OpenSense2

Crowdsourcing High-Resolution Air Quality Sensing

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Michael Riediker, Institute for Work and Health, Lausanne

MOTIVATION

RESEARCH AND DEVELOPMENT PLAN

CONCLUSION

Air Pollution

Air pollution in urban areas is a global concern

- affects quality of life and health
- urban population is increasing

Air pollution is highly location-dependent

- traffic chokepoints
- urban canyons
- industrial installations

Air pollution is time-dependent

- rush hours
- weather
- industrial activities

Air Pollution Monitoring

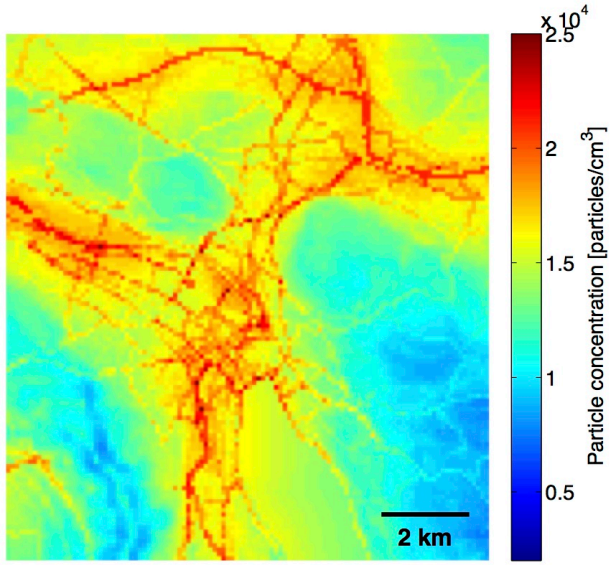
Accurate location-dependent and real-time information on air pollution is needed

Officials

- environmental engineers: location of pollution sources
- municipalities: creating incentives to reduce environmental footprint
- public health studies

Citizens

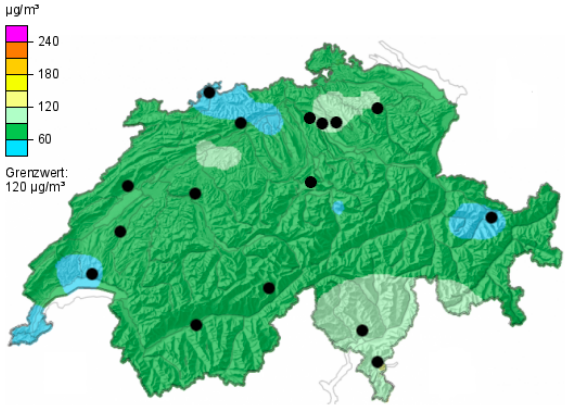
- advice for outside activities
- assessment of long-term exposure
- pollution maps



OpenSense ultra fine particle levels map in Zürich during winter months

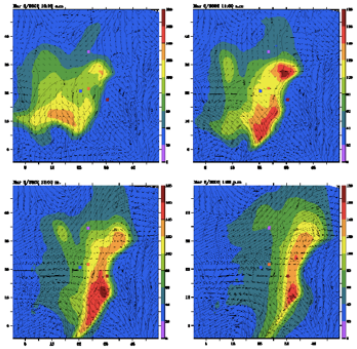
MONITORING TODAY

Stationary and expensive stations



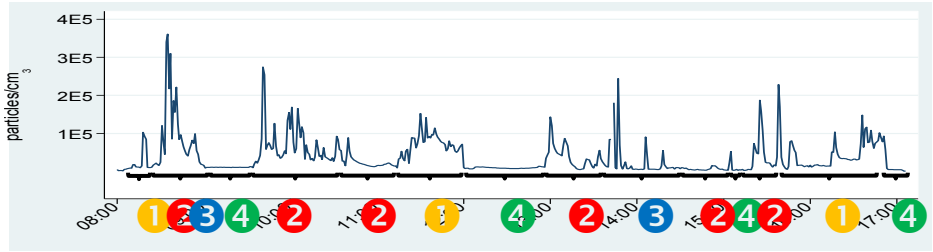
Sparse sensor network (Nabel)

Expensive mobile high fidelity equipment



Coarse models (mesoscale = 1km^2)

Personal exposure with specialized punctual studies



1 Garage
2 Vehicle
3 Road
4 Indoor

nano-tera.ch

OpenSense2

FNSNF

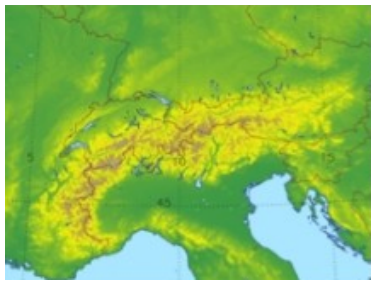
Data Validation through Measurements and Modelling over Multiple Scales

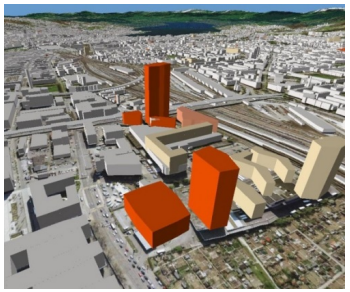
Sensor Data

Crowd-sensors, mobile sensors, monitoring stations

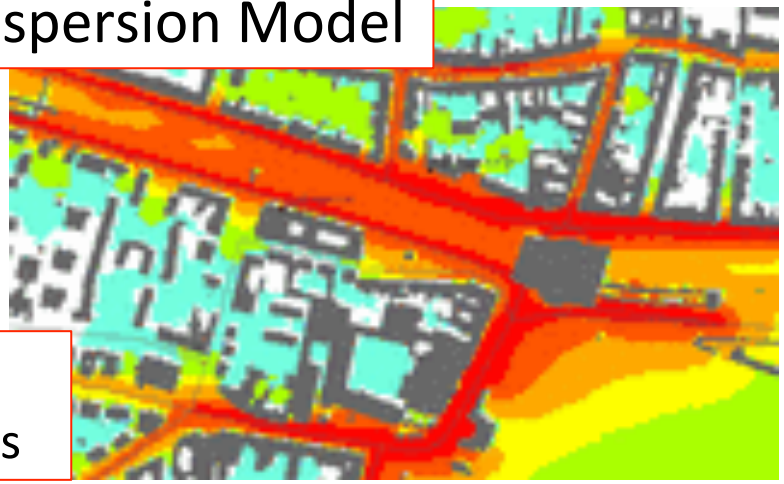
Model Input

Terrain, meteorology, source strength, background



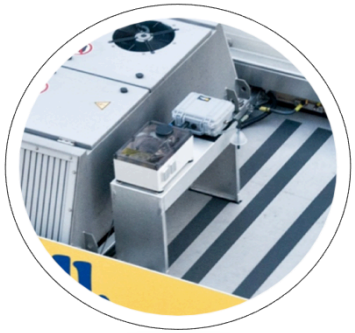


Lagrangian Dispersion Model

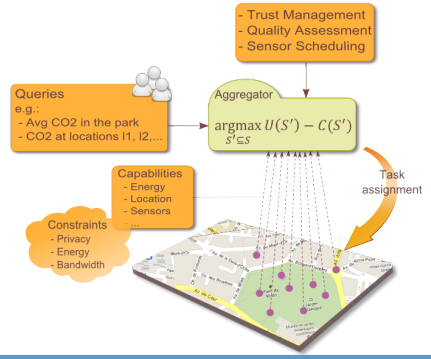


High resolution urban atmospheric pollution maps

Multi-Disciplinary Consortium



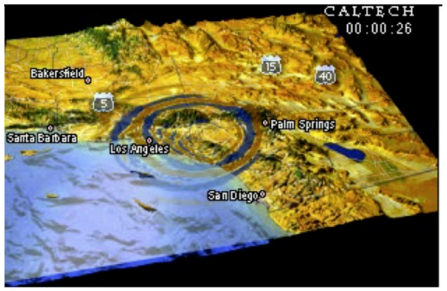
Martinoli, Thiele –
Stations and mobility



Aberer, Faltings –
Data, Models, Trust, Privacy

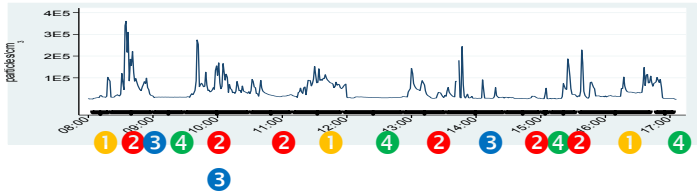
OpenSense

OpenSense2



Krause – Crowdsensing
for earthquakes

Emmenegger – Air quality
measurement and modeling



Bochud, Riediker – Studies on
health impact of air quality

SUPPORTED BY INDUSTRY, GOVERNMENT AND RESEARCH

VBZ	Transportation in Zürich	Public company
TL	Transportation in Lausanne	Public company
SensorScope	Sensor networks	Industry
Anaximen	Air quality monitoring	Industry
PSA	Car manufacturer	Industry
Wicked Devices	Air quality sensing	Industry
IBM	IT and Smarter Cities	Industry
SGX SensorTech	Gas sensing	Industry
Naneos	Particle detection	Industry
Swiss TPH	Air pollution and health studies (SAPALDIA)	Research
UGZ	Air quality and health in Zürich	Government
DSE	Environmental protection in Lausanne	Government
FOEN	Federal air pollution monitoring (NABEL)	Government

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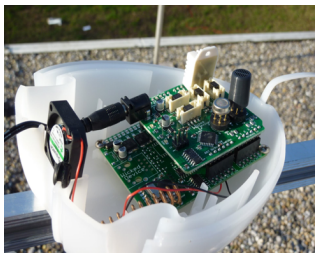
OpenSense: Deployments

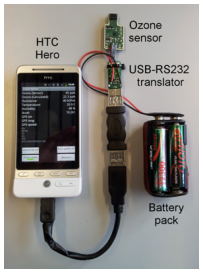
10 streetcars in Zurich & 10 buses in Lausanne

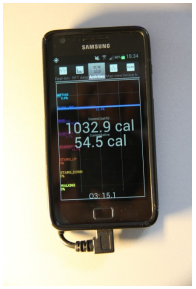
… in OpenSense2:

Integrated air quality measurement platform:

- **Institutional stations** (NABEL, Ostluft)
- **OpenSense infrastructure**
  - Maintained and upgraded
  - Integration of cutting edge sensing technologies (NO_2 laser-based sensing device developed in IrSens2)
- **Personal and portable sensors**
  - Heterogeneous devices and data
  - Human activity assessment, lifestyle and health data

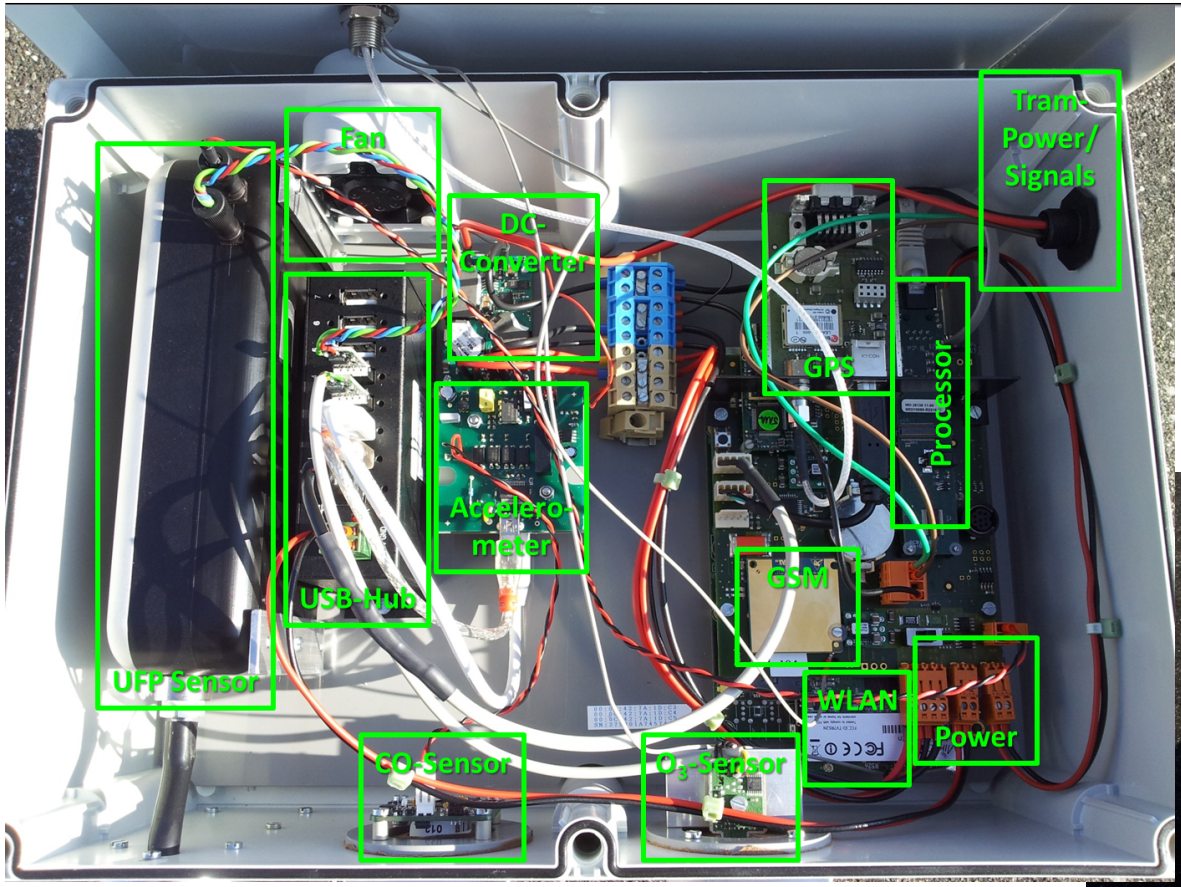






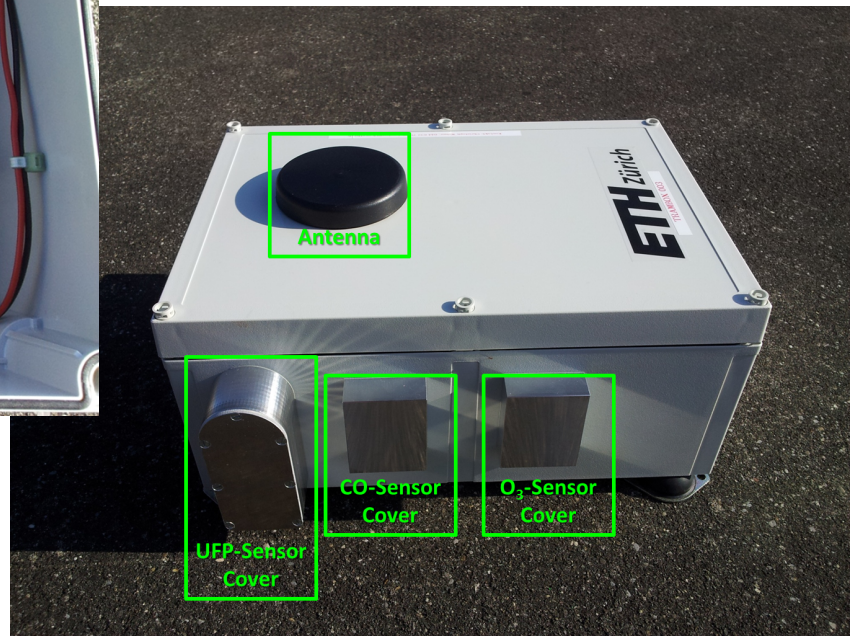
OpenSense2

OpenSense Zurich Node



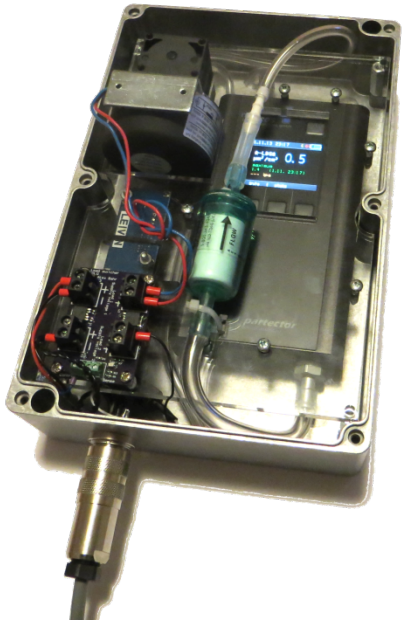
Inside the OpenSense Zurich node

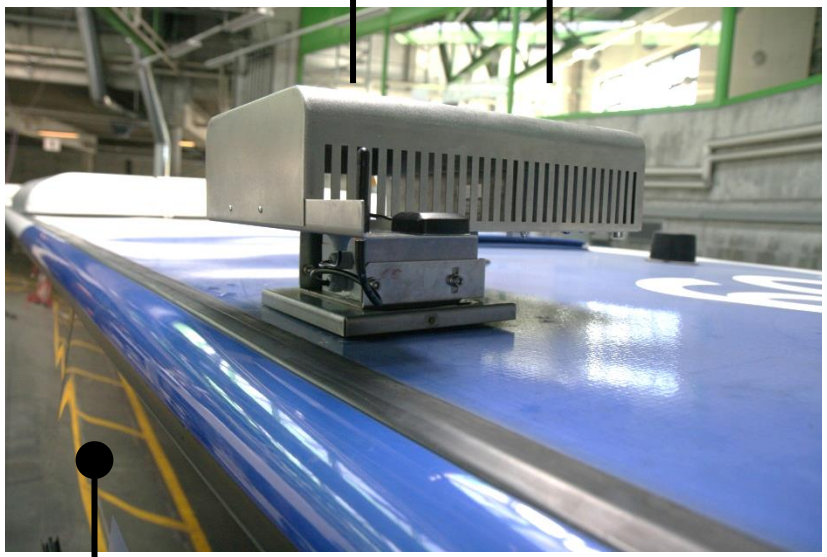
Installation on top of VBZ Cobra tram

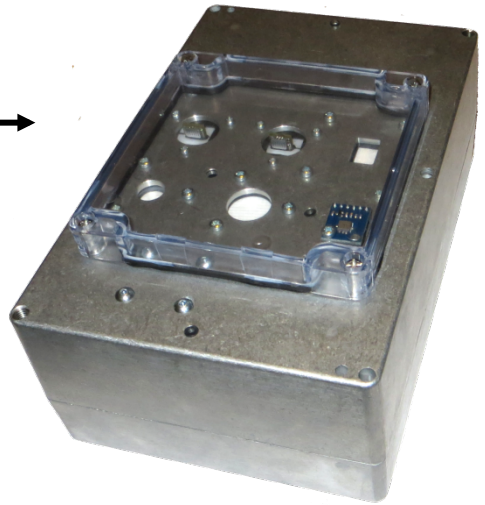


OpenSense Zurich node

OpenSense: Lausanne Node

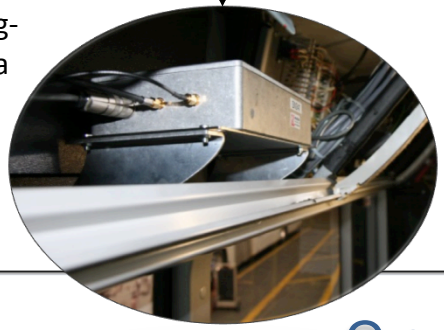






Particle sampling module

- Ultrafine particle measurements using Naneos Partector
- Measures directly lung-deposited surface area



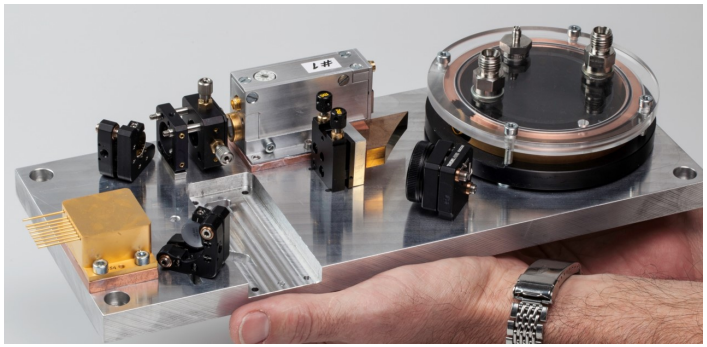
Enhanced localization & logger

- mounted inside bus
- Fused GPS, gyro and vehicle speedpulses
- Accurate sample geolocation even in difficult urban landscapes
- GPRS communication

Gas sampling module

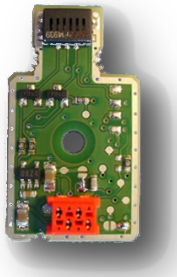
- CO, NO_2, O_3, CO_2, temperature & relative humidity
- Hybrid active sniffer/closed chamber sampling operation
- Enables absolute concentration mobile measurements

Leveraging Cutting Edge Micro-/Nano-technology Developed by Project Partners for Sensing



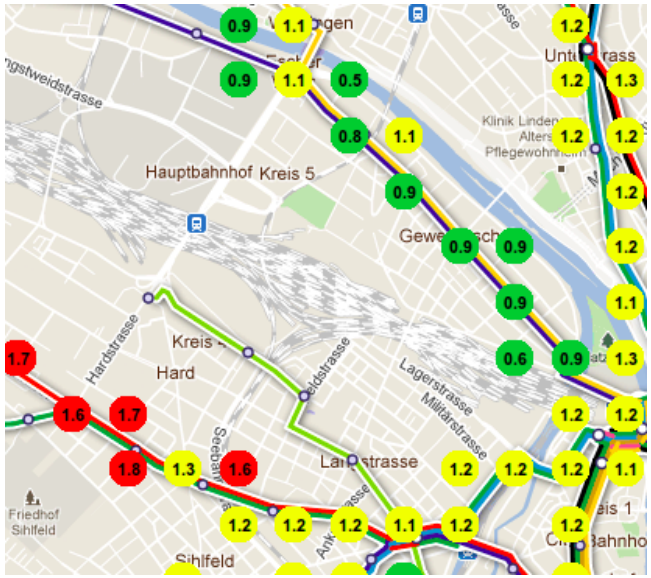
Prototype NO_2 laser-based sensor from IRSense2 (L. Emmenegger, co-PI); expected deployment on a Zurich tram: Spring 2014

MiniDisc and Partector UFP detectors invented by M. Fierz (FHNW and Naneos GmbH)



Key industrial partners in sensing technology (SGX SensorTech, Corcelles, Switzerland, E. Germain, CEO)

Pollution Data – Zurich Deployment



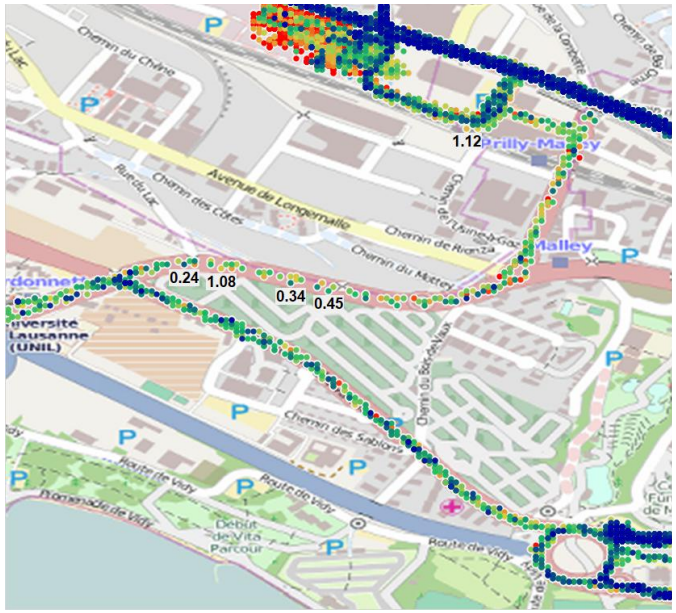
CO concentration

UFP concentration

[Keller et al., SenseApp 2012]

Pollutant	# of Measurements	Sampling rate	Time Period
UFP	24.050.000	5s	18 months
Ozone	3.430.000	20s	18 months
CO	2.820.000	20s	18 months

Pollution Data – Lausanne Deployment



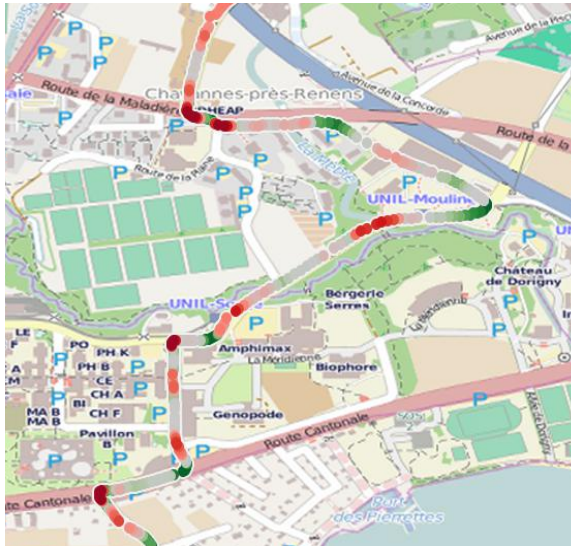
CO concentration

UFP concentration

[Arfire, unpublished, 2014]

Pollutant	# of Measurements	Sampling rate	Time Period
UFP	7.300.000	1s	3 months
Ozone	2.340.000	15s	5 months
[CO, NO2, CO2]	10.115.000	5s	5 months

Mobility Data – Lausanne Deployment



Gyro yaw rate

X-axis acceleration
& vehicle context

[Arfire, unpublished, 2014]

Coverage of Lausanne region

Measurement	# of Measurements	Sampling rate	Time Period
[GPS, gyroscope]	48.384.000	1s	5 months
[odometer, accelerometer]	201.018.000	0.25s	5 months
vehicle context info	697.000	event-driven	5 months

Tsai *et al. Particle and Fibre Toxicology* 2012, **9**:24
http://www.particleandfibretoxicology.com/content/9/1/24

PARTICLE AND FIBRE TOXICOLOGY

RESEARCH Open Access

Effects of particulate matter on inflammatory markers in the general adult population

Dai-Hua Tsai[1,2], Nadia Amyai[3], Pedro Marques-Vidal[1], Jia-Lin Wang[2], Michael Riediker[4], Vincent Mooser[5], Fred Paccaud[1], Gerard Waeber[3], Peter Vollenweider[3] and Murielle Bochud[1*]

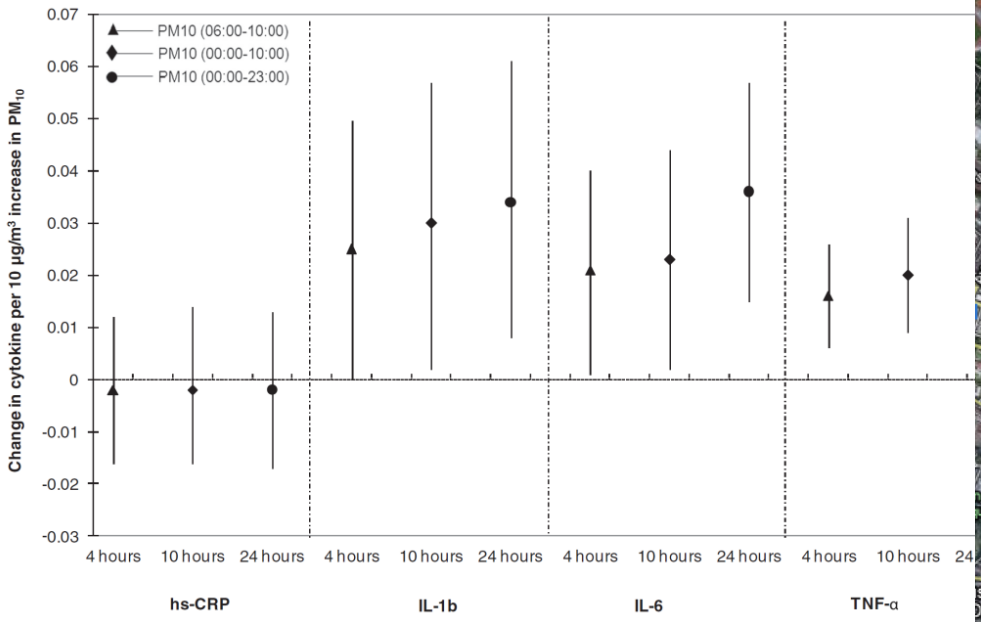
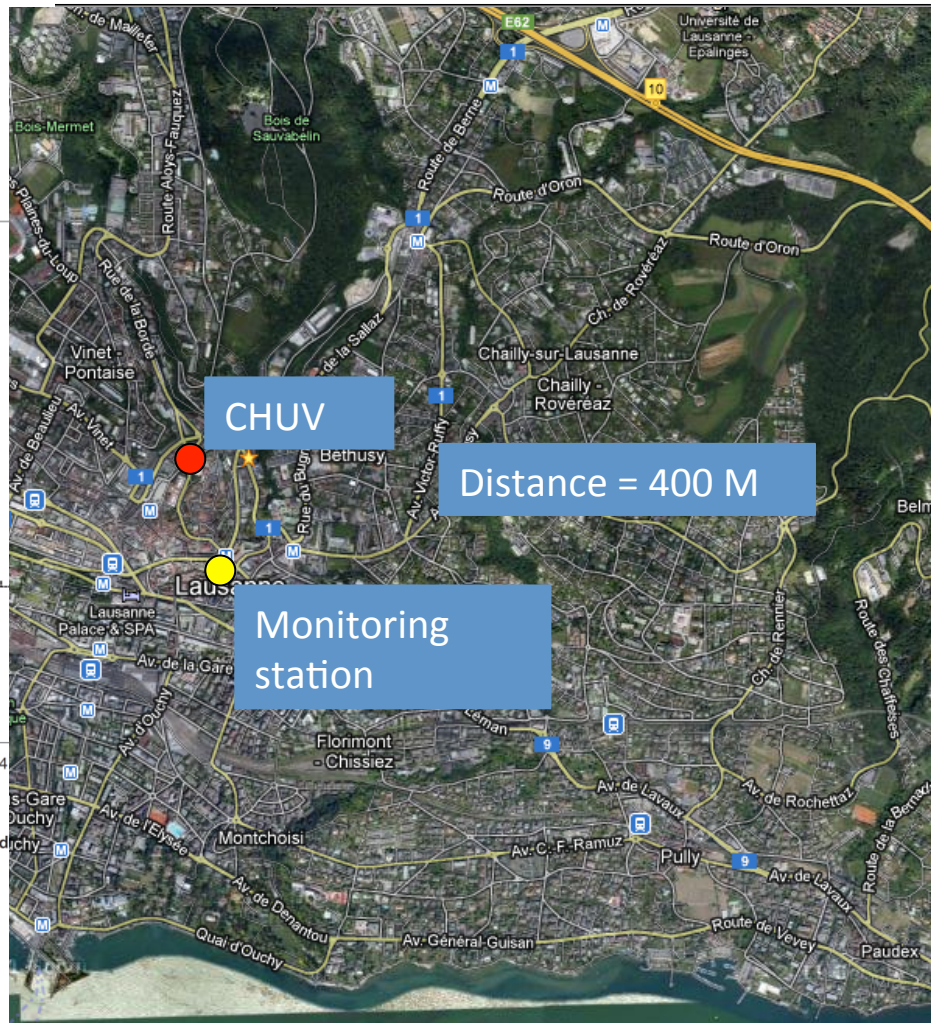


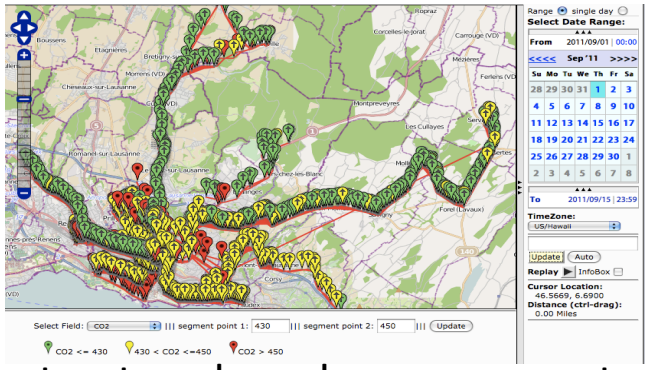
Figure 2 Association between different time-averaged PM_{10} concentrations and log-transformed inflammatory markers (adjusted effects).



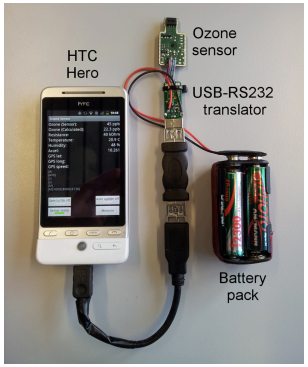
In CoLaus (N=6000) short-term (0h-24h) exposure to higher PM10 was associated with higher blood levels of inflammatory markers

OPPORTUNITIES FROM OPENSENSE

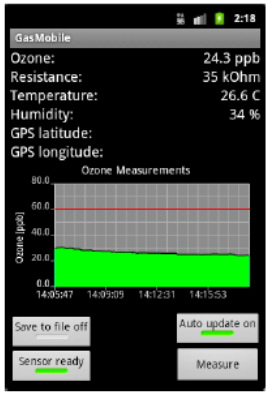
- More detailed air pollution data



Infrastructure-based measurement

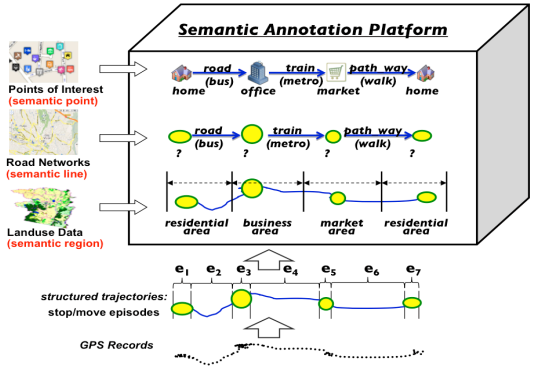


Personal sensors

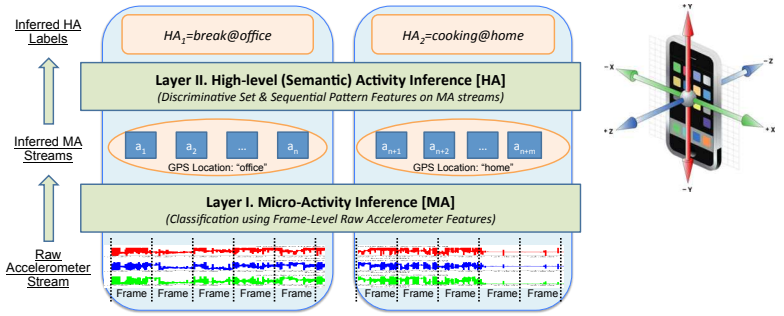


Measurements

- More detailed information on individual exposure



Activity inference from trajectory

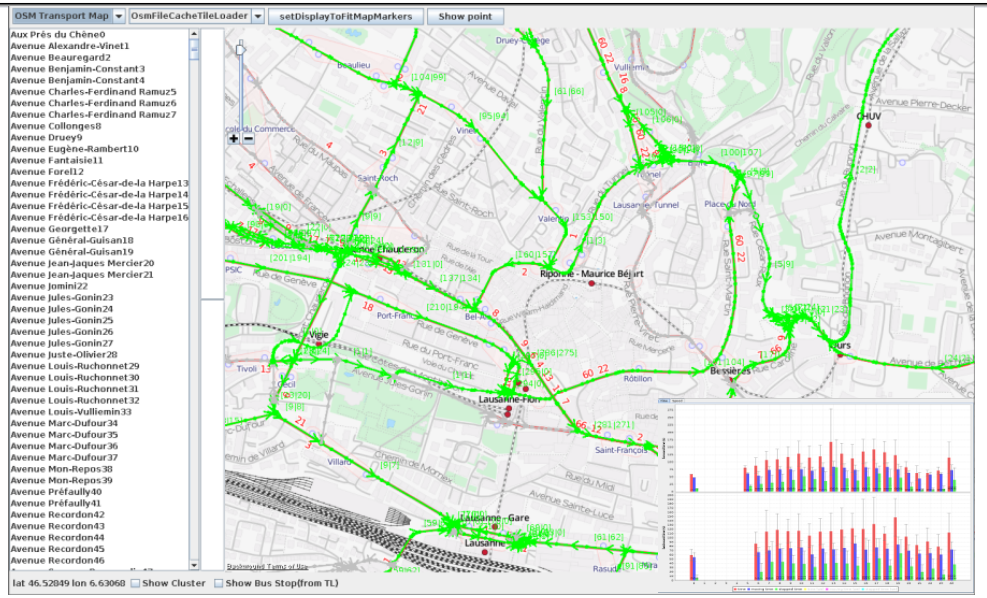


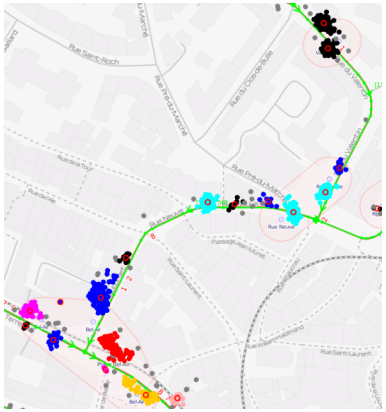
Activity inference from phone sensors

OpenSense: Mobility Modeling

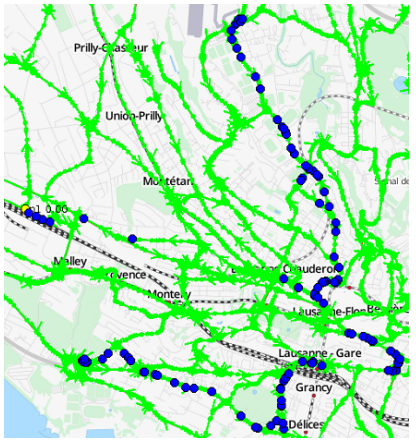
Public transport simulation framework

- Statistical data-driven modeling of road links in Lausanne
- Data sources:
  - public transport network topology
  - enhanced localization module
  - context data from vehicle communication bus (current line, destination, stop information)
- Allows the generation of vehicle trajectories for given scenarios (bus line, time of day etc.)





Modeling vehicle stops (bus stops, junctions, traffic lights etc.)



Generating vehicle trajectories

OpenSense: Mobility Modeling

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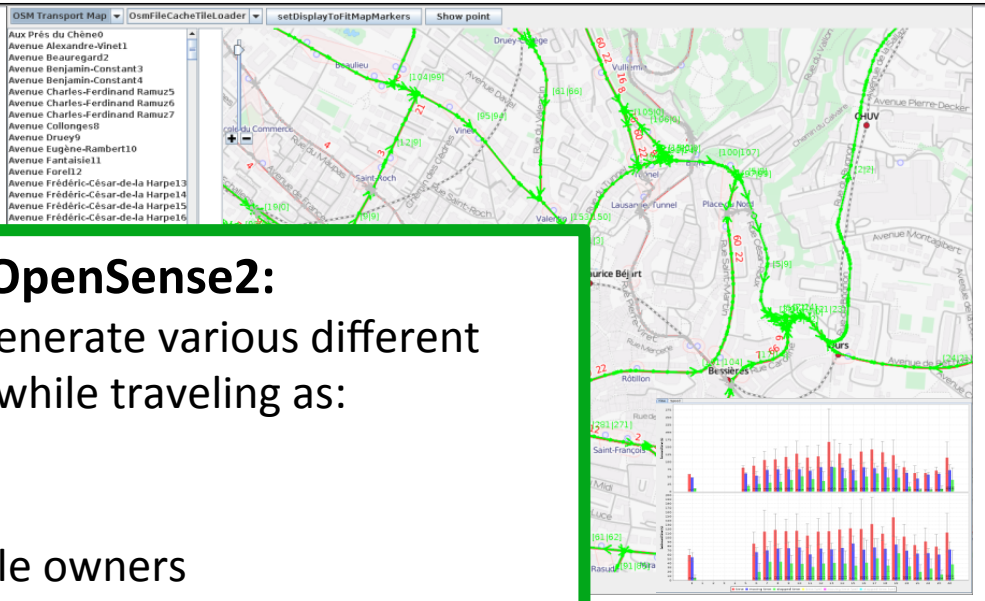
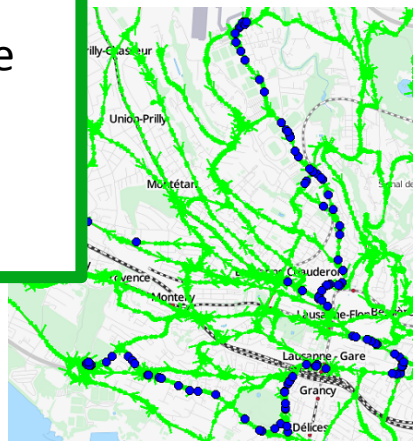


… in OpenSense2:

- Participants can generate various different mobility patterns while traveling as:
  - pedestrians
  - cyclists
  - private vehicle owners
- Utilitarian approach needed to deal with the trade-off between model complexity and accuracy

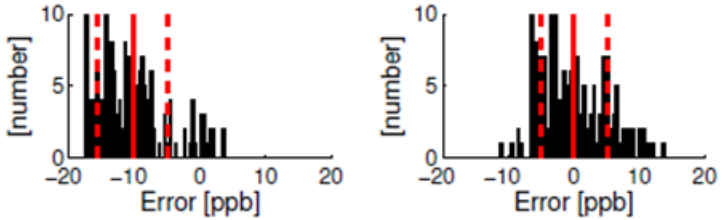
Modeling vehicle stops (bus stops, junctions, traffic lights etc.)



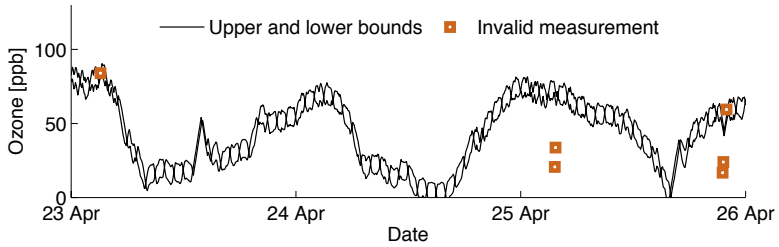
Generating vehicle trajectories

OpenSense: Data Quality

- **Automatic Sensor Calibration**
  - Based on temporal and spatial closeness of two sensors
    - Close measurements are similar
    - Measurement closeness depends on locality of a physical process
  - Evaluated calibration algorithms in static and mobile settings
- **Sensor Fault Detection**
- **Measurement Accuracy Bounds**
  - Use sensor and phenomenon models
- **Outlier detection**



Periodic calibration improves data quality from 10.5±5.3ppb to 4.2±5.1ppb. Mean error after calibration is 0.



Augment every sensor reading with accuracy bounds. Allows detecting outliers.

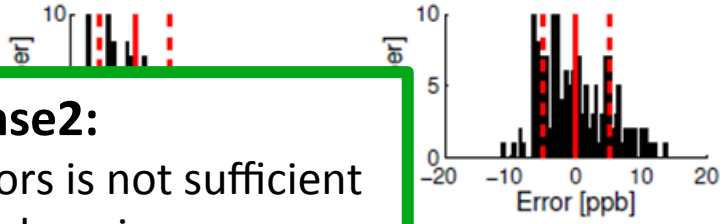
OpenSense: Data Quality

- **Automatic Sensor Calibration**
  - Based on temporal and spatial closeness of
    - Close me
    - Measure on locali
  - Evaluated ca static and m
- **Sensor Fault**
- **Measuremen**
  - Use sensor and phenomenon models
- **Outlier detection**

… in OpenSense2:

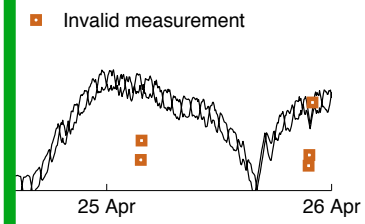
Evaluation of individual sensors is not sufficient

- Sensor **calibration** for crowdsensing:
  - Using OpenSense infrastructure to provide numerous calibration points
- Assign data with **data quality signatures**
  - Model-based data validation
  - Real-time data quality assurance
- People are less reliable than well-tested hardware
  - Introduce **reputation tools**



O_3: calibrated.

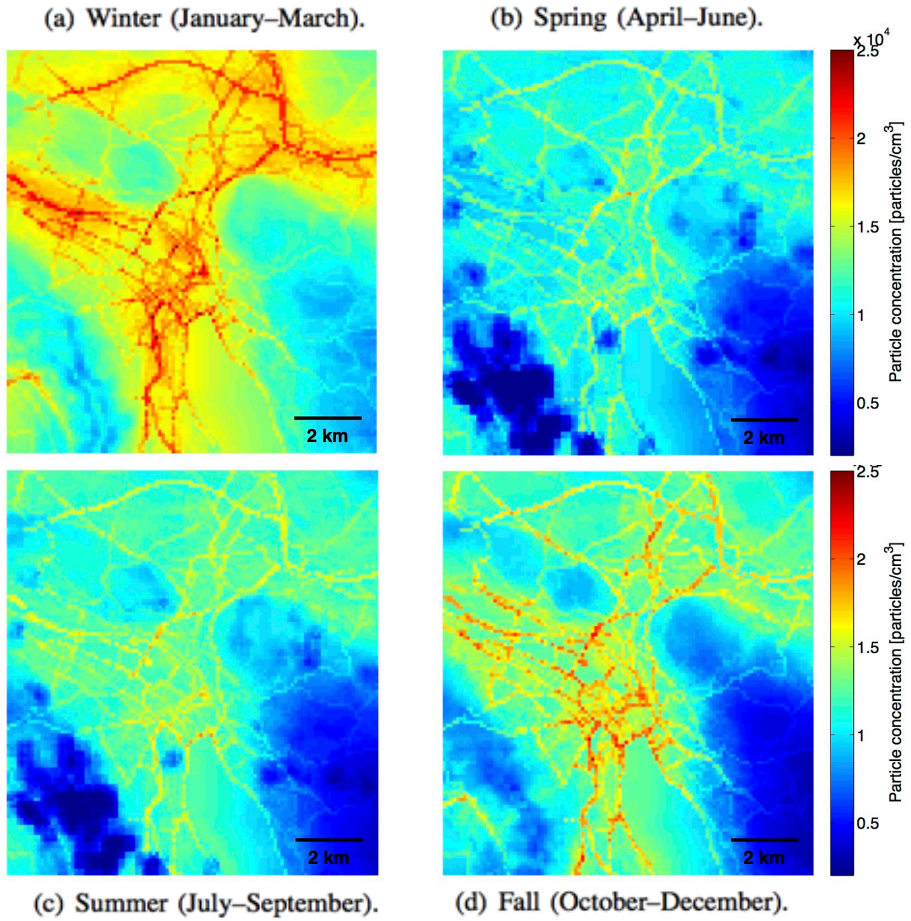
…proves data quality to 4.2±5.1ppb. …alibration is 0.



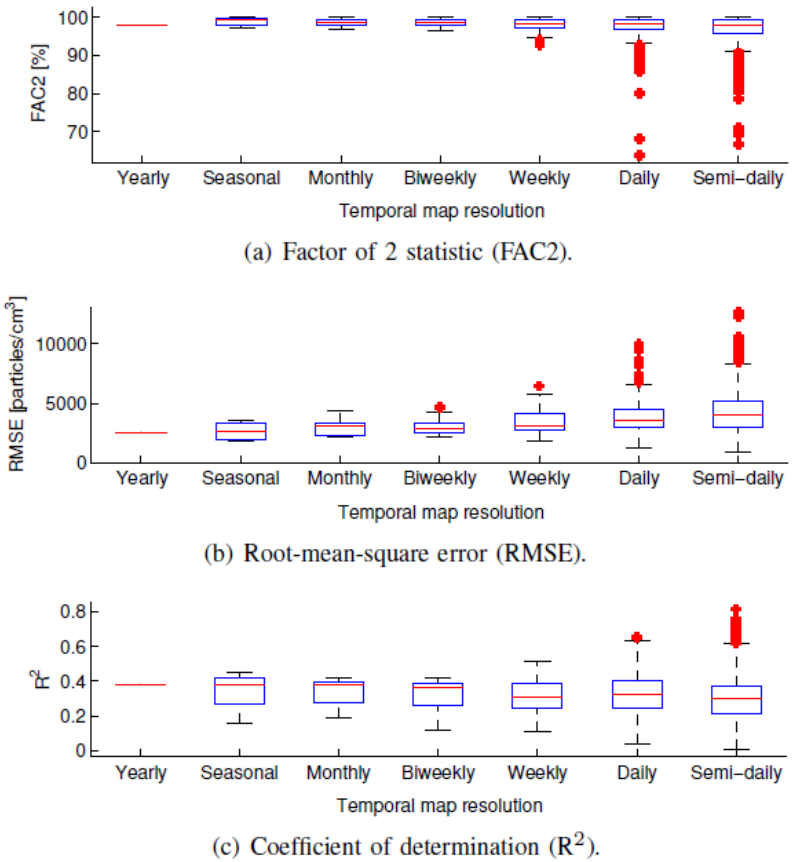
Augment every sensor reading with accuracy bounds. Allows detecting outliers.

OpenSense: High-resolution Maps

Ultrafine particle air pollution maps with 100x100m resolution



Accurate pollution maps with yearly to weekly temporal resolution



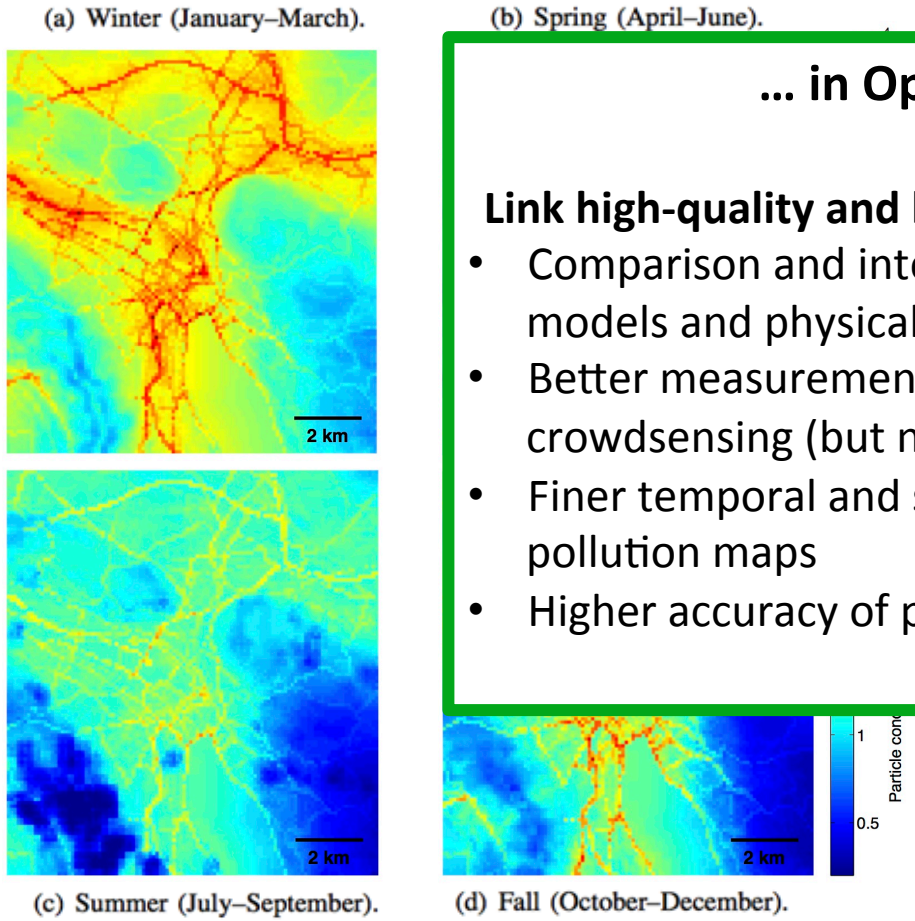
(a) Factor of 2 statistic (FAC2).

(b) Root-mean-square error (RMSE).

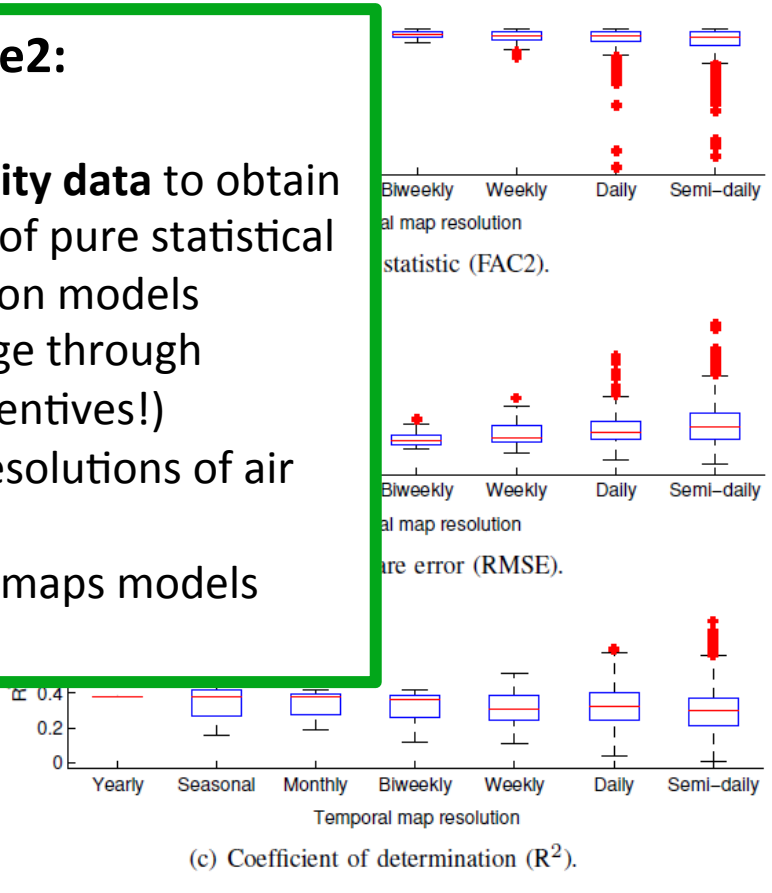
(c) Coefficient of determination (R^2).

OpenSense: High-resolution Maps

Ultrafine particle air pollution maps with 100x100m resolution



Accurate pollution maps with yearly to weekly temporal resolution



… in OpenSense2:

Link high-quality and low-quality data to obtain

- Comparison and integration of pure statistical models and physical dispersion models
- Better measurement coverage through crowdsensing (but needs incentives!)
- Finer temporal and spatial resolutions of air pollution maps
- Higher accuracy of pollution maps models

MOTIVATION

RESEARCH AND DEVELOPMENT PLAN

CONCLUSION

Project and NanoTera vision and objectives:

- Requires multi-scale engineering (leverages micro-/nano-technologies and innovates in node, network, algorithm, and model design for large environmental data management)
- Requires interdisciplinary team and industry support
- Has a highly relevant NanoTera partner project: IrSens2
- Includes end users (CHUV, IST, participants to crowdsensing/health studies) and reach out industrial and government partners
- Clear societal and industrial value
- High expected engineering impact: Swiss deployments as case studies for further urban settings worldwide
- Can be expanded beyond the NanoTera sponsoring: several technology transfer projects can be added if appropriate partners and technical interests are identified