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Towards personal exposure estimates using low-cost air quality sensors and data fusion techniques

Philipp Schneider

MC Member / ps@nilu.no

NILU – Norwegian Institute for Air Research / Norway

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Towards personal exposure estimates using low-cost air quality sensors and data fusion techniques

Philipp Schneider[1]
Nuria Castell[1]
William A. Lahoz[1]

[1]NILU - Norwegian Institute for Air Research

Introduction

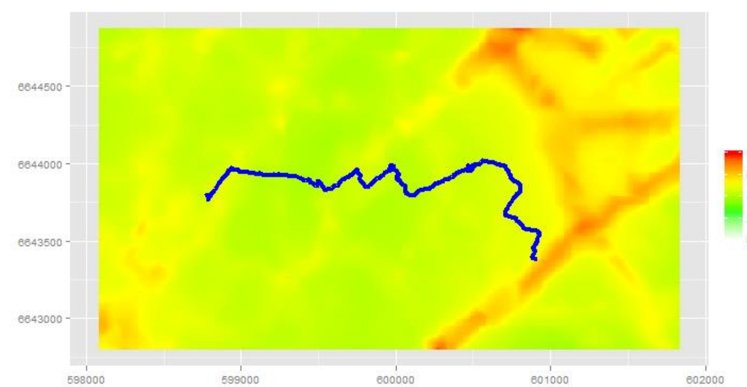
- Urban air pollution has significant impacts on citizens' health
- Exposure differs dramatically for all individuals based on a variety of factors
- Yet no easy operational system for estimating personal exposure exists
- Low-cost microsensors for air quality offer great potential for personal exposure estimates
- Objective: We describe here two different approaches for using low-cost AQ sensor for providing personal exposure/dose estimates along a user-defined path

Air pollution due to road transport (Shutterstock.com)

Air pollution in Harbin, China (STR/AFP/Getty Images)

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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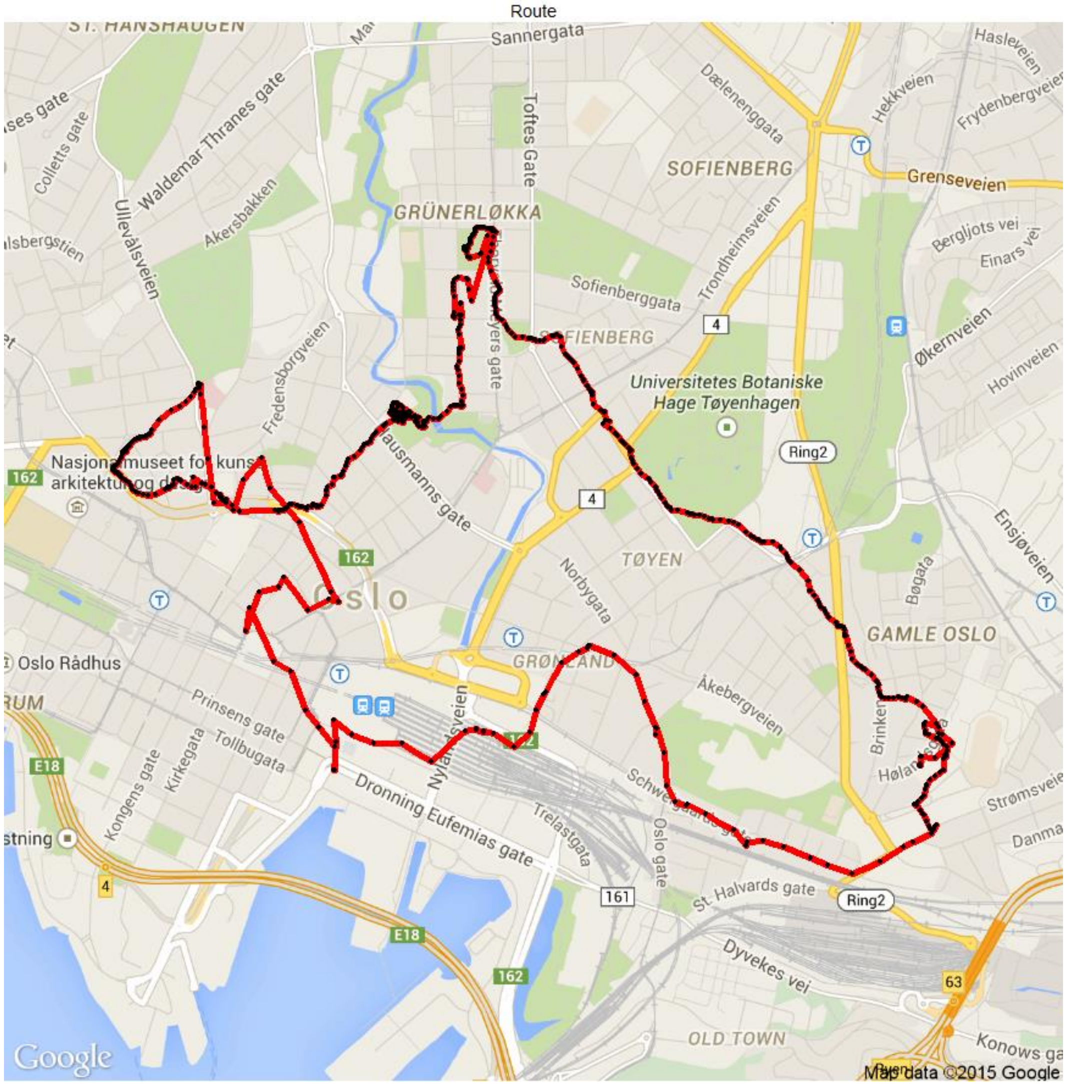
Approach 1: Route

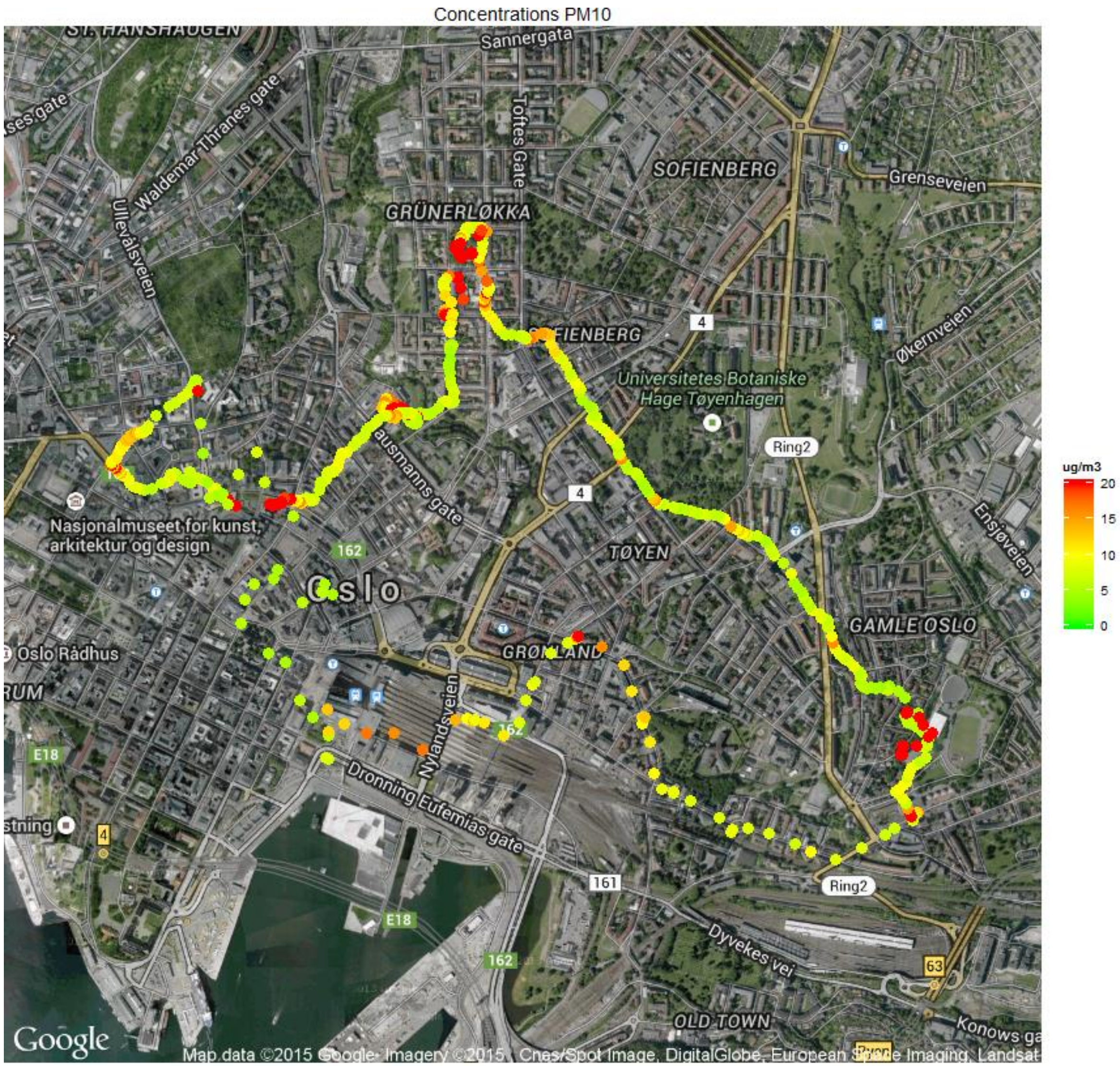


Subject could move through the urban environment while carrying a portable microsensor for air quality

Most useful for activities such as walking, running, bicycling.

A GPS device (e.g. a smartphone or GPS logger) records latitude/longitude and a time stamp.

Approach 1: Concentrations

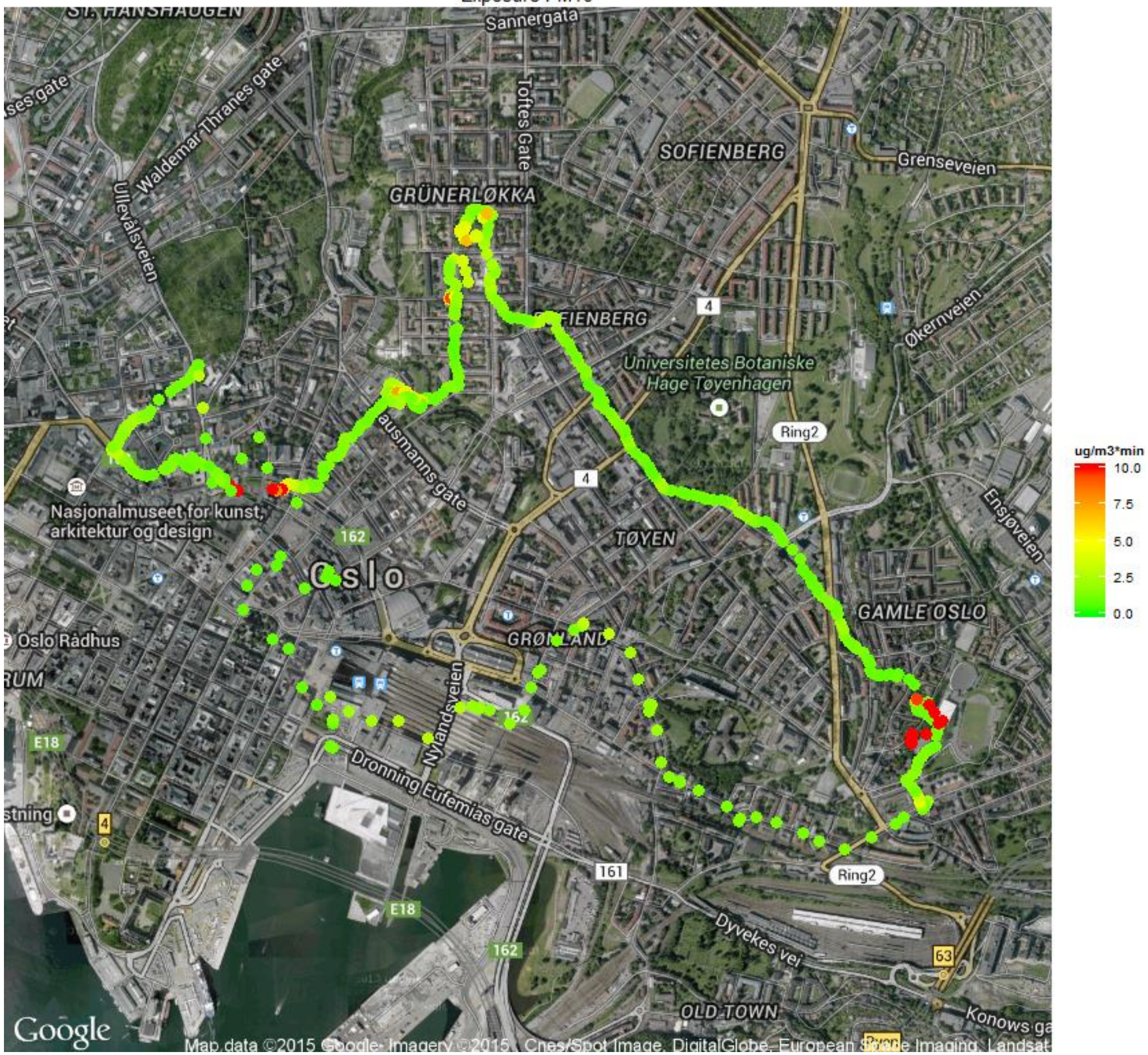


The microsensor measures concentrations at defined intervals, e.g. every 30 seconds.

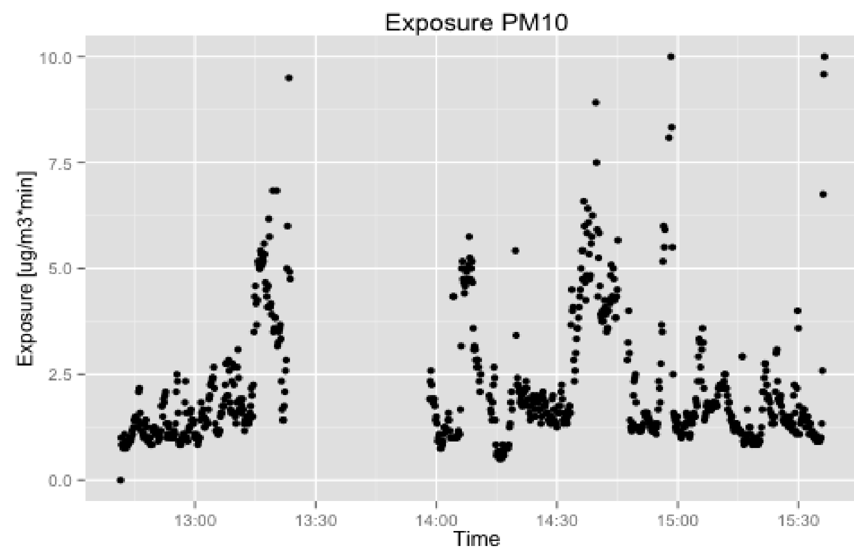
Here concentrations using a DustTrak instrument measuring PM10 are shown.

Approach 1: Exposure

Exposure PM10



The exposure for each is then computed by averaging the concentration along each line segment and multiplying it by the time spent on this segment (which is computed from the time stamps)



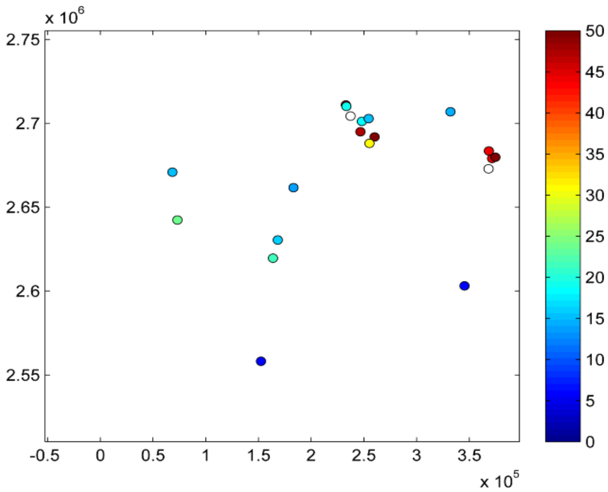
Characteristics of Approach 1

- Advantages
  - Accurate concentration measurements along the exact path the user is taking and at the exact right time
  - It is possible to also measure heart rate directly, and thus to get reasonable dose estimates
- Disadvantages
  - User always has to carry around one (or several) sensors -> can be cumbersome depending on sensor size and activity
  - The route actually has to be taken -> No exposure estimate on hypothetical routes or routes to be taken in future possible

Approach 2: Indirect exposure

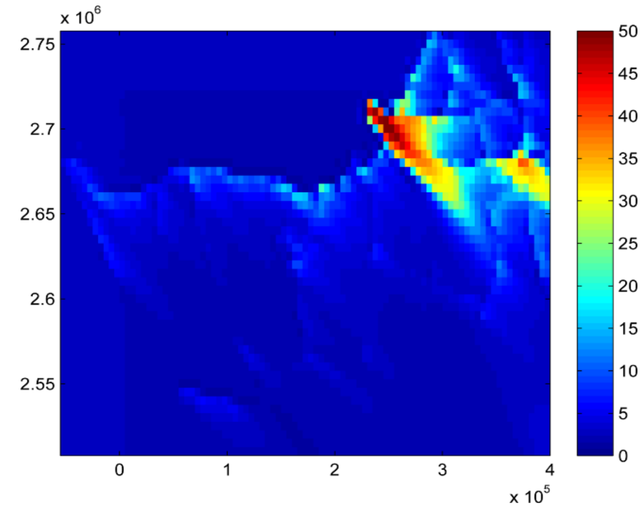
- General idea: Use data fusion techniques to combine low-cost sensor observations with modeled information to provide hourly best-guess maps of urban air quality
- Only static sensors are currently used within the mapping procedure
- Extract concentrations along a given or planned route from the up-to-date concentration map
- Route for approach 2 can be taken from any type of source
  - GPS loggers
  - Smartphone
  - Routing apps (e.g. Google Maps)
  - Hypothetical routes

Data fusion: Basic Premise

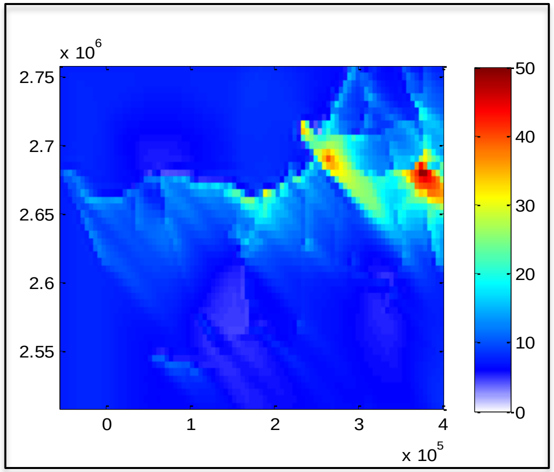


Observations

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 separately interpolating the observational residuals from a regression model and then combining both.

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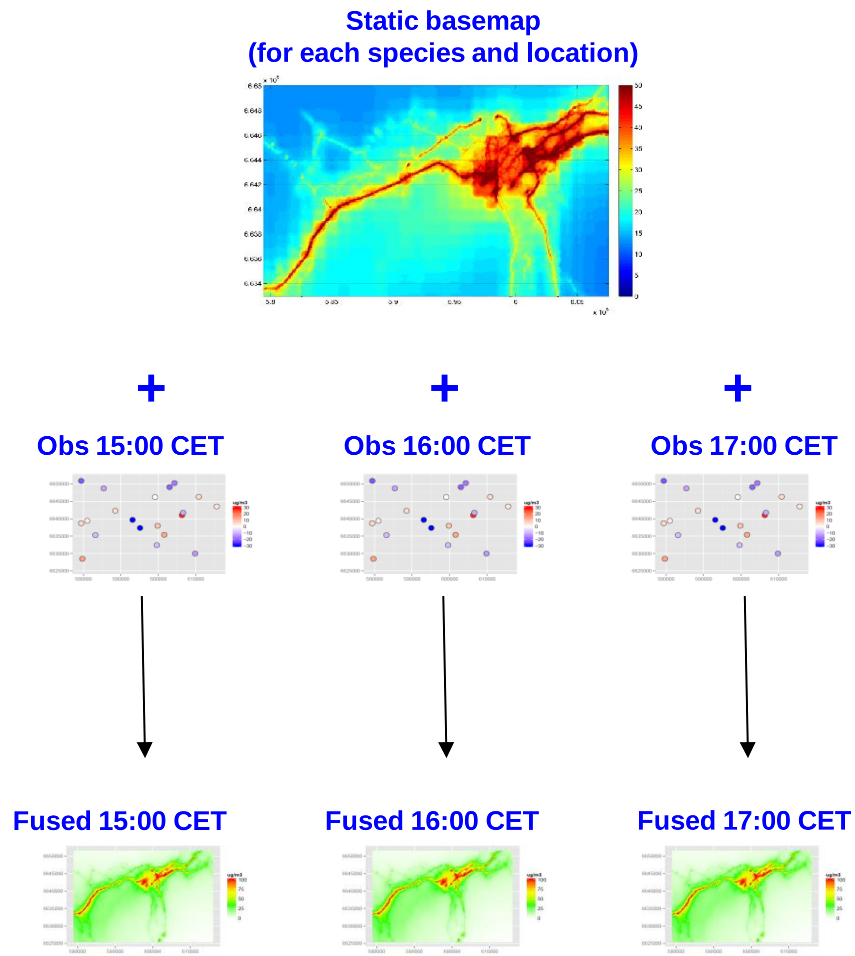
Data fusion for CITI-SENSE

- A static basemap is created for each location and each species of interest to show consistent 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

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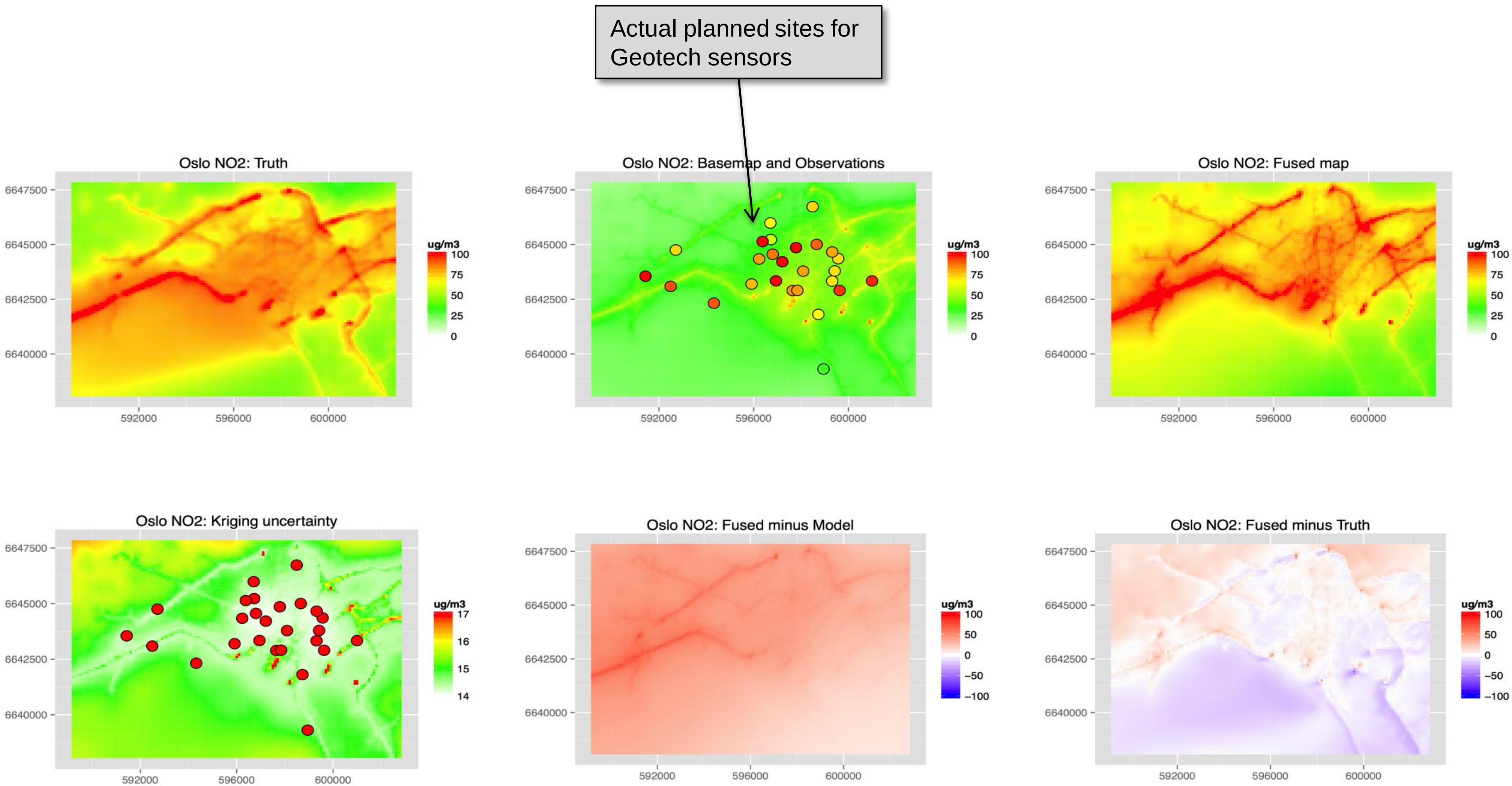

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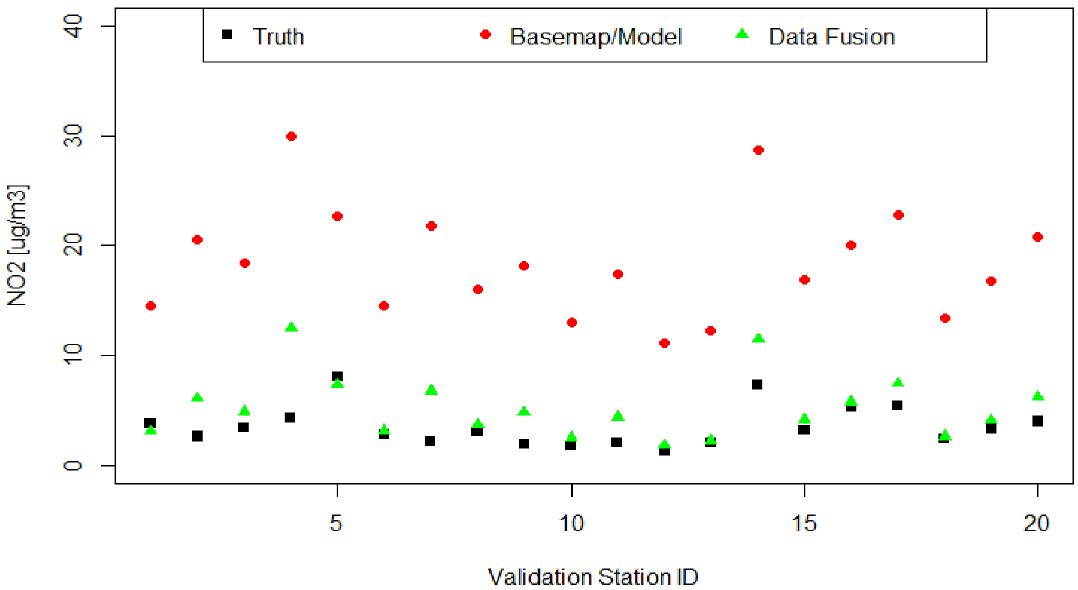
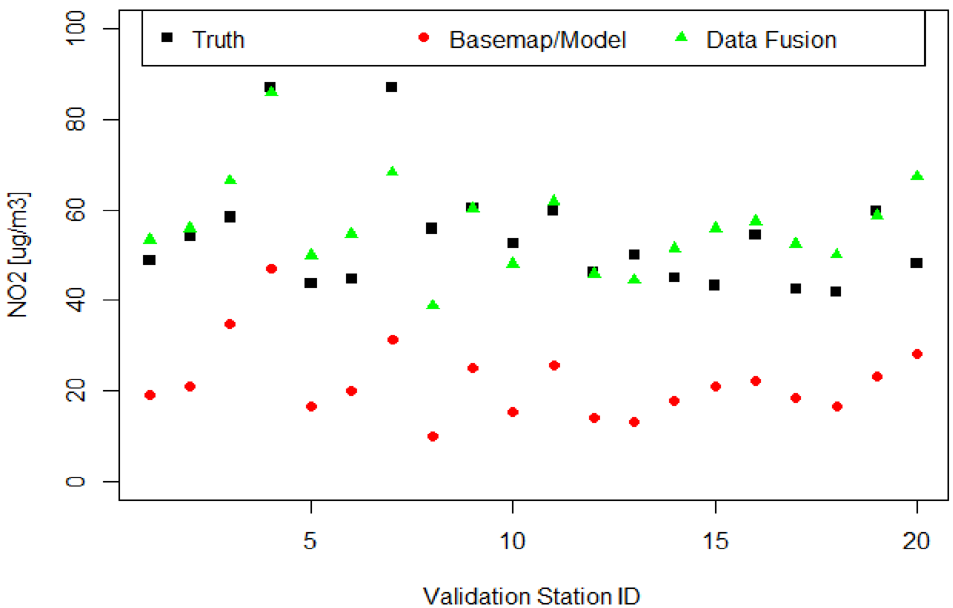
Validation against “Truth”

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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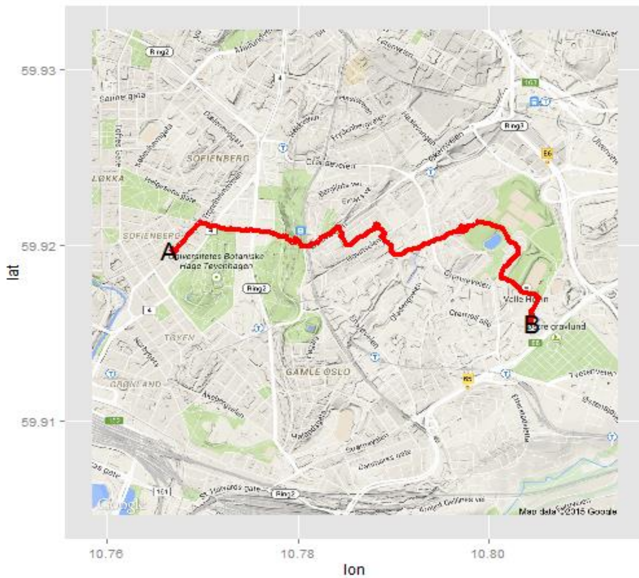
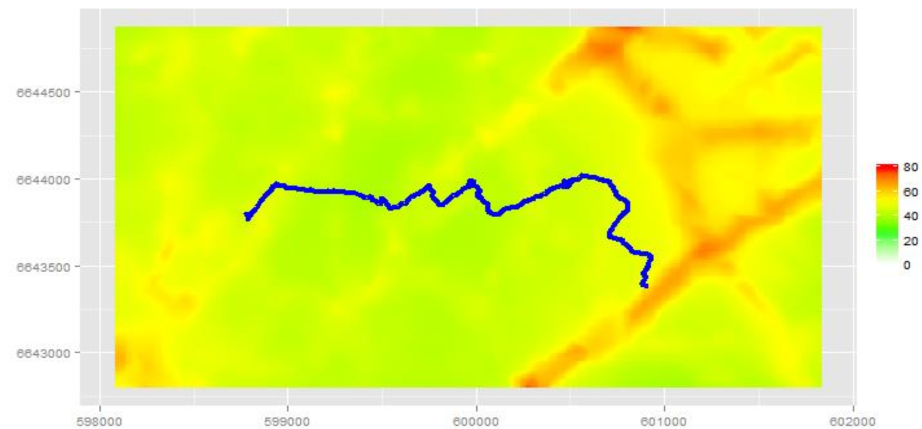
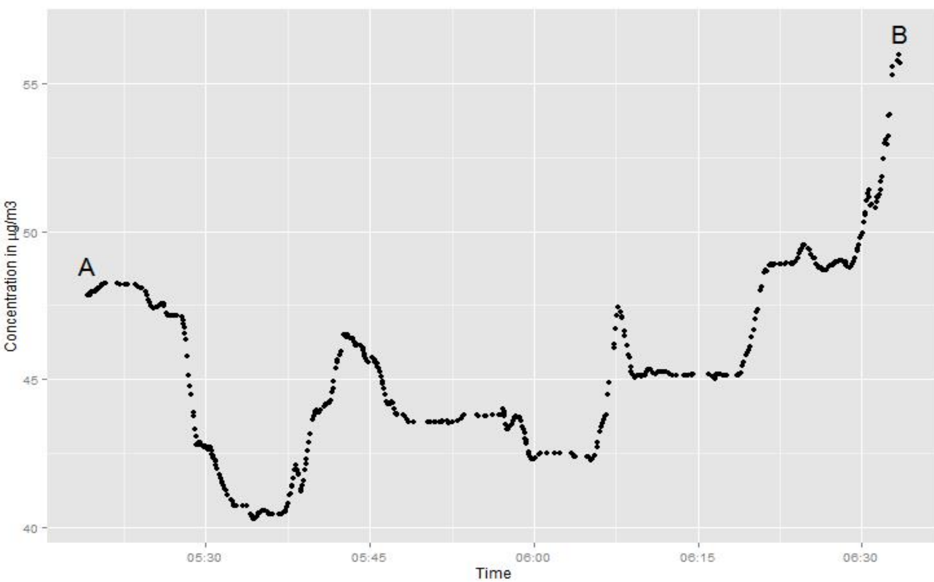
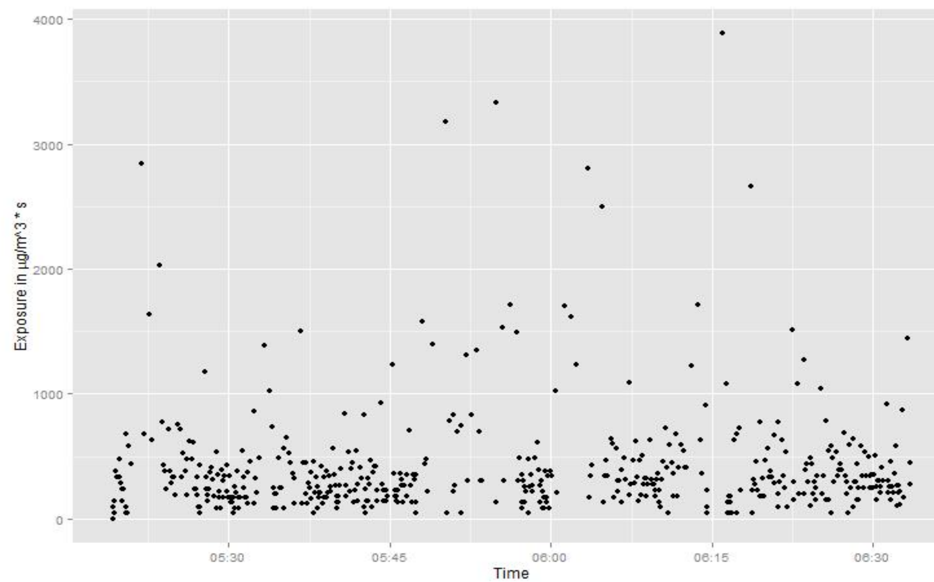
Example for approach 2: NO2 exposure along track extracted from fused air quality maps for Oslo







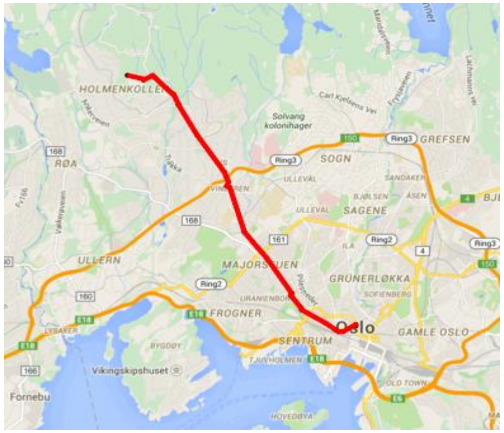


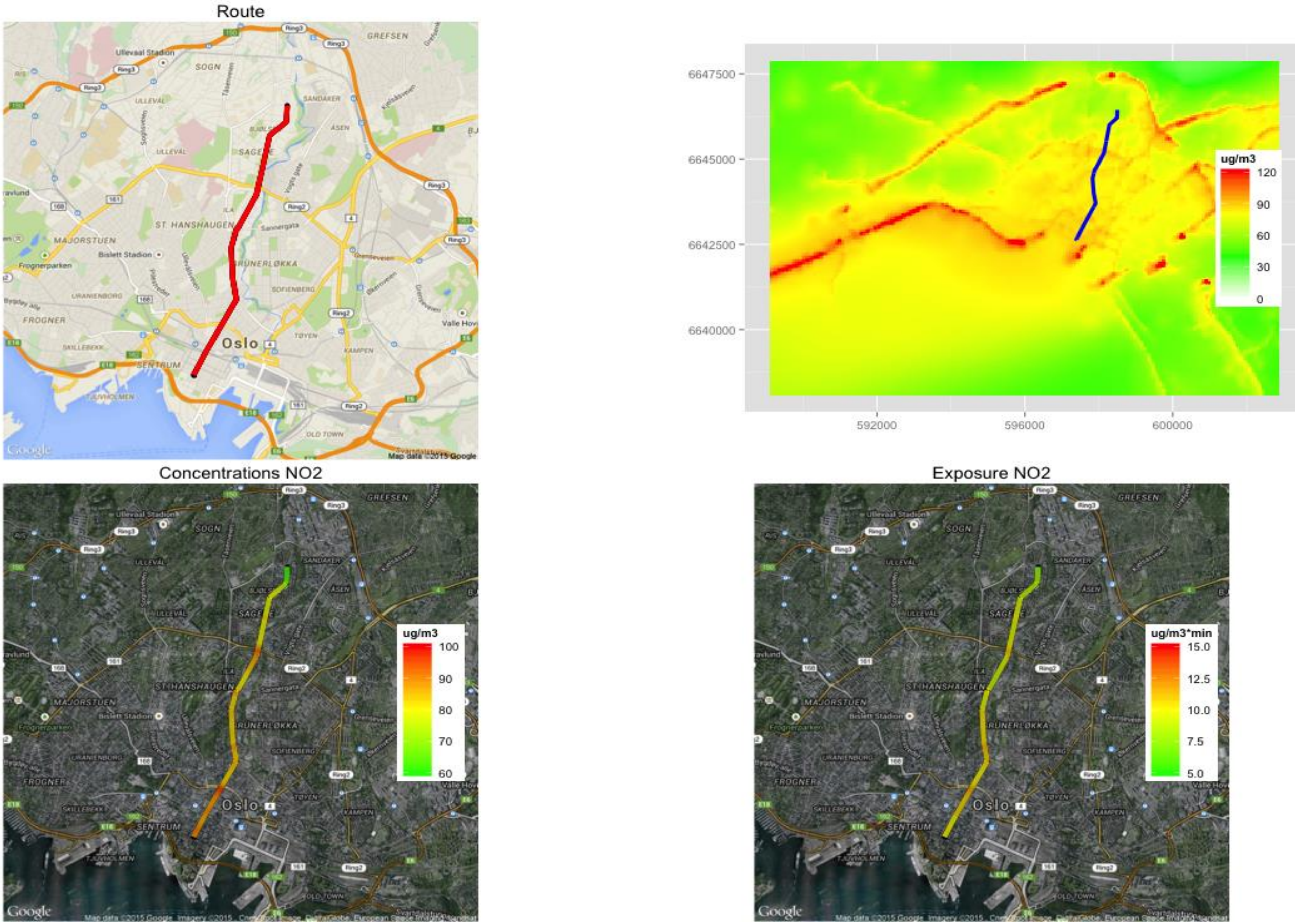
Automated Route Planning

- Code has been developed for automatically retrieving the path of a route just by supplying
  – Start address (Google Maps style)
  – Destination address (Google Maps style)
  – Transportation mode (Driving, walking, bicycling, public transit)
- This route can then be used to extract concentration levels from the fused maps

```
r = routesp('Oslo S', 'Holmenkollen', mode='walking')
```

	m	km	miles	seconds	minutes	hours	startLon	startLat	endLon	endLat	leg
1	36	0.036	0.0223704	28	0.4666667	0.007777778	10.75260	59.91394	10.75259	59.91426	1
2	314	0.314	0.1951196	238	3.9666667	0.066111111	10.75259	59.91426	10.74778	59.91280	2
3	101	0.101	0.0627614	83	1.3833333	0.023055556	10.74778	59.91280	10.74618	59.91279	3
4	88	0.088	0.0546832	66	1.1000000	0.018333333	10.74618	59.91279	10.74487	59.91321	4
5	245	0.245	0.1522430	186	3.1000000	0.051666667	10.74487	59.91321	10.74133	59.91452	5
6	599	0.599	0.3722186	484	8.0666667	0.134444444	10.74133	59.91452	10.73211	59.91728	6
7	45	0.045	0.0279630	40	0.6666667	0.011111111	10.73211	59.91728	10.73189	59.91766	7
8	391	0.391	0.2429674	332	5.5333333	0.092222222	10.73189	59.91766	10.72789	59.92031	8
9	47	0.047	0.0292058	34	0.5666667	0.009444444	10.72789	59.92031	10.72837	59.92066	9
10	999	0.999	0.6207786	796	13.2666667	0.221111111	10.72837	59.92066	10.71872	59.92801	10



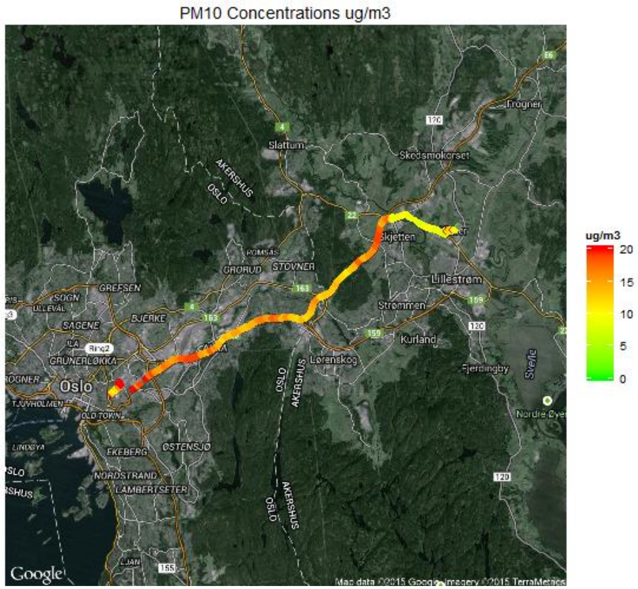


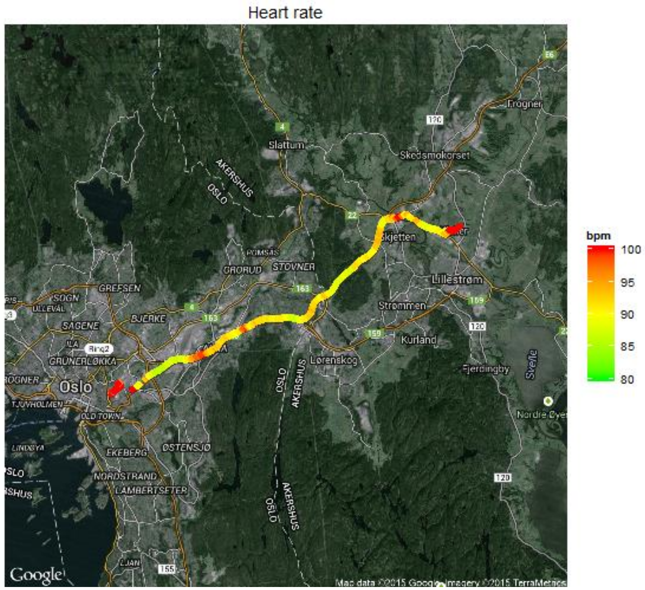
Route
Concentrations NO2
Exposure NO2
ug/m3
120
90
60
30
0
6647500
6645000
6642500
6640000
592000
596000
600000
ug/m3
100
90
80
70
60
ug/m3*min
15.0
12.5
10.0
7.5
5.0
Oslo
Map data ©2015 Google

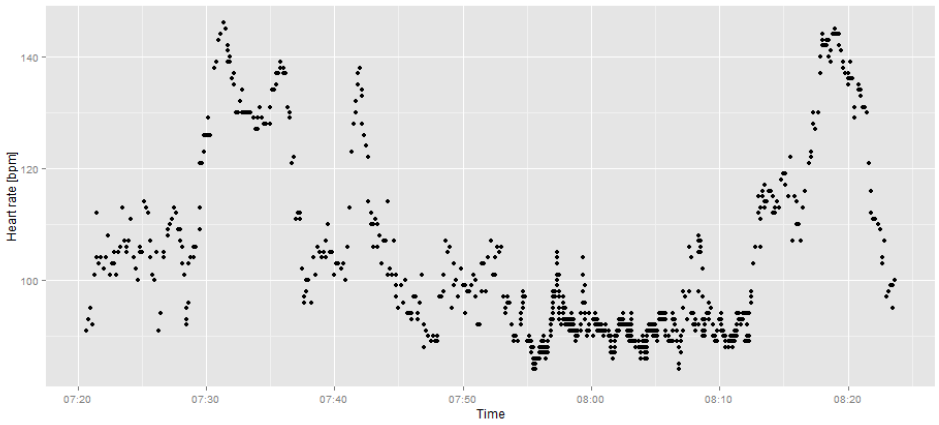
Characteristics of Approach 2

- Advantages
  - More flexible than Approach 1
  - Estimates of hypothetical routes or routes to be taken are possible
  - Based on microsensors but user does not have to carry around a sensor (or several)
  - Easier to implement in an operational fashion at large scales
- Disadvantages
  - Concentrations along path are estimated using data fusion techniques → higher uncertainty
  - Heart rate generally would be estimated based on activity (but actual measurements, i.e. using a smartwatch or similar can be used)

Heart rate





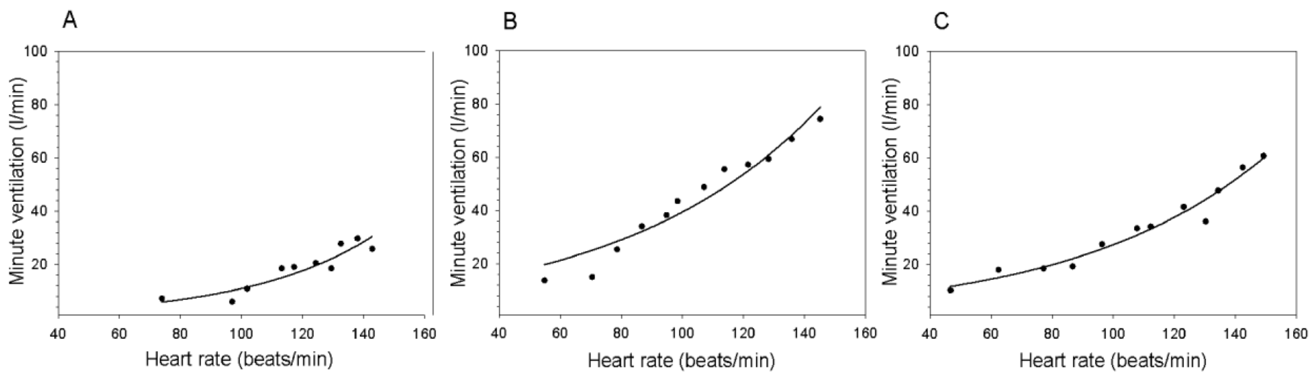


If we know the subject's hear rate we can compute the inhalation rate (ventilation)

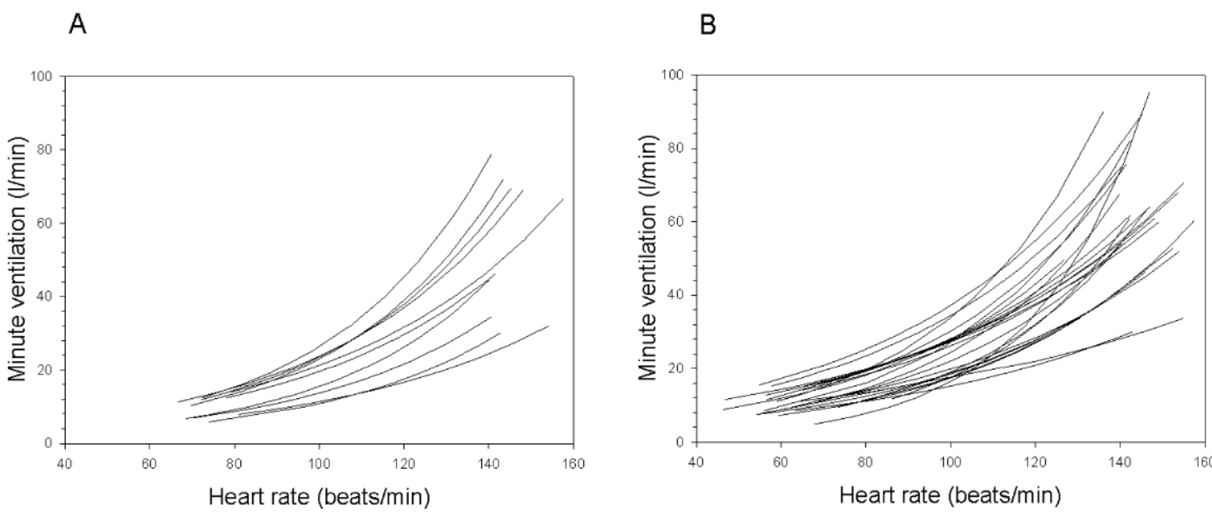
Heart rate can either be

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)

Ventilation from heart rate



Examples of fitted regression between heart rate and minute ventilation for (A) a female participant, R^2 of regression is 0.83 (B) a male participant, R^2 of regression is 0.92 (C) a male participant, R^2 of regression is 0.96.



Fitted regression lines of heart rate (beats per minute) and minute ventilation (litre per minute) for (A) 10 women and (B) 24 men.

Table 2: Relationship between minute ventilation and heart rate during bicycle ergometer tests

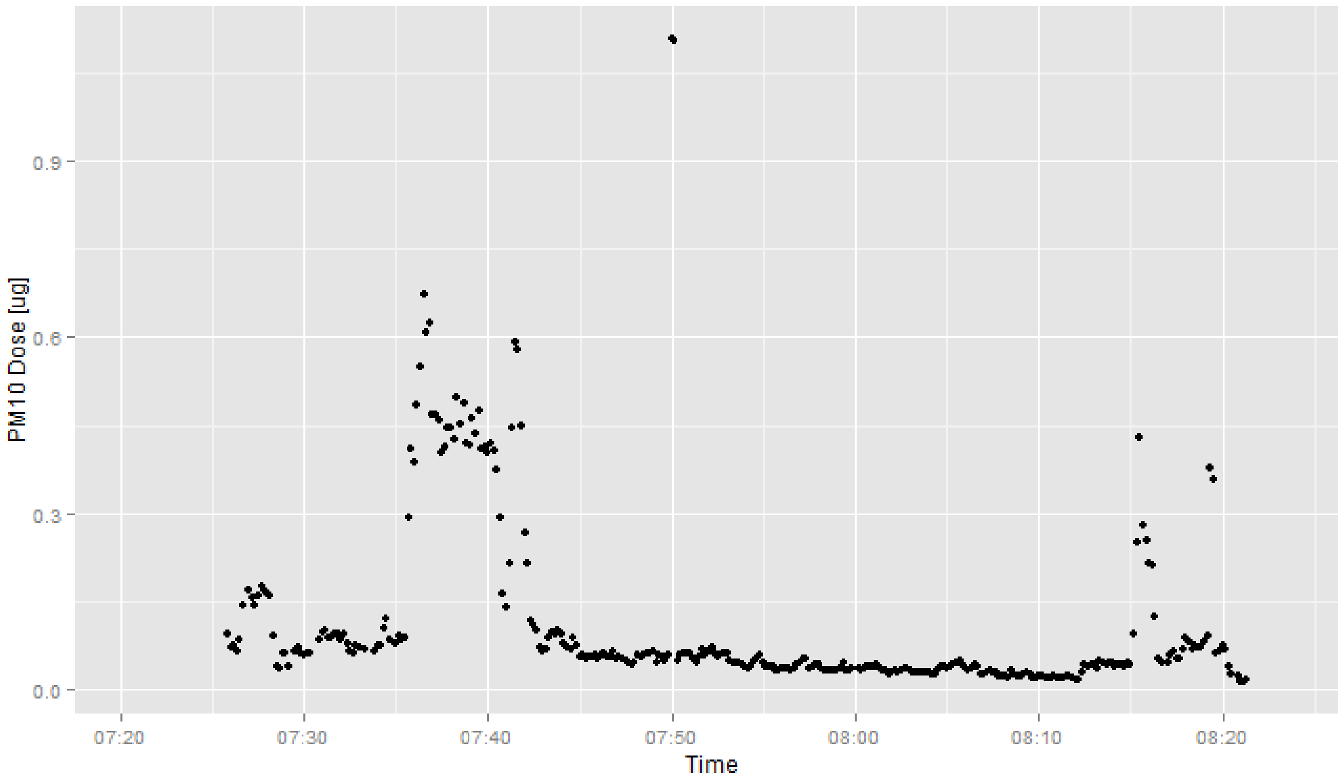
	Intercept#		Slope#		R^2	
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
All (n = 34)	0.89 (0.60)	-0.97-1.69	0.022 (0.005)	0.012-0.038	0.90 (0.07)	0.62-0.97
Men (n = 24)	1.03 (0.63)	-0.97-1.69	0.021 (0.005)	0.012-0.038	0.90 (0.07)	0.62-0.97
Women (n = 10)	0.57 (0.36)	-0.01-1.07	0.023 (0.003)	0.019-0.027	0.89 (0.06)	0.80-0.96

#Regression coefficients of the regression of natural log-transformed minute ventilation on heart rate.

Zuurbier, M., G. Hoek, P. van den Hazel, and B. Brunekreef (2009), Minute ventilation of cyclists, car and bus passengers: an experimental study., Environ. Health, 8, 48, doi:10.1186/1476-069X-8-48.

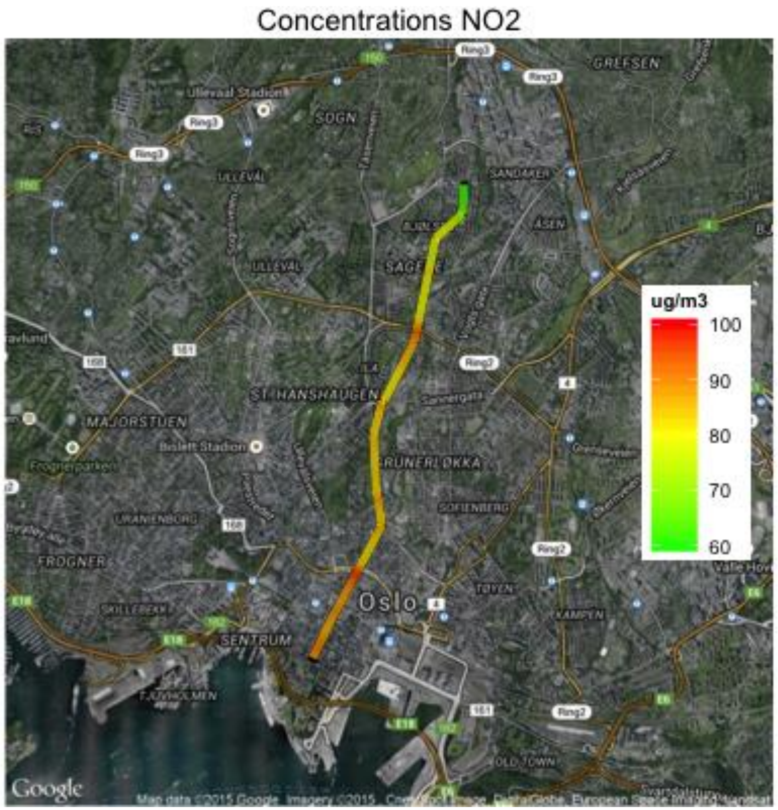
Dose

Inhaled dose = Concentration × Ventilation × Duration

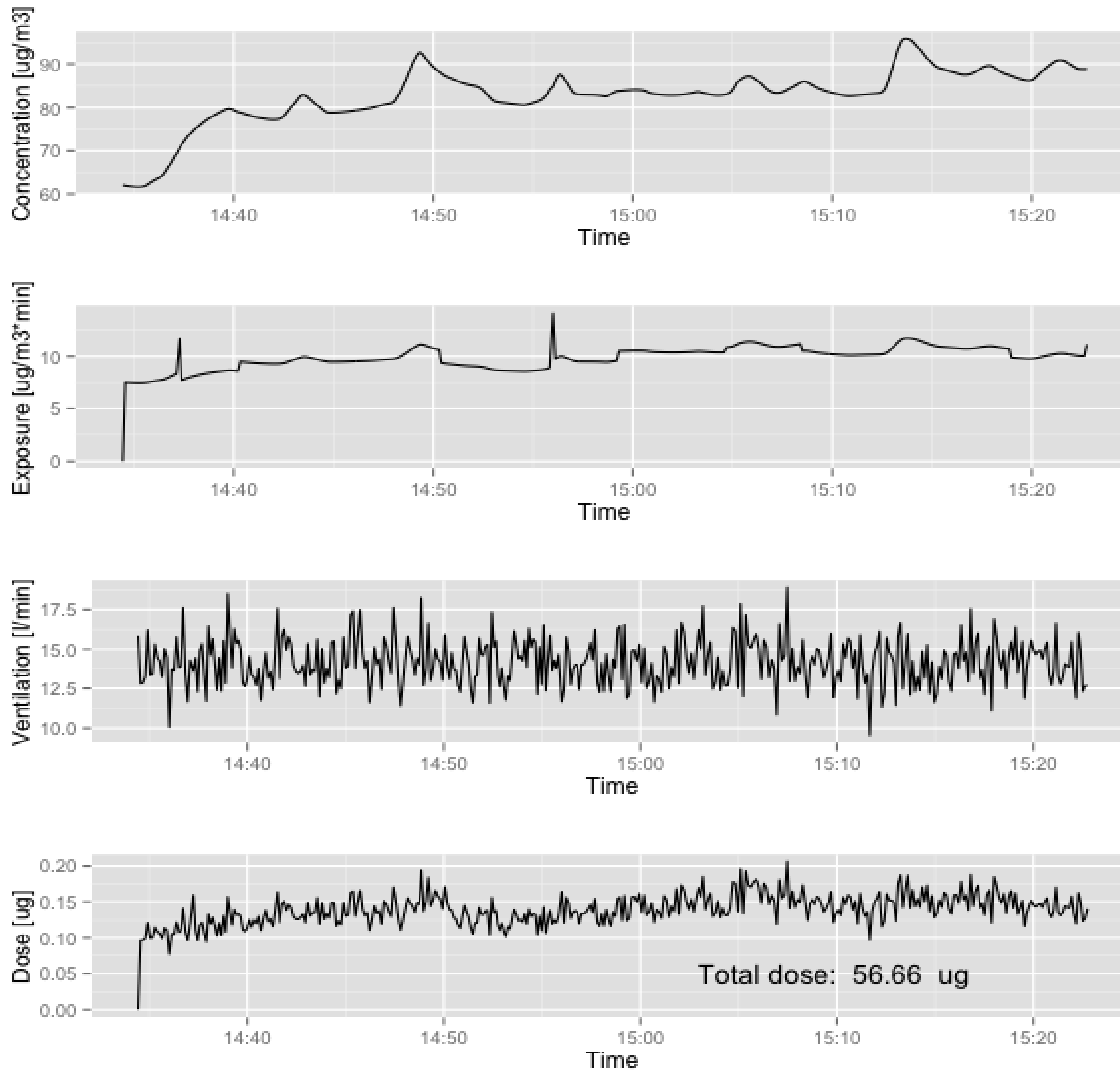


Total PM_{10} dose:

36.5 µg



Concentrations NO2
ug/m3
100
90
80
70
60
GREFSEN
SOGN
ULLEVÅL
SAGENE
ST. HANSHAUGEN
MAJORSTUEN
GRUNERLØKKA
FROGNER
Oslo
SENTRUM
Google



Concentration [ug/m3]
90
80
70
60
14:40
14:50
15:00
15:10
15:20
Time
Exposure [ug/m3*min]
10
5
0
14:40
14:50
15:00
15:10
15:20
Time
Ventilation [l/min]
17.5
15.0
12.5
10.0
14:40
14:50
15:00
15:10
15:20
Time
Dose [ug]
0.20
0.15
0.10
0.05
0.00
Total dose: 56.66 ug
14:40
14:50
15:00
15:10
15:20
Time

Exposure-based routing

- Large potential for data fusion method
- Find not the shortest but the cleanest route through an urban environment
- Or (more realistic): A route that is only slightly longer but significantly less polluted
- Optimization algorithm
- For this type of application Approach 2 is more suitable

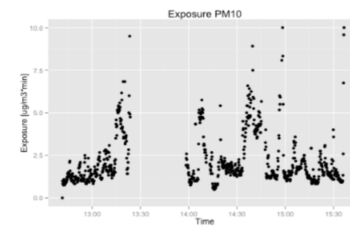
(a) Albisrieden to Wollishofen. (b) Wiedikon to Witikon. (c) Hönggerberg to ETH Zentrum.

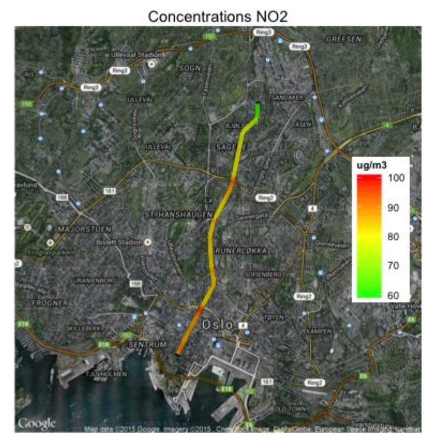
Figure 20: Three exemplary source-destination pairs within the city of Zurich, Switzerland. In (a) the shortest and health-optimal routes are completely different while they partly overlap in (b) and (c).

From: Hasenfratz, D., O. Saukh, C. Walser, C. Hueglin, M. Fierz, T. Arn, J. Beutel, and L. Thiele (2014), Deriving high-resolution urban air pollution maps using mobile sensor nodes, Pervasive Mob. Comput., doi:10.1016/j.pmcj.2014.11.008.

Conclusions

- Exposure to air pollutants is highly dependent on an individual’s location, timing, activity, etc.
- Personal exposure varies greatly between individuals
- Low-cost microsensors for air quality have potential to provide personal exposure estimates
- We present two approaches for estimating personal exposure from low-cost AQ sensors
- Approach 1 uses portable sensors to measure concentration along a path
- Approach 2 uses static sensors and data fusion techniques to produce detailed maps of urban air quality and extract concentrations along any given path from those
- Choice of approach depends on overall goal – in many ways the two approaches can complement each other





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Thank you for your attention!

Philipp Schneider

***Email*: ps@nilu.no**

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