

OpenSense2

Crowdsourcing High-Resolution Air Quality Sensing

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OVERVIEW

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

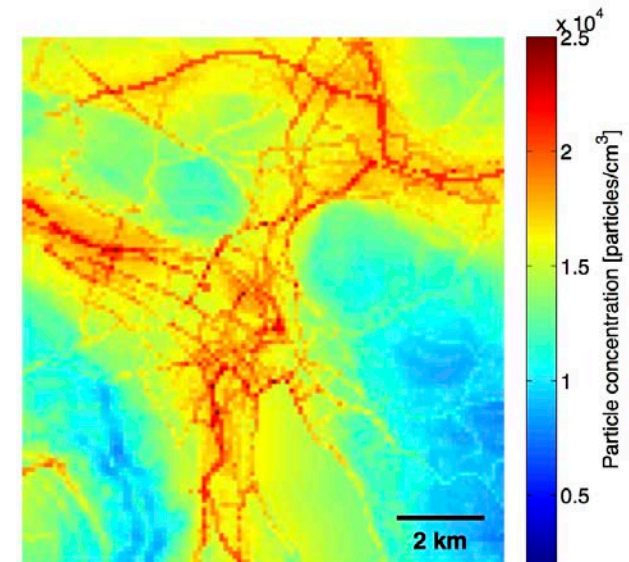
Accurate **location-dependent** and **real-time** information on air pollution is needed

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

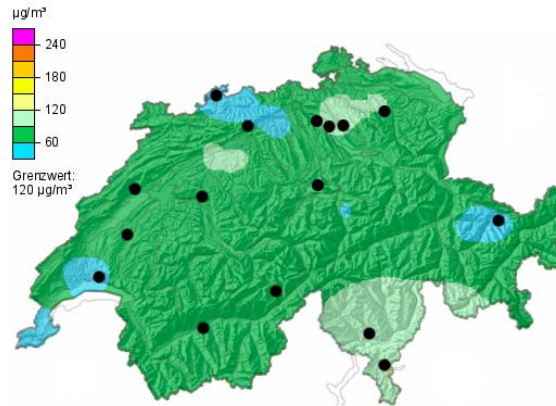


OpenSense ultra fine particle levels map in Zürich during winter months

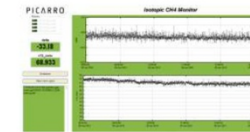
MONITORING TODAY



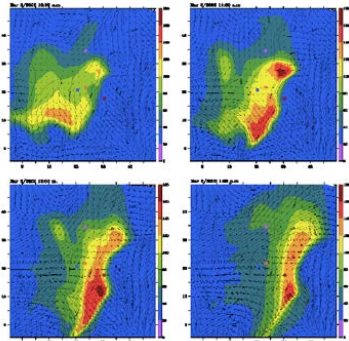
Stationary and expensive stations



Sparse sensor network (Nabel)



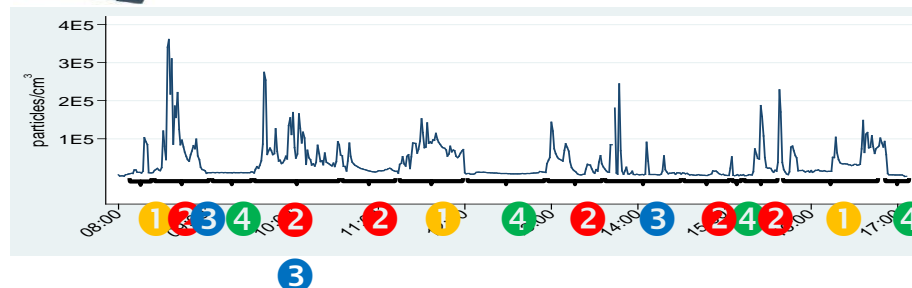
Expensive mobile high fidelity equipment



Coarse models (mesoscale = 1km²)



Personal exposure with specialized punctual studies



- 1 Garage
- 2 Vehicle
- 3 Road
- 4 Indoor

DATA VALIDATION THROUGH MEASUREMENTS AND MODELLING OVER MULTIPLE SCALES

Sensor Data

Crowd-sensors, mobile sensors, monitoring stations

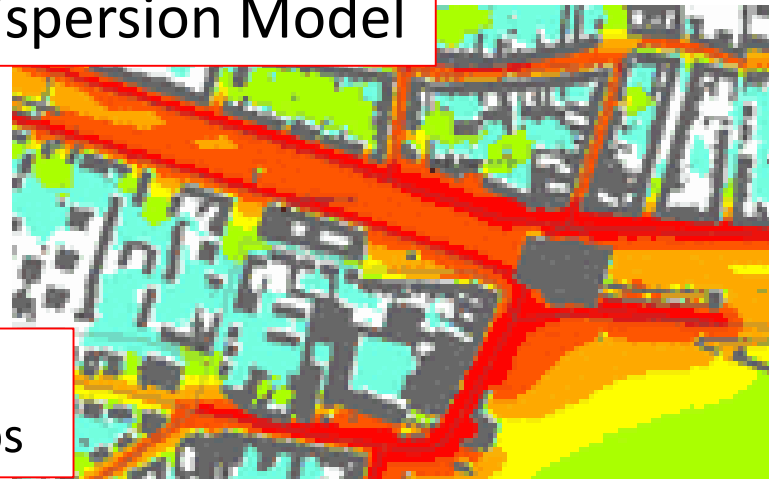


Model Input

Terrain, meteorology, source strength, background



Lagrangian Dispersion Model

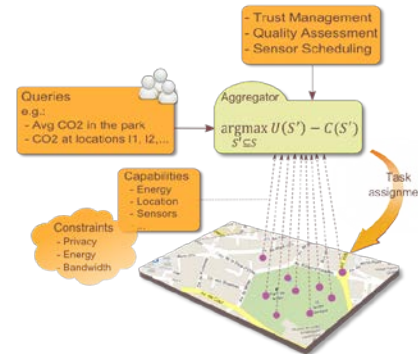


High resolution urban atmospheric pollution maps

MULTI-DISCIPLINARY CONSORTIUM



Martinoli, Thiele –
Stations and mobility

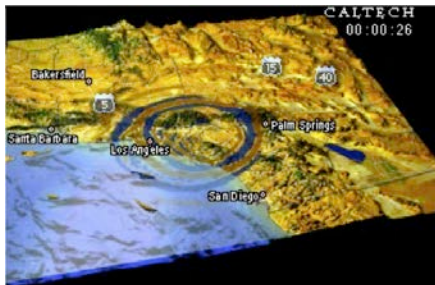


Aberer, Faltings –
Data, Models, Trust, Privacy

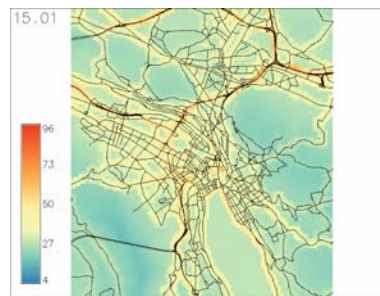
OpenSense



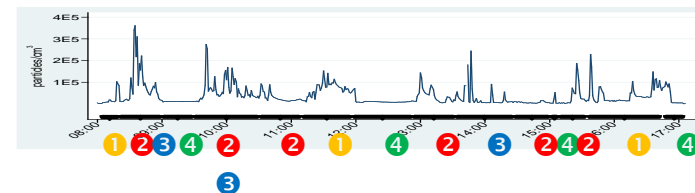
OpenSense2



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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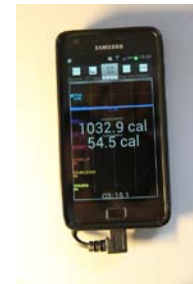
OPENSENSE: DEPLOYMENTS

10 streetcars in Zurich & 10 buses in Lausanne

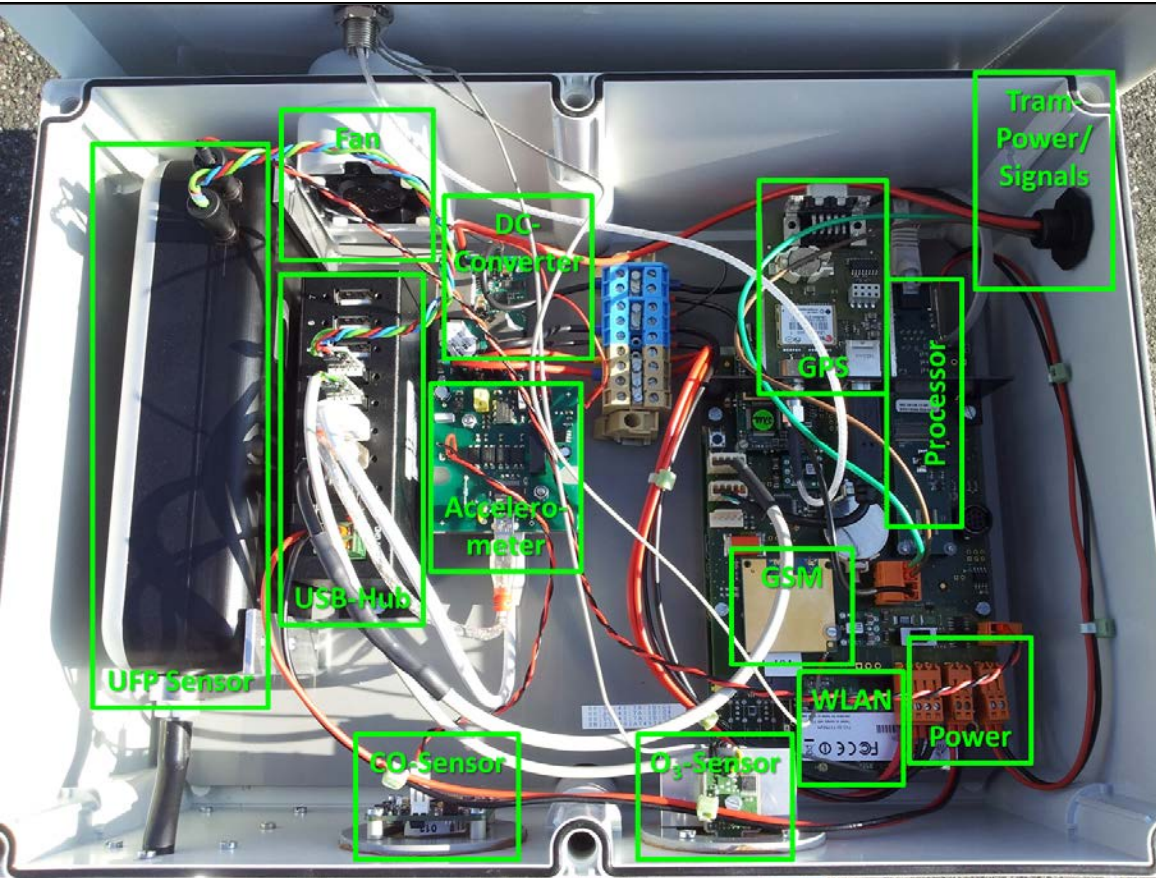
... in OpenSense2:

Integrated air quality measurement platform:

- **Institutional stations (NABEL, Ostluft)**
- **OpenSense infrastructure**
 - Maintained and upgraded
 - Integration of cutting edge sensing technologies (NO₂ laser-based sensing device developed in IrSens2)
- **Personal and portable sensors**
 - Heterogeneous devices and data
 - Human activity assessment, lifestyle and health data



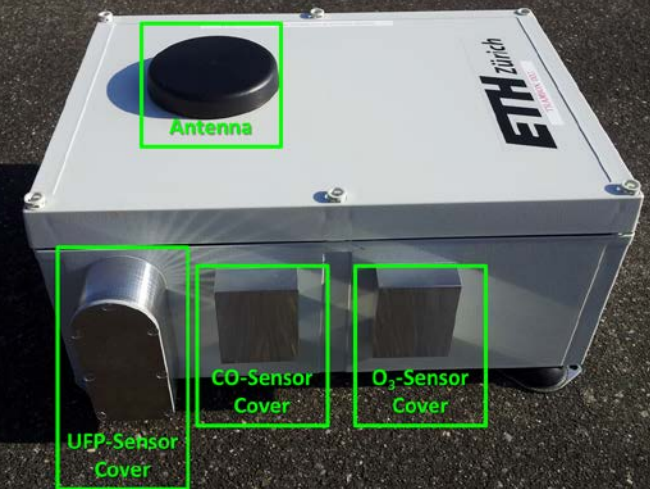
OPENSENSE ZURICH NODE



Inside the OpenSense Zurich node

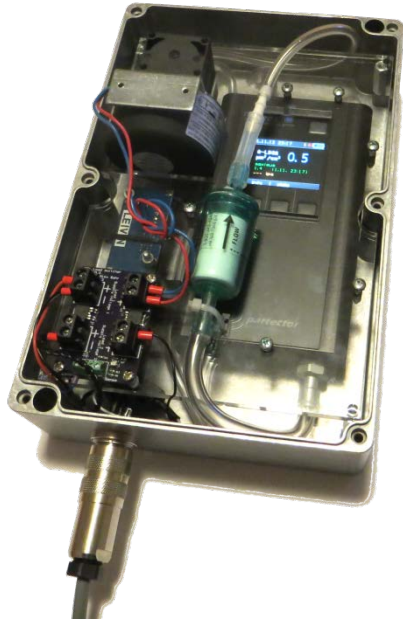


Installation on top of VBZ Cobra tram



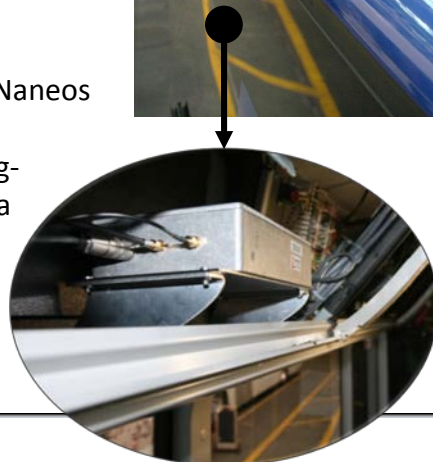
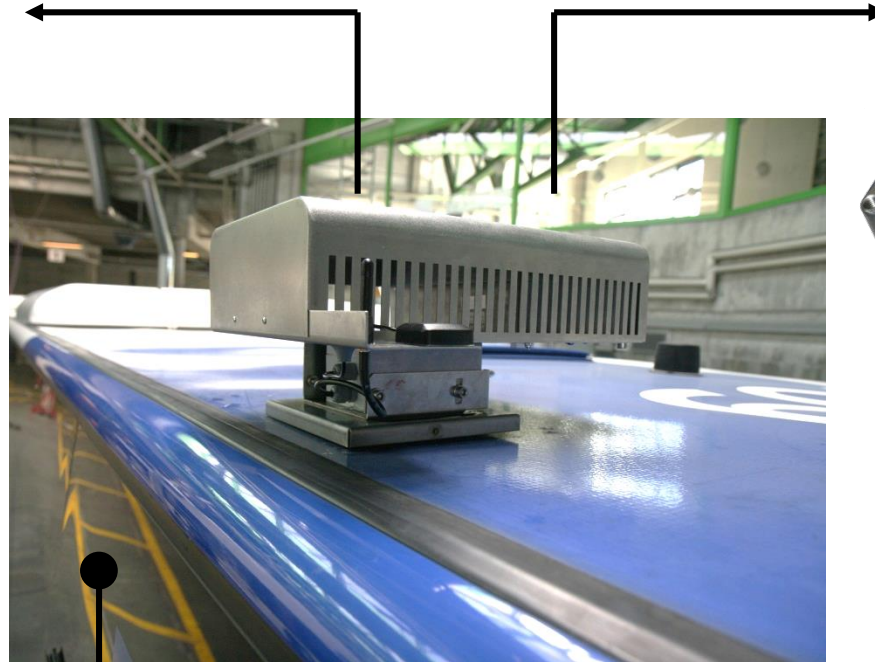
OpenSense Zurich node

OPENSENSE: LAUSANNE NODE



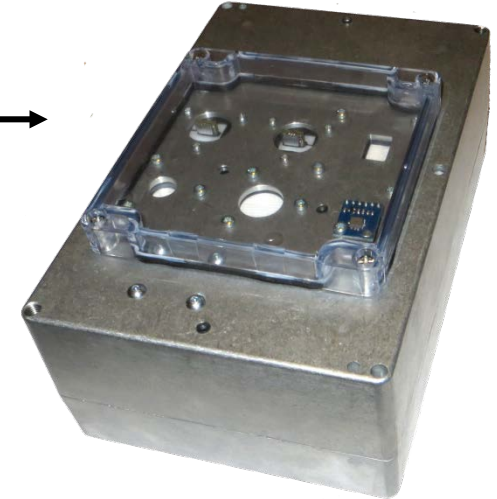
Particle sampling module

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



Enhanced localization & logger

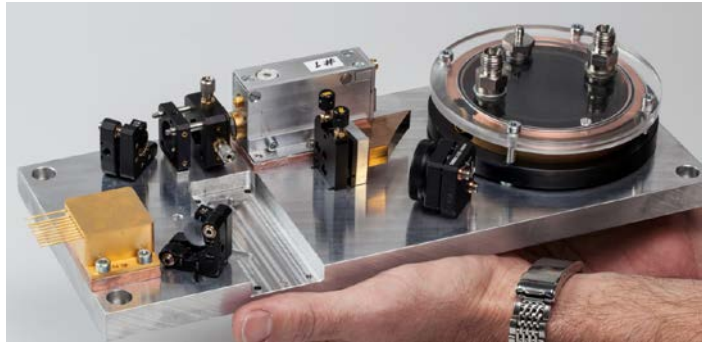
- mounted inside bus
- Fused GPS, gyro and vehicle speedpulses
- Accurate sample geolocation even in difficult urban landscapes
- GPRS communication



Gas sampling module

- CO, NO₂, O₃, CO₂, 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 NO₂ laser-based sensor from IRSense2 (L. Emmenegger, co-PI); expected deployment on a Zurich tram: Spring 2014



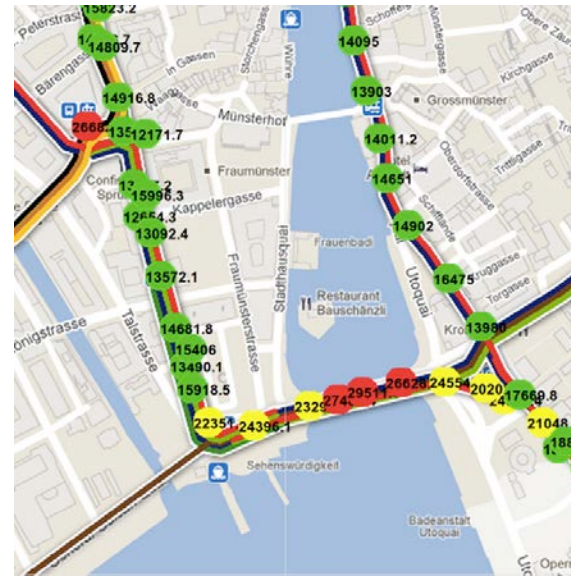
Key industrial partners in sensing technology (SGX SensorTech, Corcelles, Switzerland, E. Germain, CEO)

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

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

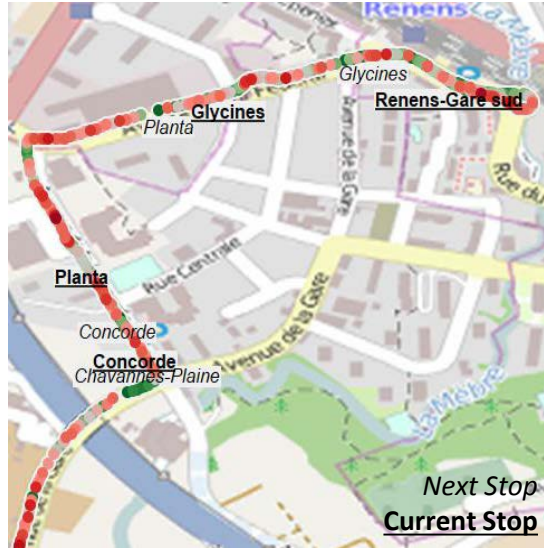
[Arfire,
unpublished,
2014]

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



Coverage of Lausanne region

[Arfire, unpublished, 2014]

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

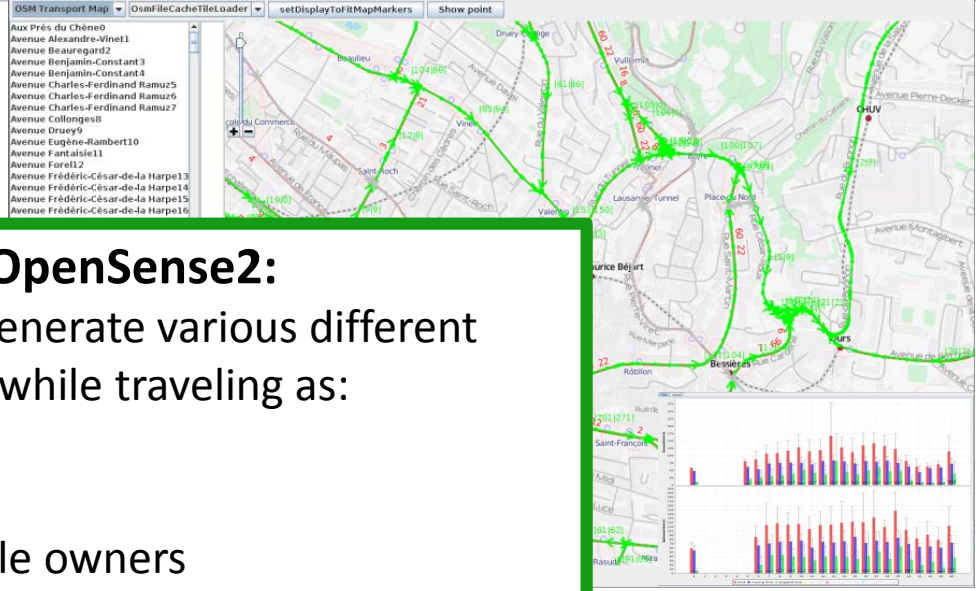
OPENSENSE: MOBILITY MODELING

Public transport simulation framework

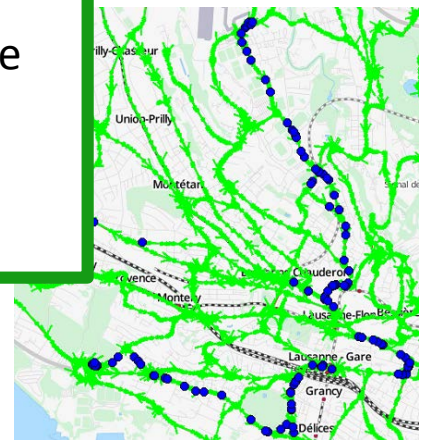
- Statistical data-driven modeling of road links in Lausanne
- Data sources:
 - public transport topology
 - enhanced location data
 - context data (e.g. communication line, destination information)
- Allows the generation of trajectories for given line, time of day etc.)

... 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

- Close measurements
- Measurements on local

- Evaluated calibration static and model-based

• Sensor Fault Detection

• Measurement Validation

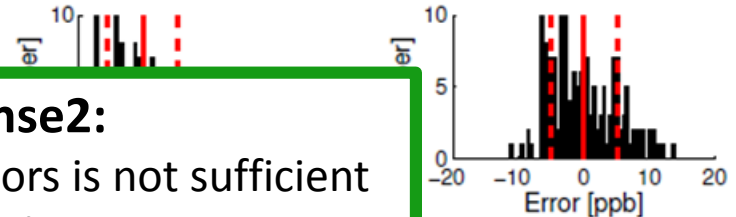
- Use sensor and phenomenon models

• Outlier detection

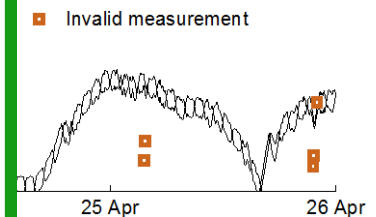
... in OpenSense2:

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.
 Improves data quality to $4.2 \pm 5.1 \text{ ppb}$.
 Calibration is 0.



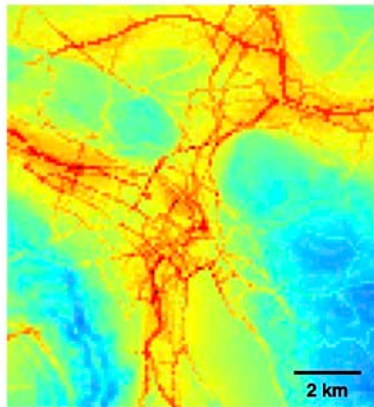
Augment every sensor reading with accuracy bounds. Allows detecting outliers.

OPENSENSE: HIGH-RESOLUTION MAPS

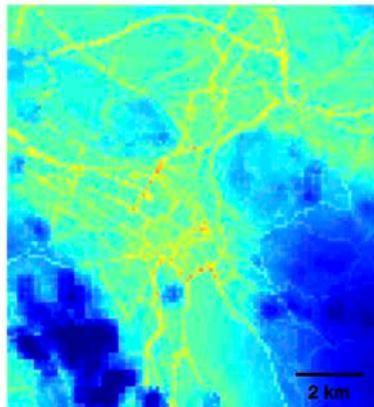
Ultrafine particle air pollution maps
with 100x100m resolution

Accurate pollution maps with yearly to
weekly temporal resolution

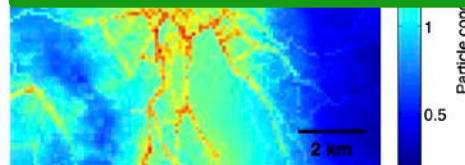
(a) Winter (January–March).



(b) Spring (April–June).



(c) Summer (July–September).

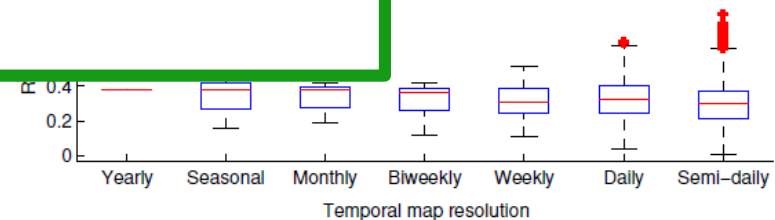
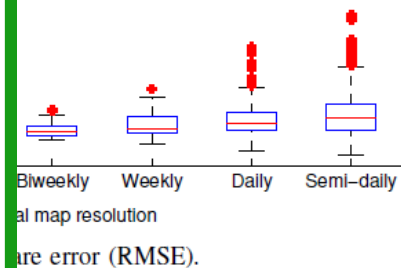
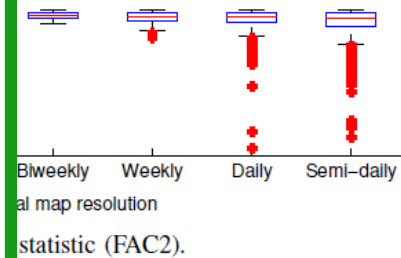


(d) Fall (October–December).

... 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



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

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Project matches 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