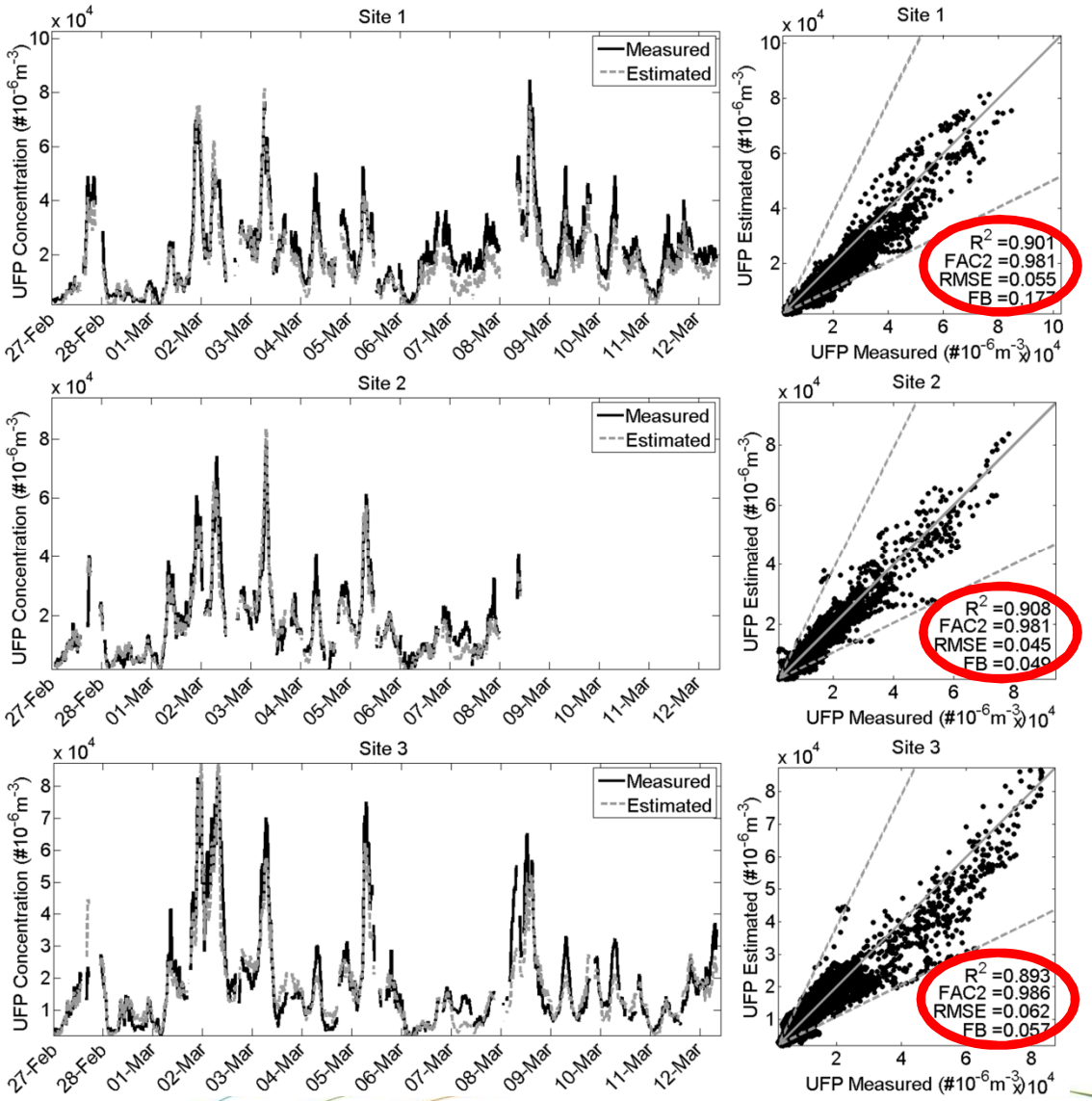
Sensor networks: sensors learning from each other: Statistical Modelling



Statistical modelling: Evaluation

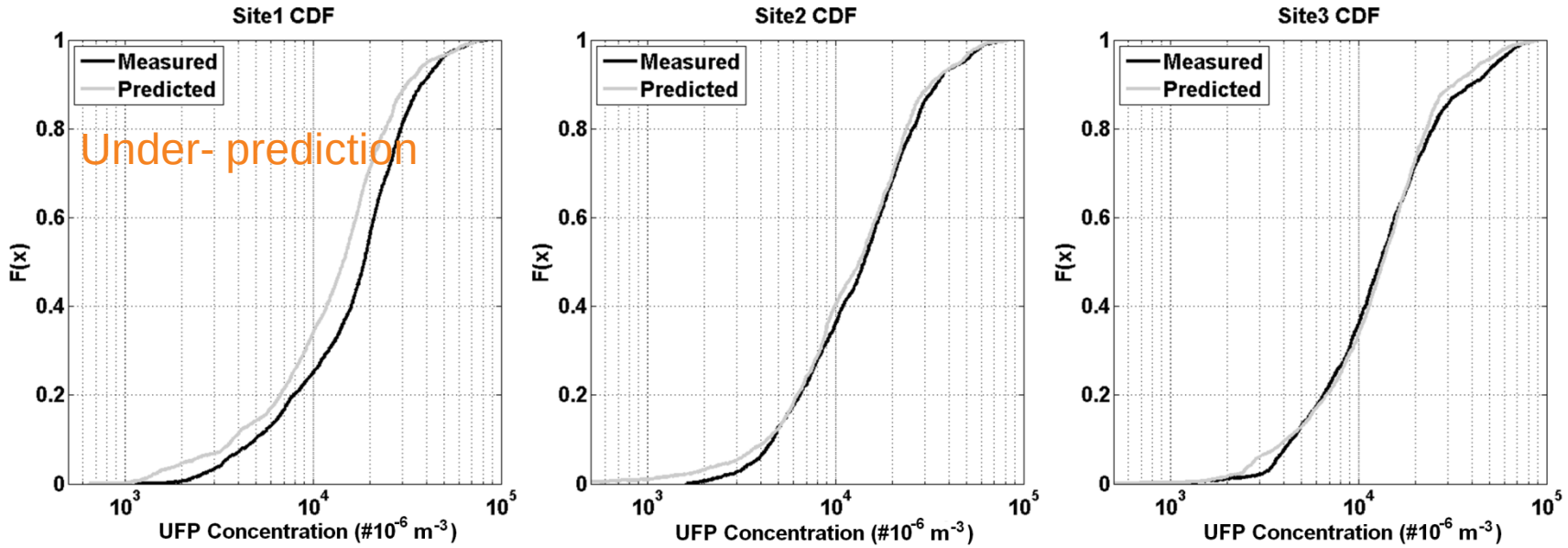
Time Series and Scatter Plot:

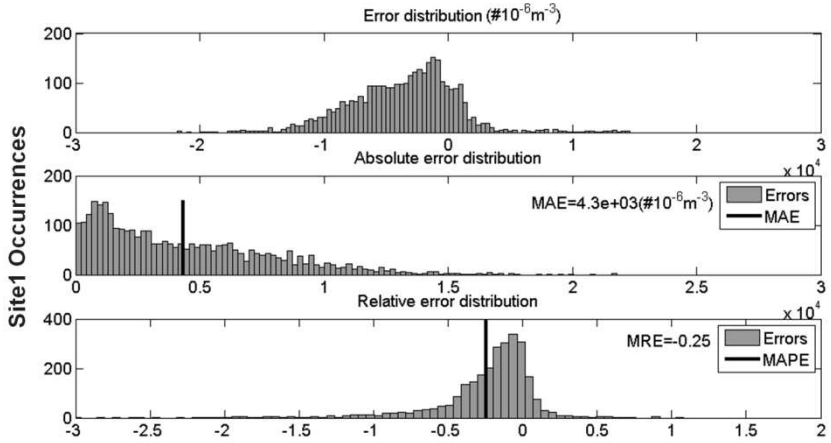
Measured versus estimated UFP concentrations

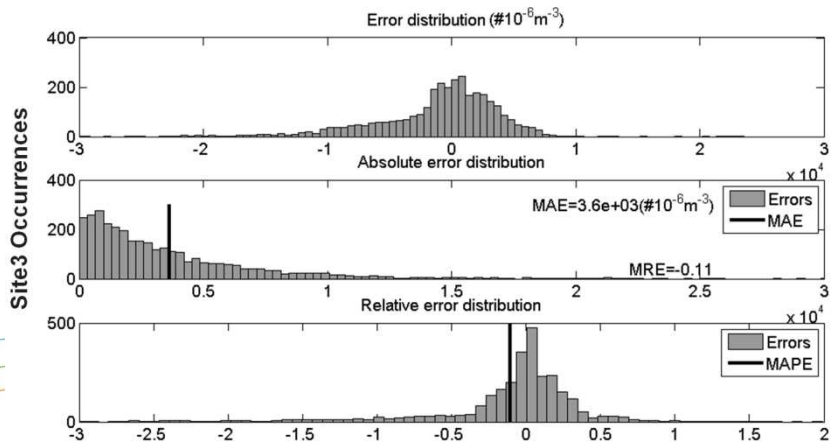


Statistical modelling: Evaluation

Empirical cumulative distribution and error distribution







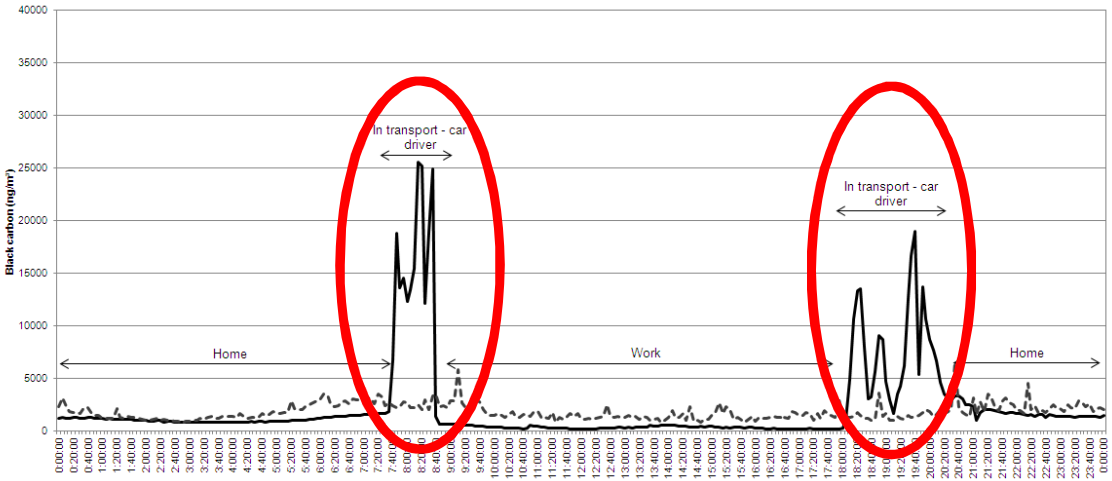
Mobile air quality monitoring

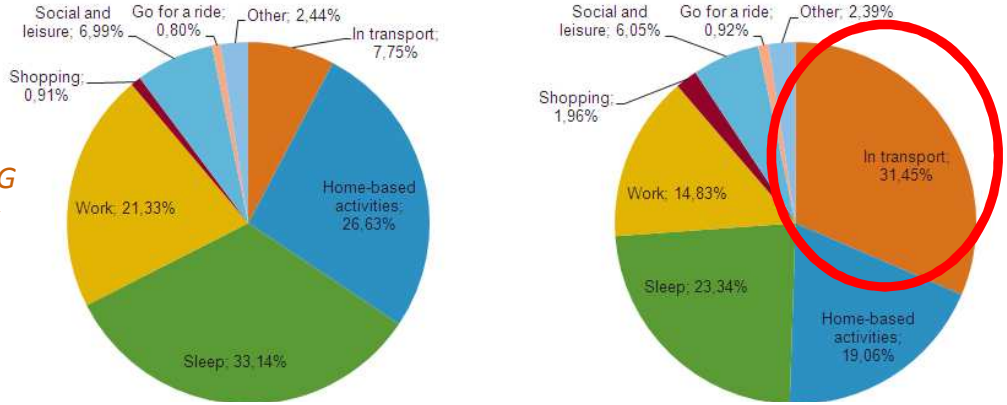
- Objectives :
  - Obtain spatially and temporally resolved data on air quality
- Applications :
  - Personal exposure monitoring
    - *Berghmans P, Bleux N, Int Panis L, Mishra V, Torfs R, Van Poppel M, 2009. Exposure assessment of a cyclist to PM10 and ultrafine particles. Science of The Total Environment, Volume 407, Issue 4, 1286-1298*
  - Hot-spot identification: mapping in urban and industrial environments to assess impact of local sources
  - High resolution mapping in urban environment
  - Data acquisition for model calibration

Dynamic exposure assessment: personal exposure monitoring

- Portable instrument
- Micro-aethalometer AE51
  - Black carbon

- Electronic diary





Average proportion of time spent on activities (left) and corresponding proportion of black carbon exposure per activity (right)

Dons E, Int Panis L, Van Poppel M, Theunis J, Willems H, Torfs R, Wets G (2011), Impact of time-activity patterns on personal exposure to black carbon, Atmospheric Environment, Volume 45, Issue 21, July 2011, p. 3594-3602,
Dons, E., Int Panis, L., Van Poppel, M., Theunis, J., & Wets, G. (2012). Personal exposure to Black Carbon in transport microenvironments. Atmospheric Environment 55, 392-398.

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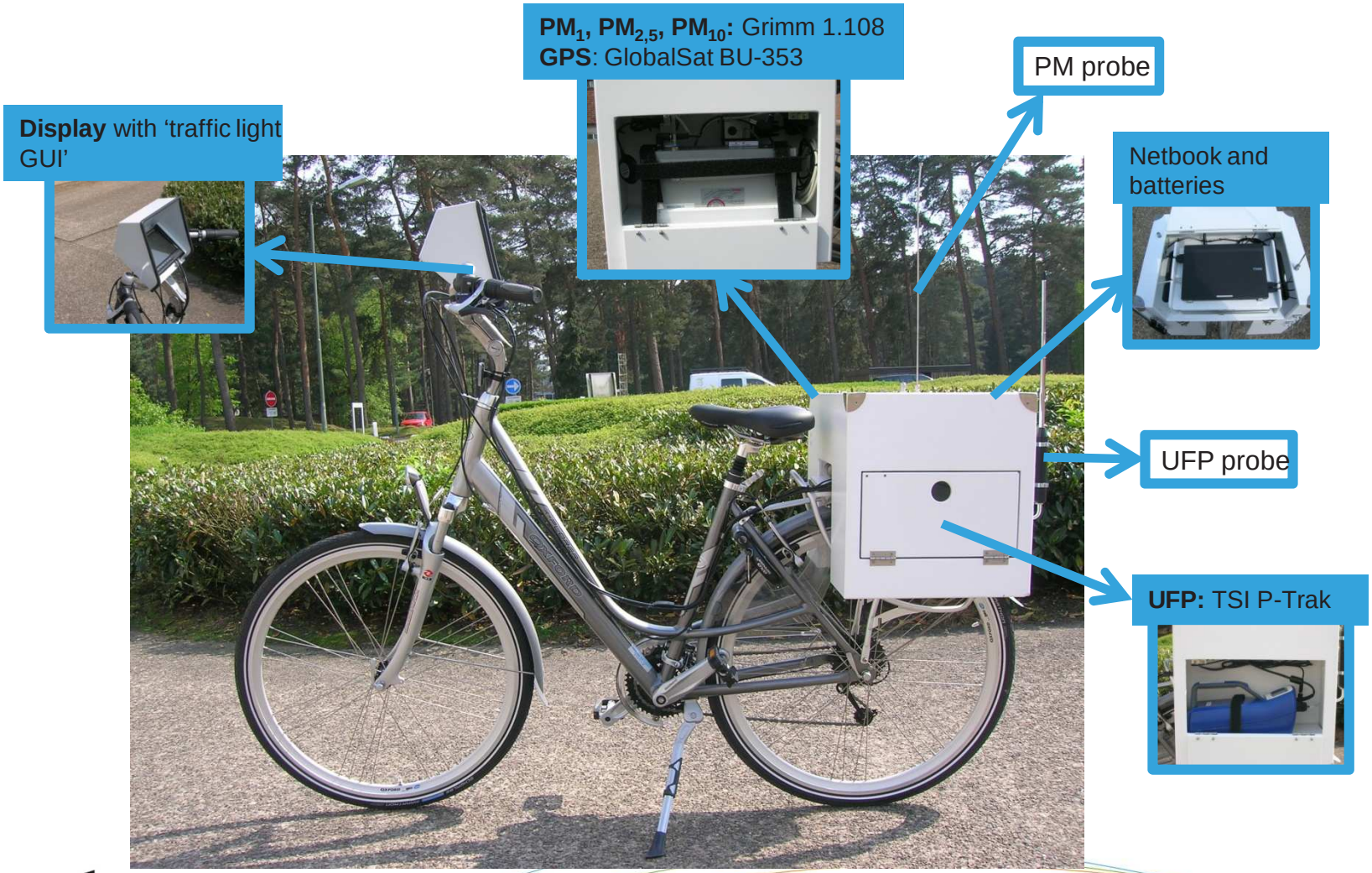
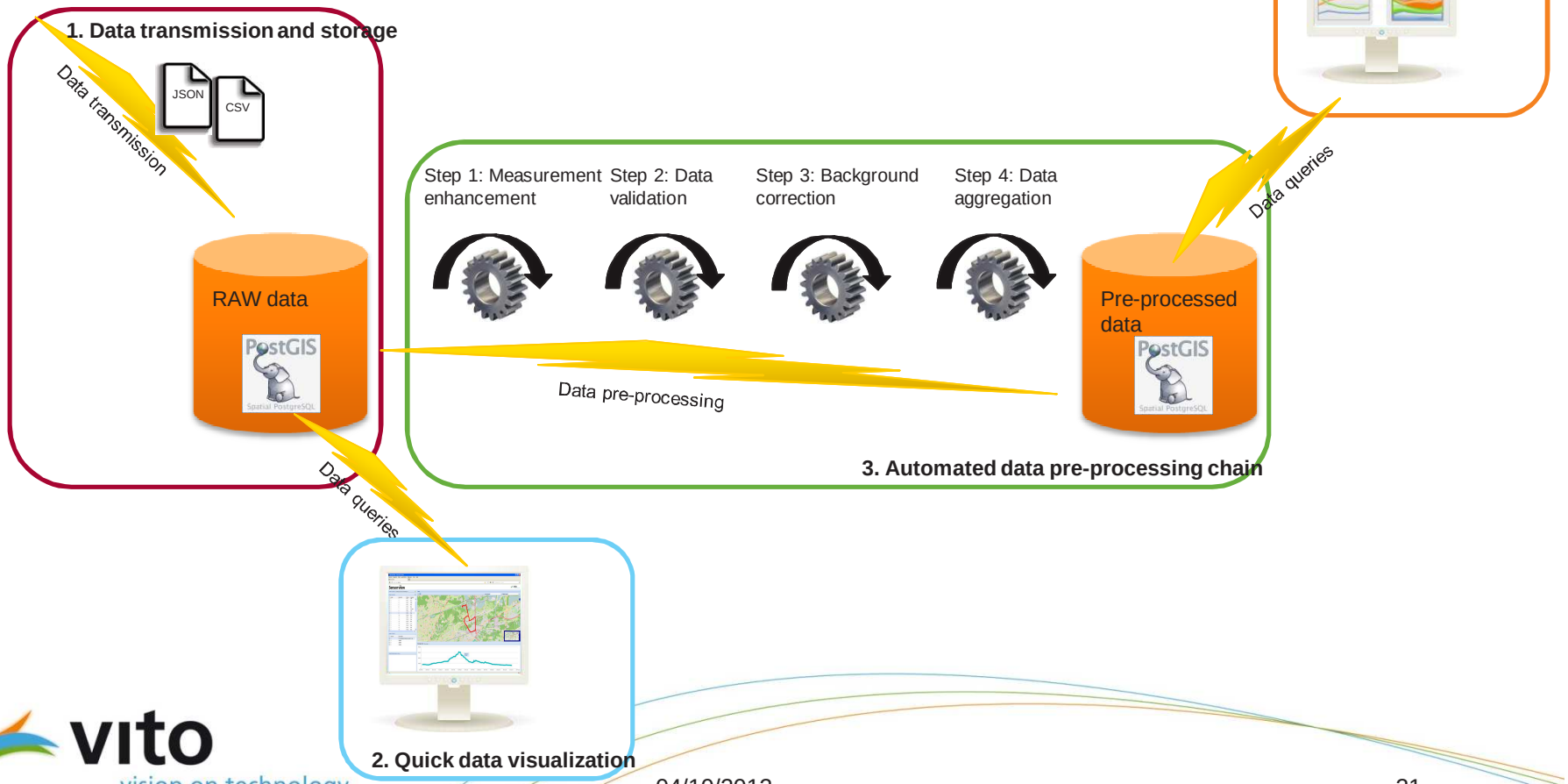
Aeroflex – Air Quality Bike

Bart Elen, Jan Peters, Martine Van Poppel, Nico Bleux, Jan Theunis, Matteo Reggente, Arnout Standaert (submitted 2012) The Aeroflex: a bicycle for mobile air quality measurements, submitted to Sensors



Aeroflex Data Infrastructure - Overview

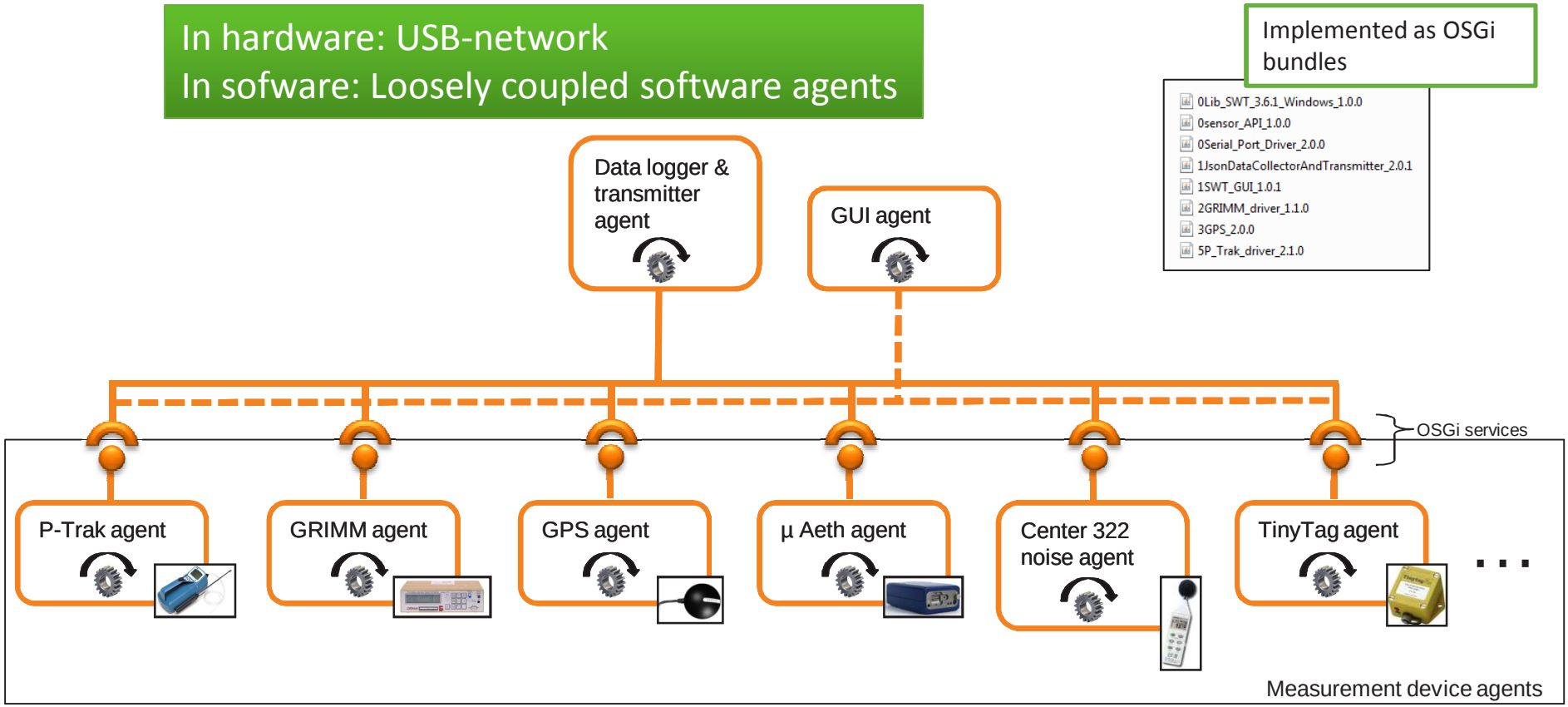
collect **lots** of mobile measurements
-> requires automated data processing



Aeroflex Data Infrastructure – Need for adaptability

» Must be ready to adapt set of measurement devices:

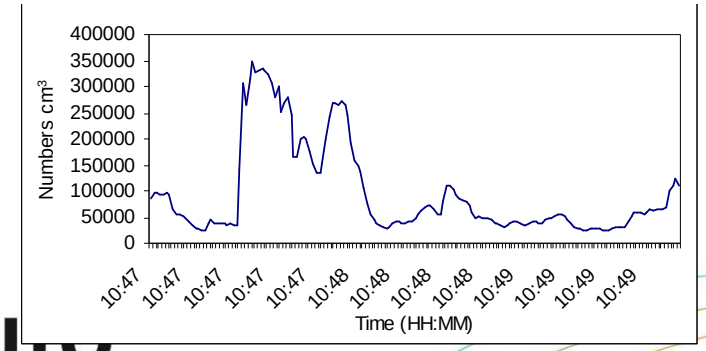
In hardware: USB-network
In sofware: Loosely coupled software agents

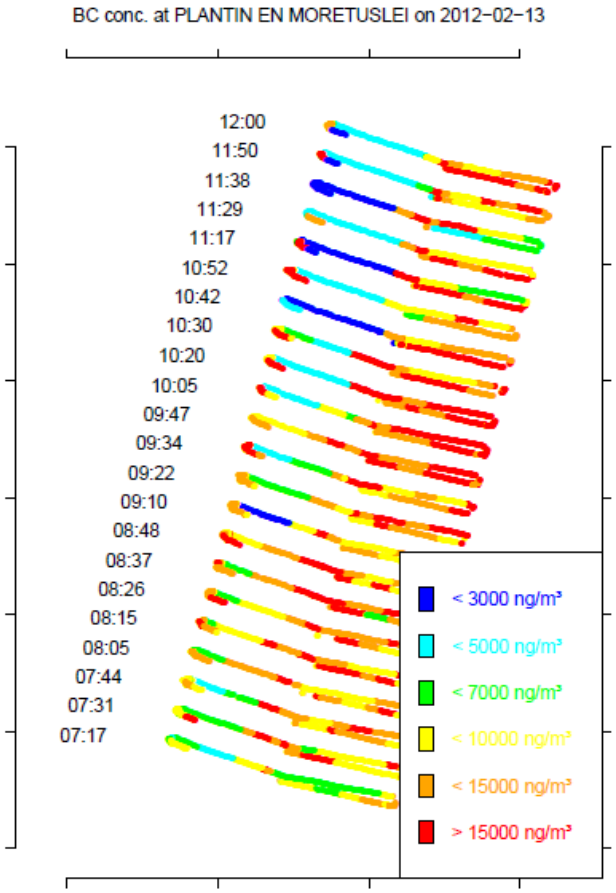


Mobile monitoring: methodology

- Spatio-temporal data
  - $L = \{\text{time, location, air quality}\}$
  - Single run: snap shot - Highly influenced by traffic discontinuity and short term incidents
  - Spatio-temporal series of measurements
    - Fixed route
    - Repeated measurements + data aggregation
    - Background correction

UFP number concentration Provinciestraat during a single passage



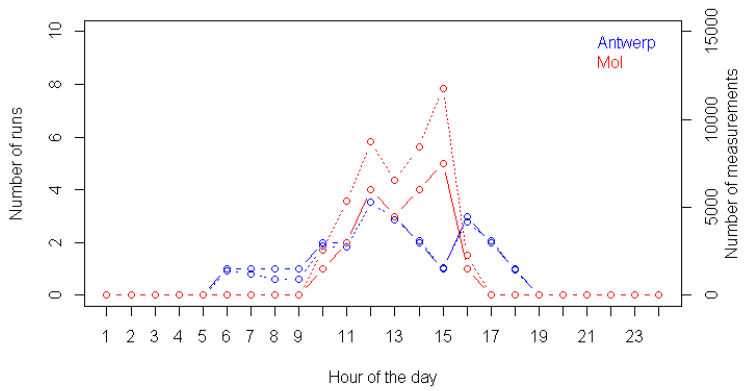


Spatio-temporal series

Repeated measurements: one morning

Case study

- Two locations: **Antwerp** (medium-sized city, 480 000 inhabitants, 985 inhabitants km-2) and **Mol** (provincial town, 34 000 inhabitants, 300 inhabitants km-2)
- Fixed route at both study sites :
  - 24 runs in Antwerp, 8 dates in the period between March 16 and April 8, 2009
  - 20 runs in Mol, 10 measurement dates between April 7 and April 23, 2010
  - Measurement times



Antwerp (5 km)

Mol (10 km)

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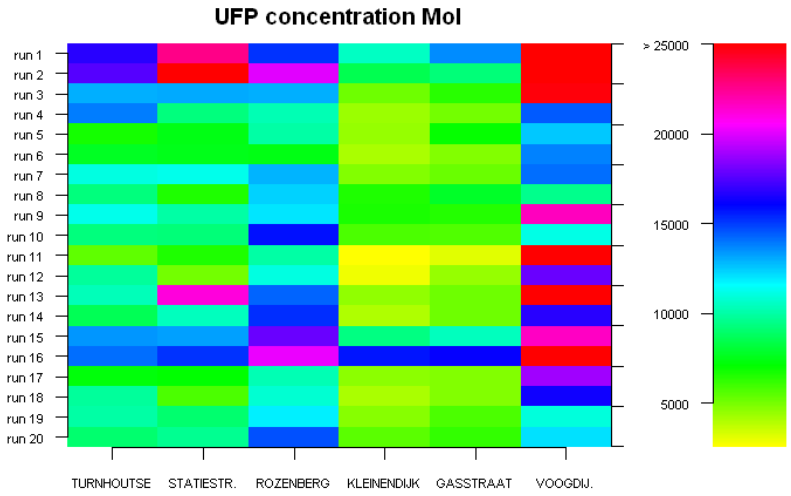
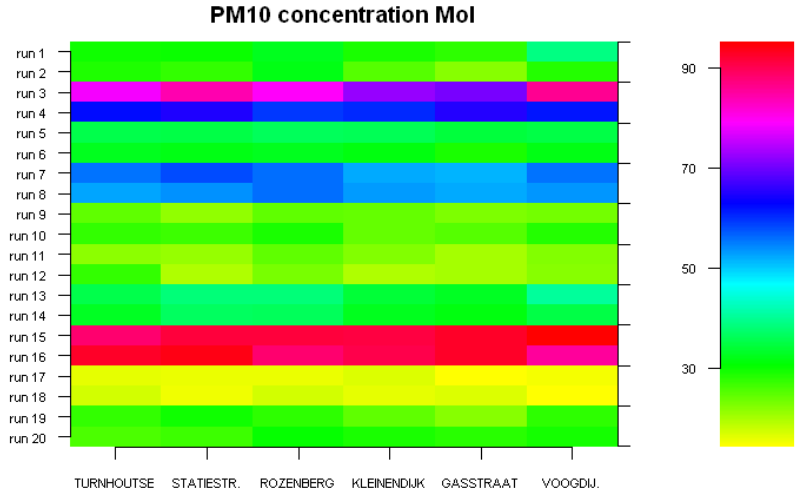
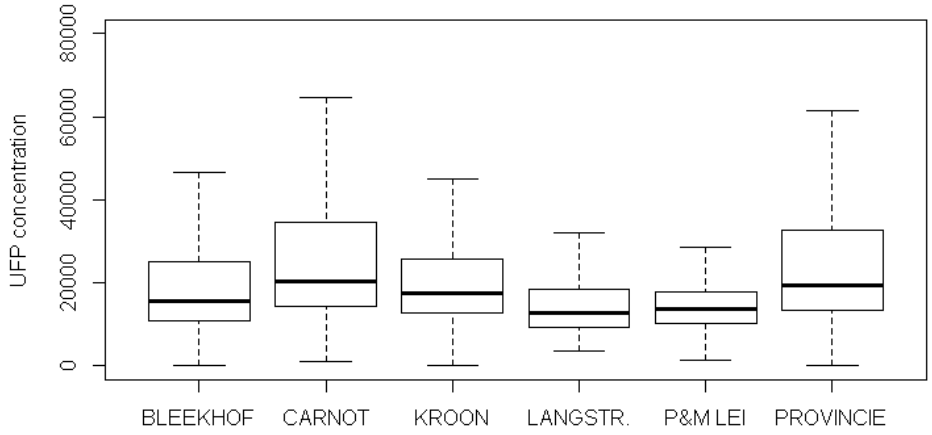
Methodology : street level aggregation





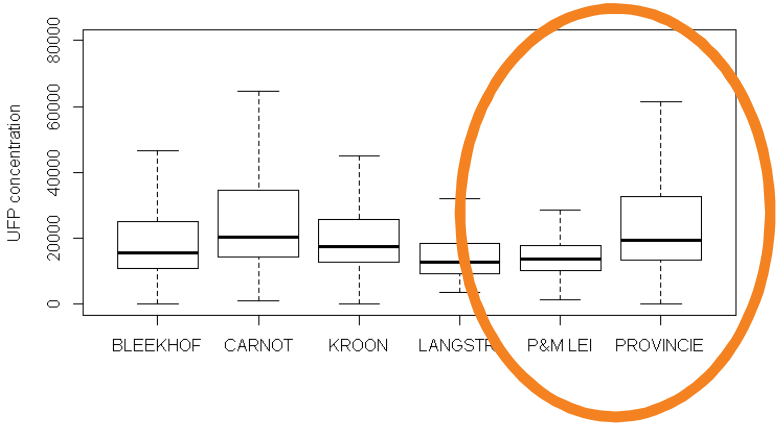


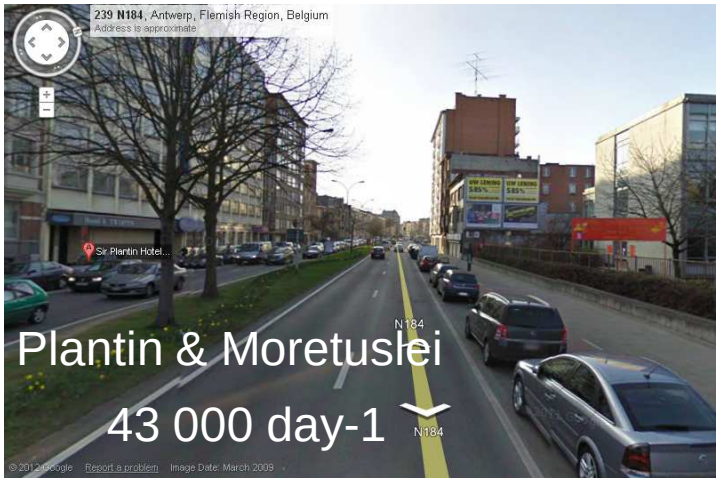
Street level aggregation of all data of the Mol route (above) and the Antwerp route (below) show significant differences in UFP concentrations between streets

Jan Peters, Jan Theunis, Martine Van Poppel, Patrick Berghmans (submitted 2012) Monitoring PM10 and ultrafine particles in urban environments using mobile measurements, submitted to Aerosol and Air Quality Research

Methodology : street level aggregation

- Exponential decay
- Distance Aeroflex – traffic important
- → Restrictions for use of Aeroflex : measurements are representative in the first place for the pollutant concentrations that cyclists are exposed to.

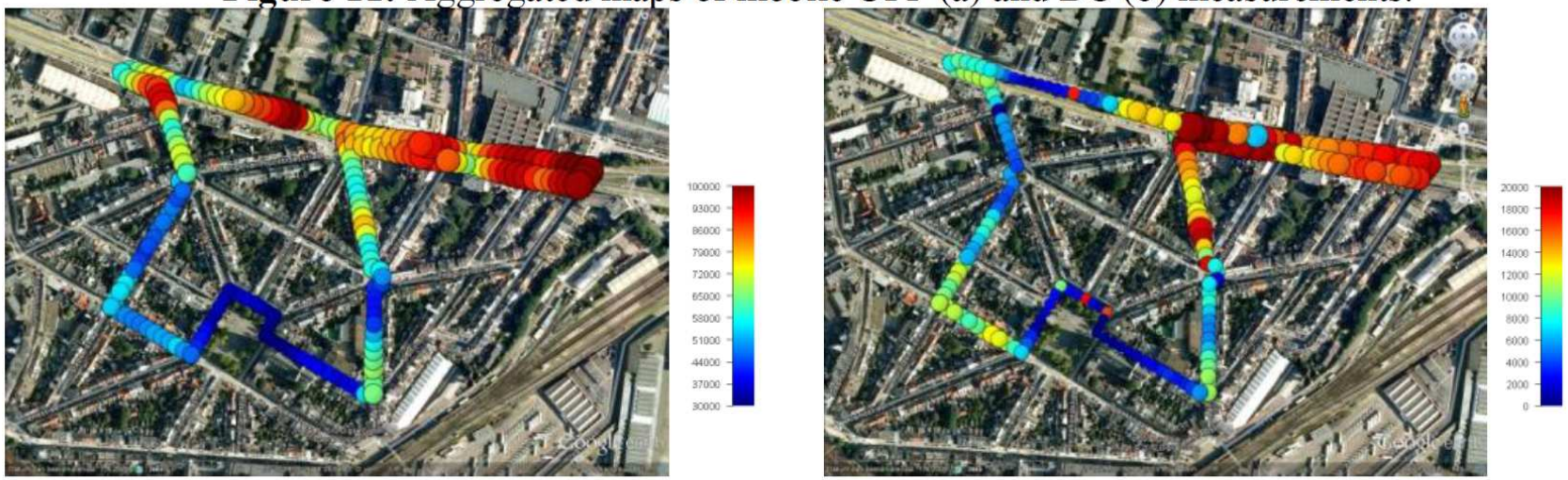




Methodology : traffic discontinuity and short-term incidents

- Data aggregation → representativeness
  - Gaussian kernel smoothing of spatio-temporal data
  - Level out part of the variability that is related to traffic discontinuity and short-term incidents
  - Smooth accumulated data (eg. at traffic light)

Figure 11: Aggregated maps of mobile UFP (a) and BC (b) measurements.



(a) (b)

Participatory monitoring

• detailed spatial and temporal scale dynamic exposure assessment

• corresponding to people's personal environment and activities

• collaborative efforts to collect large representative datasets for mapping urban environment

• enhance people's understanding of the urban environment

• contribute to collaborative decision-making processes

Participatory sensing – Portable air quality monitoring devices

» Opportunistic sensing: people collecting data during their normal daily routine

User friendly !

3 groups of 'City Guards' measuring air quality in Antwerp during 6 months

BC Mapper

Portable air quality monitoring kit with **minimal impact** on volunteers

Home station:
- reading out the data
- clock synchronisation
- send data to database
- recharge equipment

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Participatory sensing – Portable air quality monitoring devices

- https://sites.google.com/site/urbanbcmeasurements/home

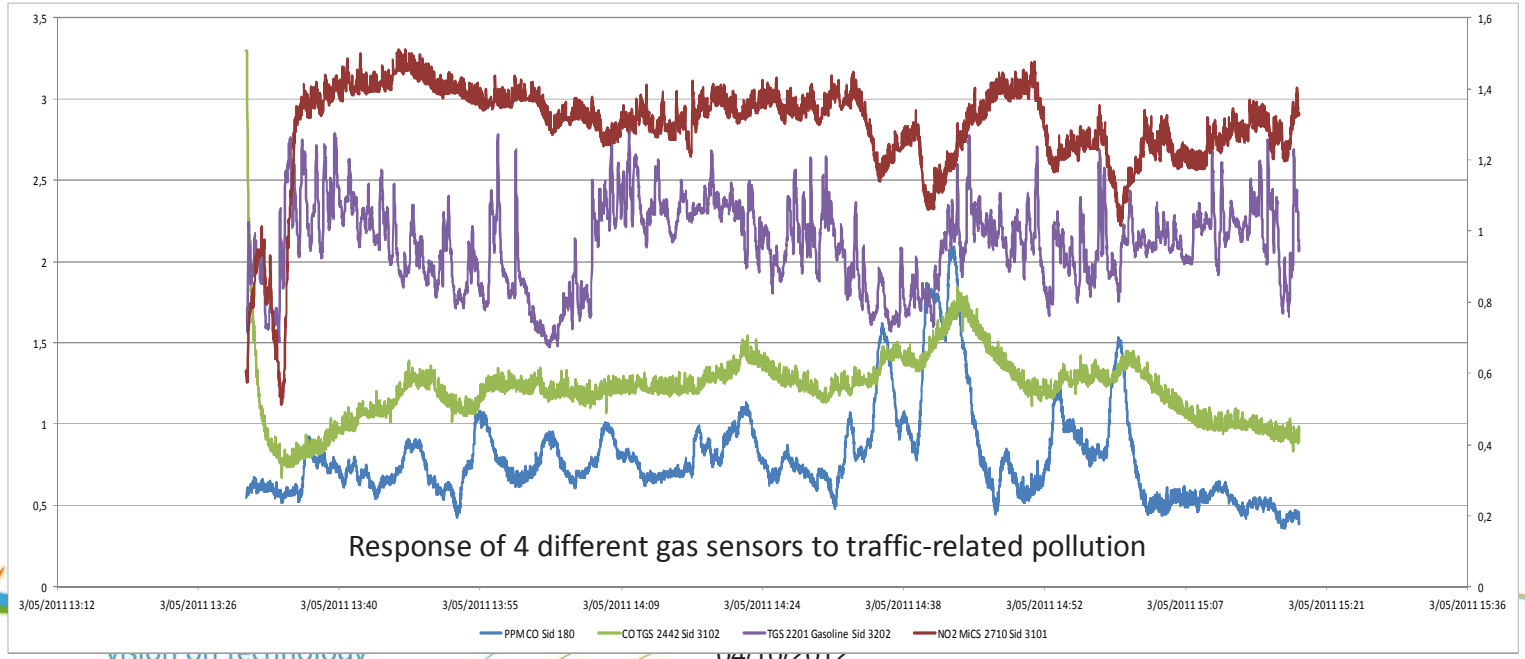
- Challenges:
  - GPS corrections and exact locations
  - Indoor versus outdoor
  - Interferences, e.g. smoking

Low cost measurement devices for large scale data collection: EveryAware SensorBox

Individual low-cost sensors → Sensor array (e-nose)

→ poor selectivity
→ cross-interference
→ drift
→ T and humidity effects

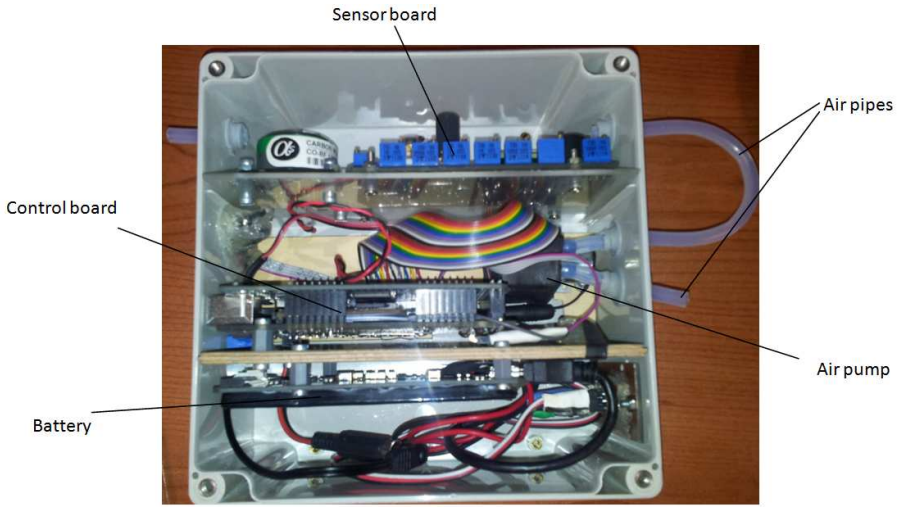
→ Exploit partial selectivity towards different gas components using machine learning tools to achieve multivariate calibration

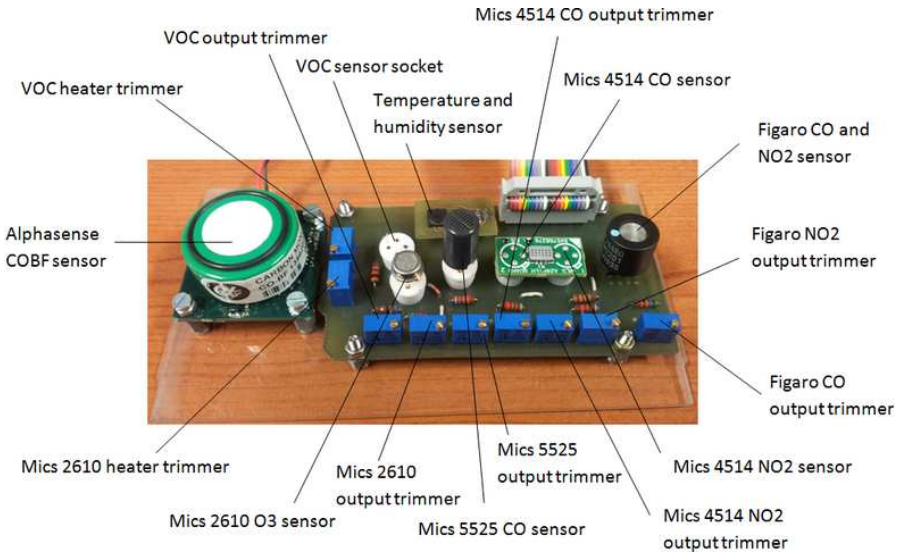


Response of 4 different gas sensors to traffic-related pollution

Low cost measurement devices for large scale data collection: EveryAware SensorBox

Bart Elen, Jan Theunis, Stefano Ingarra, Andrea Molino, Joris Van den Bossche, Matteo Reggente and Vittorio Loreto (2012) The EveryAware SensorBox: a tool for community-based air quality monitoring, paper presented at the Workshop Sensing a Changing World, May 9-11, 2012, Wageningen, The Netherlands. (http://www.geo-informatie.nl/workshops/scw2/papers/Elen_etal_EveryAware_SensorBox.pdf)

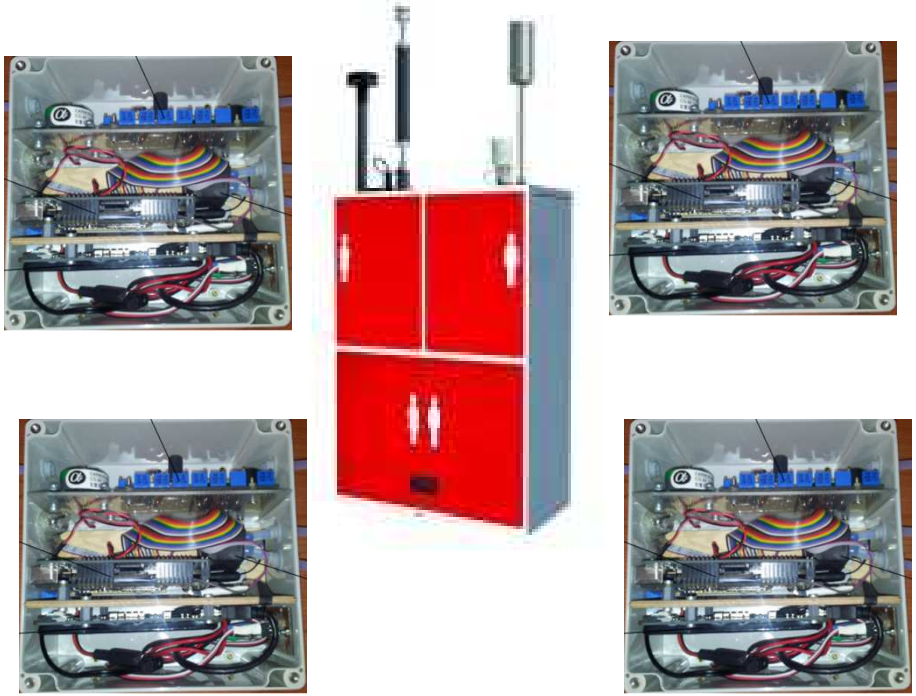




10 sensor e-nose
- 7 sensors which react on traffic pollution
-Ozone, Temperature and Relative humidity for sensor correction

Low cost measurement devices for large scale data collection: Multivariate Calibration

- Deployment of the Sensor Boxes close to a monitor device
- Use them both stationary and mobile

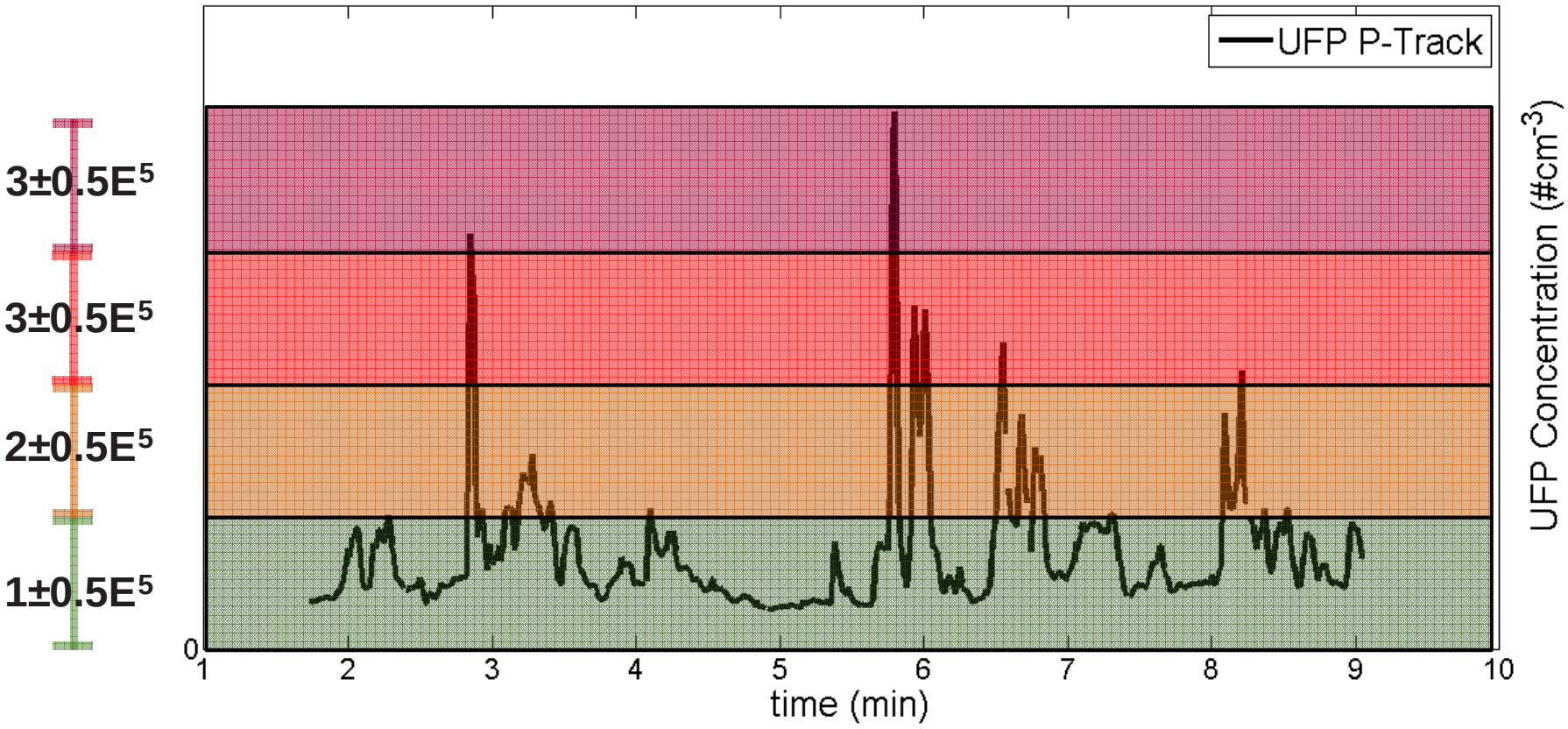


Alternative 1 – Continuous Mobile Calibration

» **Deployment of a subset of Sensor Boxes close to portable and "TRUSTABLE" device in a mobile contest**

Alternative 2 – Discrete Mobile Calibration

- Deployment of a subset of Sensor Boxes close to portable and “TRUSTABLE” device in a mobile contest
- **Classification Problem**
  - **Target: [BC, UFP]**



Acknowledgments

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» *The IDEA project is funded by the Flemish Agency for Innovation through Science and Technology*

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