Applications of sensors for urban air quality monitoring

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Source: Olga Saukh, ETH Zurich, OpenSense project

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Outline

– Motivation: Why sensors for air quality measurements ?

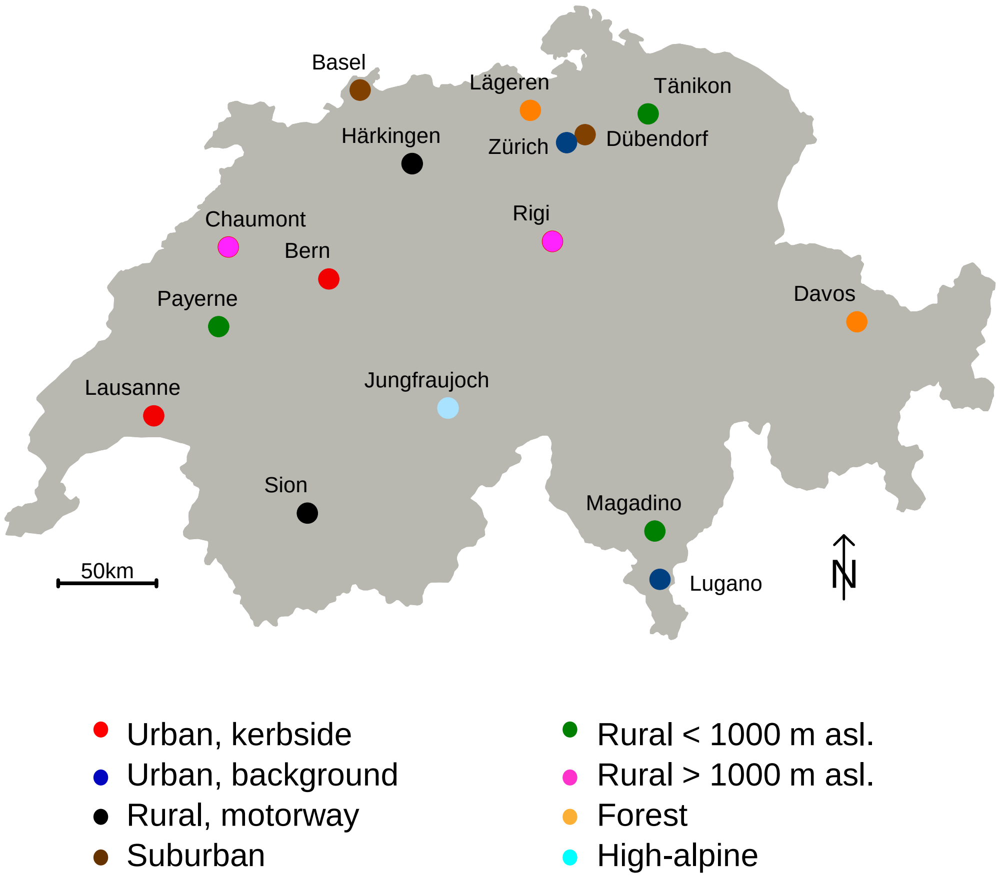
– Challenges: Assurance of data quality

Sensor deployment

Data analysis / modeling

– Summary

Air Quality Monitoring Today – e.g. Swiss National Air Pollution Monitoring Network



Monitoring networks provide reliable and accurate information about air quality at **representative** sites

Approach suitable for

- compliance measurements
- assessment of temporal trends
- action planning
- …

Approach not ideal for

- assessment of spatial variability at ***small scales*** (e.g. urban scale)
- exposure assessment / health effects studies

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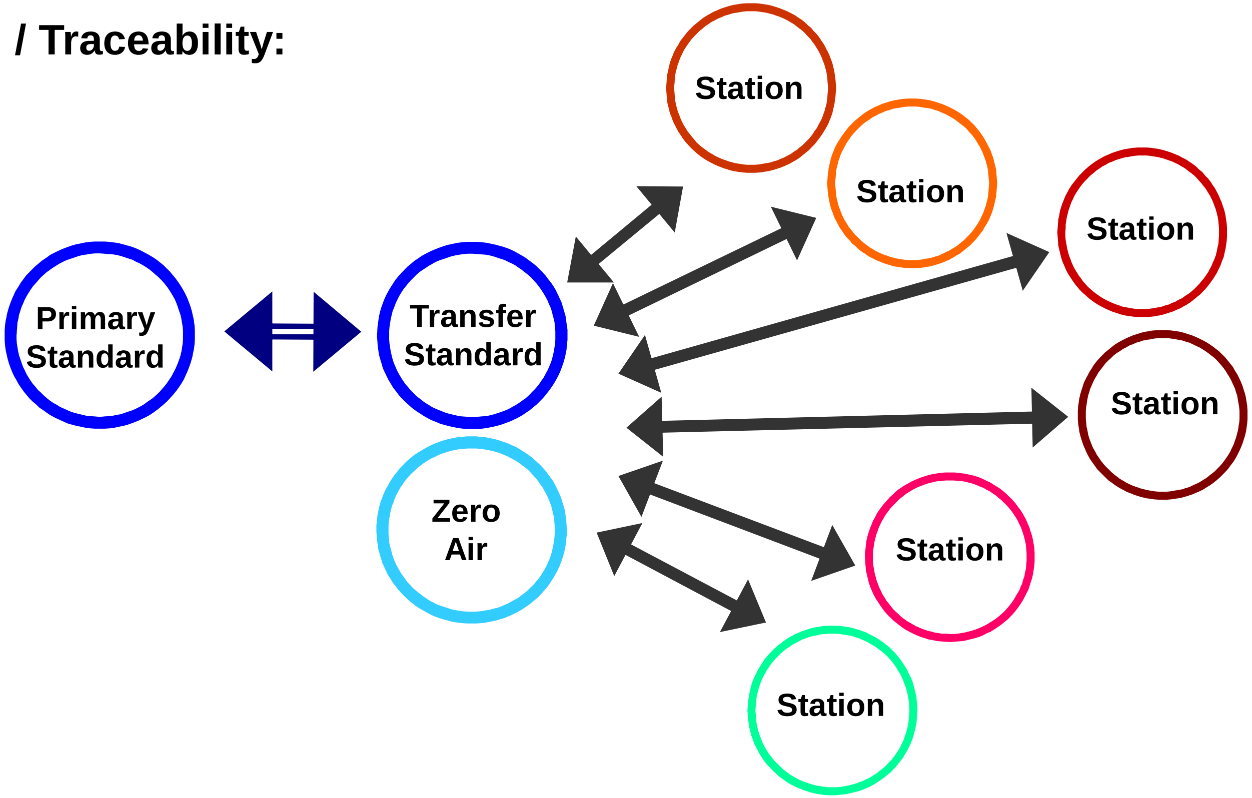
Assurance of data quality in «traditional» Air Quality Networks

Calibration / Traceability:



Primary Standards (Reference Material) | Transfer Standards | Analyzer

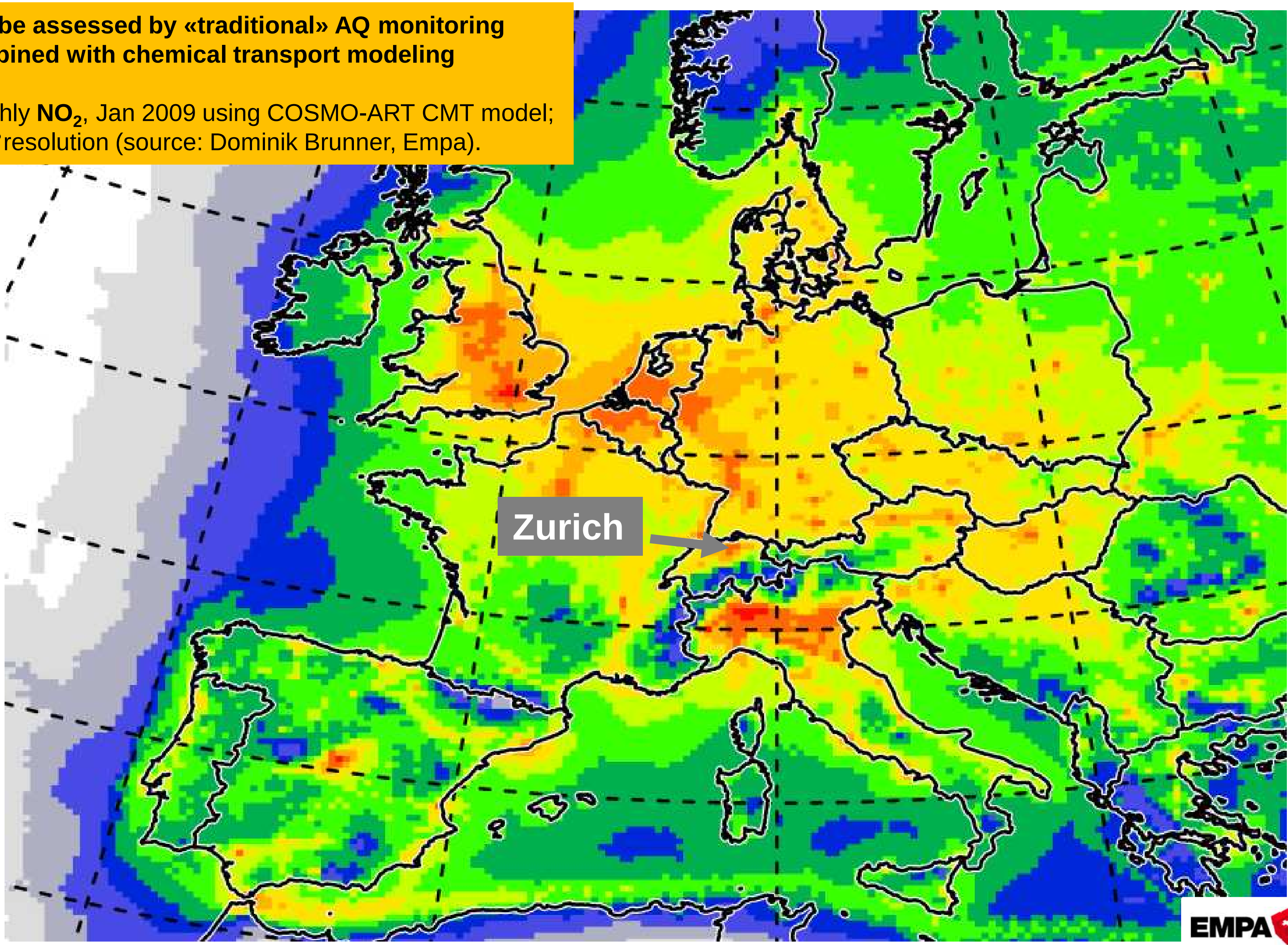
NO_x, CO, SO_2, VOCs, CO_2 etc.

O_3

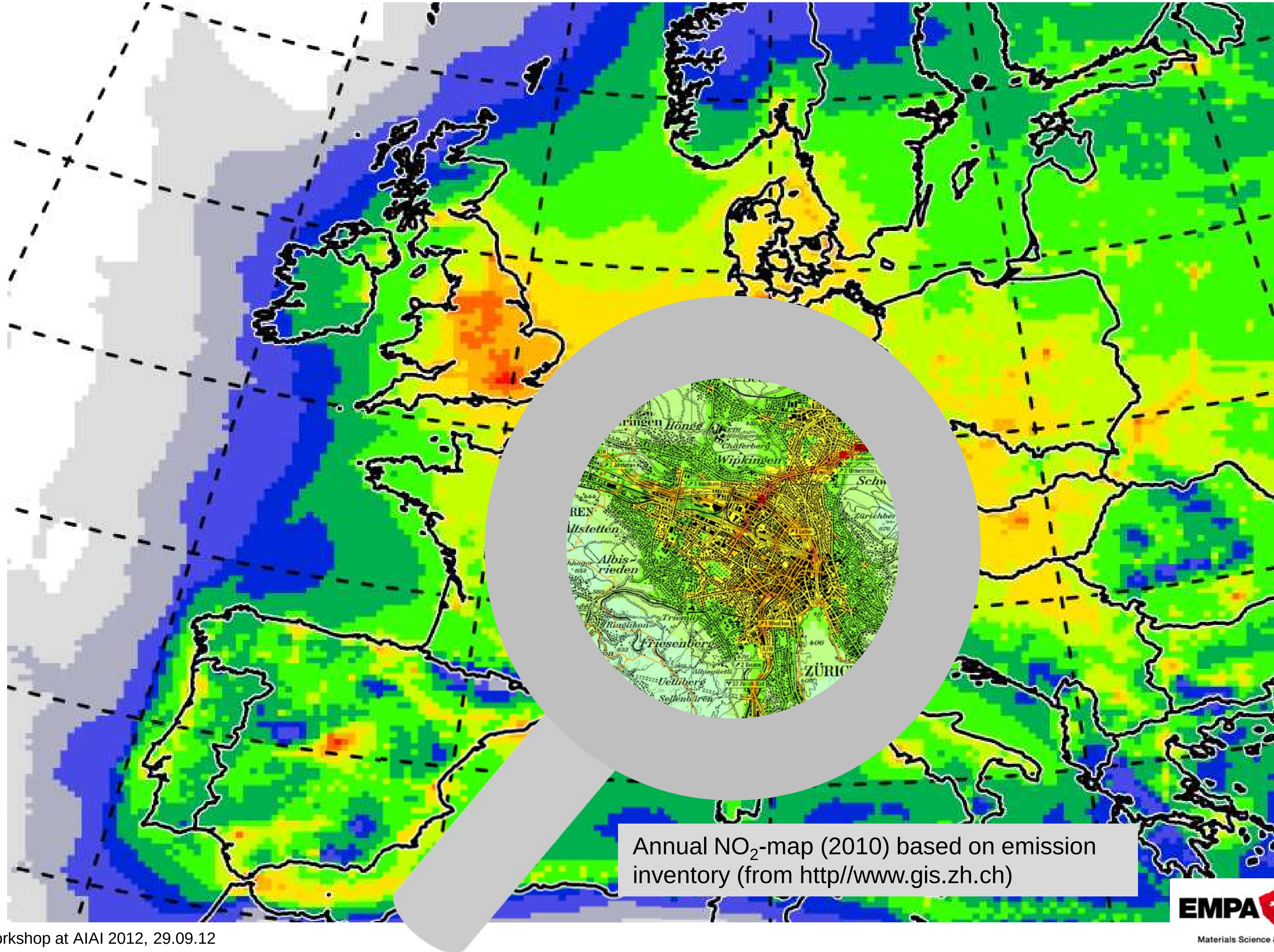
Spatial variability of Air Pollutants – mesoscale/regional scale

Can be assessed by «traditional» AQ monitoring combined with chemical transport modeling

Monthly **NO_2**, Jan 2009 using COSMO-ART CMT model; 0.17°resolution (source: Dominik Brunner, Empa).



Spatial variability of Air Pollutants – urban scale?



Annual NO_2-map (2010) based on emission inventory (from http//www.gis.zh.ch)

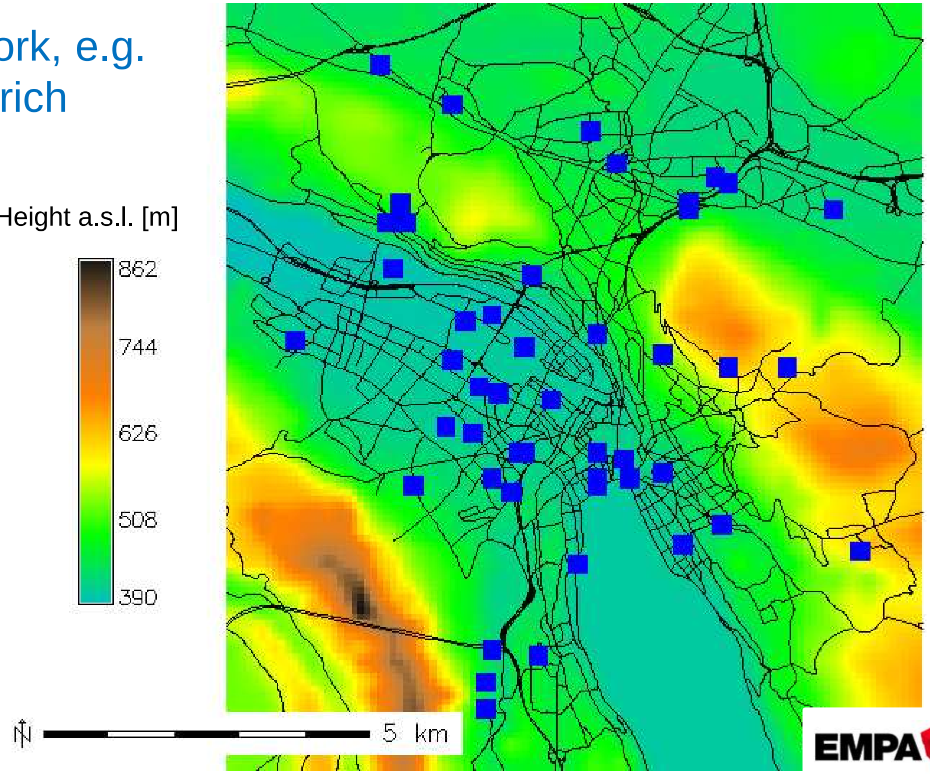
Spatial variability of Air Pollutants – urban scale

Models for estimation of spatial variability of air pollutants at urban scale with good temporal resolution (e.g. hourly)

- are hardly available
- would be important for detailed personal exposure assessment

→ **Sensor Networks** could be a solution

- o hypothetical Wireless Sensor Network, e.g. 50 low cost sensors deployed in Zurich



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– Are sensors for this application available ?

– What about data quality of sensors ?

– How to use them (deployment, calibration and QA/QC in general) ?

– How to derive spatial information from point measurements (air pollution maps) ?

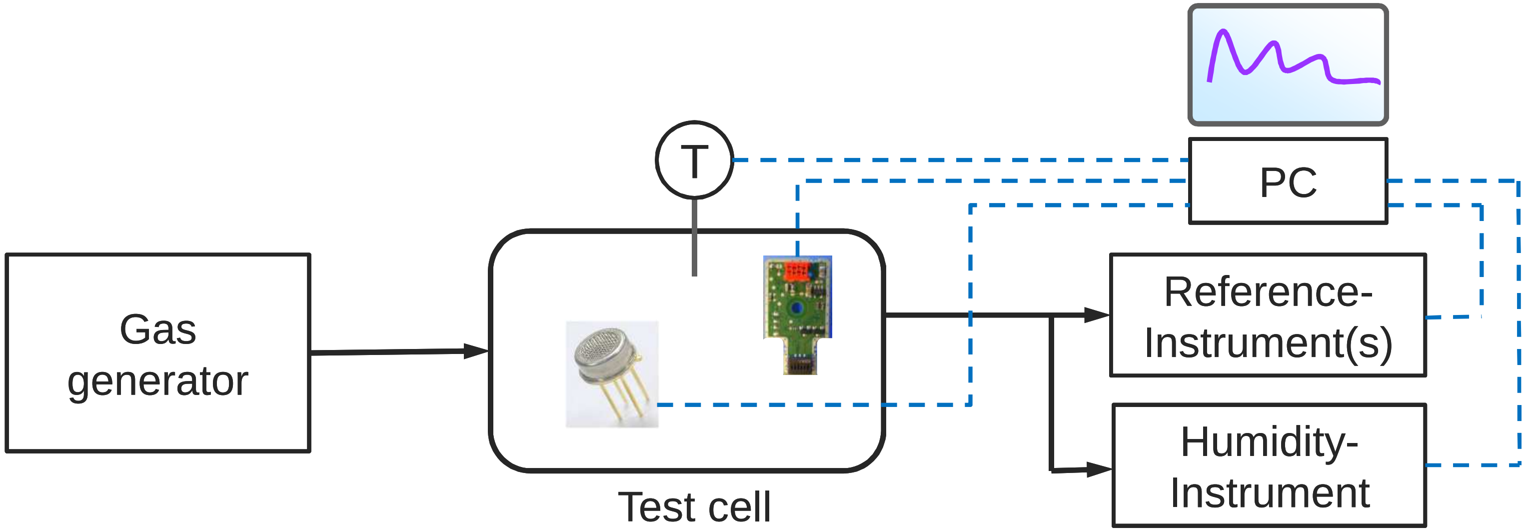
Sensors Exist - Examples

Electrochemical Gas Sensors: measure the concentration of a target gas by oxidizing or reducing the target gas at an electrode.

O_3 - Metal Oxide Semiconductor Gas Sensor: tiny chip heated up to several 100°C, which also contains a thin layer of a semiconducting metal oxide. When a specific gas is present, the electric conductivity of the semiconductor is altered.

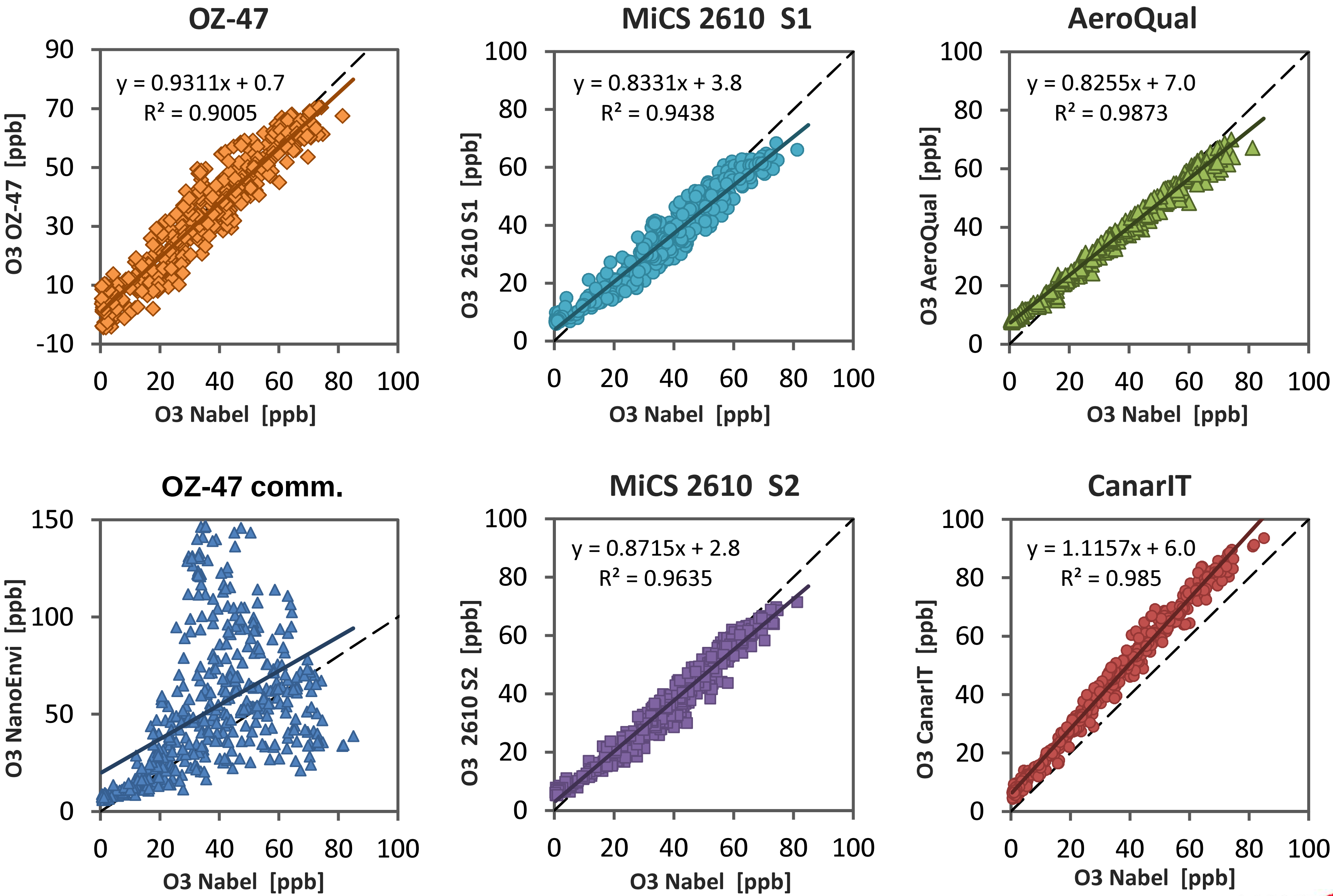
Particulate Matter: miniature diffusion size classifier instrument for nanoparticle measurement (small but not low-cost), sensors based on light scattering (low-cost)

Assessment of Sensor Performance - Tests in the Lab.



Side by side measurements at fixed (reference) site in Duebendorf

Side by side measurements of O_3 using sensors and a reference monitor (TEI 49i) at Duebendorf (hourly values 31.07.12 – 27.08.12)



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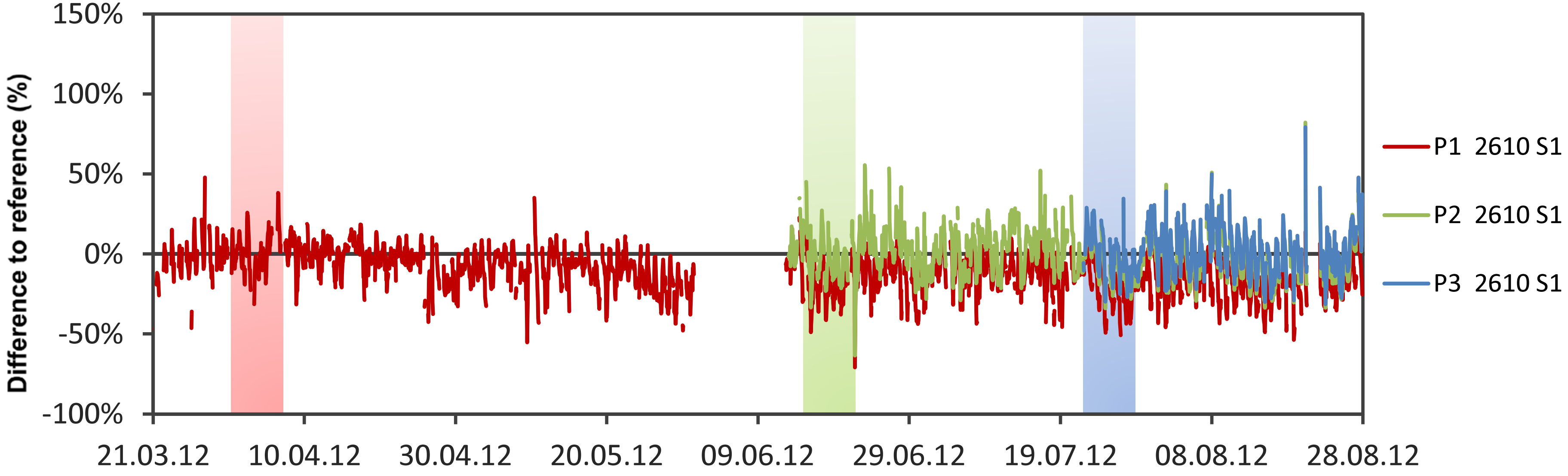
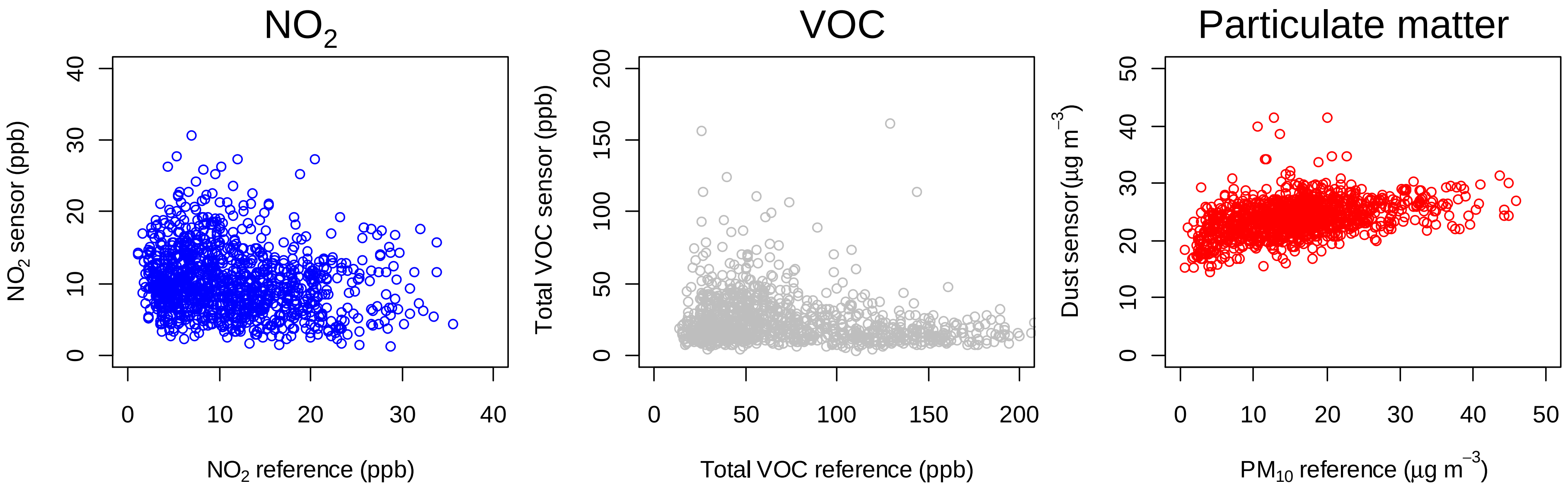
Comparison of an MiCS 2610 O_3-sensor with a reference monitor (TEI 49i) at Duebendorf site



– Periodic re-calibration required (here ≈ every 2 month)

Other air pollutants – Low-cost sensor data vs. reference instruments Duebendorf, 09.08. – 01.09.2012



– Data quality of these sensors not sufficent for ambient air quality applications !

Deployment example – OpenSense project (ETH Zurich)

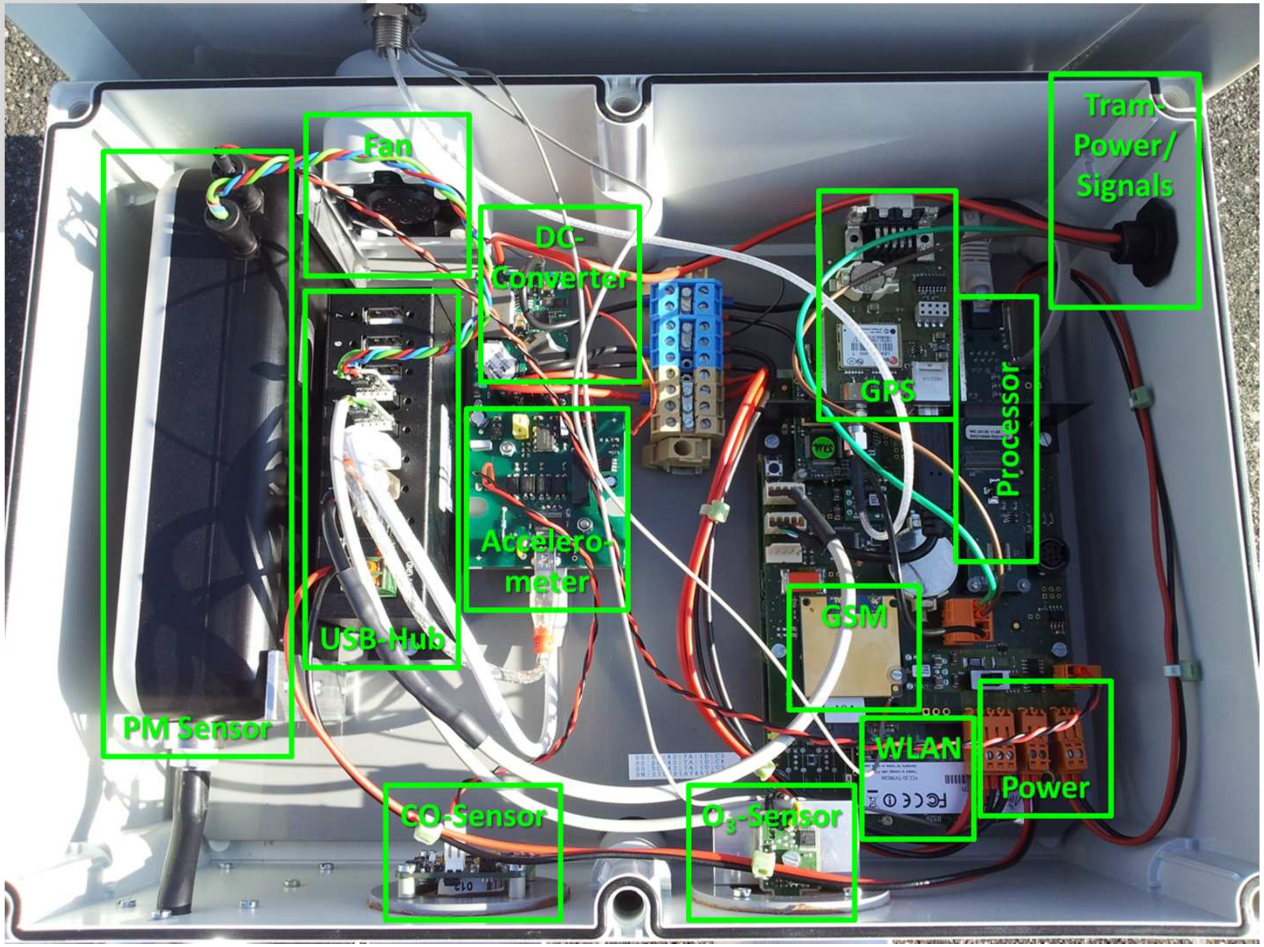
OpenSENSE ETH Zürich

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

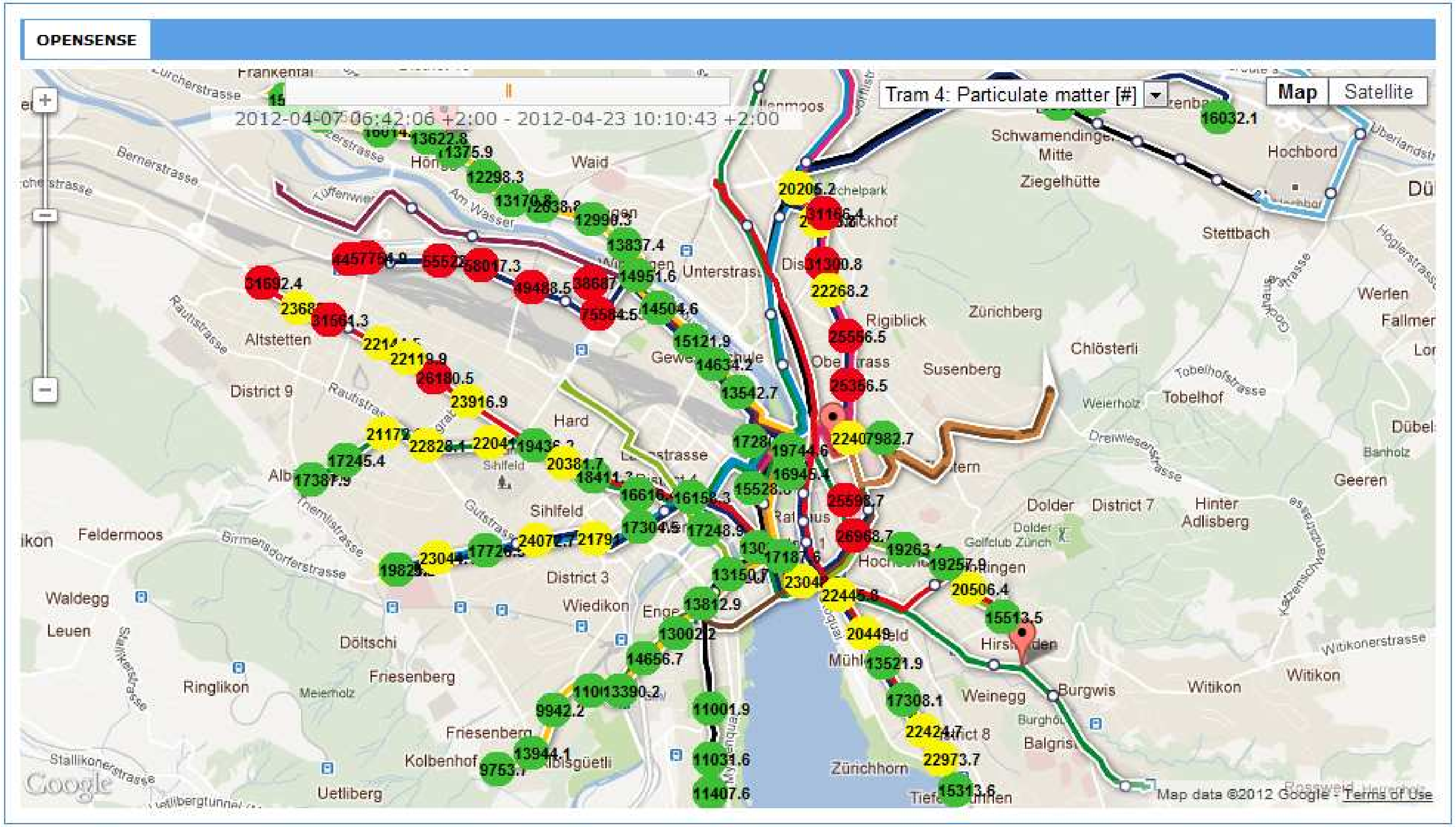
opensense.ethz.ch

OpenSense nodes

- Currently 5 stations (end 2012: 10 stations)
- Sensors: O_3, CO, particulate matter (PM), temperature, humidity, accelerometer
- GPS
- Communication: WLAN, Ethernet and GSM
- External power supply



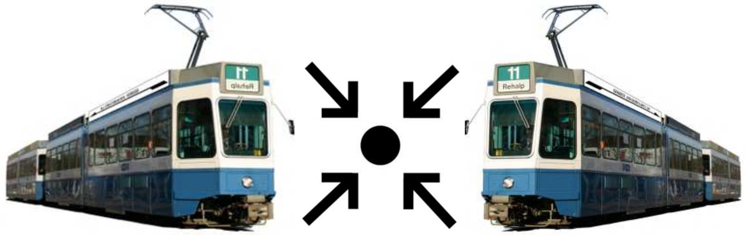
Deployment of mobile sensor nodes – Which routes to select ?

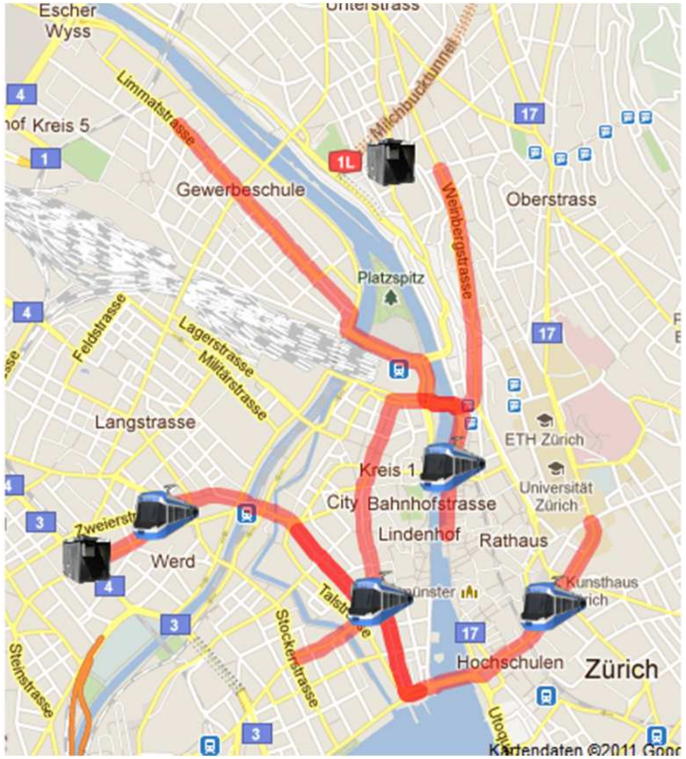


Spatial coverage is one aspect !

Possibilities for sensor calibration and testing is another aspect !

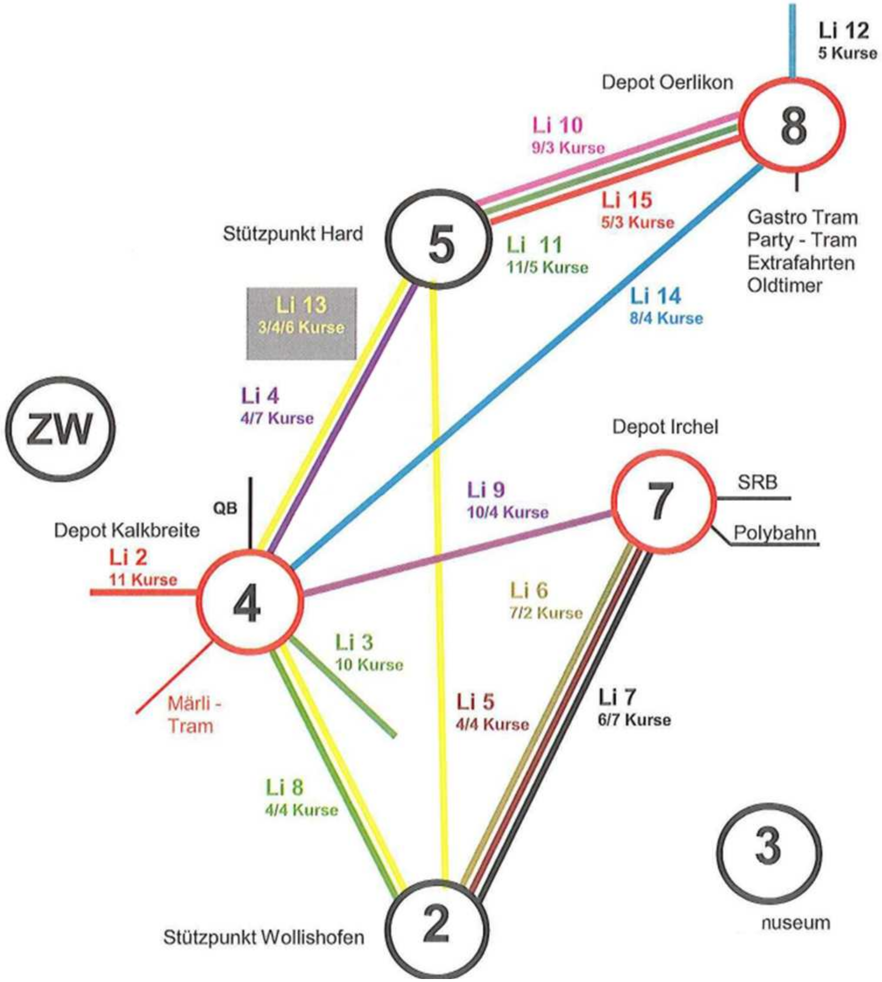
SENSOR CHECKPOINTS



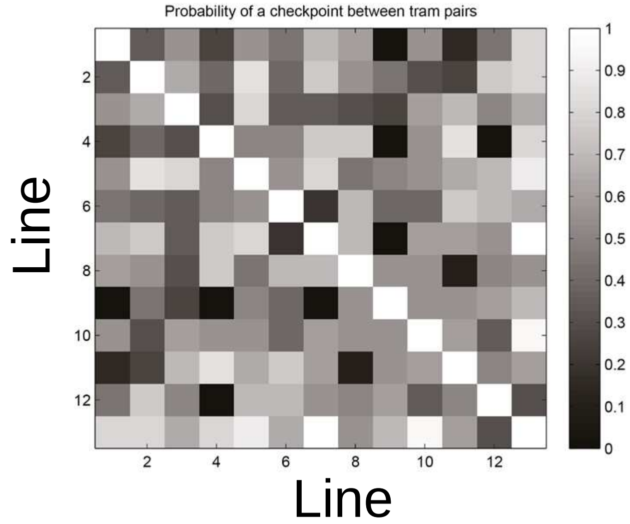


- Two vehicles make a **checkpoint** if the distance between them is below a certain threshold.
- **Checkpoints** are used for:
  - Relating measurements in space and time
  - Comparing sensor readings and sensor calibration
  - Recognizing faulty sensors
- Types of checkpoints:
  - Between two nodes
  - Between node and a reference station

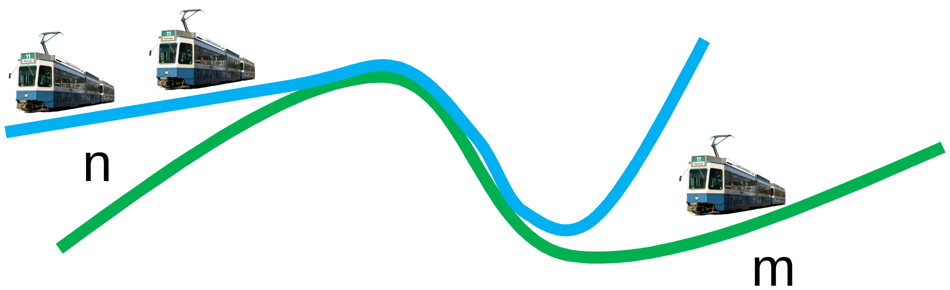
ROUTE SELECTION UNDER UNCERTAINTIES



Pairwise checkpoints



$$P(\text{ckpt}_{nm}) = 1 - (1 - p)^{nm}$$



Research Challenge

Calibration & testing of sensors deployed in networks

(e.g. how to assure data quality in mentioned hypothetical network of 50 fixed sensors in Zurich?)

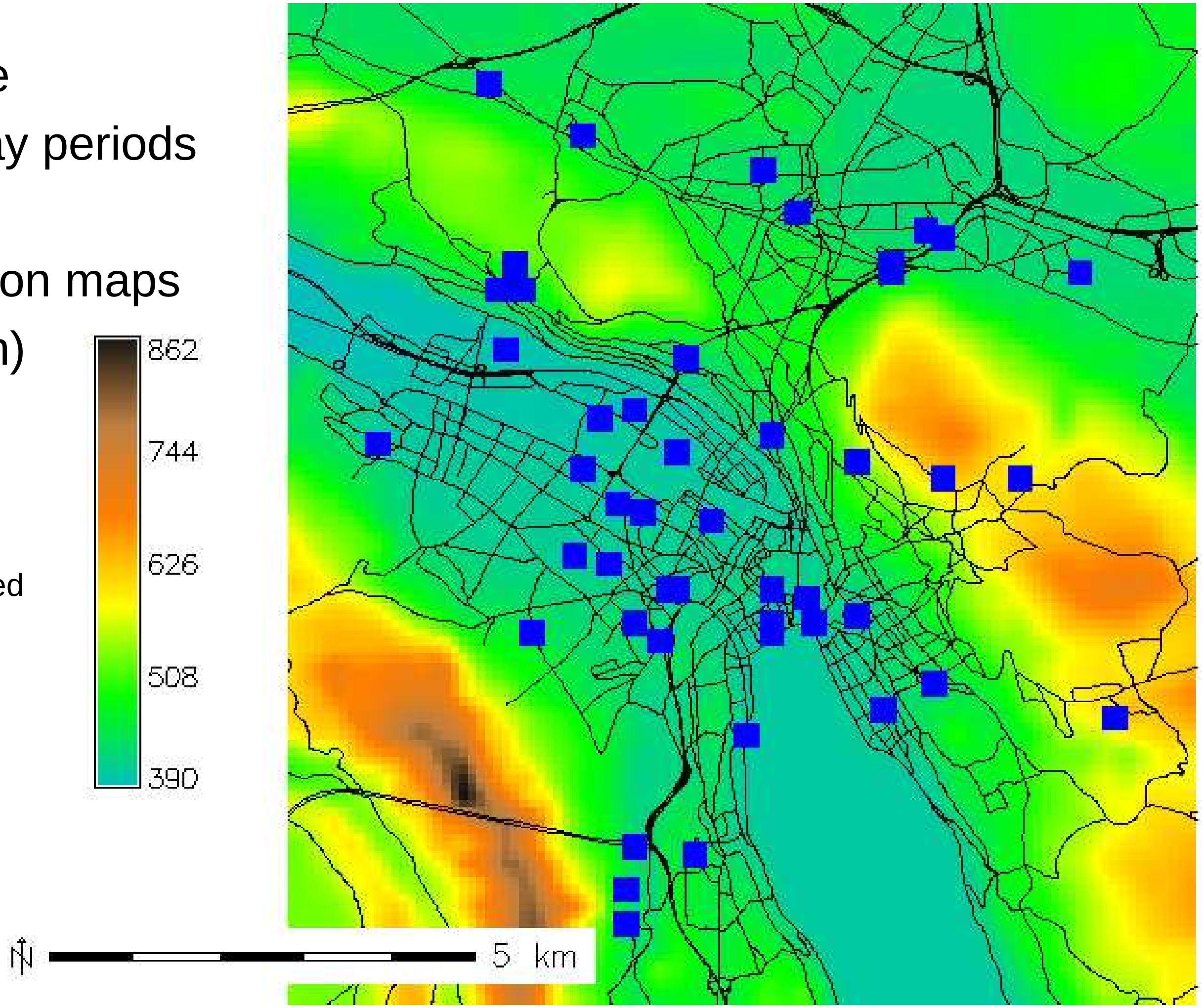
NO_2-measurements in Zurich using passive samplers

– 50 NO_2 - passive sampler tubes deployed

– Measurement of average concentration over 14 day periods

→ Estimation of NO_2-pollution maps (14-d temporal resolution)

– Barmpadimos & Hueglin, Environ. Sci. Technol. (2012) submitted



Estimation of 14-d NO_2-pollution maps – Data

- NO_2 measurements at 49 sites in Zurich (Umwelt und Gesundheit Zürich). 14-d mean concentrations for von 2008

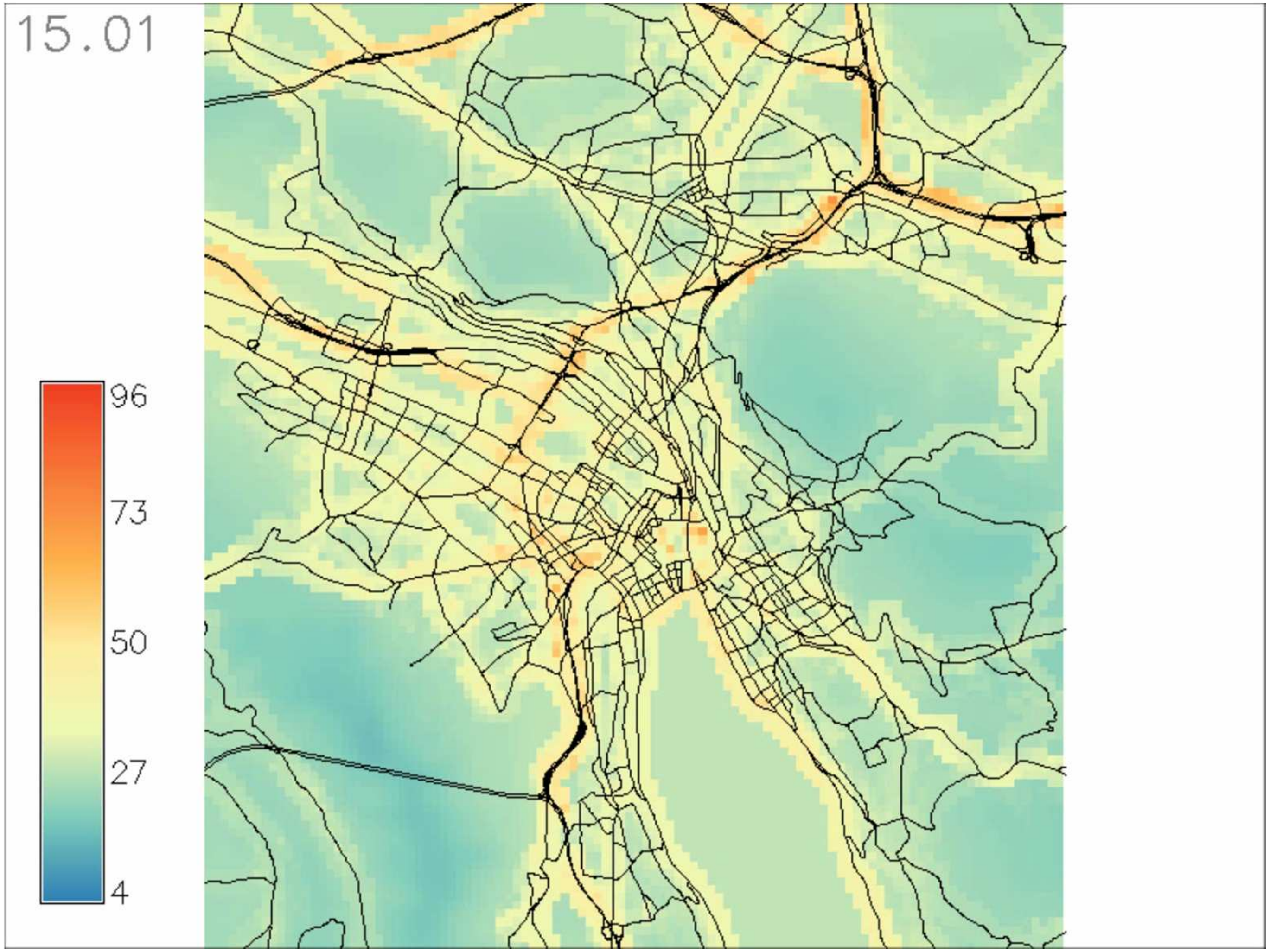
- Landuse data (100m x 100m grid cells)
  - Traffic density (number of vehicles day^{-1})
  - Total length of streets in grid cell
  - Topographic height
  - Population density
  - Number of buildings
  - Total number of building floors
  - Number of buildings using fuel oil or gas for heating
  - Number of jobs in grid cell
  - …

Estimation of 14-d NO_2-pollution maps – Method

- Land use regression (LUR)
- e.g. $\ln(NO_2) = f(\text{Traffic}) + g(population\ density) + \cdots$
- f, g etc. are smooth non-parametric functions (Generalized Additive Model, GAM)
- Separate model for each 14-d period estimated
- Automated variable selection
- 10-fold cross validation
- see Barmpadimos & Hueglin *Environ. Sci. Technol.* (2012) submitted

Estimation of 14-d NO_2-pollution maps – Results

2008



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Summary

- Low-cost sensors offer unique possibilities for assessment of spatial variability of air pollutants on small scales (e.g. urban environments)
- For some air pollutants suitable low-cost sensors are available (e.g. O_3),
- for others probably not
  - Sensitivity and selectivity are issues
  - Room for improvement - New sensing technologies (COST action TD1105 EuNetAir)
- Assume sensors are available: Novel concepts for calibration and testing of deployed sensors (QA/QC) are needed
- Combination of sensor data and landuse (GIS) data allow estimation of pollution maps in near real-time
- No need to play sensor networks against «traditional» AQ networks

  (near future / mid-term: sensor networks as a valuable complement)

Thank you!

Acknowledgements

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