Real-time mapping of air quality in cities for improved exposure estimation

Christoph Hueglin¹, Robert Gehrig¹, David Hasenfratz², Michael Müller¹, Olga Saukh², Beat Schwarzenbach¹, Lukas Emmenegger¹

¹ Empa, Laboratory for Air Pollution and Environmental Technology
² ETH Zurich, Computer Engineering and Networks Laboratory
“There is increasing, though as yet limited, epidemiological evidence on the association between short-term exposures to ultrafine (<0.1 μm) particles and cardiorespiratory health as well as the central nervous system. Clinical and toxicological studies have shown that ultrafine particles in part act through mechanisms not shared with larger particles that dominate mass-based metrics such as PM2.5 or PM10.”

“Although there is considerable evidence that ultrafine particles can contribute to the health effects of particulate matter, for ultrafine particles, measured by the number of particles, the data on concentration-effect functions are too scarce to evaluate and recommend an AQG.”

Review of health aspects of air pollution – REVIHAAP project, first results (WHO, 2013)
Motivation

Why is it so difficult to find epidemiological evidence for health effects of ultrafine particles – UFPs?
Differences between Swiss sites (NABEL, data from 2012)

- **PNC (Particle Concentration #/cm³):**
  - Rural > 1000m asl.: Base line
  - Suburban: ~10000
  - Urban Background: ~20000
  - Urban Roadside: ~30000
  - Rural > 1000m asl.: x2.2

- **BC (Black Carbon ug/cm³):**
  - Rural: Base line
  - Suburban: ~1
  - Urban Background: ~2
  - Urban Roadside: ~3
  - Rural: x3.1

- **PM10 (Particulate Matter 10 ug/cm³):**
  - Rural: Base line
  - Suburban: ~20
  - Urban Background: ~30
  - Urban Roadside: ~40
  - Rural: x1.5

- **PM2.5 (Particulate Matter 2.5 ug/cm³):**
  - Rural: Base line
  - Suburban: ~10
  - Urban Background: ~20
  - Urban Roadside: ~30
  - Rural: x1.3

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ETH Nanoparticles Conference, Zurich 24-26 June 2013 4
Small-scale (urban scale) variability of UFP

**PNC near Zurich HB**
(Feb.-Mar. 2013, data from tram based mobile sensor network - Opensense)

**Traffic activity near Zurich HB**
Exposure estimation

Small-scale spatial and temporal variability of air pollutants such as UFPs, BC, NO$_2$ is difficult to capture

Lack of epidemiological evidence might (partially) be due to insufficient information about spatial variability and thus inaccurate exposure estimates

**Approaches for improvement**

1. Personal monitoring
2. Air pollution maps  
   (high spatial and temporal resolution)
   a. Dispersion models
   b. Sensor networks & statistical models

Modelled annual NO$_2$ surface concentration (2011)

from http://www.stadt-zuerich.ch/content/gud/de/index/umwelt/luft
Hypothetical air quality sensor network in Zurich

- NABEL/AWEL/UGZ Sites
- Sensor Nodes
Parallel measurements using low-cost sensor and reference instruments
Opensense mobile sensor network in Zurich
Currently 10 nodes
- Sensors: O₃, CO, PNC, temperature, humidity, accelerometer
- GPS
- Communication: WLAN and GSM
- External power supply
Sensors for air quality measurements – issues to address

- How good are available sensors (performance characteristics)?
- How to operate sensor networks (calibration, QA/QC in general)?
- How to derive spatial information from a sensor network (air pollution maps with high spatial and temporal resolution)?
- ...
Model association between air pollutant concentration and land use information (Land use regression - LUR)

\[ Y_i = f(geo_{i1}) + g(geo_{i2}) + h(geo_{i3}) + \cdots + meteo + E \]

- \( Y_i \): air pollutant concentration at location i
- \( f, g, h, \text{etc.} \): smooth non-parametric functions
  
  (Generalized Additive Model, GAM)

- \( geo_{ij} \): road traffic (road network)
  - rail traffic
  - built environment, buildings, street configuration
  - heating systems used
  - industries
  - topography
  - ...

- \( meteo \): meteorological variable(s)

Use model for prediction of air pollutant concentration in each grid cell of modeling domain
3D – city model for Zurich

accuracy: x/y = ±10-15cm; z = ±50cm
Seasonal PNC maps for Zurich (100m x 100m)

Data from the mobile sensor network in Zurich (modeling by D. Hasenfratz, ETHZ)
Estimation of 14-day NO$_2$-pollution maps

2008, 100m x 100m resolution

Barmpadimos & Hueglin, ES&T, in review
Summary

− It is currently difficult to find epidemiological evidence linking spatially highly variable air pollutants with health effects

− This is especially relevant in the urban environment which inherently combines dense population and high variability of air pollutants

− Sensor networks offer new opportunities for the mapping of air pollutant concentrations in cities (combining sensor data and geo-referenced information)

− Operation of sensor networks? – Sensors need to be linked in a smart way to reference site(s)
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