European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

WGs & MC Meeting at SOFIA (BG), 16-18 December 2015

New Sensing Technologies for Indoor Air Quality Monitoring: Trends and Challenges

Action Start date: 01/07/2012 - Action End date: 30/04/2016 - Year 4: 1 July 2015 - 30 April 2016

High-resolution mapping of urban air quality using low-cost sensors

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

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EuNetAir 5th Scientific Meeting
16-18 December 2015, Sofia, Bulgaria

Making sense of crowdsourced observations:

High-resolution mapping of urban air quality using low-cost sensors

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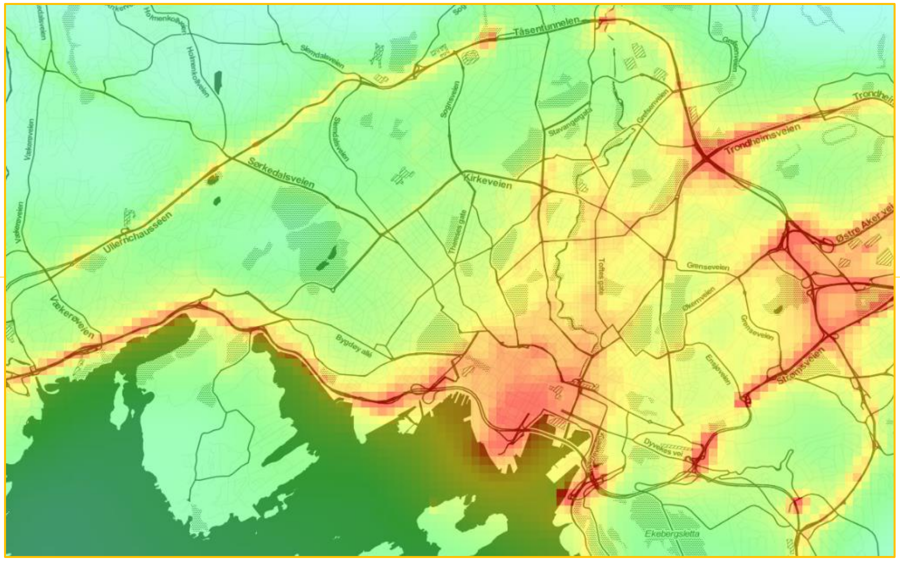
and the entire CITI-SENSE team

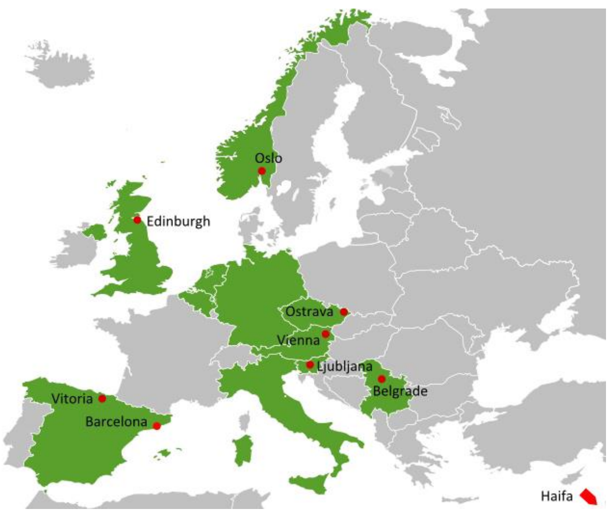


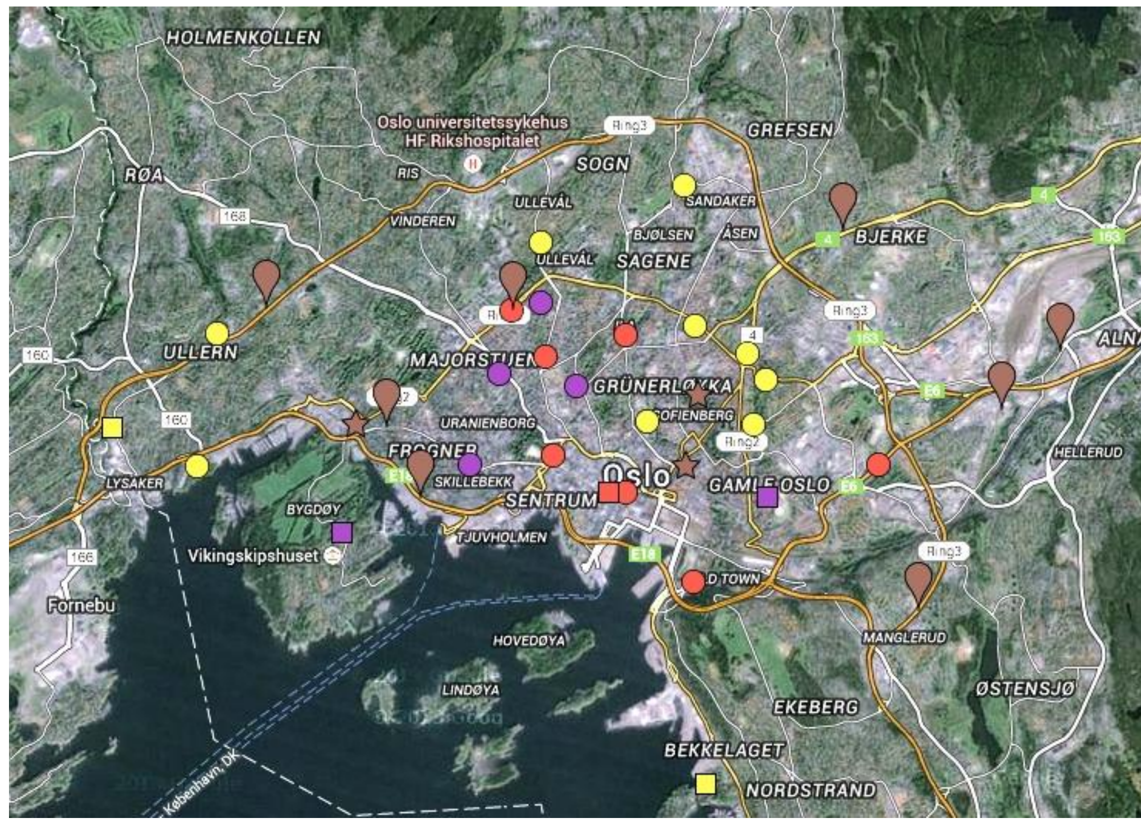
[1]NILU – Norwegian Institute for Air Research
[2]VITO – Flemish Institute for Technological Research

Static observation network

- AQMesh by Geotech
- Wireless air quality monitor
- Measures a variety of pollutants: NO, NO_2, O_3, CO, SO_2, PM_{10}, $PM_{2.5}$, as well as temperature, humidity, and pressure
- Compares reasonably well with reference equipment (but dependent on species)

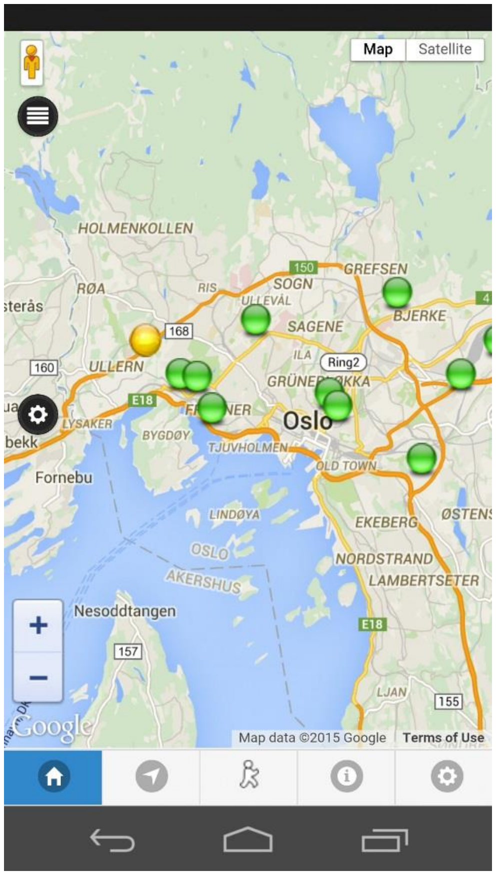
Geotech
AQMESH





Schneider et al. (2015). High-resolution mapping of urban air quality using low-cost sensors. EuNetAir 5th Scientific Meeting, 16-18 December 2015, Sofia, Bulgaria

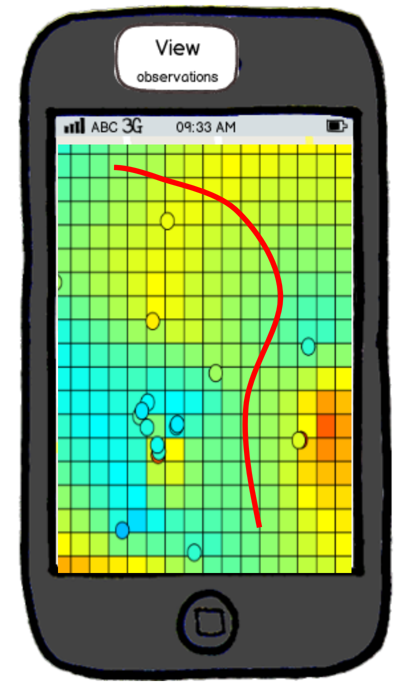
Point-based observations: The problem



CITI-SENSE app: Android-based mobile app for real-time AQ monitoring

How do we get from this:

To this:



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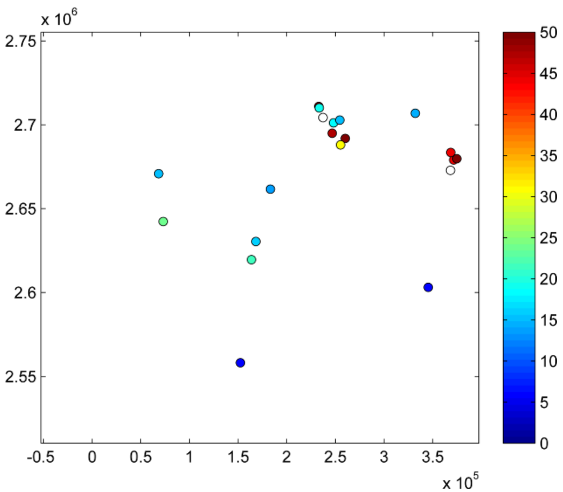
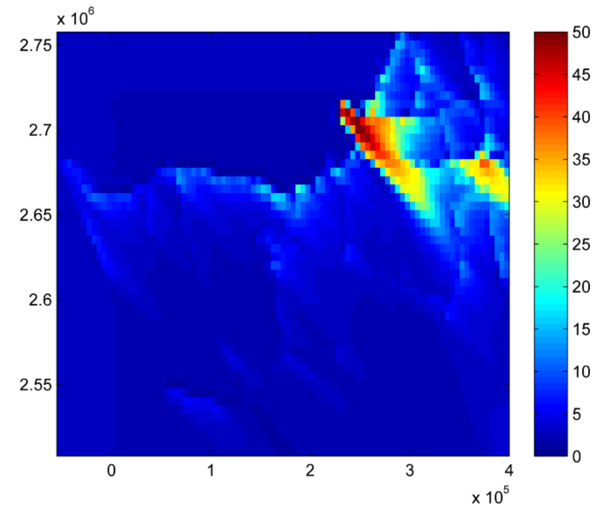
Data fusion: Basic Premise

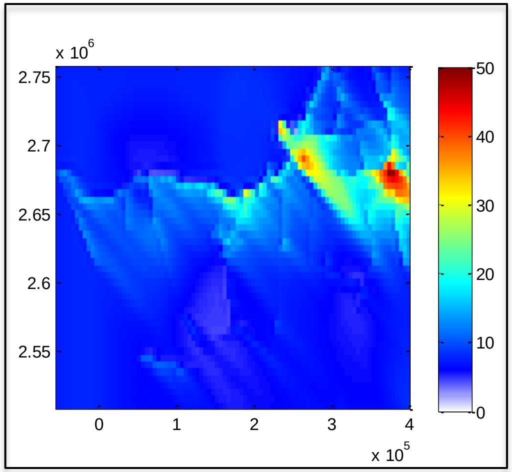


Observations

DATA FUSION



Modelling results or other auxiliary data



Combined map

Data fusion (as a subset of data assimilation) creates a value-added product by

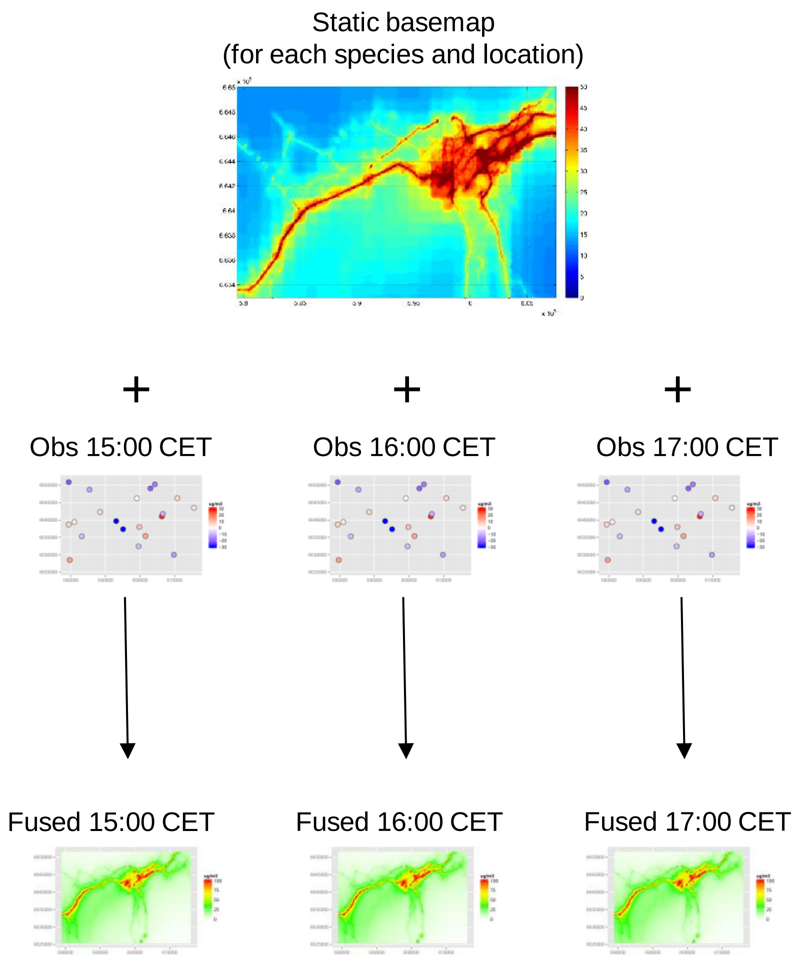
a) Interpolating the observations in an objective way
b) "correcting" the model estimates with true observations

Data fusion method used here provides a combined concentration field by regressing the observations against model data and spatially interpolating the residuals

Schneider et al. (2015). High-resolution mapping of urban air quality using low-cost sensors. EuNetAir 5th Scientific Meeting, 16-18 December 2015, Sofia, Bulgaria

Data fusion for CITI-SENSE

- A static basemap is created for each location and each species of interest to show the long-term spatial patterns
- This basemap is then modified according to the observations made by the static Geotech sensors
- This is essentially a location-dependent level-shift of the basemap
- The final result are hourly maps with the current best guess for the $NO_2/PM_{10}/PM_{2.5}$ concentration field at all CITI-SENSE locations



Basemap: Provides information about general spatial patterns

Geotech observations: Provide information about current state of atmosphere at a few sampling locations

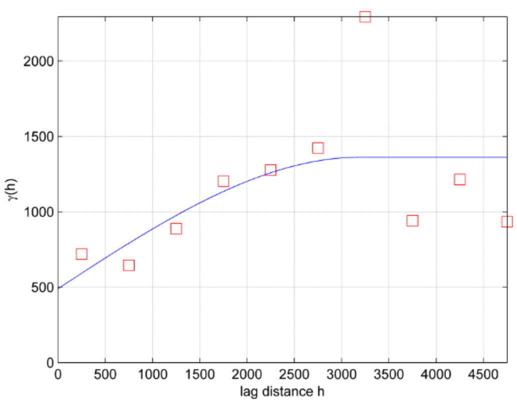
Fused map: Value-added product providing a best guess of current state of atmosphere for the entire domain

Data fusion methodology

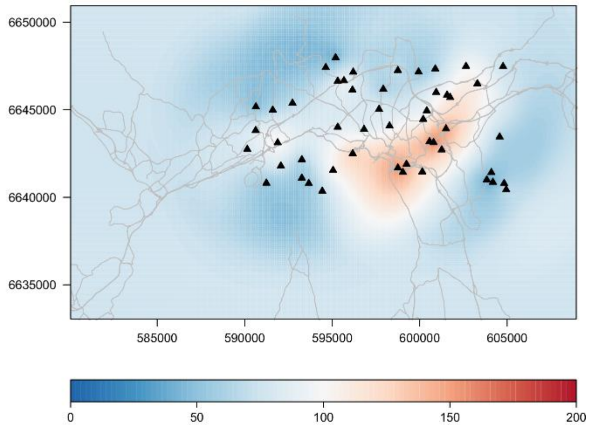
- Data fusion is a subset of data assimilation techniques (Lahoz and Schneider, 2014)
- Uses geostatistical framework
- Analysis performed entirely in log-space
- Universal kriging approach
- Spatial interpolation guided by proxy
- Explicit automated modelling of spatial autocorrelation

Lahoz, W. A., and P. Schneider (2014), Data assimilation: making sense of Earth Observation, *Front. Environ. Sci.*, *2*(16), 1–28, doi:10.3389/fenvs.2014.00016.

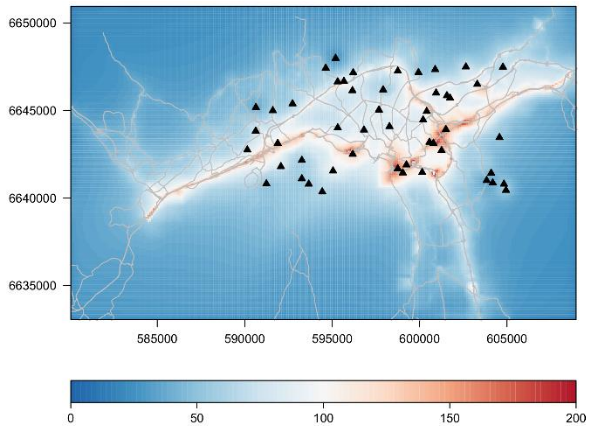
Theoretical model of spatial autocorrelation



Using simple spatial interpolation

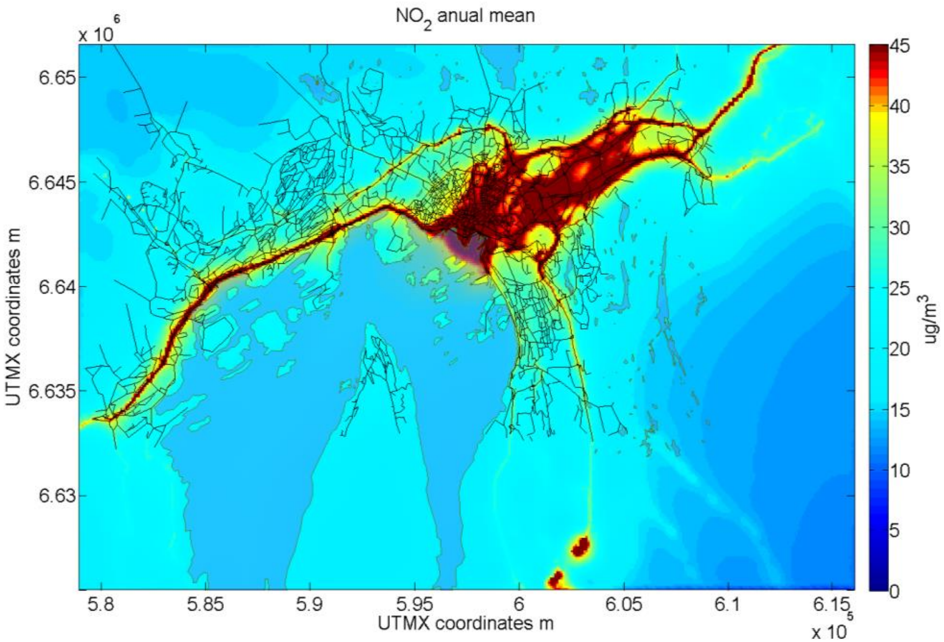


Using data fusion with spatial proxy

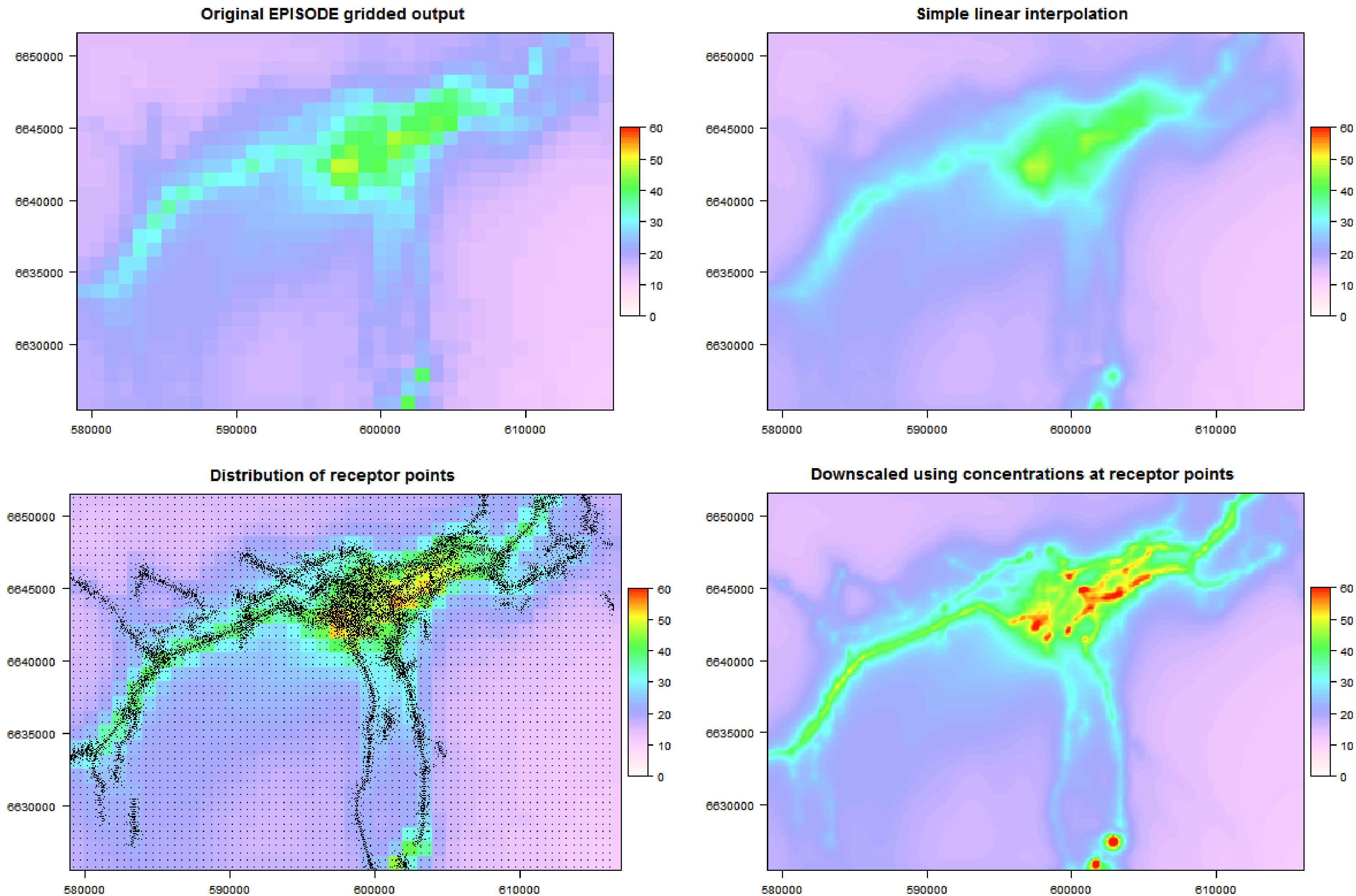


Modelling of the basemaps

- Can be nearly any spatially exhaustive dataset that is related to the observation
- Best to use are urban-scale dispersion models
- Alternatively concentration map created through LUR modelling
- We use the EPISODE model
  - Three-dimensional, combined Eulerian/Lagrangian air pollution dispersion model, developed at NILU
  - Combined modelling and postprocessing approach to obtain basemaps at 10-100 m spatial resolution

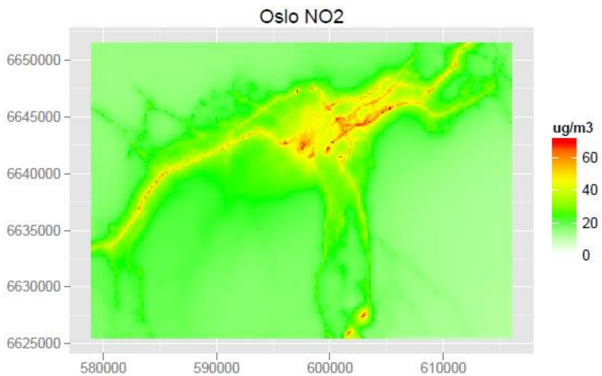


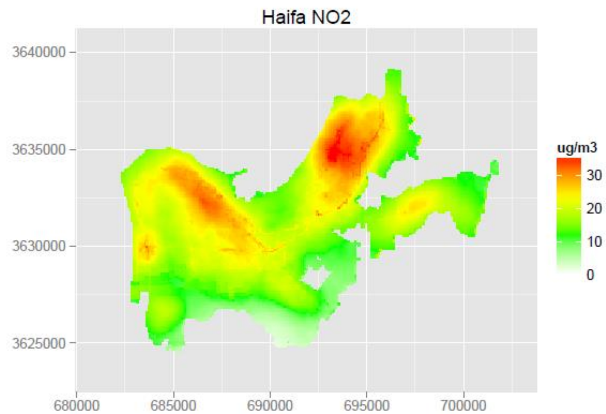
High-resolution map of NO_2 in Oslo from the EPISODE dispersion model. These kind of maps are ideally suited as a spatially distributed auxiliary dataset.

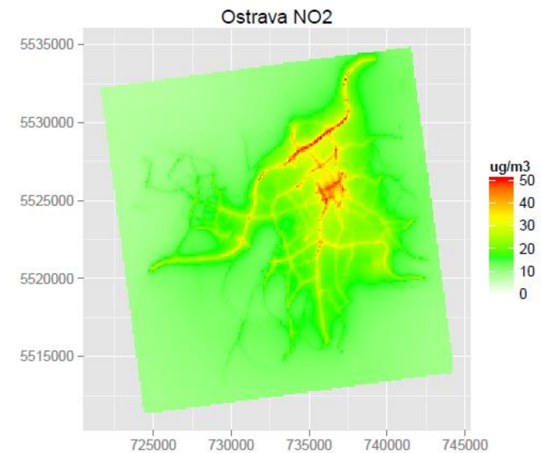


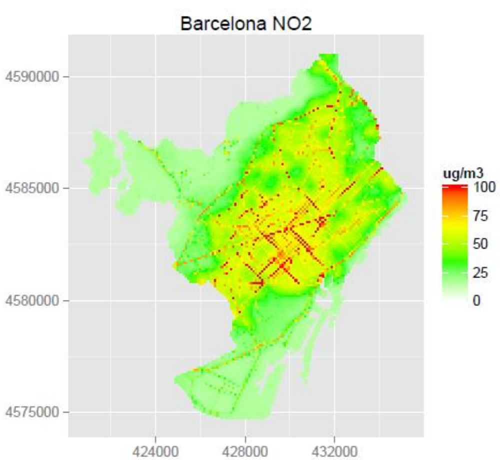
Receptor-point based downscaling of the gridded EPISODE output

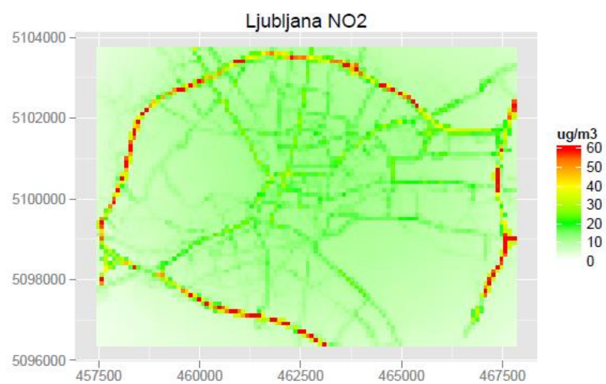
Example basemaps for NO_2

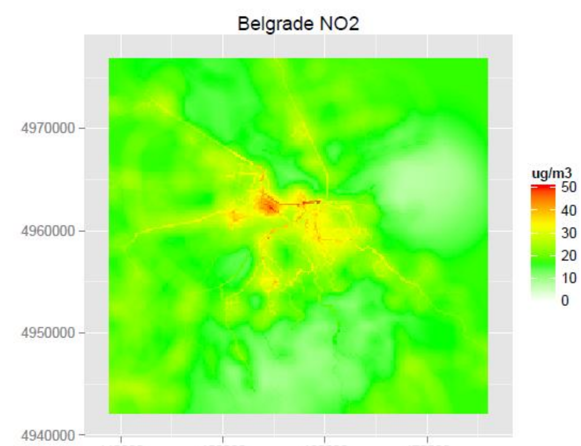






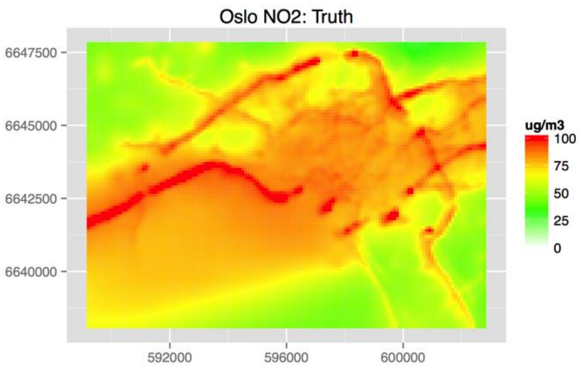


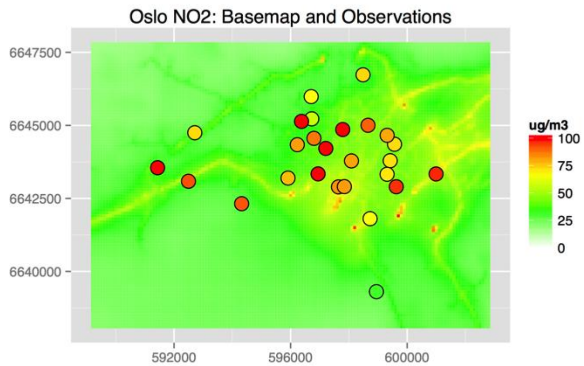


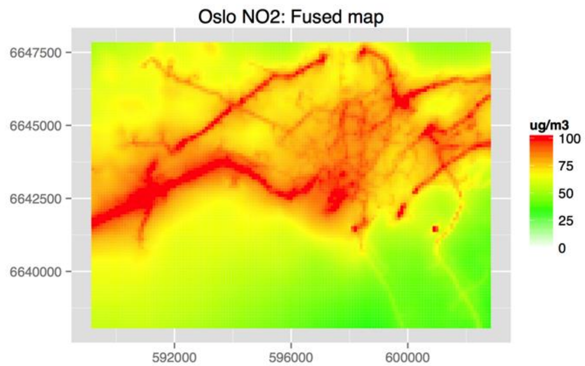


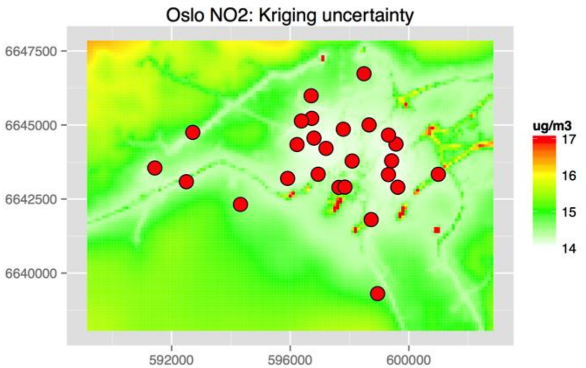
Schneider et al. (2015). Making sense of crowdsourced observations. EGU General Assembly 2015, Session ESSI1.10/SSS0.26, 15 April 2015, Vienna, Austria

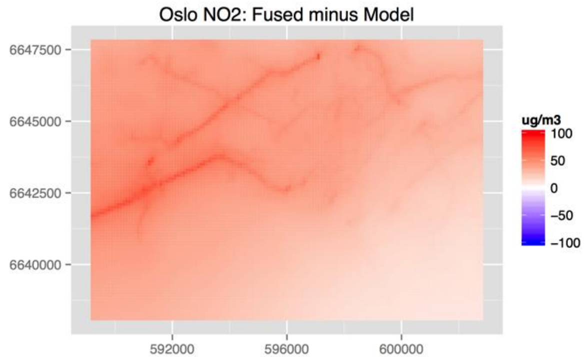
A fusion example for Oslo

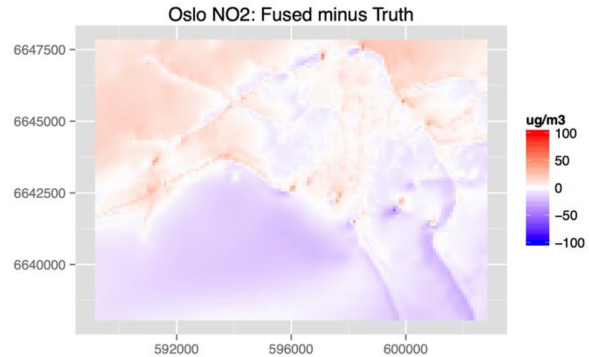










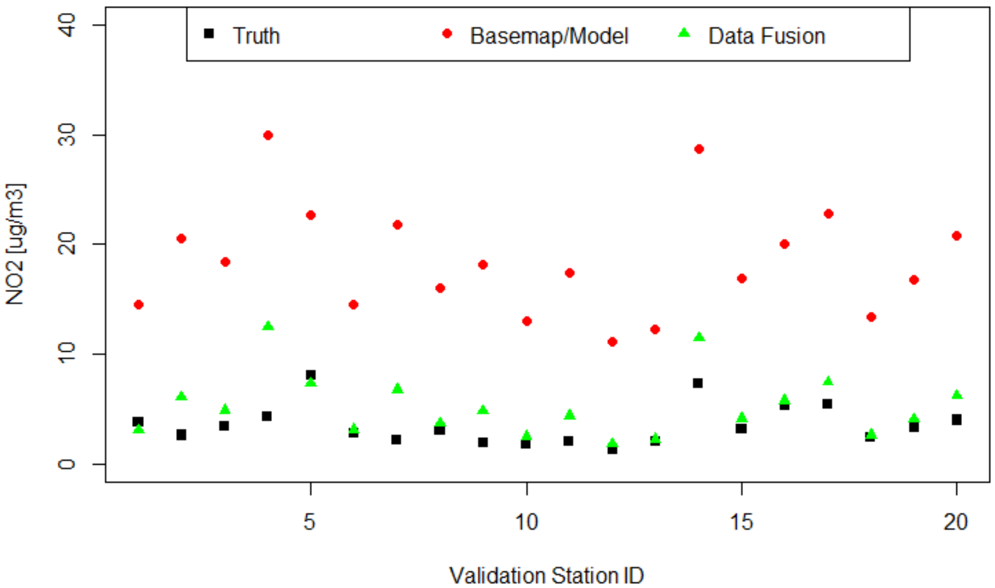


Schneider et al. (2015). High-resolution mapping of urban air quality using low-cost sensors. EuNetAir 5th Scientific Meeting, 16-18 December 2015, Sofia, Bulgaria

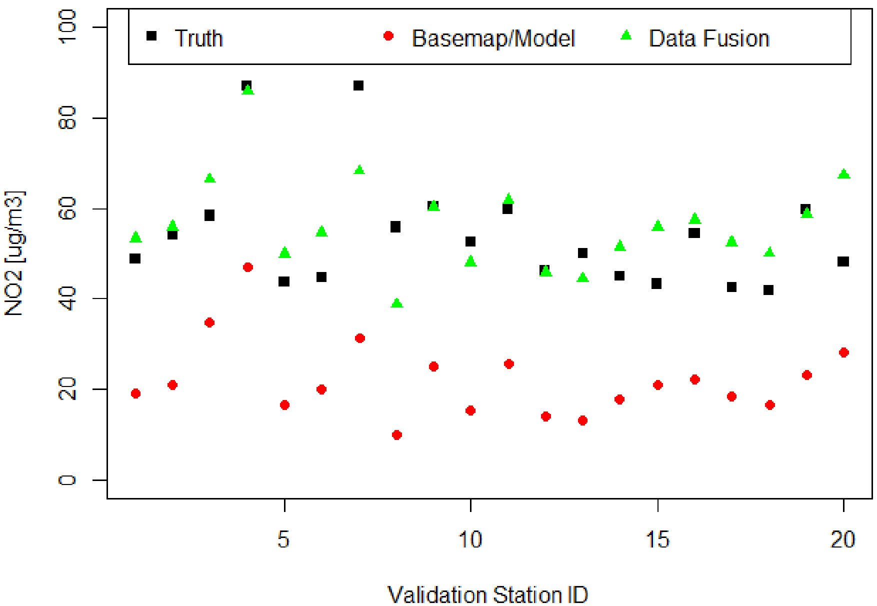
Validation against “Truth”

Validation sites are randomly selected throughout the image. Concentration values at these sites can be extracted from the truth, the basemap, and the fused result and compared.

Example 1: Basemap overestimates “truth”



Example 2: Basemap underestimates “truth”



This shows that the method can predict the true concentration field quite well even in areas where no observations are available.

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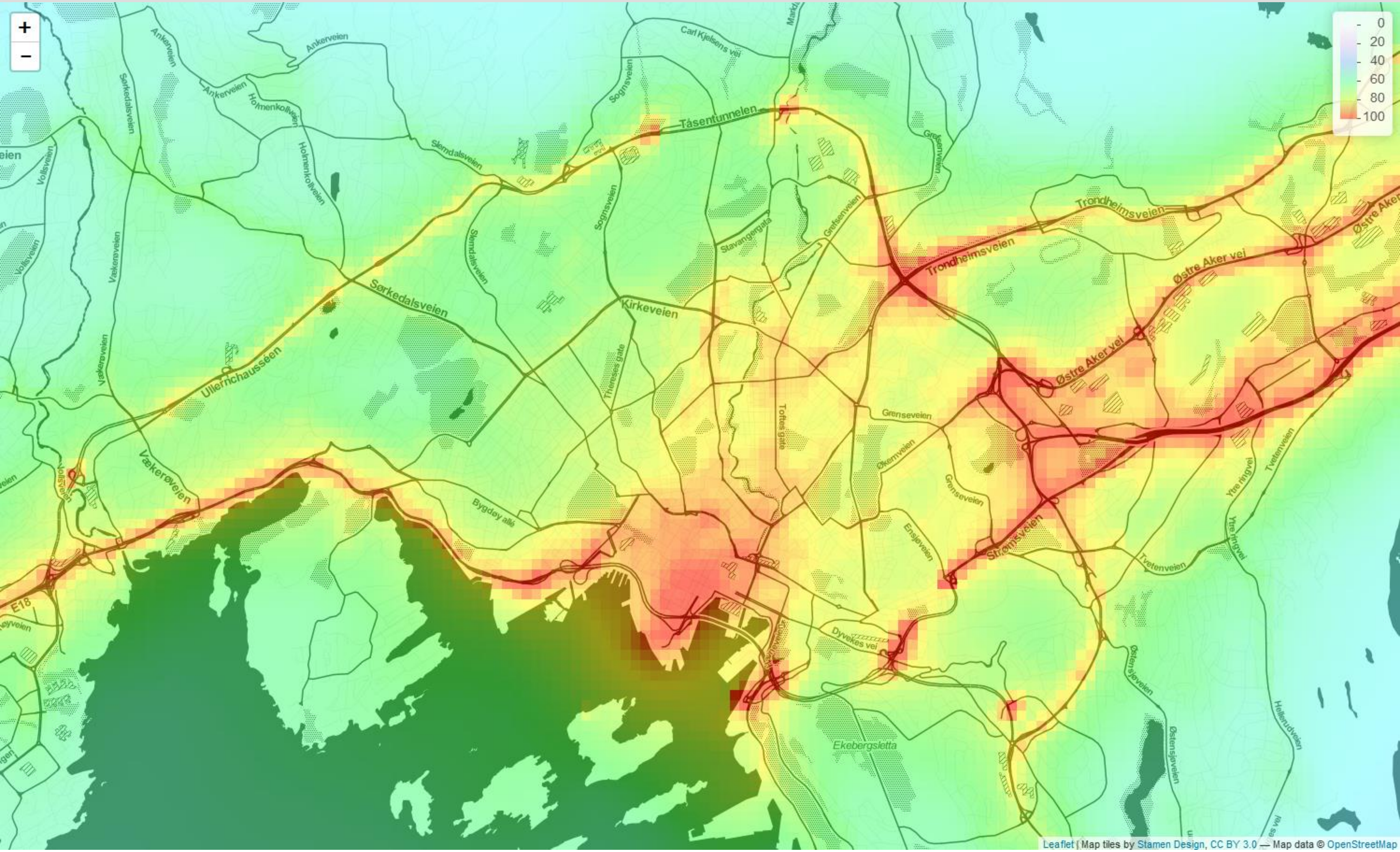
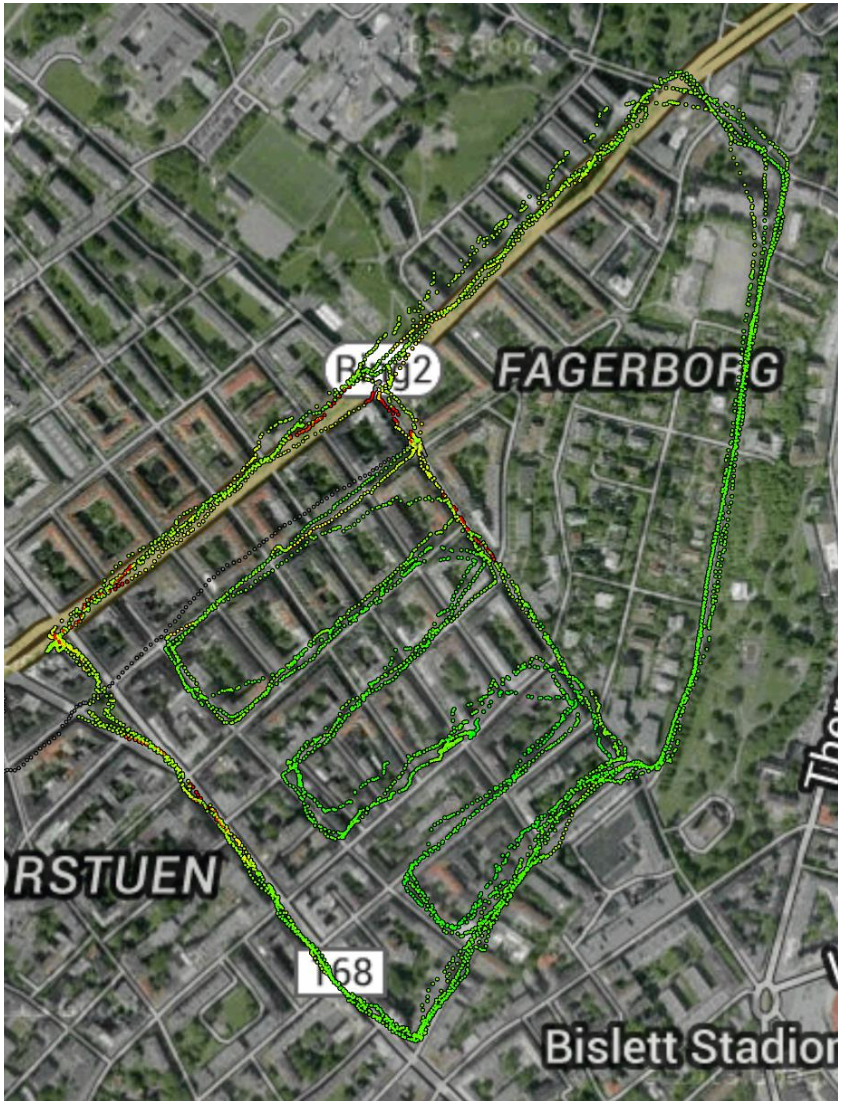


Typical example of a data fusion-based surface concentration field of NO_2 for Oslo, Norway, at 100 m spatial resolution.

Urban AQ mapping using mobile measurements of Black Carbon

AethLabs Microaethalometer

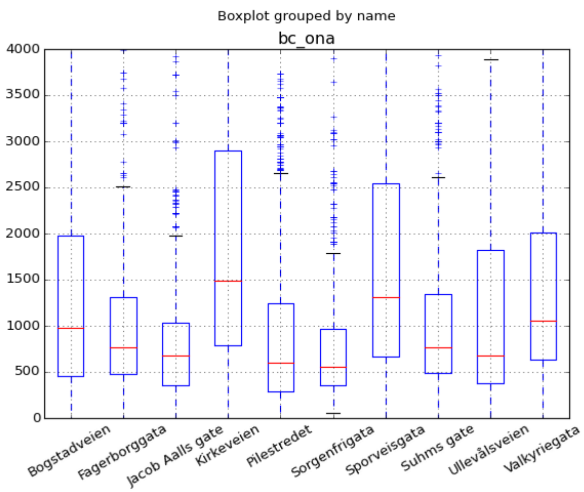
Black Carbon measurements campaign in Majorstuen/Oslo, May 2015



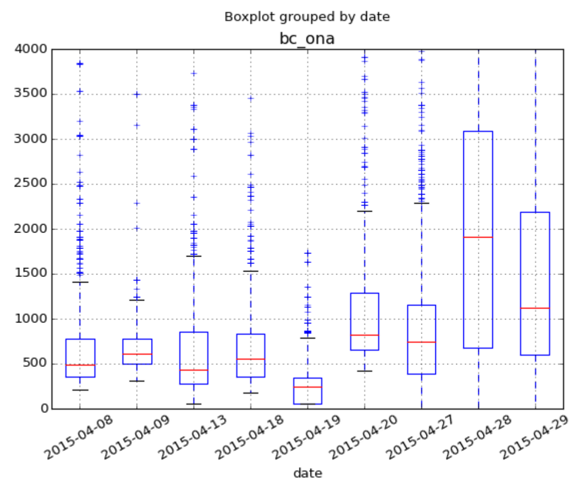
Schneider et al. (2015). High-resolution mapping of urban air quality using low-cost sensors. EuNetAir 5th Scientific Meeting, 16-18 December 2015, Sofia, Bulgaria

Spatial and temporal averages

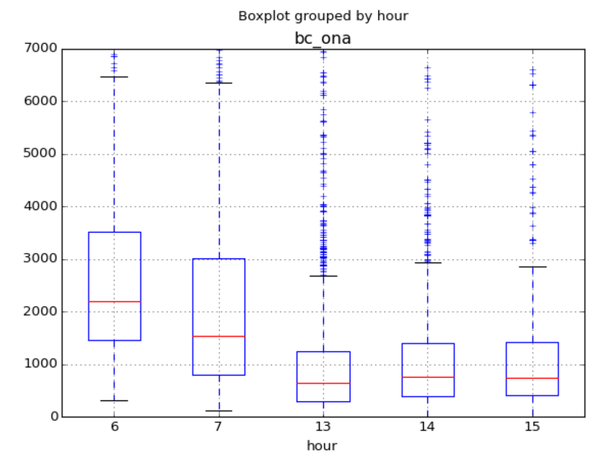
Streetwise averages



Daily averages



Hourly averages



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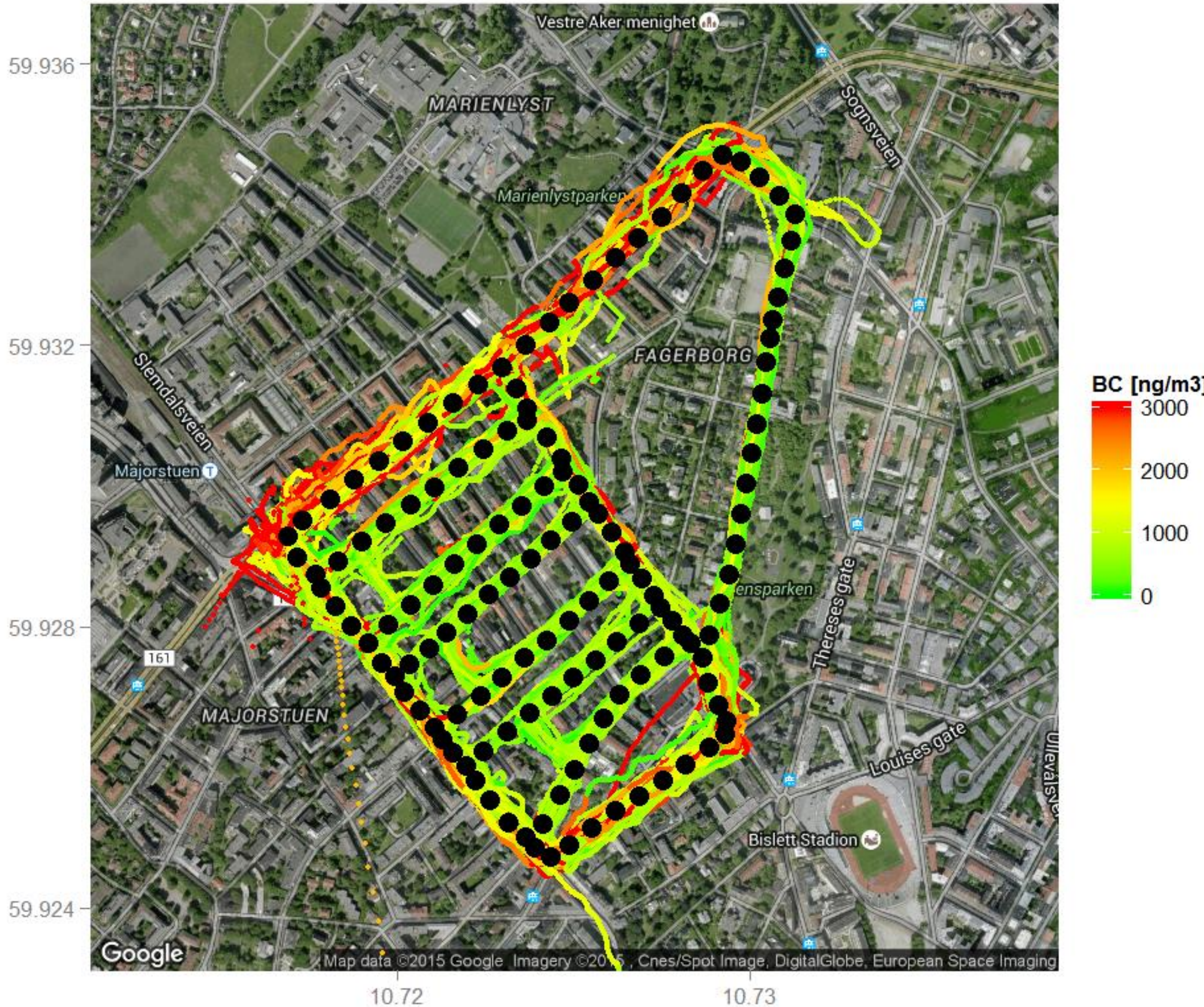

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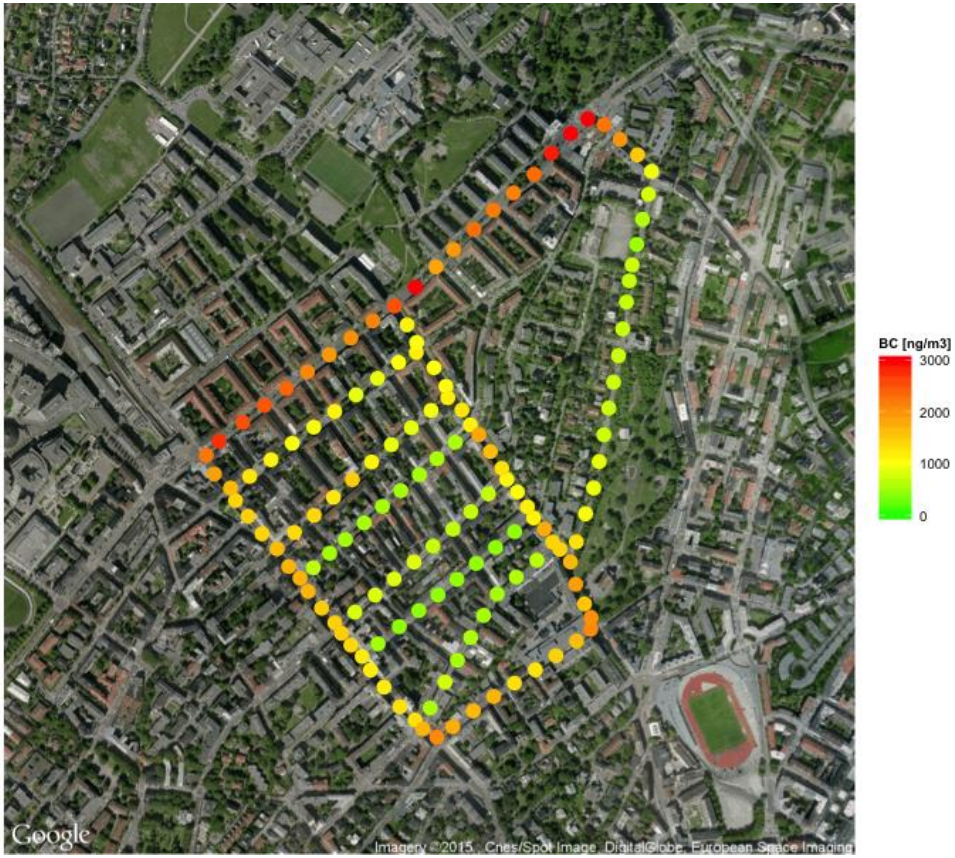
Data fusion of BC observations



Spatially and temporally averaged BC observations

BC observations fused with EPISODE model output -> Extension to the entire road network

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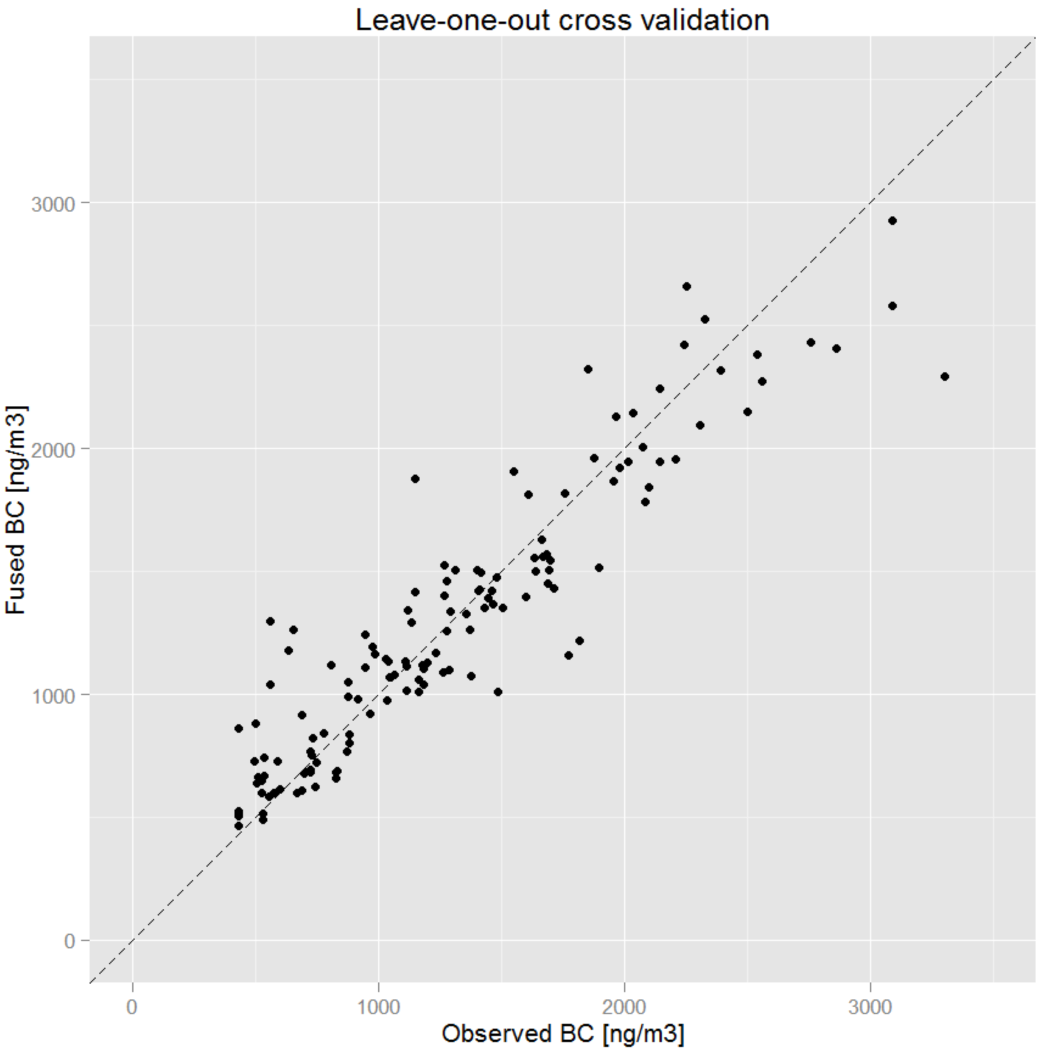
Validation



Leave-one-out cross validation of the fused road map against averaged BC concentrations

R^2 = 0.87

RMSE = 240.8 ng/m3

Conclusions

- We developed a technique for merging point-based crowdsourced observations of air quality with model information
  - **Geostatistics**-based: Builds upon decades of experience; best linear unbiased estimator; provides uncertainty estimates
  - **Fully automated** implementation: Can be run operationally in real time with large datasets
- Provides a much more **realistic estimate of true concentration field** than observations or model data alone
- Methodology can be used for a **static** sensor network as well as observations from **portable** instruments
- Realistic high-resolution near real-time concentration fields in urban areas for the first time allow for **personalized air quality information**
  - "How much particulate matter will I breathe in if I ride my bike **from home to work right now**?"
  - "What **route** to work is the **least polluted/healthiest**?"
- A first step towards **making sense of highly distributed observations** in the age of *crowdsourcing, Citizen Science*, *ubiquitous sensing*, and *Big Data*

Thank you for your attention!

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www.citi-sense.eu

Extra Slides

Outline

- The general problem
- High-resolution mapping using a network of static AQ sensors
- High-resolution mapping of black carbon concentrations using observations with portable sensors


Air pollution
is the top
environmental
risk factor for
premature death
Getty


In 2011, 458000 premature deaths in Europe were attributed to particulate matter in the air
The Guardian

Traditional Air Quality Monitoring

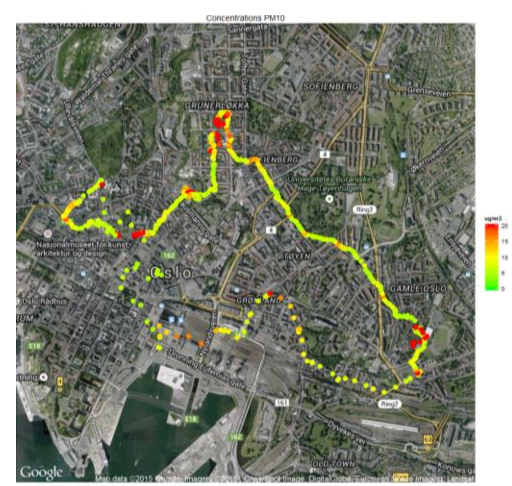
Is there another way?

- Large
- Complex
- High-maintenance
- Expensive

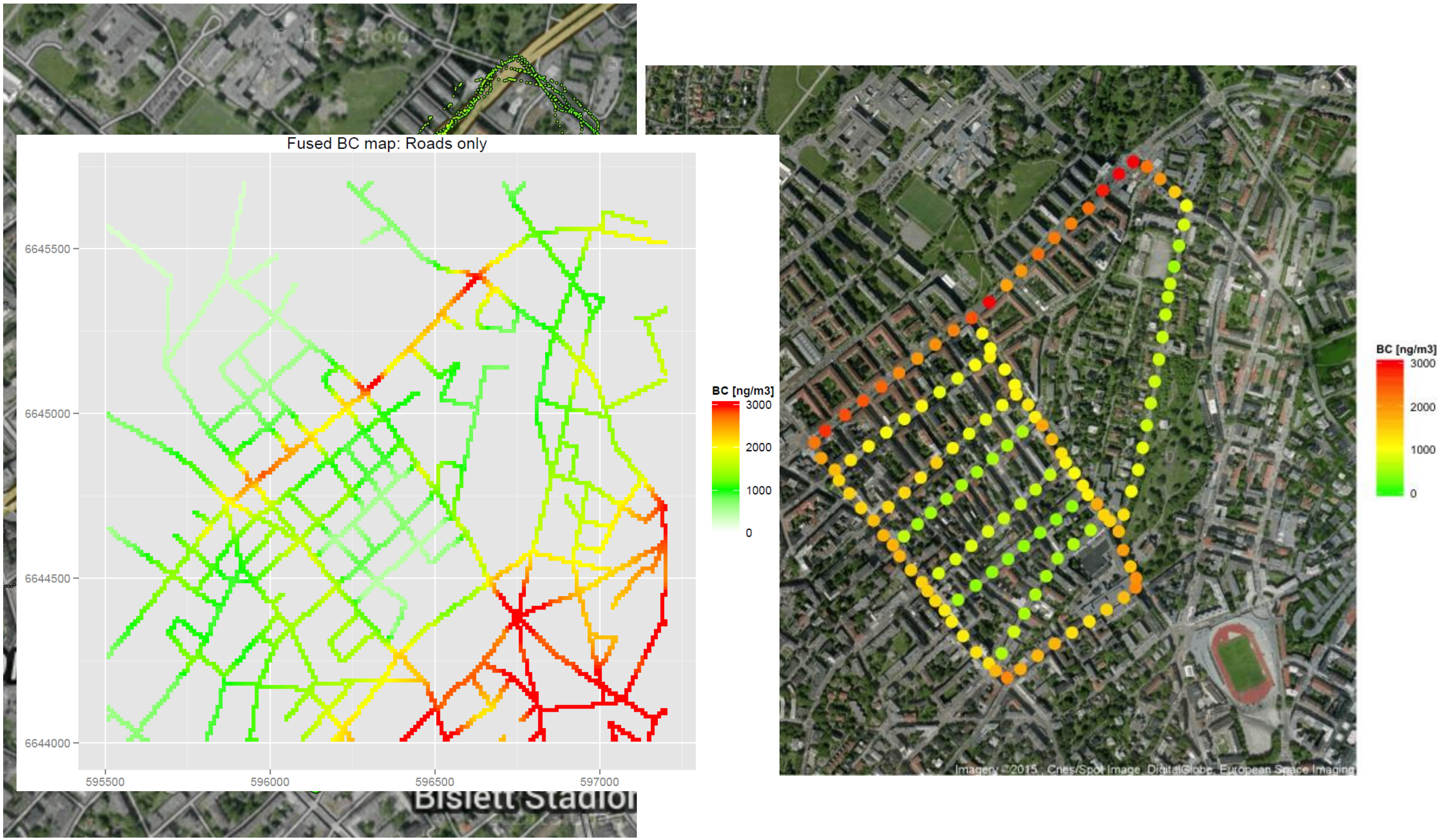
→ Very sparse

Bidgee

There might be…



Data fusion of mobile measurements of Black Carbon



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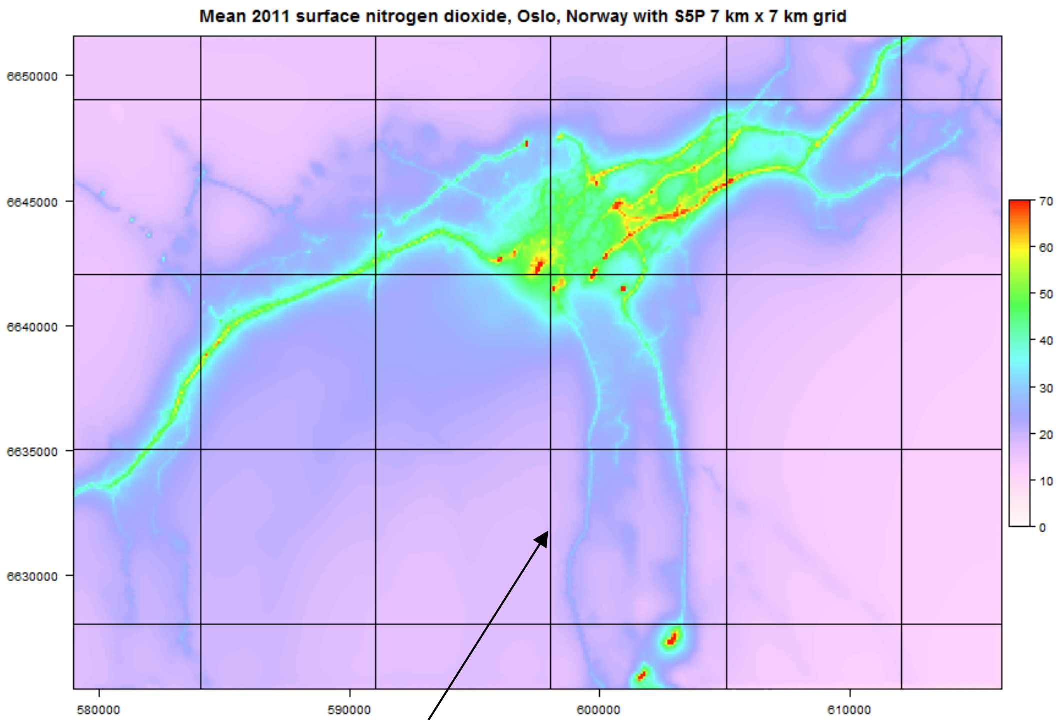
Applications for Sentinel-5P



7 km by 7 km grid of Sentinel-5P products for atmospheric composition

High-resolution urban air quality maps based on the combination of crowdsourced observations and model data provides sub-pixel information for Sentinel-5P

Could be used for:

- Validation/verification of S5P data (e.g. NO_2)
- Downscaling of the S5P products to higher spatial resolution using the fused map as proxy for spatial patterns

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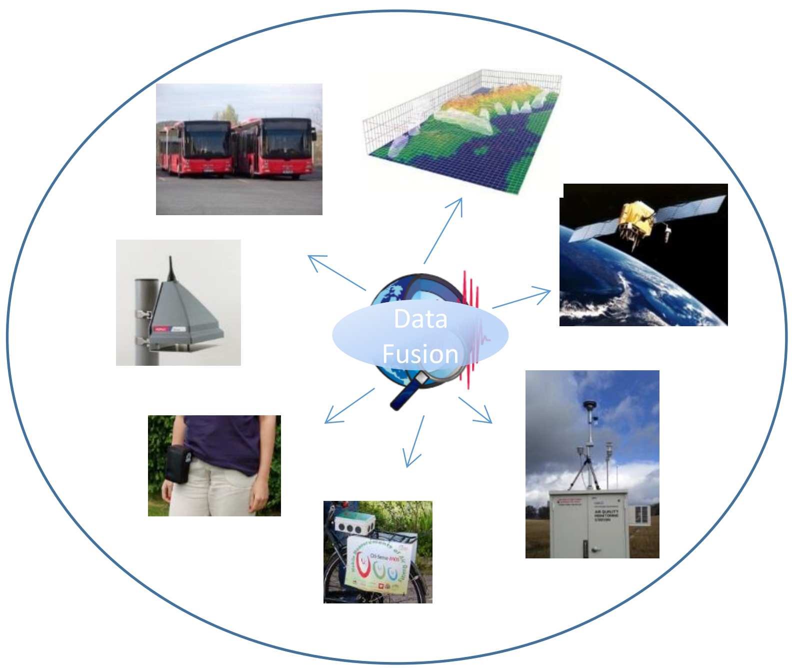
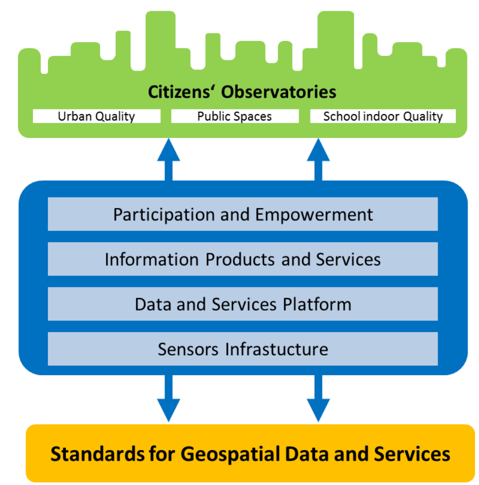
The CITI-SENSE project

- Collaborative Project funded by FP7-ENV-2012
- 28 project partners from 12 countries (Europe, South Korea, and Australia)
- Objective: Development of sensor-based Citizen’s Observatories for improving urban quality and for empowering citizens to
  - Contribute to and participate in environmental governance
  - Support and influence community and policy priorities and associated decision making
  - Contribute to the Global Earth Observation System of Systems (GEOSS)

Partners:

CITI-SENSE is a four year Collaborative Project partly funded by the EU FP7-ENV-2012 under grant agreement 308524, started in October 2012.





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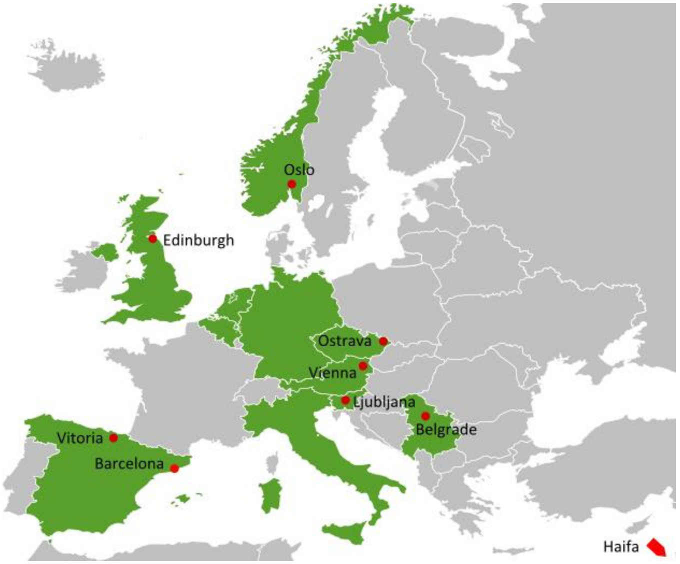
Observations

- There are many aspects to CITI-SENSE
  - Air quality observations using static and mobile sensor nodes
  - Indoor environment in schools
  - Public Spaces
- Here we focus on a network of static sensor nodes for air quality that are being deployed in various cities throughout Europe
  - Measuring the major air pollutants
  - Mounted at stakeholder's premises



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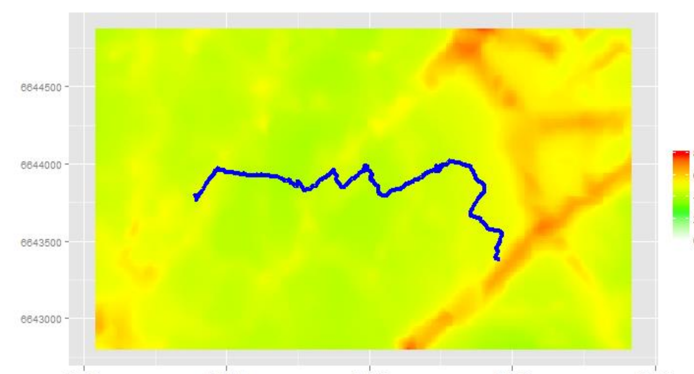
Towards personal exposure estimates

- There are two alternative ways for accomplishing personalized exposure/dose estimates
  - Approach 1: **Direct use of sensors**
    People move through the urban environment with portable sensors measuring concentrations
  - Approach 2: **Indirect use of sensors**
    Sensor data is used with model info and data fusion techniques to provide up-to-date air quality maps for the city -> these maps are then used to estimate exposure along a given track



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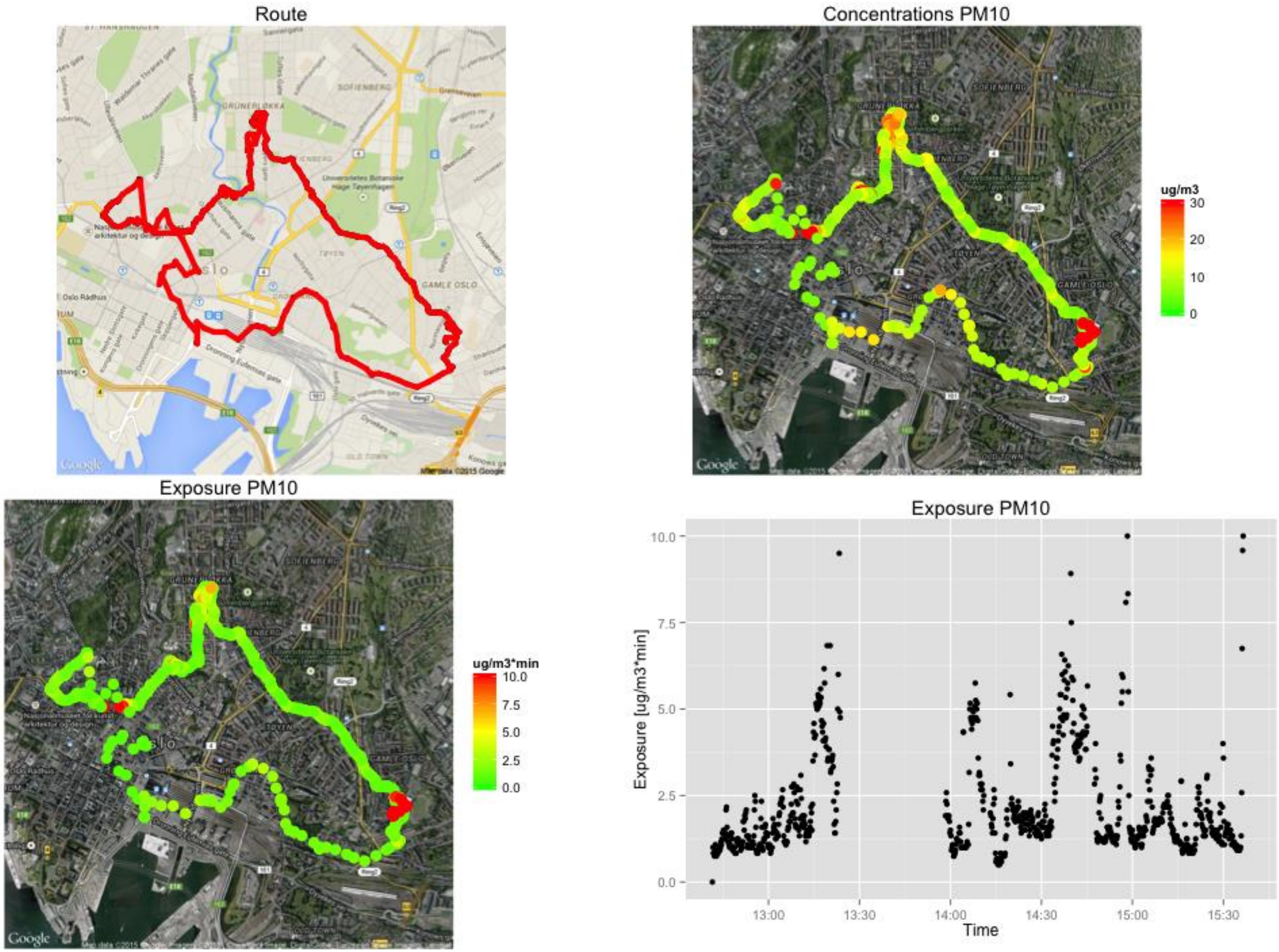
Sensor-based exposure and dose



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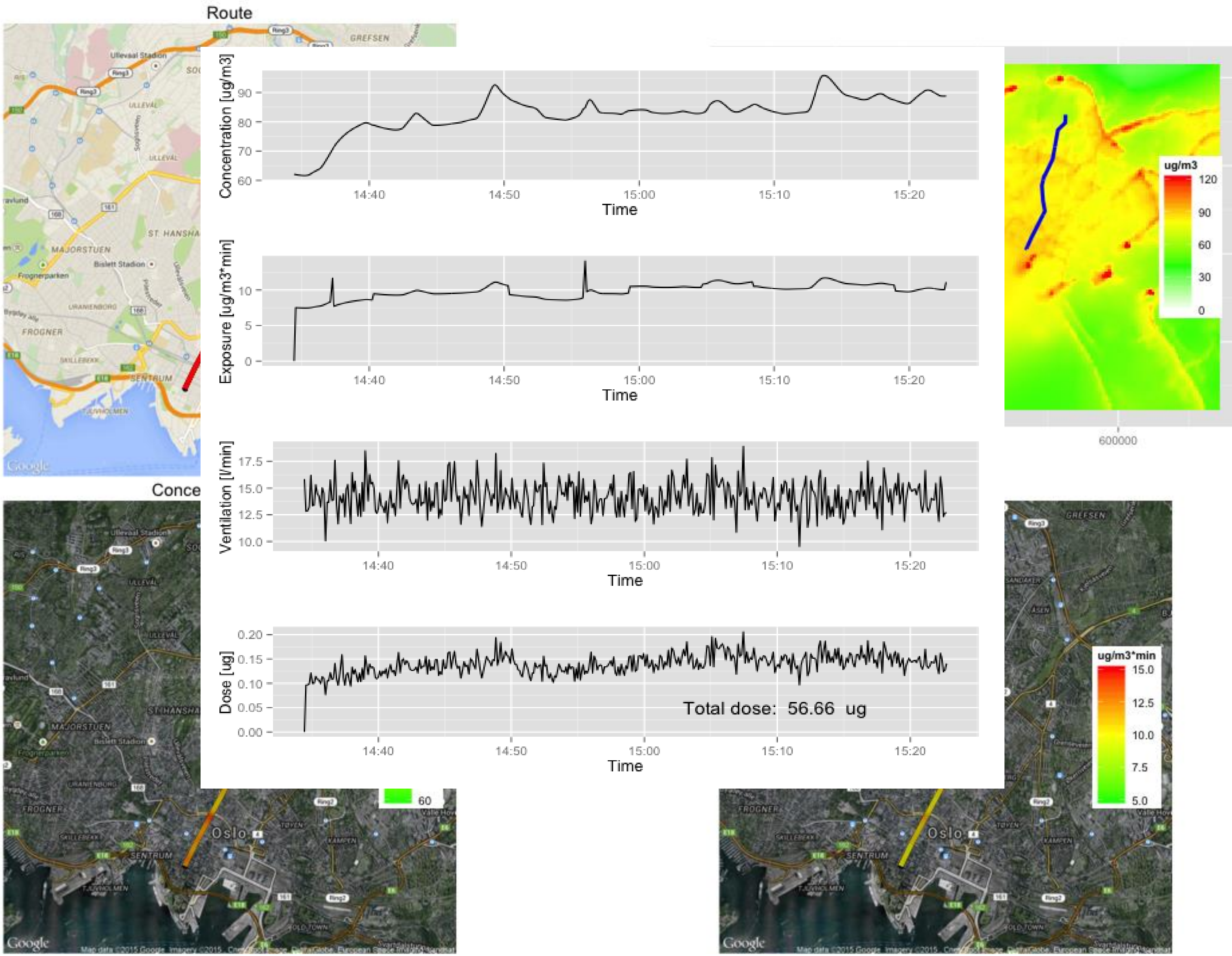
Route
Conce
Concentration [ug/m3]
Time
Exposure [ug/m3*min]
Ventilation [l/min]
Dose [ug]
Total dose: 56.66 ug
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14:50
15:00
15:10
15:20
ug/m3
120
90
60
30
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600000
ug/m3*min
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12.5
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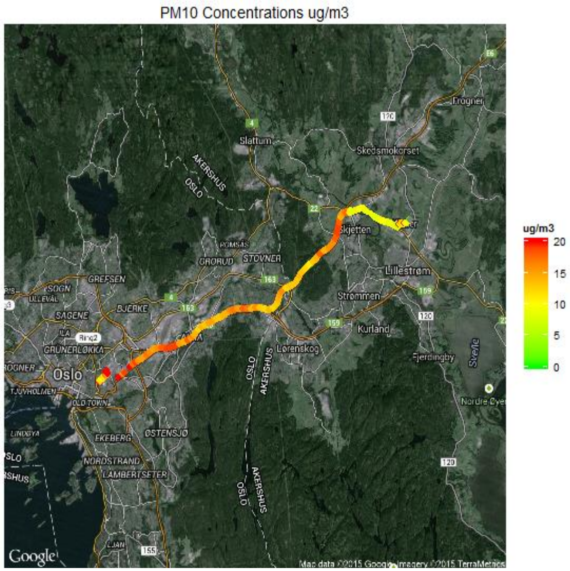
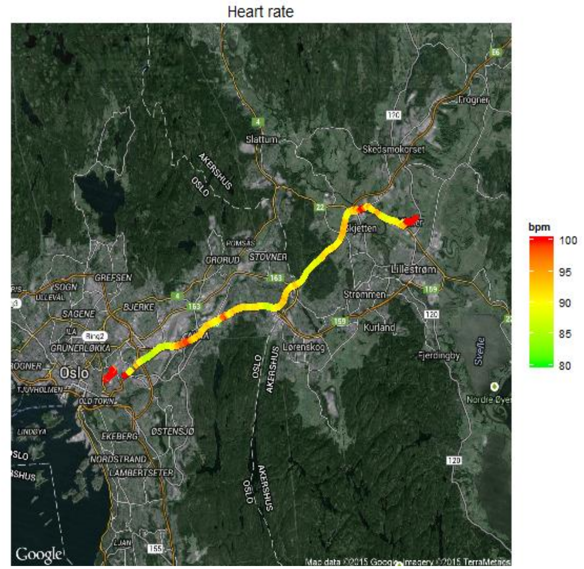
7.5
5.0
60
Oslo
SENTRUM
FROGNER
MAJORSTUEN
GREFSEN
ST. HANSHA
Google

Heart rate -> Dose



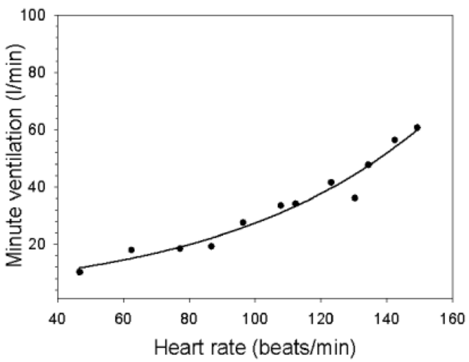


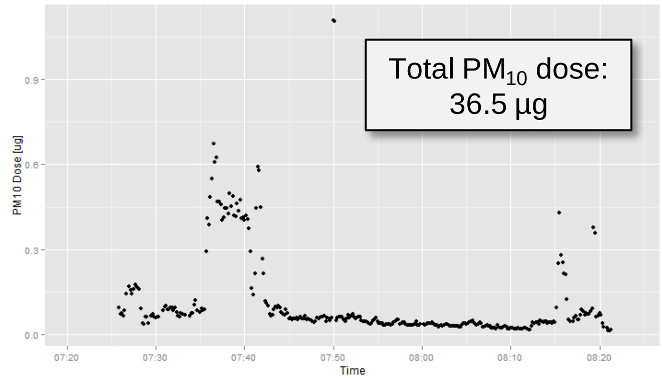
If we know the subject's hear rate we can compute the inhalation rate (ventilation) and the inhaled dose

Heart rate can either be

1. Measured by a heart rate monitor (mostly Approach 1)
2. Derived from accelerometer data (Approach 1+2)
3. Estimated by activity (mostly Approach 2)

Inhaled dose = Concentration × Ventilation × Duration





Total PM_{10} dose: 36.5 µg