



25/11/2013

Low-cost Air Quality Monitorin Methods

MACPoll Workshop on Ambient air Quality, IES JRC, European Commission - Ispra (VA), Italy- November 19, 2013

Low-cost Air Quality Monitoring

Objectives

- *Spatial variability*
- *Health relevance*
- *Traffic related*
- *BC, UFP >> PM10/2.5*
- *NO₂/(NO) >> O₃, CO*

High-resolution mapping

- Spatio-temporal dynamics of air pollutants
- Potential users: authorities, urban planners, air pollution modellers

Hot-spot identification

- Fast and reliable method for hot spot detection
- Targeted measurements to potential hot-spots
- Potential users: city authorities, environmental agencies

Exposure monitoring

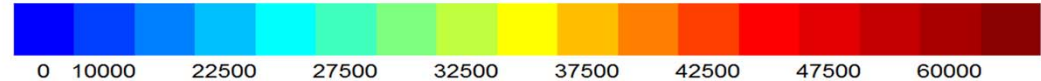
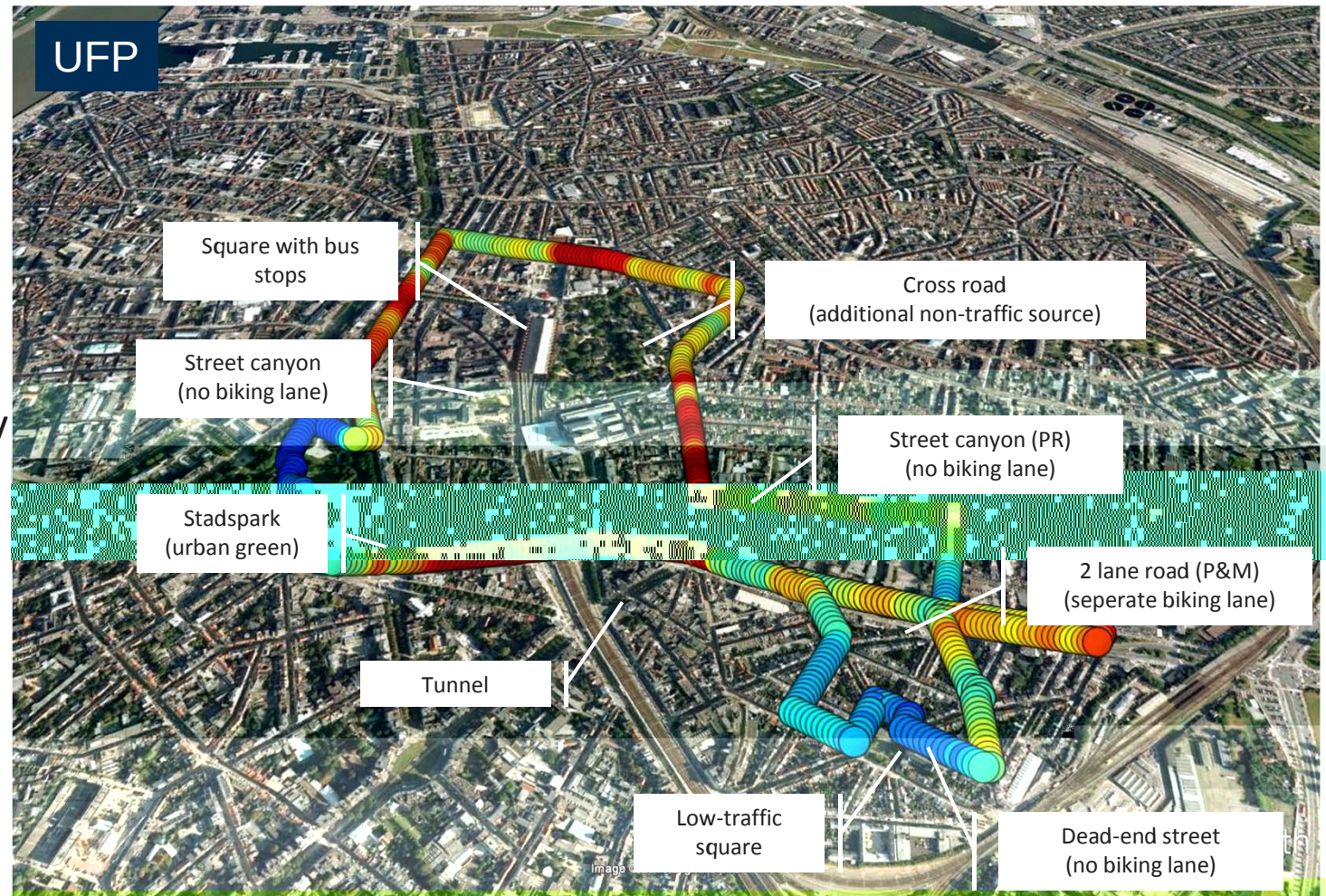
- Validity for confined area and period : extrapolation?
- Combine with activity patterns for exposure assessment

Low-cost Air Quality Monitoring Methods Strategies

- » Portable monitors in mobile applications
- » Low cost sensors in dense networks
- » Low cost sensors in mobile applications

Portable monitors in mobile applications - **Lar e systematic data set**

- 2 routes in Antwerp
- repeated
  - » 259
  - » 94
- UFP and BC
- Representativity
- Street-level comparisons



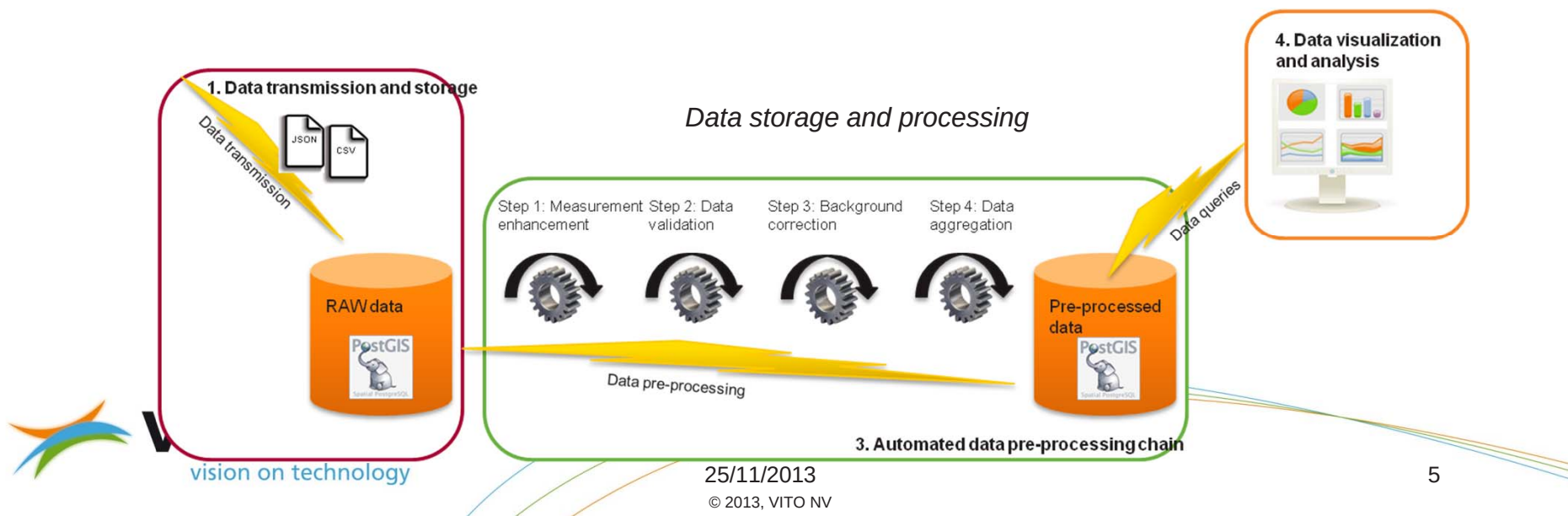


Portable monitors in mobile applications – Black Carbon Mapper

→ *Black Carbon Mapper*



left : micro-Aethalometer with GPS in carrier bag;
right: 'home station' with software to read out data,
send to database, synchronise , recharge equipment





Portable monitors in mobile applications - **targeted**

Cyclists look for clean path on commuting routes
Measurements carried out by volunteers of a local action group





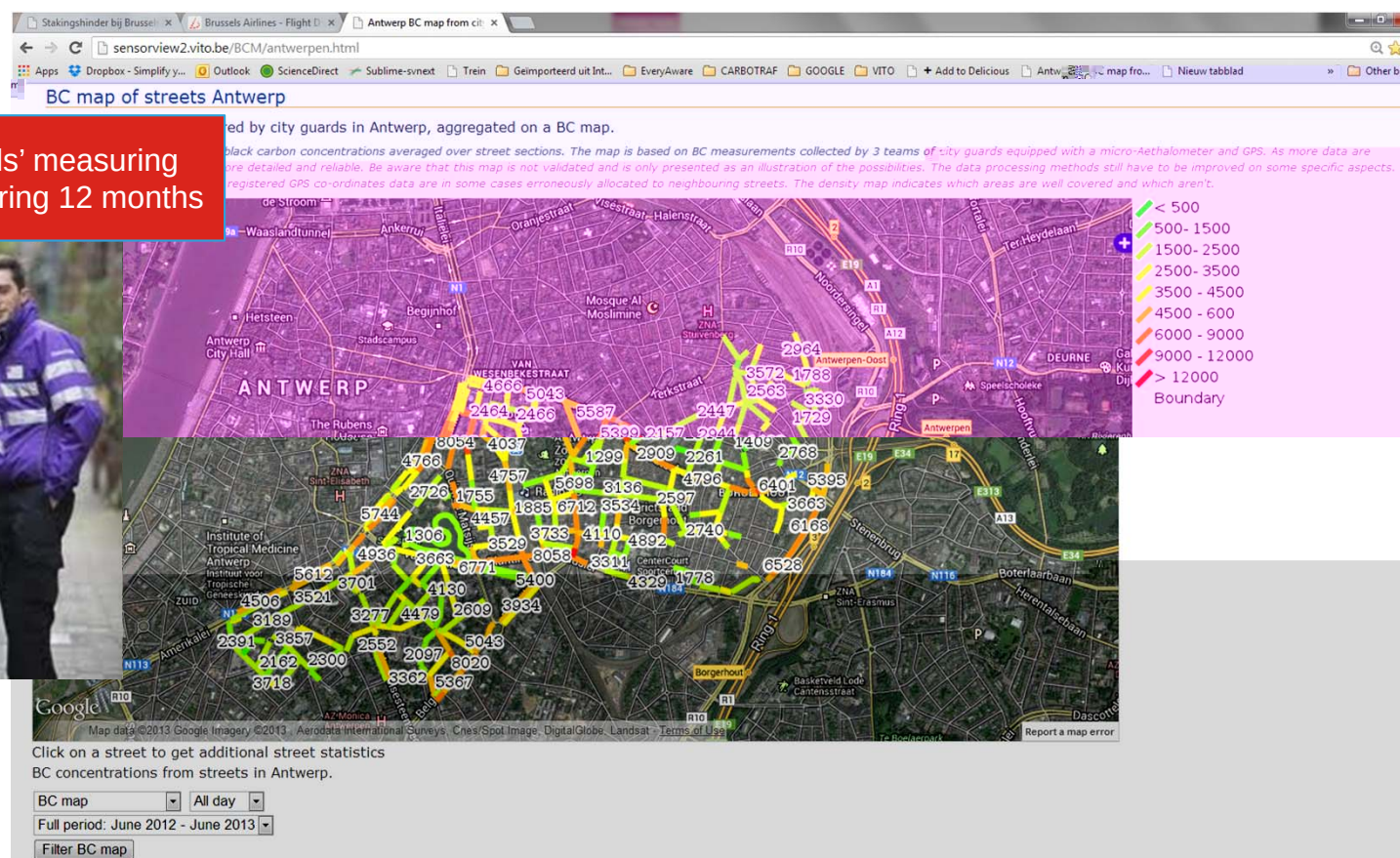
Portable monitors in mobile applications – opportunistic

City employees monitor air quality during their normal working routine

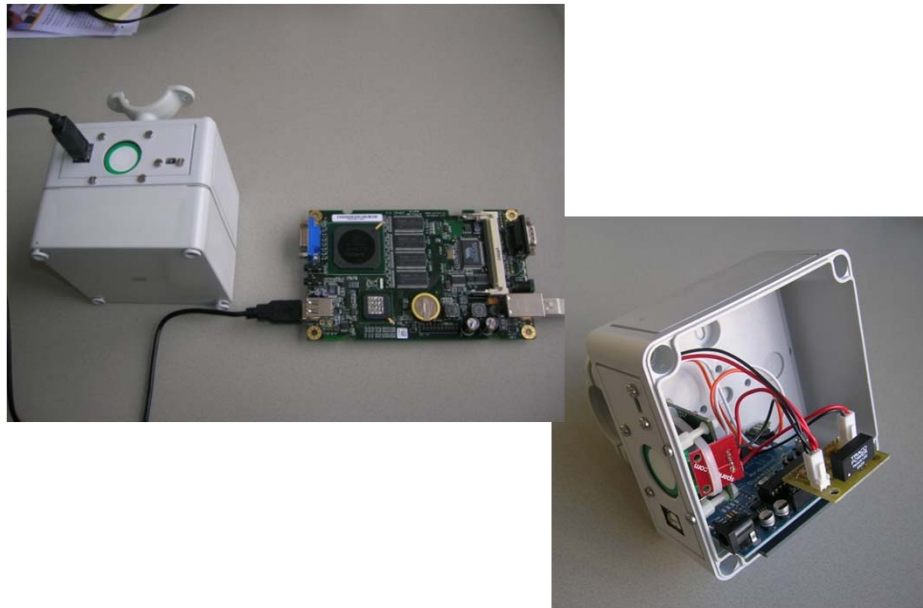
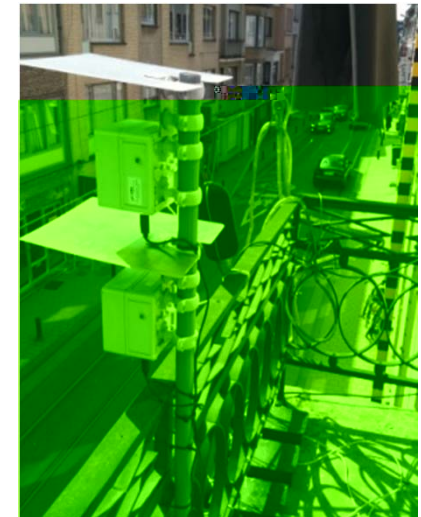
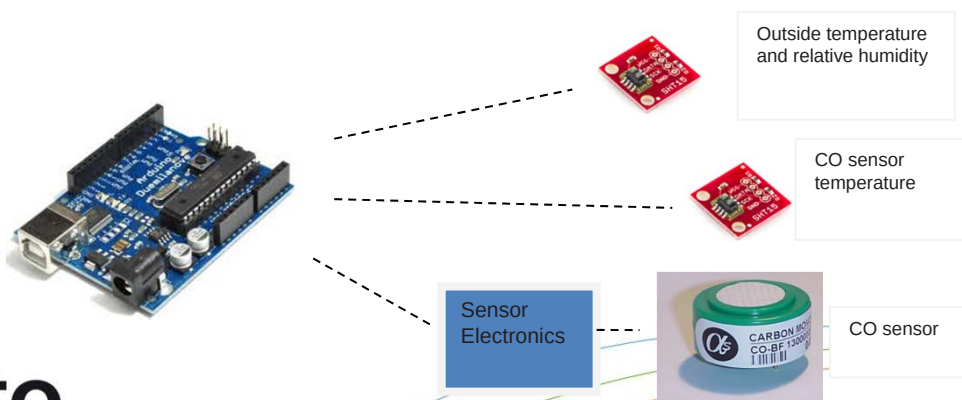
3 teams of 'City Guards' measuring air quality in Antwerp during 12 months



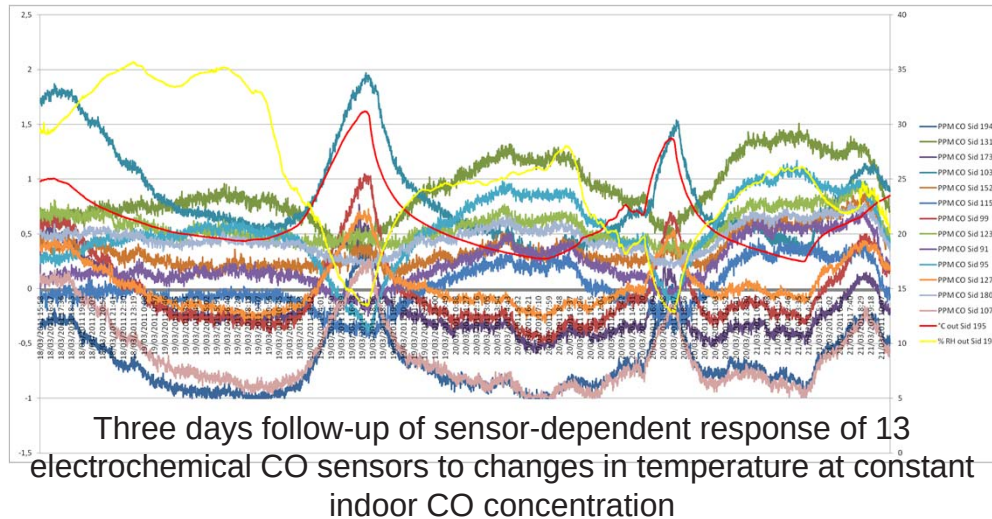
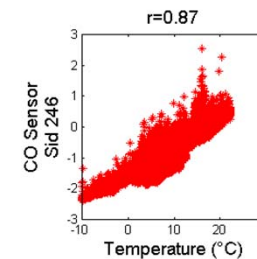
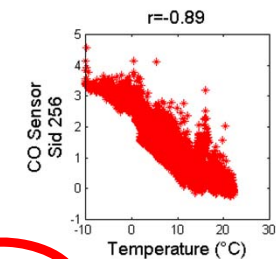
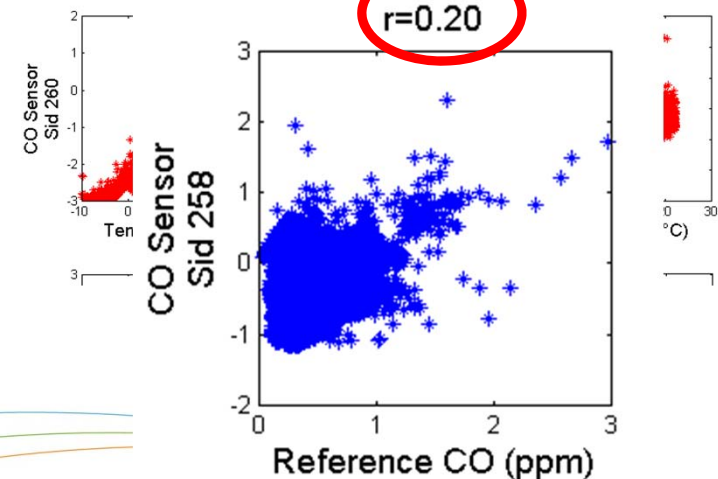
BC Mapper



Low cost sensors in dense networks - Sensor node with low-cost CO sensor



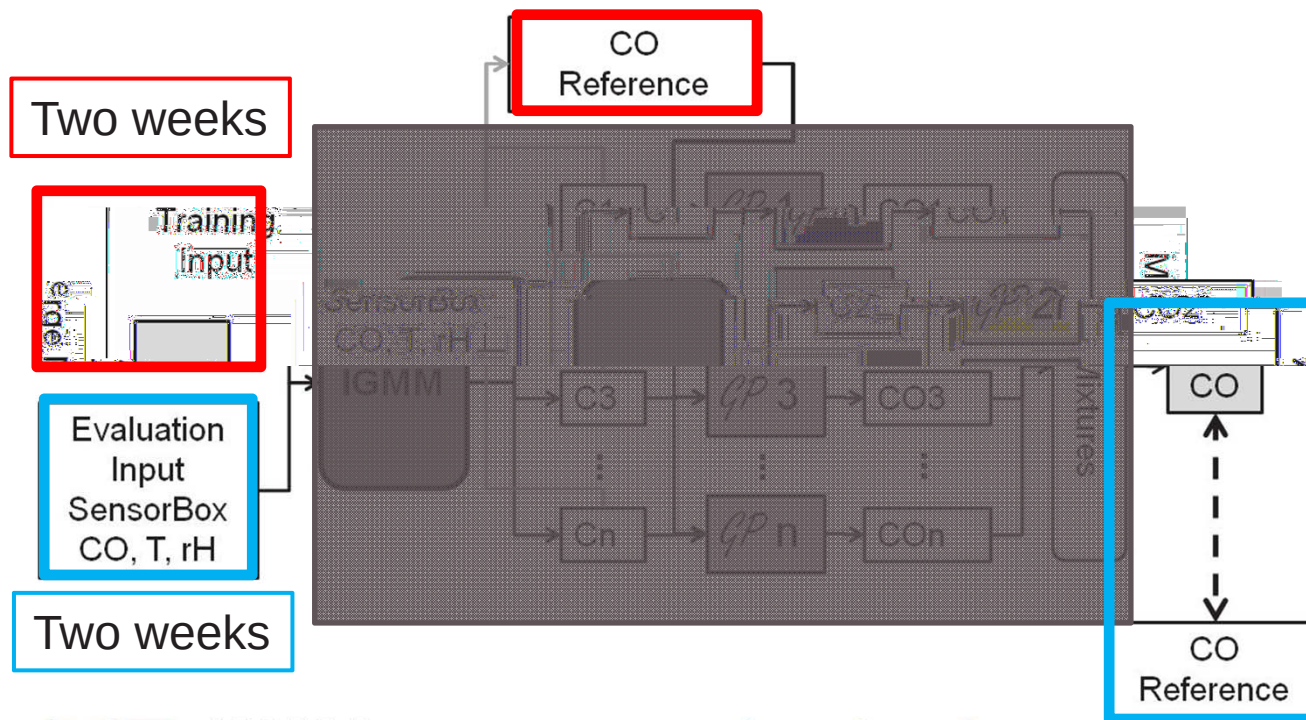
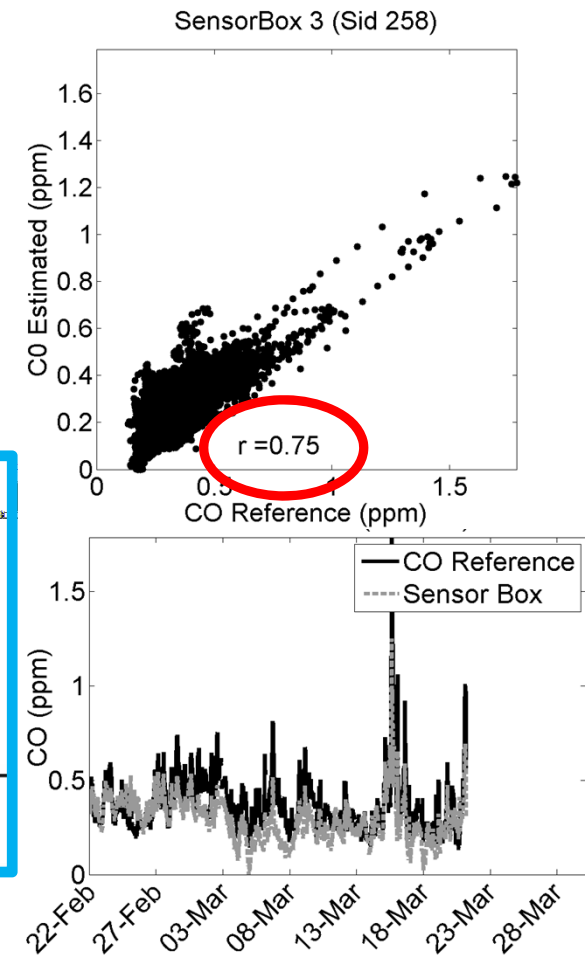
Low cost sensors in dense networks - Sensor node with low-cost CO sensor



Low cost sensors in dense networks - **Sensor node with low-cost CO sensor**



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



Low cost sensors in mobile applications



- » Need for large datasets with a lot of repetition
- » Available instruments too expensive for wide-scale deployment



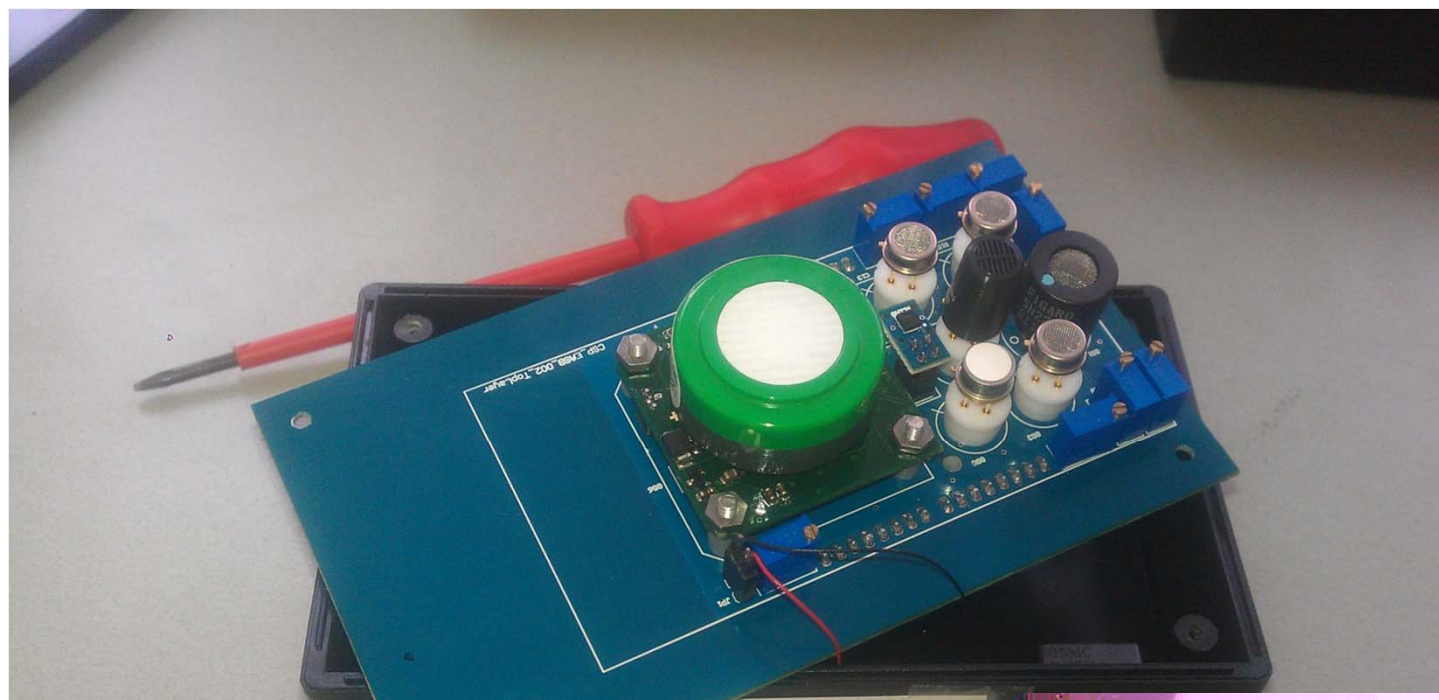
- *Widescale participatory measurements of urban environment*
  - *Using low-cost instruments based on commercially available components*
  - *Providing direct feedback to the user*
- collaborative efforts to collect large representative datasets for mapping urban environment corresponding to people's personal environment and activities
  - enhance people's understanding of the urban environment → awareness and involvement

The EveryAware SensorBox

Individual low-cost sensors



Sensor array (e-nose)



6 metal oxide
sensors

1 electrochemical

7 sensors which react on traffic pollution
Ozone, Temperature and Relative humidity

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)

Data collection – two campaigns



» Antwerp – long term

- » Stationary measurements at reference station (traffic location)
  - » Long time deployment of 6 sensor boxes :
    - » 2 sensor boxes : October 2012 - ...
    - » 6 sensor boxes : March 2012 - ...
- » Mobile measurements
  - » October – December 2012
  - » 17 people, > 300 h measurements



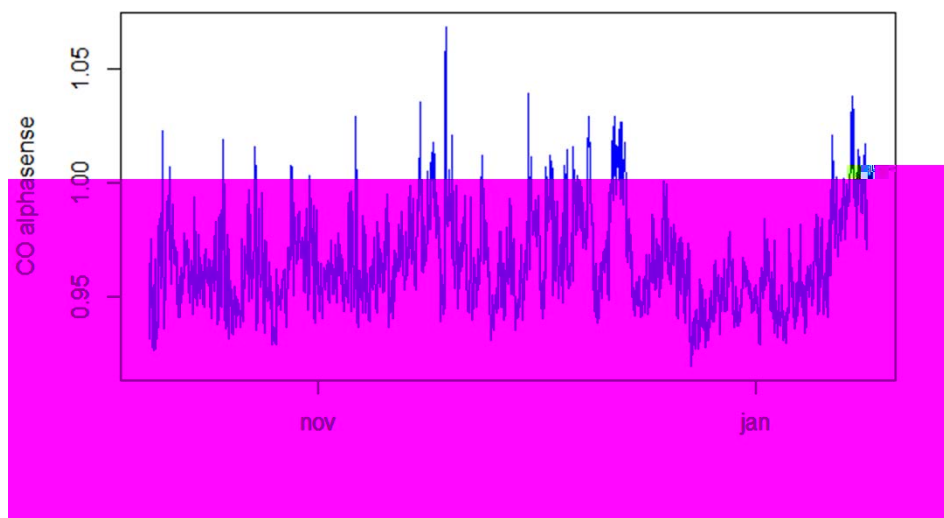
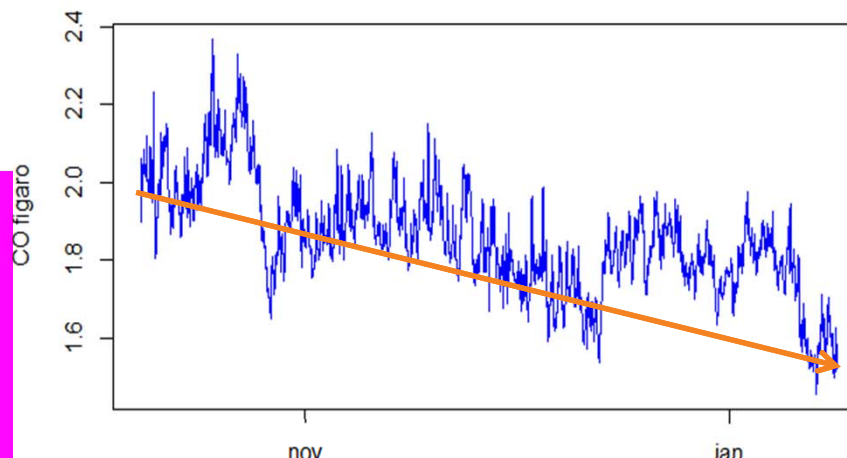
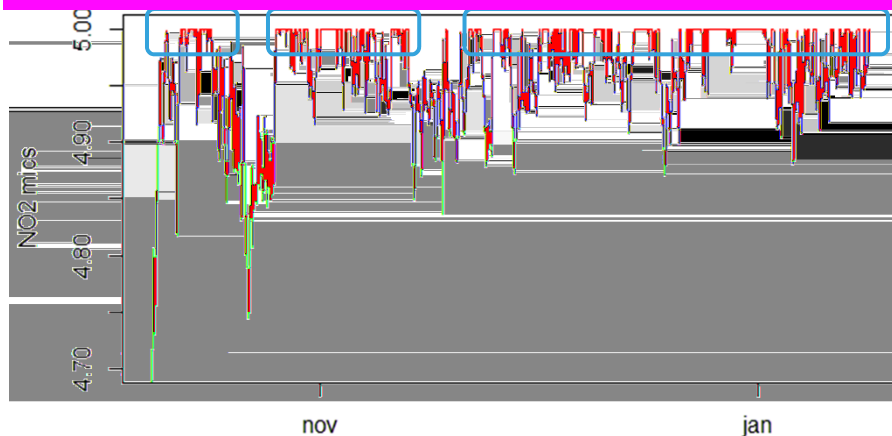
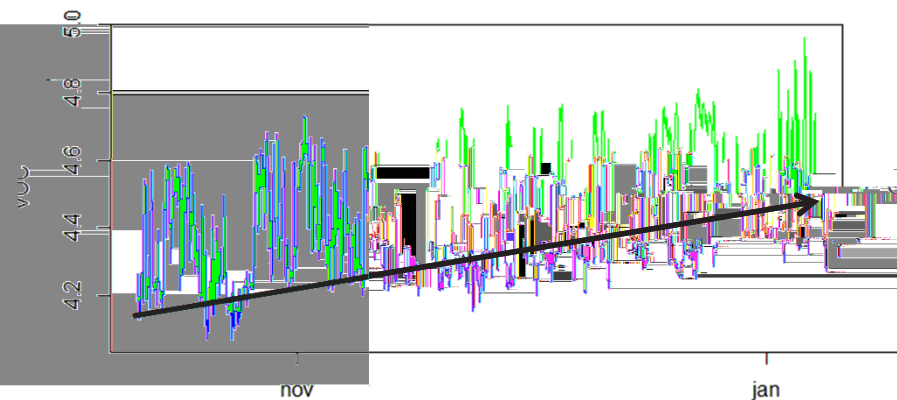
» Turin – short term

- » Stationary measurements at entrance gate (near busy road)
  - » 2 weeks (end Januari 2013) - 20 SBs
- » Mobile measurements
  - » 2 trips (approx. 4 h) - 4 SBs

» *Always together with micro-aethalometer : BC as reference indicator*

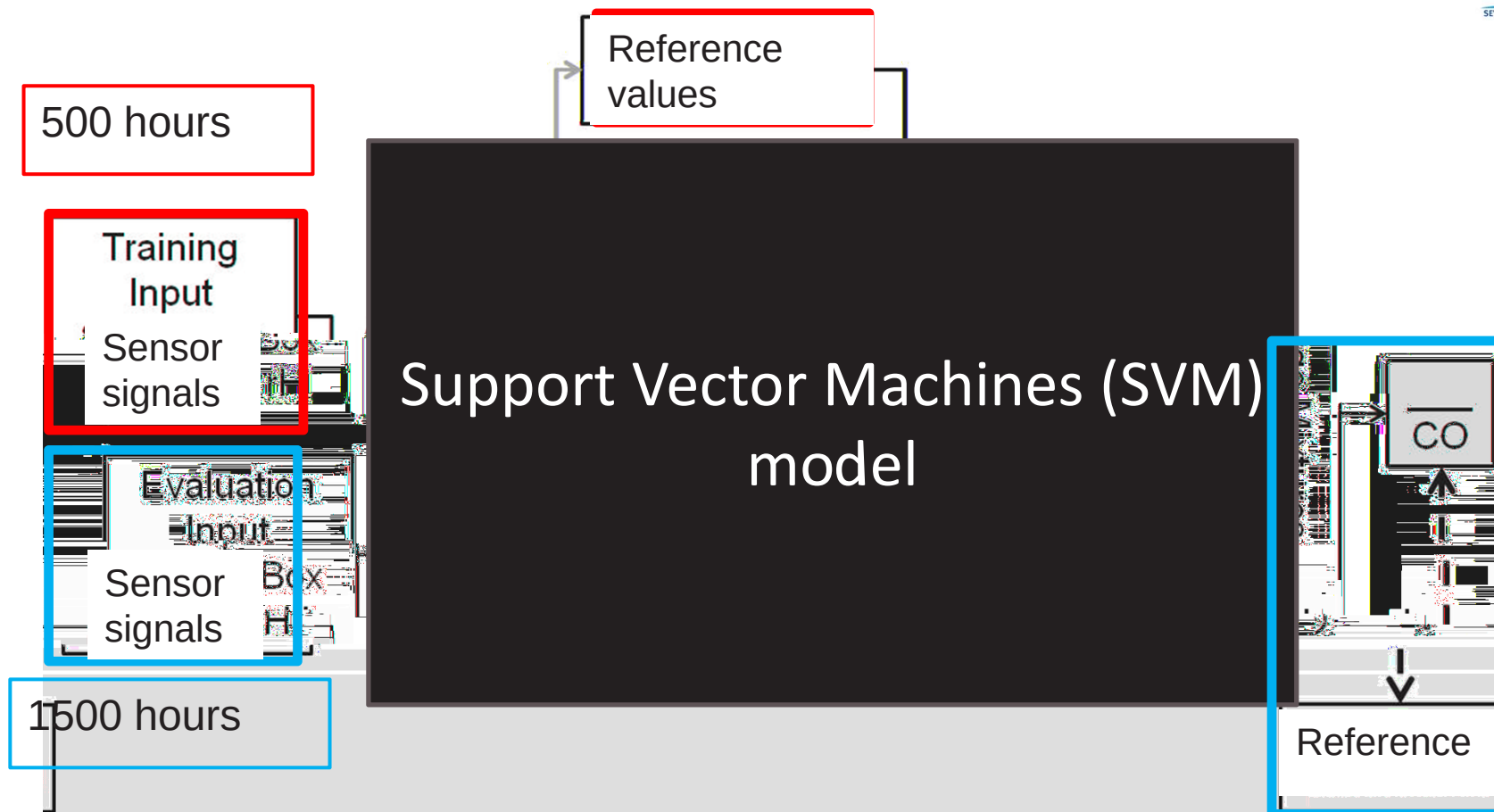
Experiences with the SB - stationary

- » Data series are very complete: SB is reliable system
- » Baseline drift - Temperature dependency

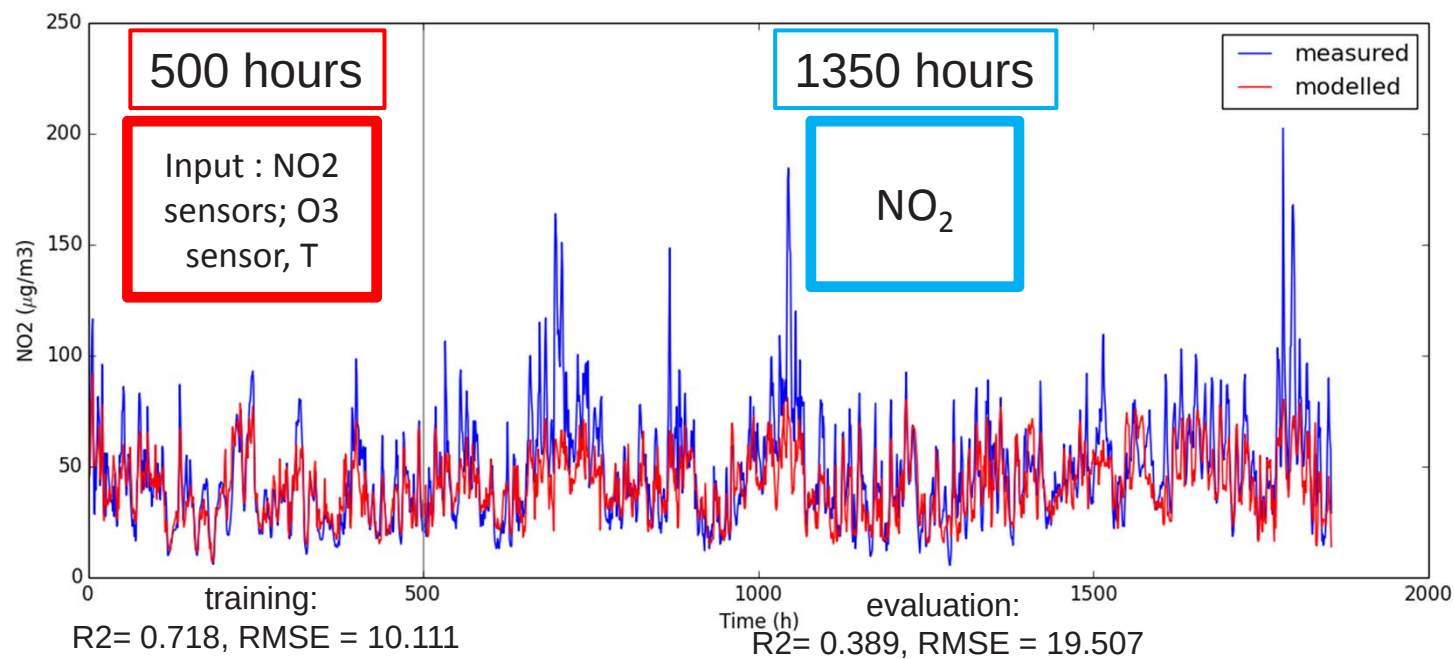
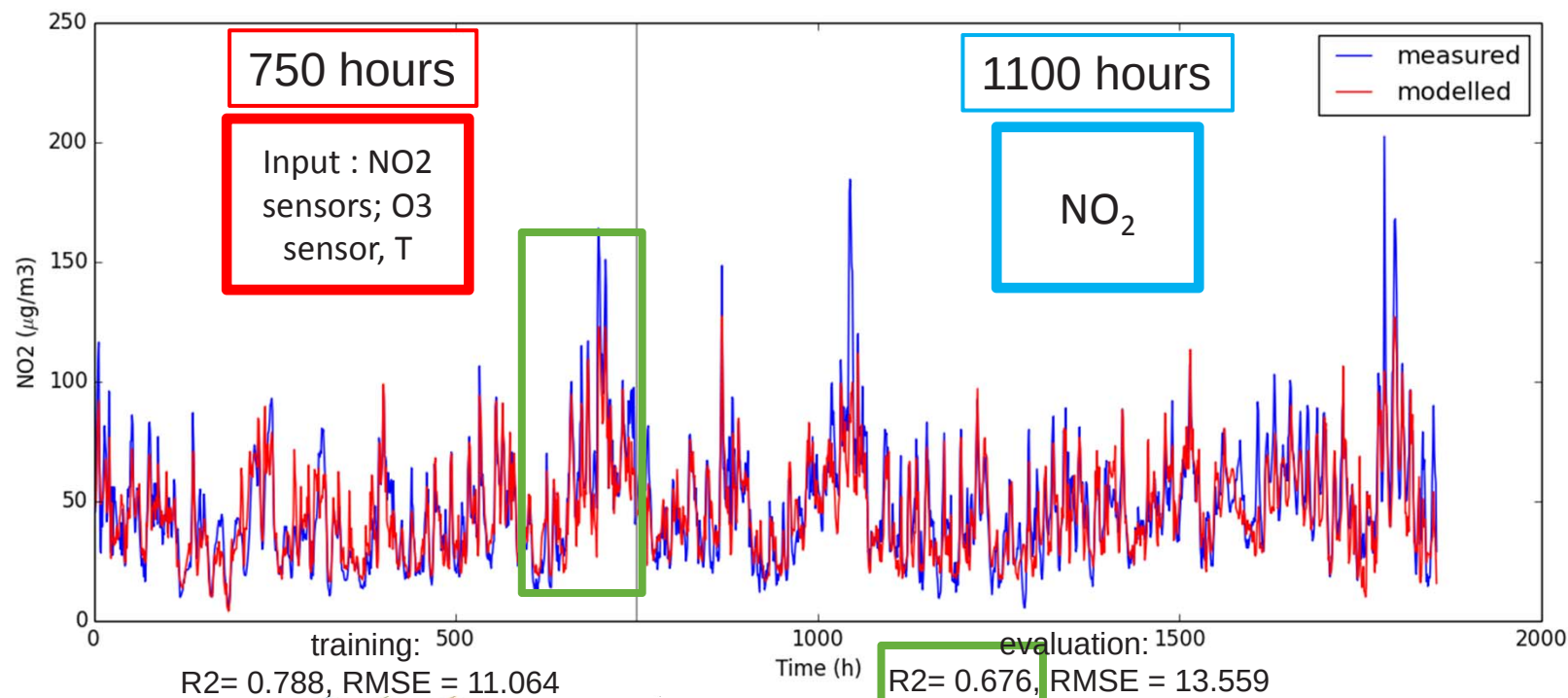


	co_alpha	co_mics_1	co_mics_2	co_figaro	no2_mics	no2_figaro	voc_as	o3_mics	temp	rh	CO	NO2	O3	BC
co_alpha	1.00	-0.69	-0.38	-0.27	0.24	0.37	0.22	-0.21	-0.91	-0.11	0.46	0.26	-0.15	0.21
co_mics_1	-0.69	1.00	0.68	0.19	-0.31	-0.38	0.24	-0.28	0.80	-0.17	0.34	0.37	-0.07	0.42
co_mics_2	-0.38	0.68	1.00	0.20	-0.54	-0.48	0.62	-0.44	0.42	0.24	0.57	0.56	-0.66	0.53
co_figaro	-0.27	0.19	0.20	1.00	-0.29	-0.12	0.29	-0.43	0.45	0.48	0.25	0.17	-0.49	0.38
no2_mics	0.24	-0.31	-0.54	-0.29	1.00	0.88	-0.36	0.73	-0.30	-0.25	-0.58	-0.33	0.67	-0.51
no2_figaro	0.37	-0.38	-0.48	-0.12	0.88	1.00	-0.21	0.49	-0.37	-0.17	-0.77	-0.16	0.39	-0.39
voc_as	0.22	0.24	0.62	0.29	-0.36	-0.21	1.00	-0.36	-0.08	0.18	0.66	0.56	-0.59	0.50
o3_mics	-0.21	-0.28	-0.44	-0.43	0.73	0.49	-0.36	1.00	-0.28	0.25	-0.73	-0.61	0.82	-0.65
temp	-0.91	0.80	0.42	0.45	-0.30	-0.37	-0.08	-0.28	1.00	-0.03	-0.08	0.09	-0.13	0.23
rh	-0.11	-0.17	0.24	0.48	-0.25	-0.17	0.18	0.25	-0.03	1.00	-0.08	-0.24	-0.23	-0.08
CO	0.46	0.34	0.57	0.25	-0.58	-0.77	0.66	-0.73	-0.08	-0.08	1.00	0.62	-0.55	0.83
NO2	0.26	0.37	0.56	0.17	-0.33	-0.16	0.56	-0.61	0.09	-0.24	0.62	1.00	-0.53	0.81
O3	-0.15	-0.07	-0.66	-0.49	0.67	0.39	-0.59	0.82	-0.13	-0.23	-0.55	-0.53	1.00	-0.54
BC	0.21	0.42	0.53	0.38	-0.51	-0.39	0.50	-0.65	0.23	-0.08	0.83	0.81	-0.54	1.00

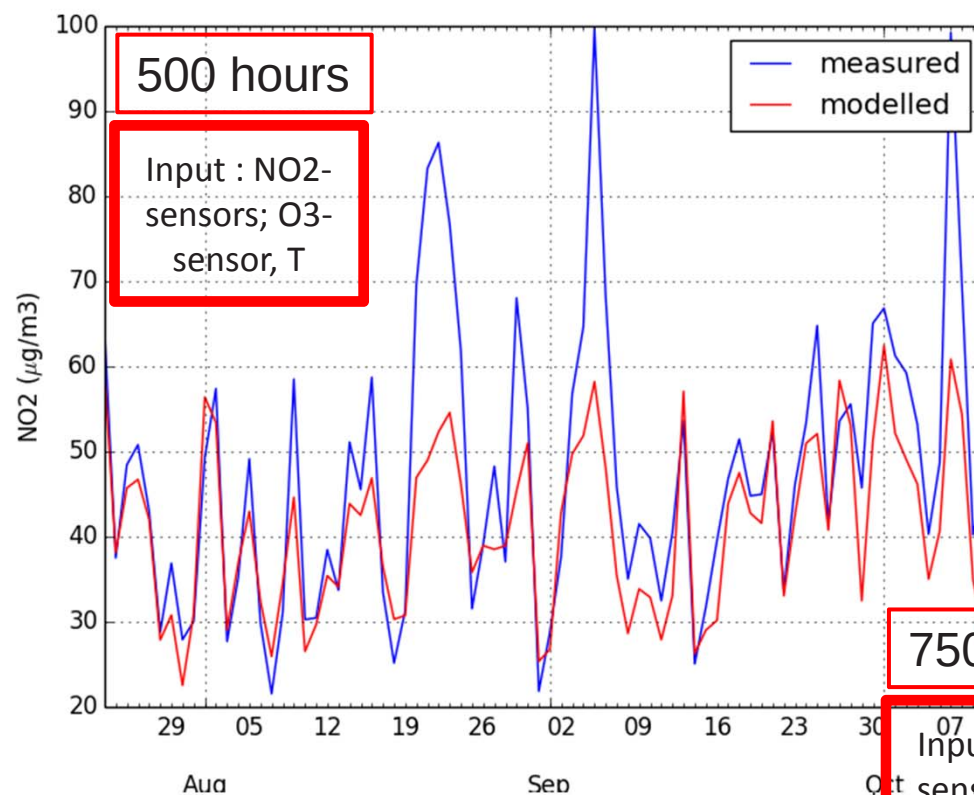
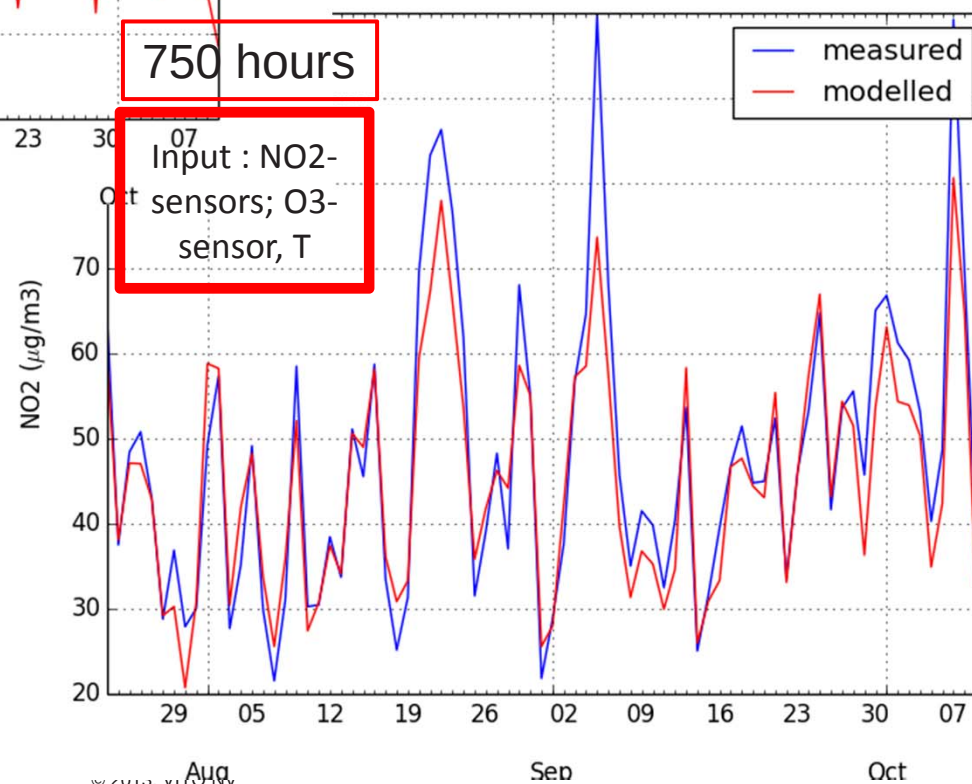
SB - Stationary – Estimation models



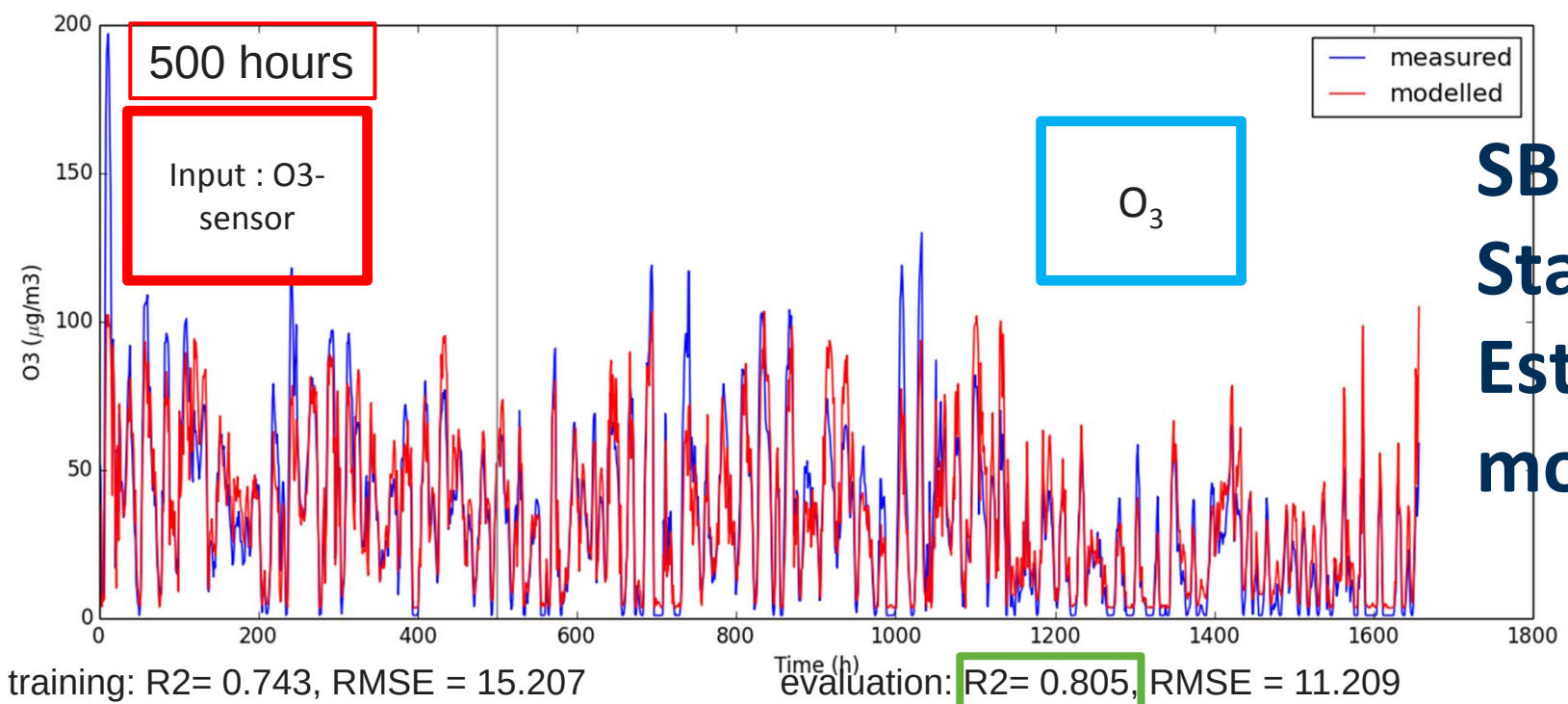
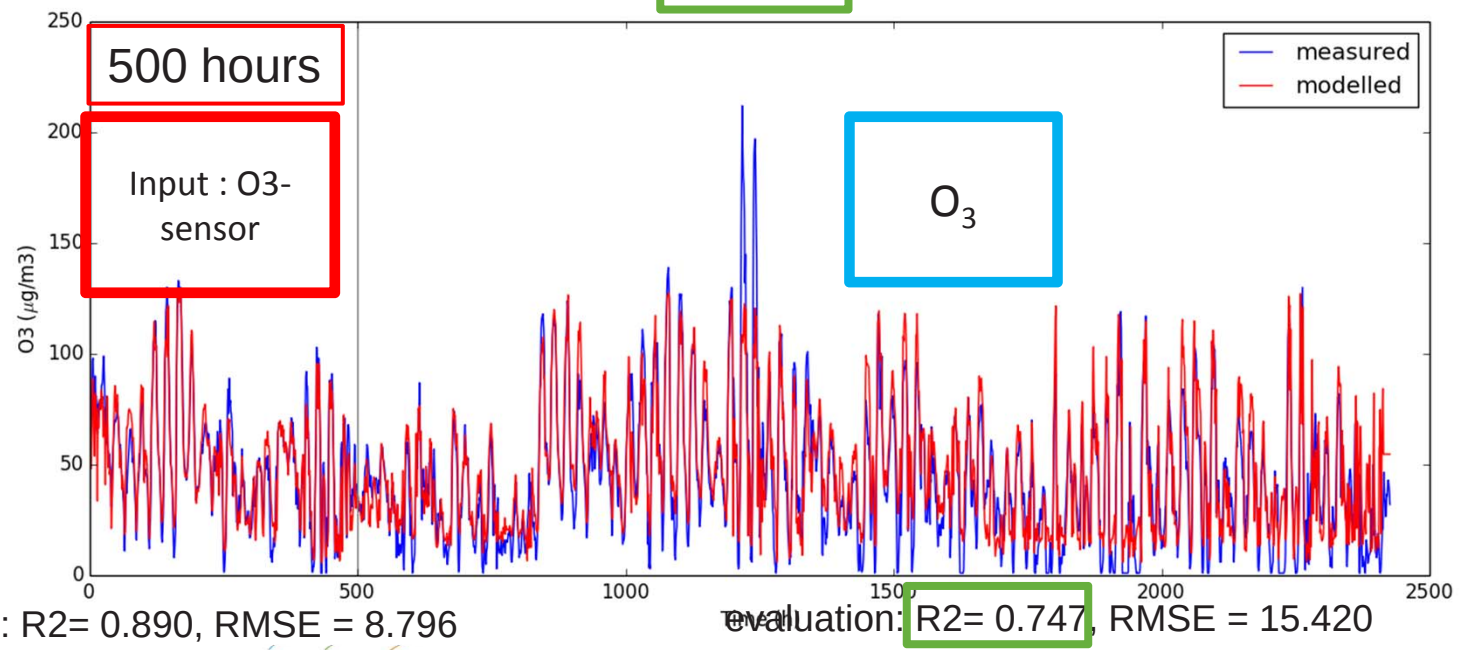
SB – Stationary Estimation models



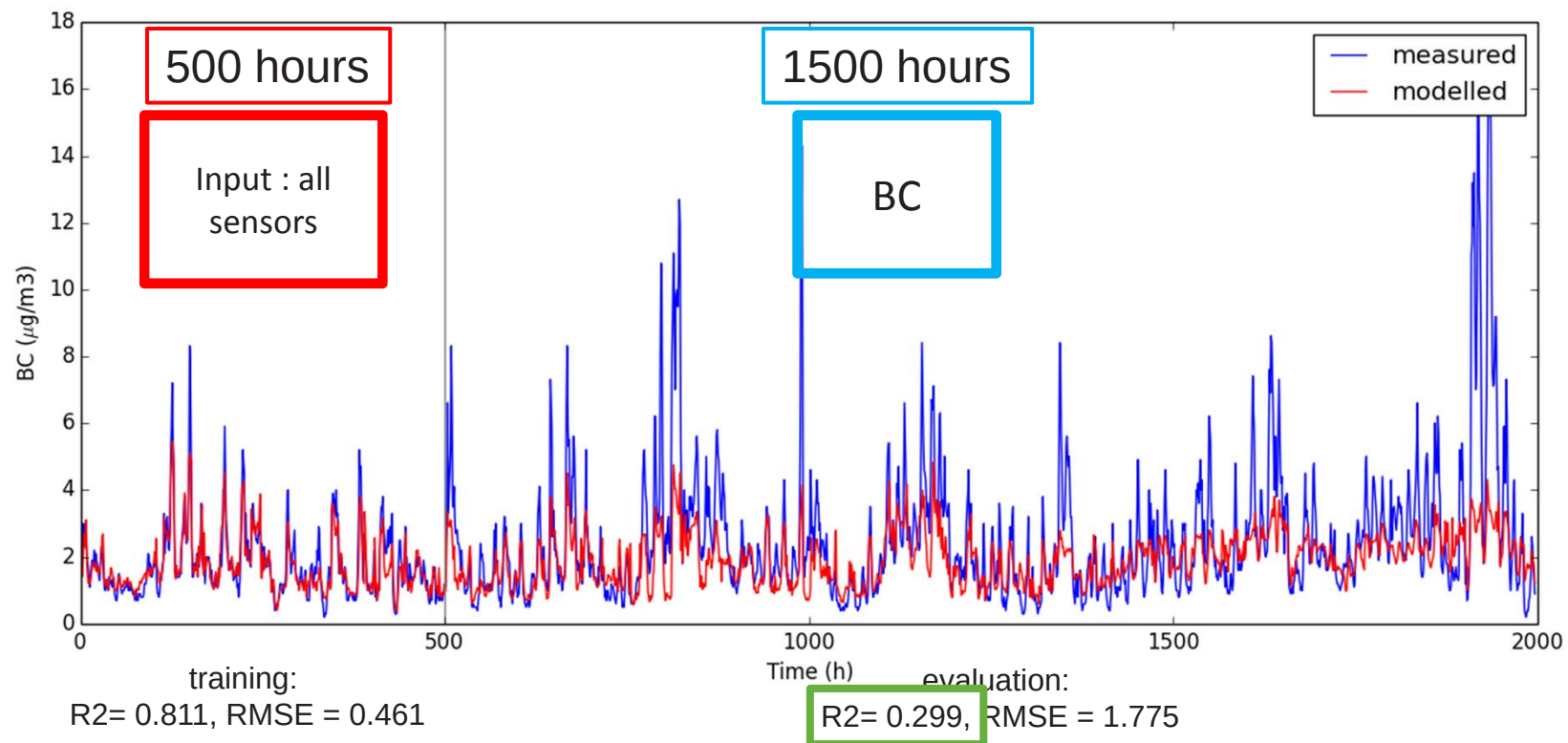
SB – Stationary Estimation models



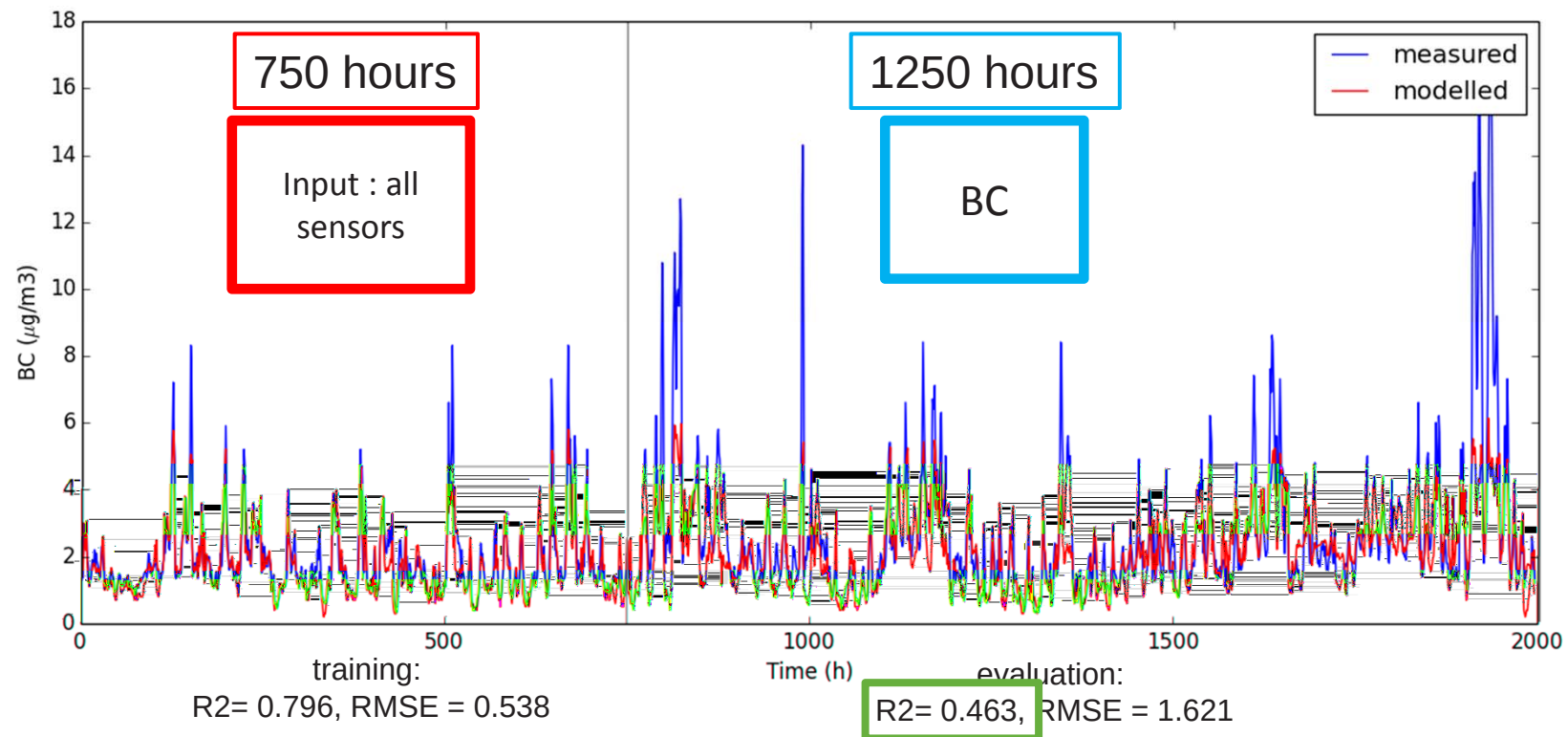
Every **SB – Stationary Estimation models**



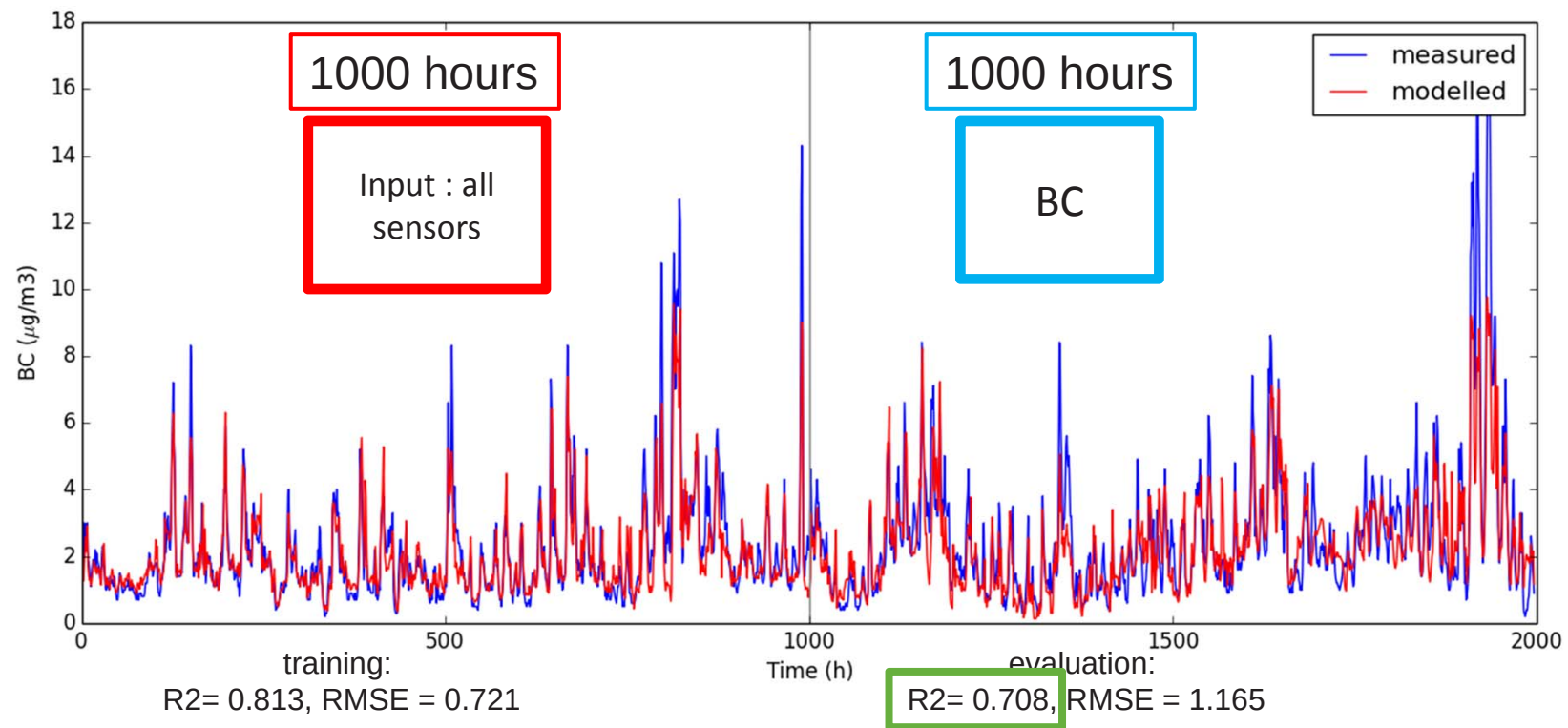
SB - Stationary – Estimation models - BC



SB - Stationary – Estimation models - BC



SB - Stationary – Estimation models - BC



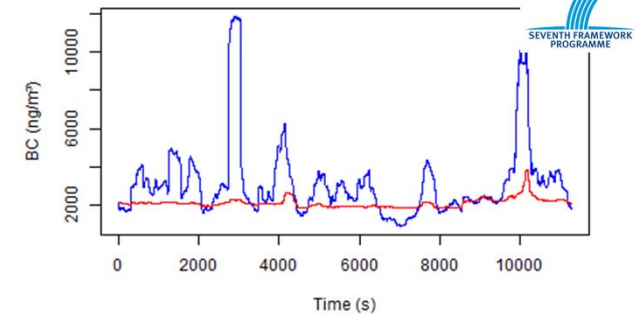
SB – Mobile – Estimation models - BC



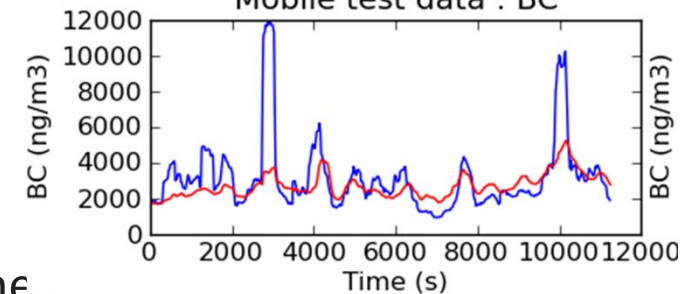
	R^2	rmse
RF	-0,13	2,10 $\mu\text{g}/\text{m}^3$
ANN	0,26	1,70 $\mu\text{g}/\text{m}^3$
SVM	0,23	1,72 $\mu\text{g}/\text{m}^3$

- Random Forests : very bad performance
- Artificial Neural Networks, SupportVectorMachine_
  - similar results
  - Patterns roughly coincide
  - Underprediction for peaks!

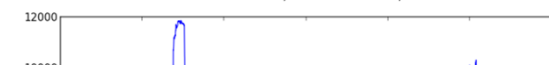
5SBs (train); mobile (test) r-square =



Mobile test data : BC



SVM fitted on SB4, best features, C=0.1



SB – Mobile – Estimation models - BC

- Auto-correlation analysis
  - Higher response time for sensors – higher auto-correlation
  - BC (Micro-aethalometer) : rapid response
    - Incompatible
    - Smoothing of sensors and micro-aeth timeseries
    - Loose the ability to model high frequency events!

Sensor	Correlation with original BC data	Correlation with smoothed BC data
co_alpha	0.45	0.72
co_mics_1	0.01	0.06
co_mics_2	0.40	0.61
co_figaro	0.40	0.60
no2_mics	-0.03	-0.05
no2_figaro	0.04	0.05
O3_mics	-0.47	-0.72
VOC	0.44	0.66

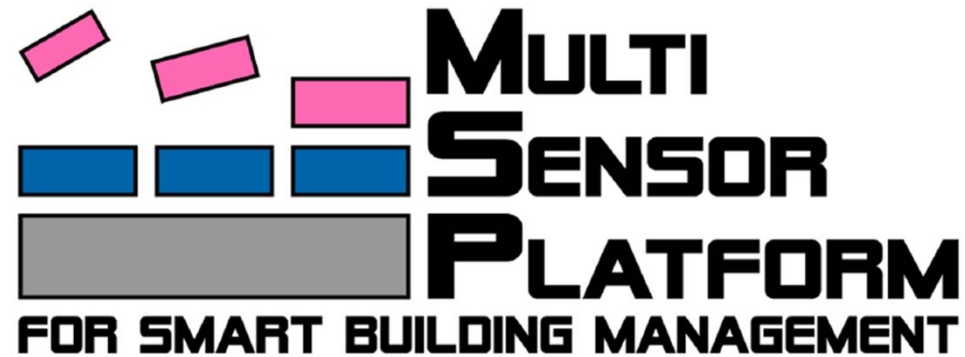
Conclusions and future work

- » Portable monitors in mobile applications
  - » Promising approach
  - » Results in clear view on spatial variability
  - » Involve non-expert volunteers to collect representative dataset
  - » Targeted and repeated data collection schemes
  - » Opportunistic data collection schemes : adapted data cleaning methods
  - » Further results will be published

Conclusions and future work

- » Low cost sensors in stationary networks
  - » Calibration models – results depending on variation in training data set
  - » Further research into
    - » Long term behaviour sensor and models
    - » Transferability of models between individual sensor boxes
    - » Location dependency
- » Low cost sensors in mobile applications
  - » Results not satisfying
  - » Key issue = short response time
  - » Need for improved sensors

*FP7 ICT-2013.3.3 Heterogeneous
Integration and take-up of Key
Enabling Technologies for Components
and Systems*



- » Sept 2013 – Aug 2016
- » Development of specific MSP demonstrator systems by integrating different types of devices and components for three specific applications:
- » MSP Device for Smart Building Management
- » MSP Device for Wearable Wristwatch Application
- » MSP Device for Outdoor Environmental Monitoring

Devices	SBM	WWA	OEM
CMOS platform	X	X	X
μ-controller SoC	X	X	X
Transceiver	X	X	X
Gas sensors	CO, CO ₂ , VOCs	CO, VOCs, NO ₂ , O ₃	CO, VOCs, NO ₂ , O ₃
Humidity and T	X	X	X
LWIR	X	-	X
UV-A/B	-	X	X
V-light	-	-	X
Particle sensor	-	X	X
Battery	X	X	X
PE energy harvester	-	X	-
PV energy harvester	-	-	X

Acknowledgements



» *The EveryAware project is funded under FP7 - Information Society Technologies, IST - FET Open Scheme*



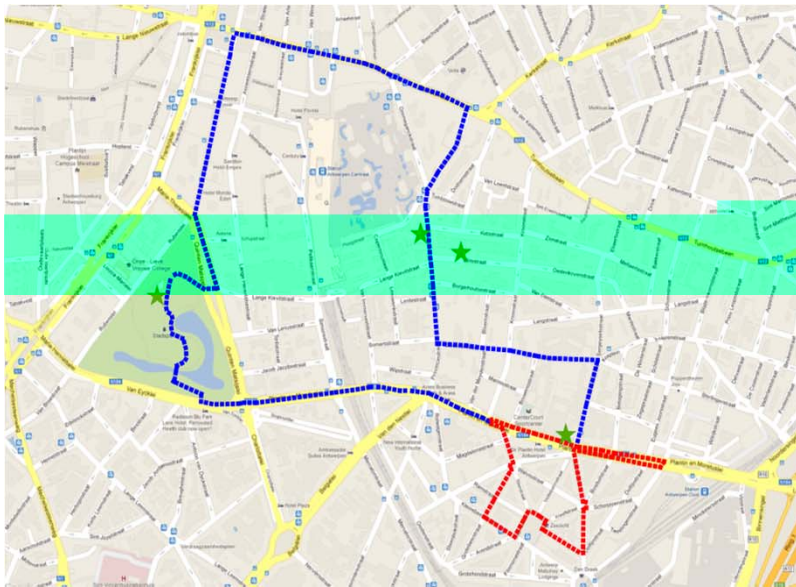
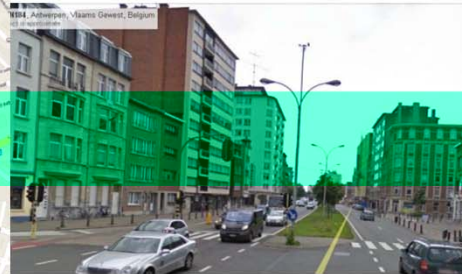
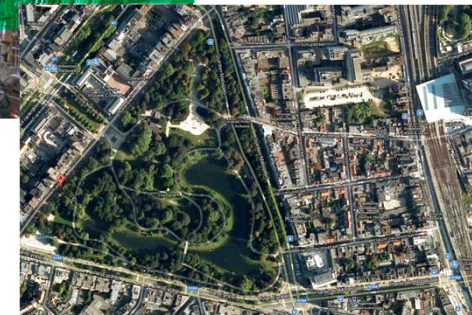
» *The IDEA project is funded by the Flemish Agency for Innovation through Science and Technology*

Contact

» jan.theunis@vito.be

Portable monitors in mobile applications - Large systematic data set

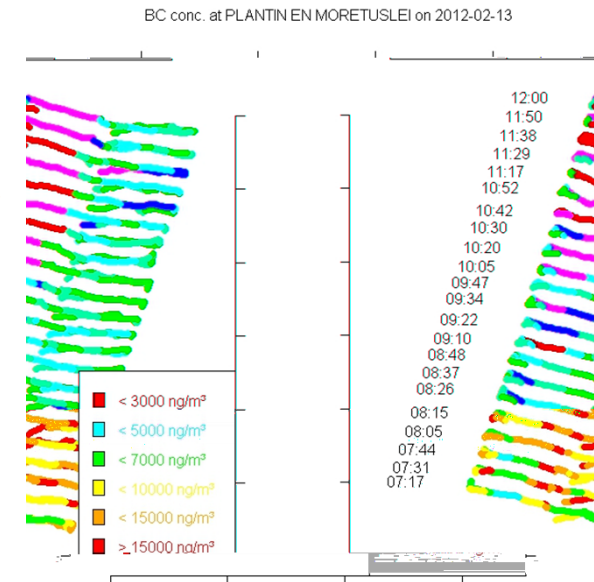
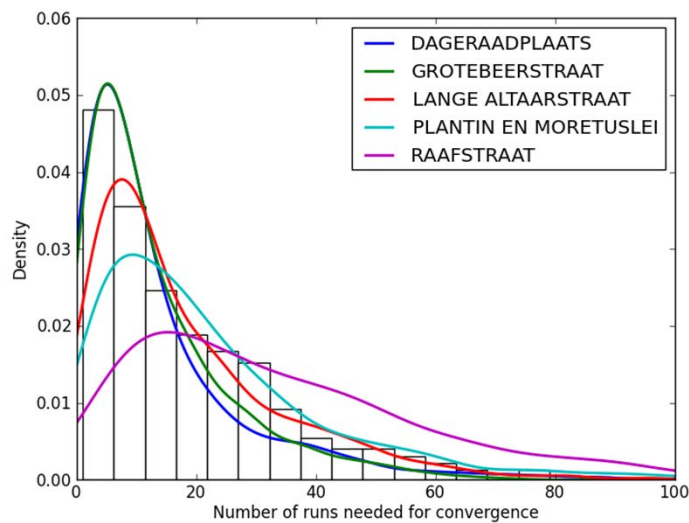
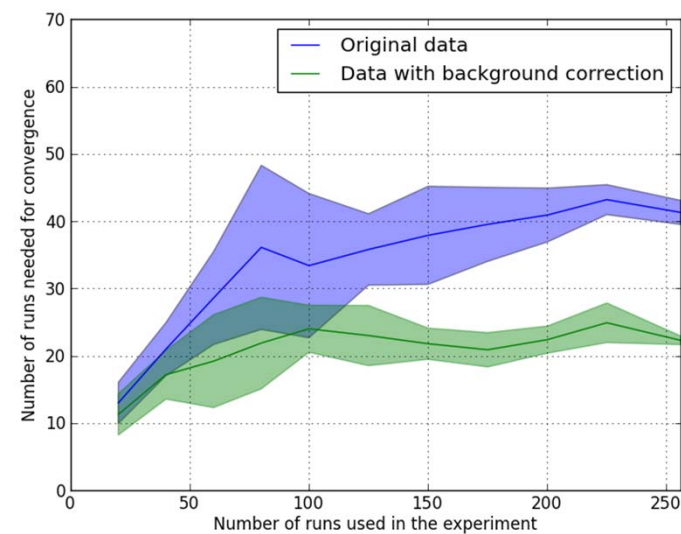
- » 2 routes in Antwerp
- » repeated 259 94



Plantin en Moretuslei	70 km/h	2 lane, biking lane	43,000 veh/day
Provinciestraat	50 km/h	No biking lane, street canyon	13,000 veh/day
Quellinstraat	50 km/h	No biking lane	9,500 veh/day
Stadspark	/	Urban green	/

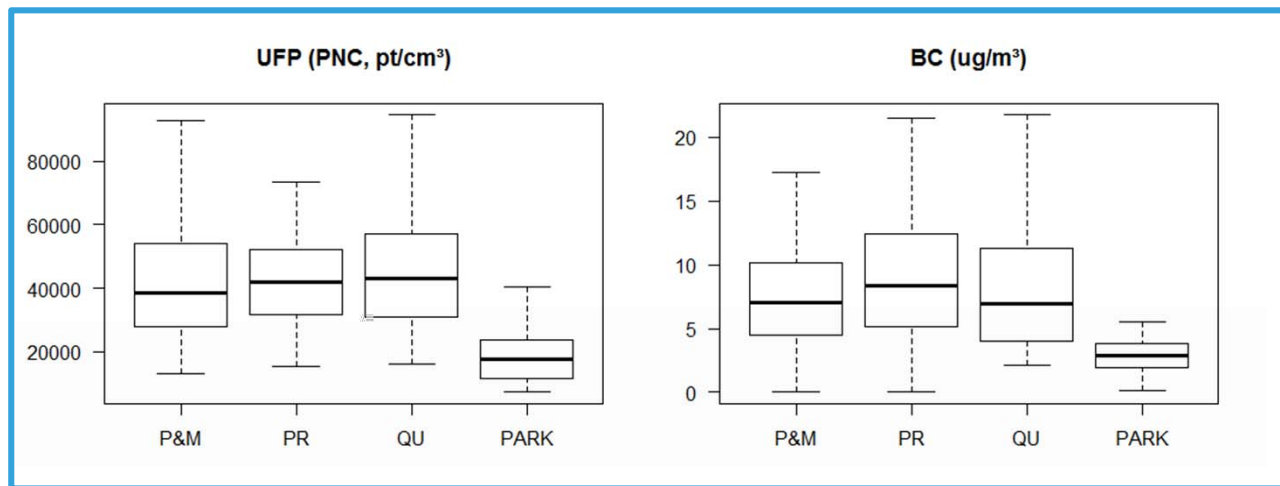
Portable monitors in mobile applications – Representativity

- » Number of repeated runs ?
  - » Absolute :
    - » dependent on street characteristics : 20 - 80
  - » Relative :
    - » “normalising” for background



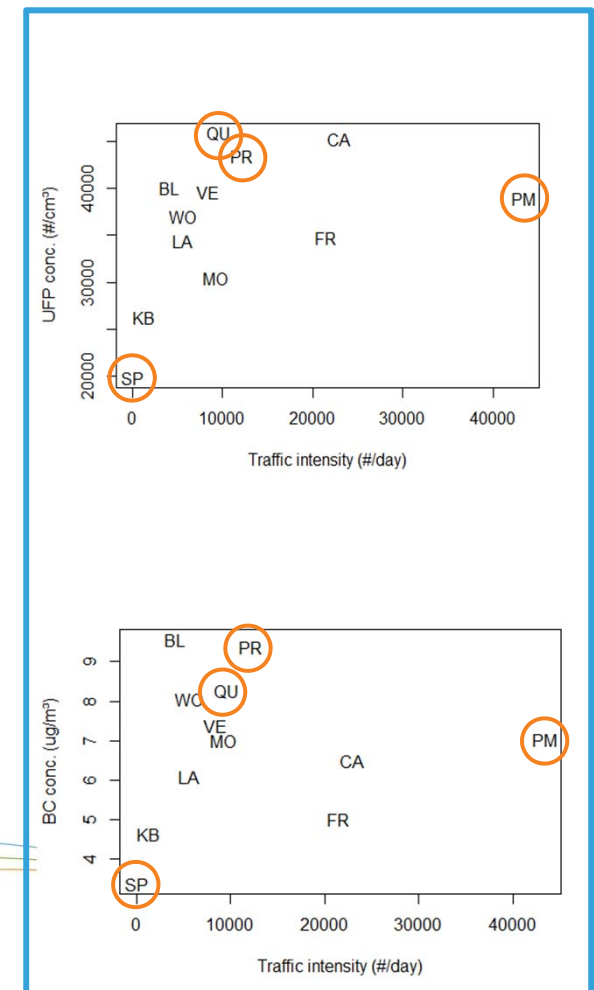
Portable monitors in mobile applications – **Street level a re ation**

» Link measurements with geo-database (street names)



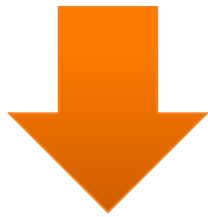
» Variability caused by:

- » Intensity of the sources (traffic)
- » Distance to the road
- » Others



GPS quality in city centers

GPS signal is blocked and reflected by buildings



Currently we mitigate this issue by:

- Filtering low quality (and irrelevant) GPS data
- Intelligent map matching: measurement are assigned to closest street segment followed from start till end

We plan to try out new approaches in the future



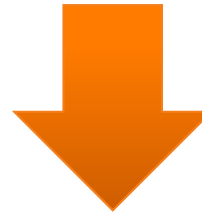
Brown: GPS tracks
Purple: Enhanced GPS tracks

Working with volunteers



Working with volunteers requires:

- Recruitment
- Keeping them motivated
- Their privacy needs to be protected
- Very good usability of measurement tools



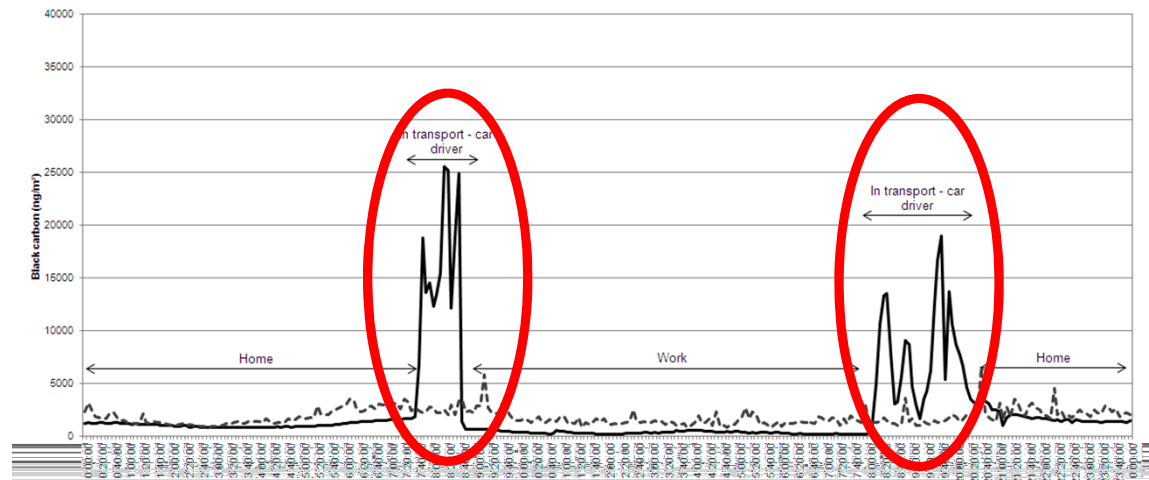
In our experience, this is often not evident

Dynamic exposure assessment: personal exposure monitoring

- » Portable instrument
- » Micro-aethalometer AE51
  - » Black carbon



Micro-aethalometer AE51



- » Electronic diary – relate to activities

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.

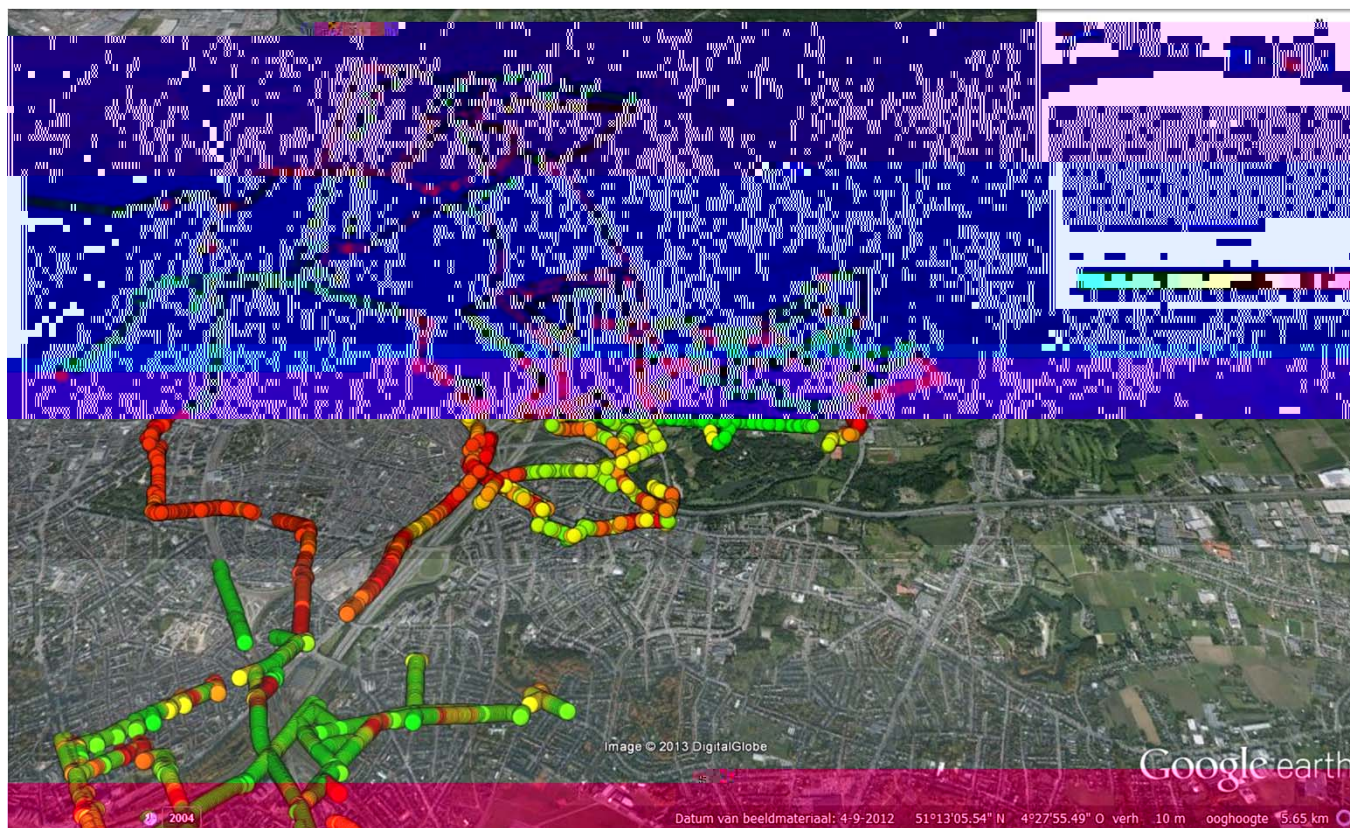
Mappin with portable monitors in mobile applications

- » UFP: P-trak, MiniDISC, ...; BC: micro-aethalometer



Portable monitors in mobile applications – opportunistic

Volunteers collecting data during commuting



Hi h-resolution spatio-temporal patterns

» Stratification per hour of the day :



