Sensor-Based Monitoring Techniques – Their Potential for Use in Local Air Quality Management

Dr Mikko Laakso, Vaisala Oyj

IAPSC Conference

22. November 2018, Telford, UK

VAISALA

Outline

1. Vaisala Oyj in a nutshell
2. Emergence of compact air quality sensors
   - Market evolution
   - Technology evolution
   - Standardisation activities
3. A network deployment example: Helsinki Metropolitan Air Quality Testbed
4. Use case examples
   - Community monitoring and outreach close to an urban port: Jätkäsaari port
   - Support for mitigation activities: Street dust event detection
   - Extending source apportionment in a city: time series analysis
   - Urban planning support: gradients in street canyons
   - Compact sensors to support air quality monitoring in developing countries
5. Conclusions and acknowledgements

Vaisala - 82 years of environmental observations

1936

Professor Vilho Väisälä establishes the company on the success of the radiosonde

1937

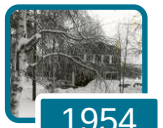
Radiosonde RS11 was displayed at World Fair in Paris where it wins a gold medal

1946

Vaisala builds it's first own manufacturing site in Ilmala, Helsinki

1951

A radiotheollite for upper-air wind measurements is introduced



1954

Vaisala moves to it's current location, Vantaa. Vaisala employs 60 people.

1965

The Vaisala Radiosonde RS13 is the world's first truly transistorized

1973

Thin-film technology is developed for Vaisala HUMICAP humidity sensors, the first of its kind..

1975

Vaisala introduces the first automatic weather station and aviation weather system. Vaisala employs over 200 people

1977

Road weather business is initiated with the development of the road weather station.

1979

Subsidiaries are established in the UK, USA, Japan, and Germany between 1979-1986.

1980

The first cleanroom is built, enabling the design and manufacturing of semiconductors in-house.

1983

A new pocket size and light Radiosonde

1990

Subsidiaries are established in France (1990) and China (1994).

1994

Vaisala A Series shares are listed on the Helsinki stock exchange.

2000

Growth through acquisitions - eg. Lightning (2000) and Weather Radars signal and processing (2005).

2003

New Radiosonde family is introduced

2007

Vaisala introdices C-band weather radars with accurate dual polarimetric measuring and a new concept in antenna design.

2011

Vaisala's pressure sensing technology was launched towards Mars in Mars's Rover, Curiosity.

Safety, Efficiency and Better Decision Making

















Weather and Environment Markets

METEOROLOGY

TRANSPORTATION

RENEWABLE ENERGY

AMBIENT AIR QUALITY

MEGA TRENDS

- Climate Change
- Renewable Energy
- Digitalization & Big Data
- Future of Mobility
- Urbanization
- Sustainability Awareness

Employs
1600
professionals worldwide

EMEA **69%** Americas **23%** APAC **8%**

Has over
30 offices in **16** countries

38% of Vaisala people work outside Finland

Serves **customers** in over
150
countries annually

2016 net sales
319.1 million euros

EMEA **29%** Americas **44%** APAC **27%**

2016 R&D investments over
11% of net sales

20% of employees work in R&D activities

Committed to using
100%
renewable energy by
2020

Actions for cleaner air and healthier people

Urban and regional planning

- Public transport made attractive and clean
- Green corridors and areas in city
- Location of industries and waste disposal sites

Legislation affecting pollution sources

- Clean fuels regulations
- Legislation for control measures in industry

Targeted efforts during air quality episodes

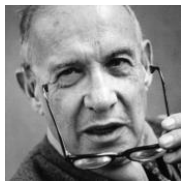
- Traffic restrictions
- Advisories for industries and construction sites
- Situational awareness in accidental release incidents

Limiting exposure of people

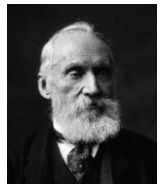
- Up to date information on conditions
- Accurate advisories and warnings
- Modern tools for avoiding exposure (mobile apps etc)

All of these require an accurate understanding of the air quality situation

"You can't manage what you don't measure."



Peter Drucker



Lord Kelvin

Emergence of compact AQ sensors

Picture modified from K. Benedict EPA, ASIC Conference, Oakland, CA 2018

Air quality sensor reports and events

WORLD METEOROLOGICAL ORGANIZATION

Low-cost sensors for the measurement of atmospheric composition: overview of topic and future applications

NPL

Science + Technology | Commercial Services | Educate + Explore | Joint Ventures

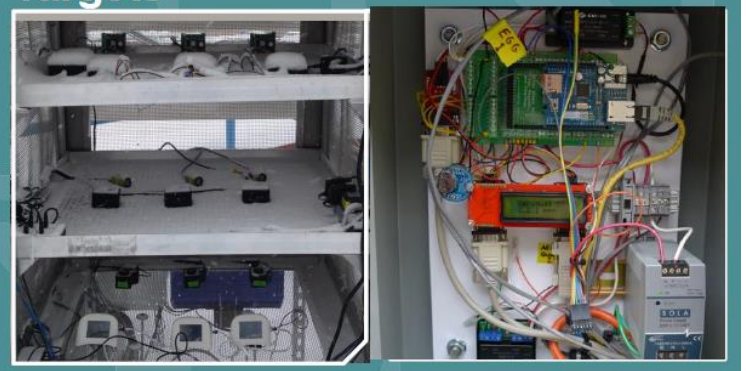
Home > News + Events > Events

APRIL meeting : Low cost-air quality sensors

Date: 17 April 2018

EPA United States Environmental Protection Agency

Peer Review and Supporting Literature Review of Air Sensor Technology Performance Targets



Air Sensors International Conference

Advancing Science and Engaging Communities

About | Program | Registration | Abstract Submission | Sponsorship | Your Visit

September 12th-14th, 2018

Hosted by the UC Davis Air Quality Research Center in partnership with US EPA & CA ARB

ASIC will bring together stakeholders from academia, government, communities, and commercial interests to promote and advance air pollution sensors, improve the data quality from these sensors, expand the pollutants measured, and foster community involvement in monitoring air quality.

What are we discussing?

- Sensors and Smart Cities
- Data Management Platforms
- Development/Improvement of tech.
- Data analytics and communication
- Much more...

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Air Quality Sensor Conference 2017

"Making Sense of Sensors"

*** SOLD OUT ***

Activities towards sensor certification

Europe: CEN TC 264 WG42

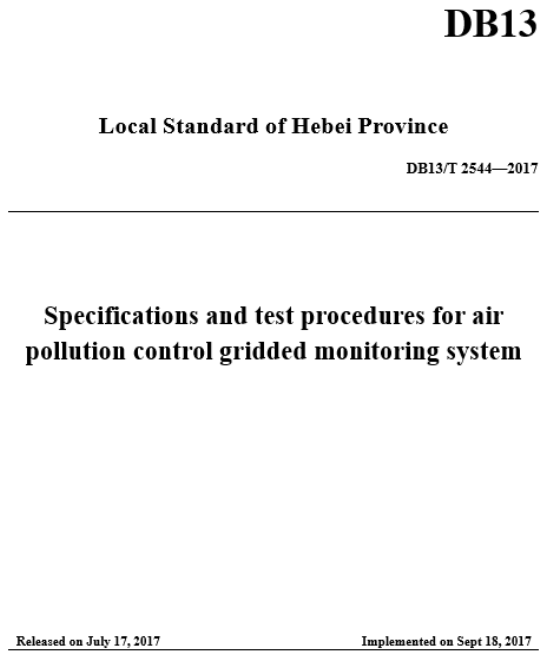
Technical specification for AQ sensors

USA: SCAQMD, California

Sensor testing center

China: Hebei Province

Performance requirements for sensor grid monitoring



WMO/GAW sensor usage classification

Temporal variability

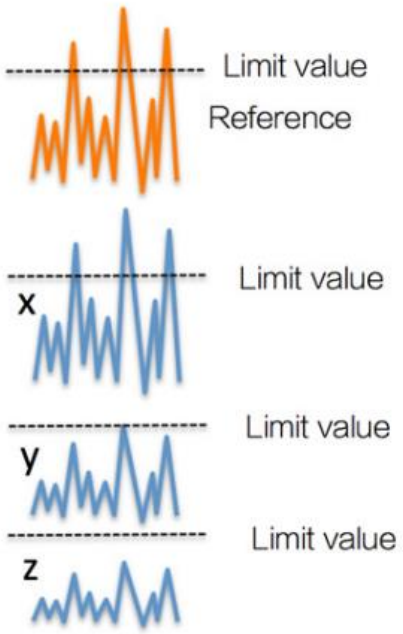
e.g. traffic counting, 'Pollution is highest in the morning'

1. Sensors are stabile over the period of interest
2. Sensors respond broadly to pollution

Spatial variability

e.g. 'location x has higher pollution than location y and z'

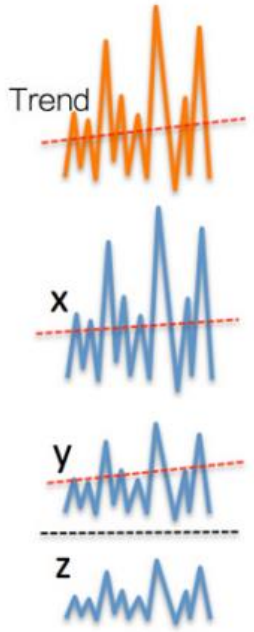
1. Stable over the period of interest
2. Responds broadly to pollution
3. Sensors are **internally** reproducible



Concentration dependence

e.g. 'location x exceeds the limits but y and z do not'

1. Stable over the period of interest
2. Sensors are compound specific
3. Sensors are **externally** reproducible



Long-term trends

e.g. 'species at location x is increasing at 3% / yr'

1. Stabile over the period of interest
2. Sensors are compound specific
3. Sensors are **globally intercomparable**

Source: WMO/GAW report Lewis A.C. et al: "Technical Advice Note on Low Cost Air Pollution Sensors"

Evolution of technology and practices

Current state

Basic sensor technology

Temporal variability

e.g. traffic counting, 'Pollution is highest in the morning'

1. Sensors are stabile over the period of interest
2. Sensors respond broadly to pollution

stability

Industrial manufacturing

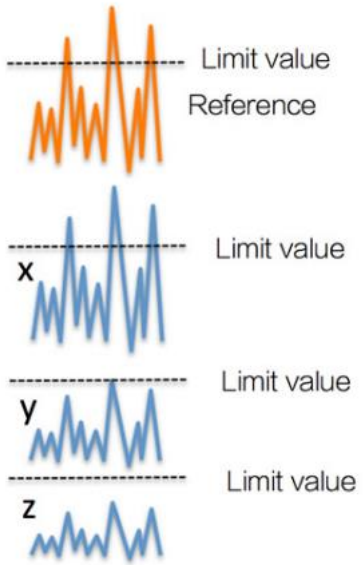
Spatial variability

e.g. 'location x has higher pollution than location y and z'

1. Stable over the period of interest
2. Responds broadly to pollution
3. Sensors are **internally** reproducible

reproducibility

Performance standards



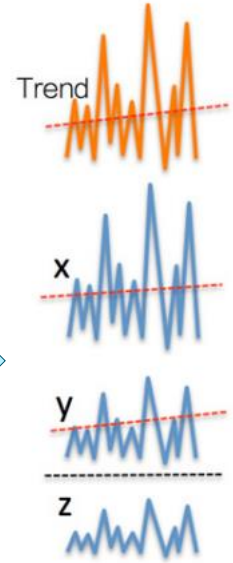
Concentration dependence

e.g. 'location x exceeds the limits but y and z do not'

1. Stable over the period of interest
2. Sensors are compound specific
3. Sensors are **externally** reproducible

accuracy

Traceable calibrations, intercomparisons



Long-term trends

e.g. 'species at location x is increasing at 3% / yr'

1. Stabile over the period of interest
2. Sensors are compound specific
3. Sensors are **globally intercomparable**

traceability

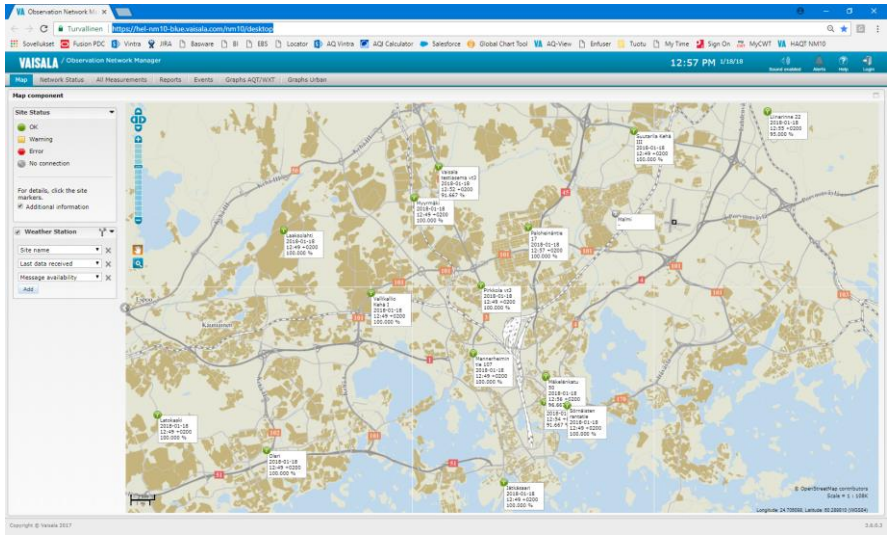
Adapted from: WMO/GAW report Lewis A.C. et al: "Technical Advice Note on Low Cost Air Pollution Sensors"

Helsinki Metropolitan Air Quality Testbed

New air quality monitoring infrastructure to Helsinki Metropolitan area:

- Network of 15 air quality sensors to complement regulatory network
- Real time air quality model and forecast based on the improved resolution data
- Dissemination to citizens through internet, public displays etc.
- Open interface to data for application development

- Services for air quality forecasting, alerting, traffic, urban planning – local IT startups encouraged to utilize open data



VAISALA

pegasor

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

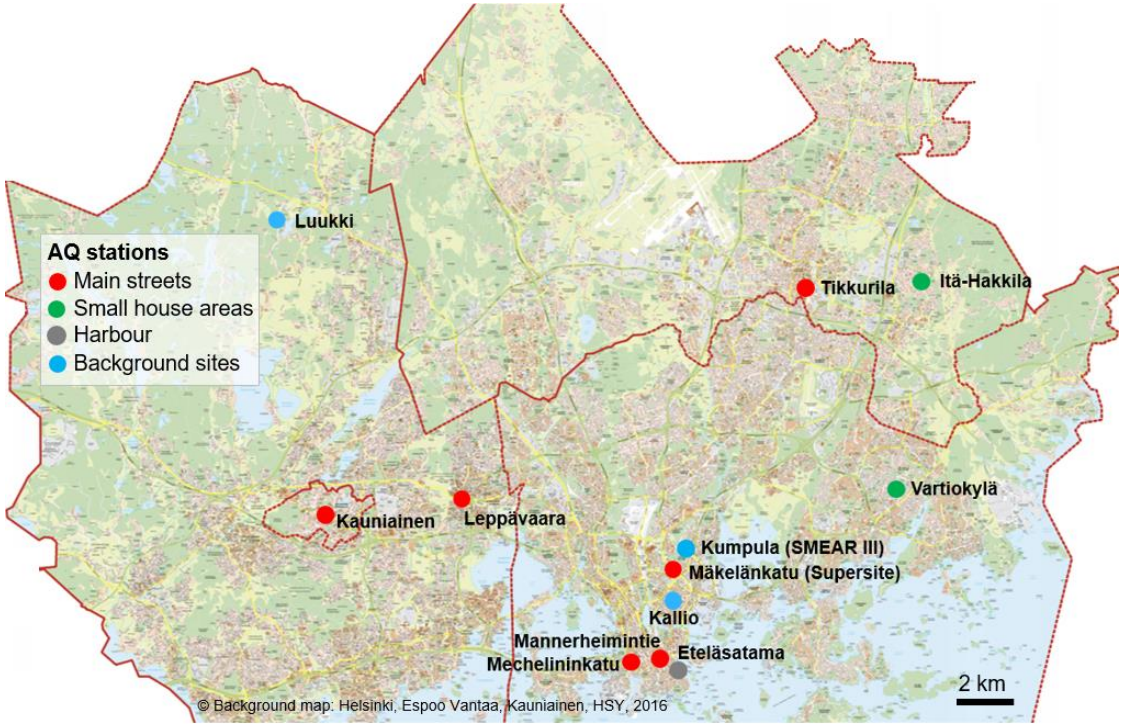
Smart & Clean

HSY

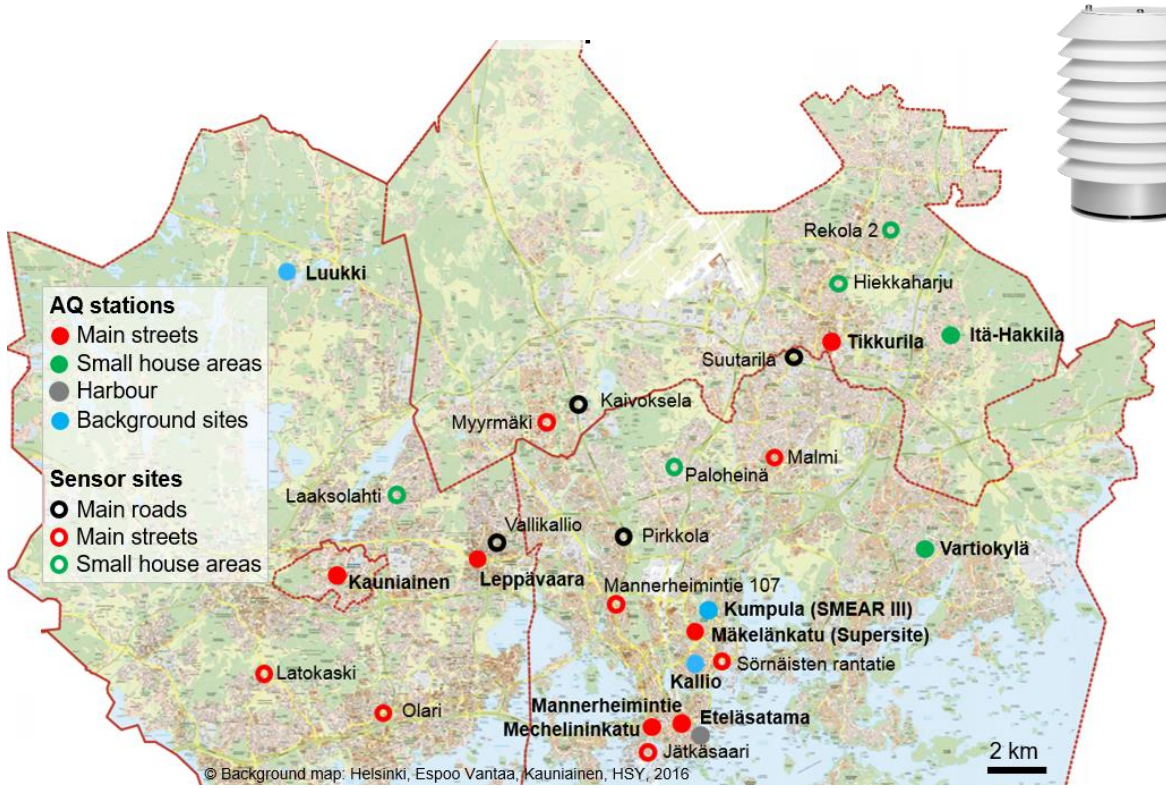
FINNISH METEOROLOGICAL INSTITUTE

Testbed network

Before – 12 reference sites



After – 15 x AQT420 sensor sites added



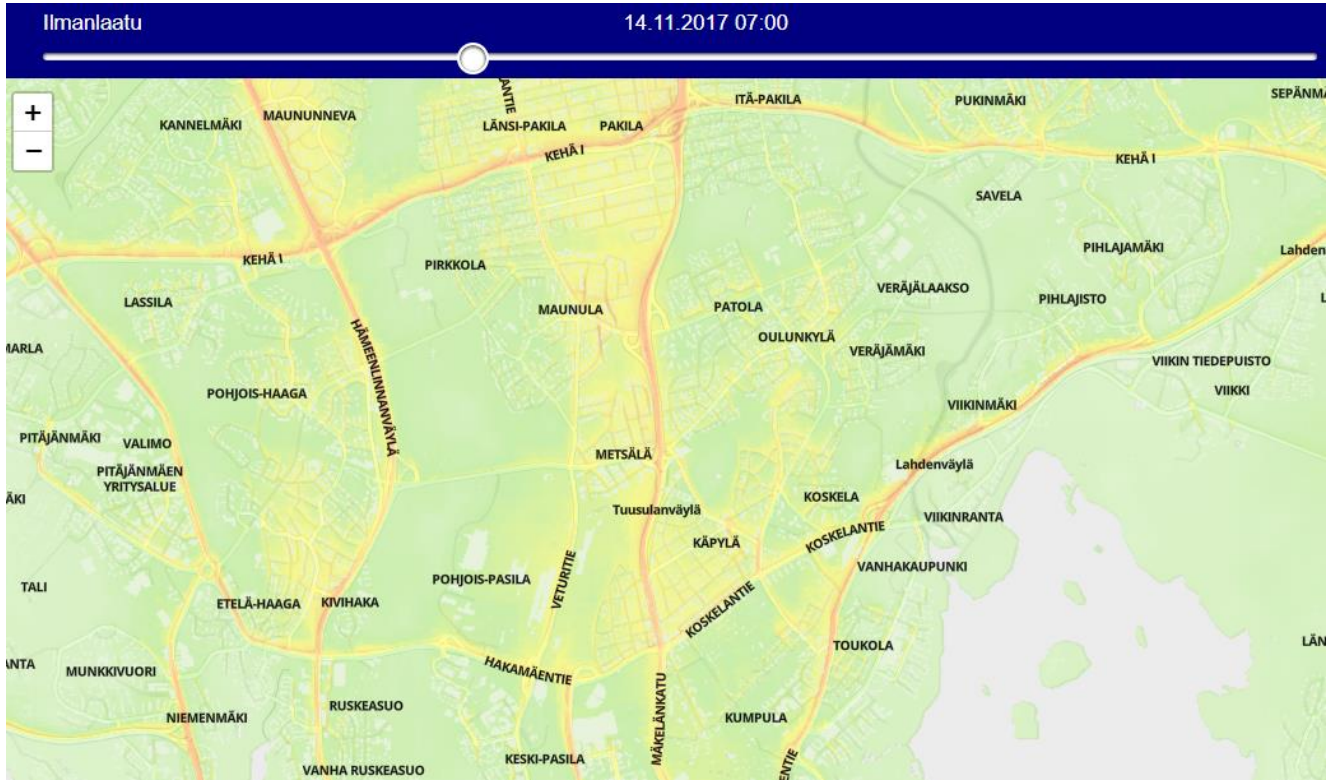
Courtesy Jarkko Niemi Helsinki Region Environmental Services Authority

Co-location optimizes sensor performance

	NO_2			CO			O_3			PM_{10}		
Sensor site	Slope	Constant	R^2	Slope	Constant	R^2	Slope	Constant	R^2	Slope	Constant	R^2
Olari	0.90	-2.32	0.88	1.30	-0.09	0.61	1.43	10.72	0.51	1.17	-0.06	0.90
Laaksolahti	0.92	-10.32	0.70	1.12	0.02	0.89	1.25	8.45	0.49	2.23	-0.96	0.56*
Rekola 2	0.87	-1.17	0.87	1.34	-0.02	0.82	1.27	8.74	0.64	3.78	-0.98	0.55*
Pakila	0.94	-1.24	0.84	1.05	0.03	0.87	2.17	13.64	0.58	1.92	-1.24	0.54*
Hiekkaharju	0.85	0.02	0.74	1.12	-0.02	0.81	1.76	-0.46	0.36	2.59	-1.11	0.50*
Pirkkola	0.90	-4.36	0.85	1.16	0.03	0.85	1.28	11.76	0.60	0.87	1.08	0.91
Kaivoksela	0.82	-1.55	0.88	1.31	-0.02	0.88	1.17	7.37	0.47	1.41	2.21	0.90
Vallikallio	0.90	-3.46	0.88	1.37	0.01	0.88	1.24	13.98	0.67	2.39	2.76	0.90
Suutarila	0.91	-4.33	0.86	1.32	0.04	0.86	0.84	9.25	0.57	2.06	3.52	0.89
Mannerheimintie	0.90	-3.67	0.85	1.11	0.05	0.85	1.33	14.14	0.71	1.68	2.81	0.91
Sörnäisten Rantatie	0.91	-0.62	0.90	1.20	-0.01	0.90	1.08	12.74	0.77	1.08	3.99	0.90
Myyrmäki	0.88	-6.50	0.86	1.37	-0.07	0.81	0.80	8.89	0.79	0.31	4.65	0.93
Itä-Hakkila	0.92	-5.10	0.87	1.22	0.03	0.82	0.92	10.71	0.81	0.51	5.23	0.92
Malmi	0.87	-7.22	0.83	1.18	0.03	0.82	0.82	8.48	0.79	0.51	4.94	0.93
Jätkäsaari	0.89	-4.07	0.87	1.18	0.04	0.83	0.81	11.07	0.74	0.58	3.78	0.94
Latokaski	0.89	-3.74	0.90	1.20	0.02	0.78	1.20	0.99	0.51	0.57	4.84	0.90

Operational high resolution modelling 24/7

ENFUSER fusion model by Finnish Met Institute FMI



Main local air quality issues in Helsinki

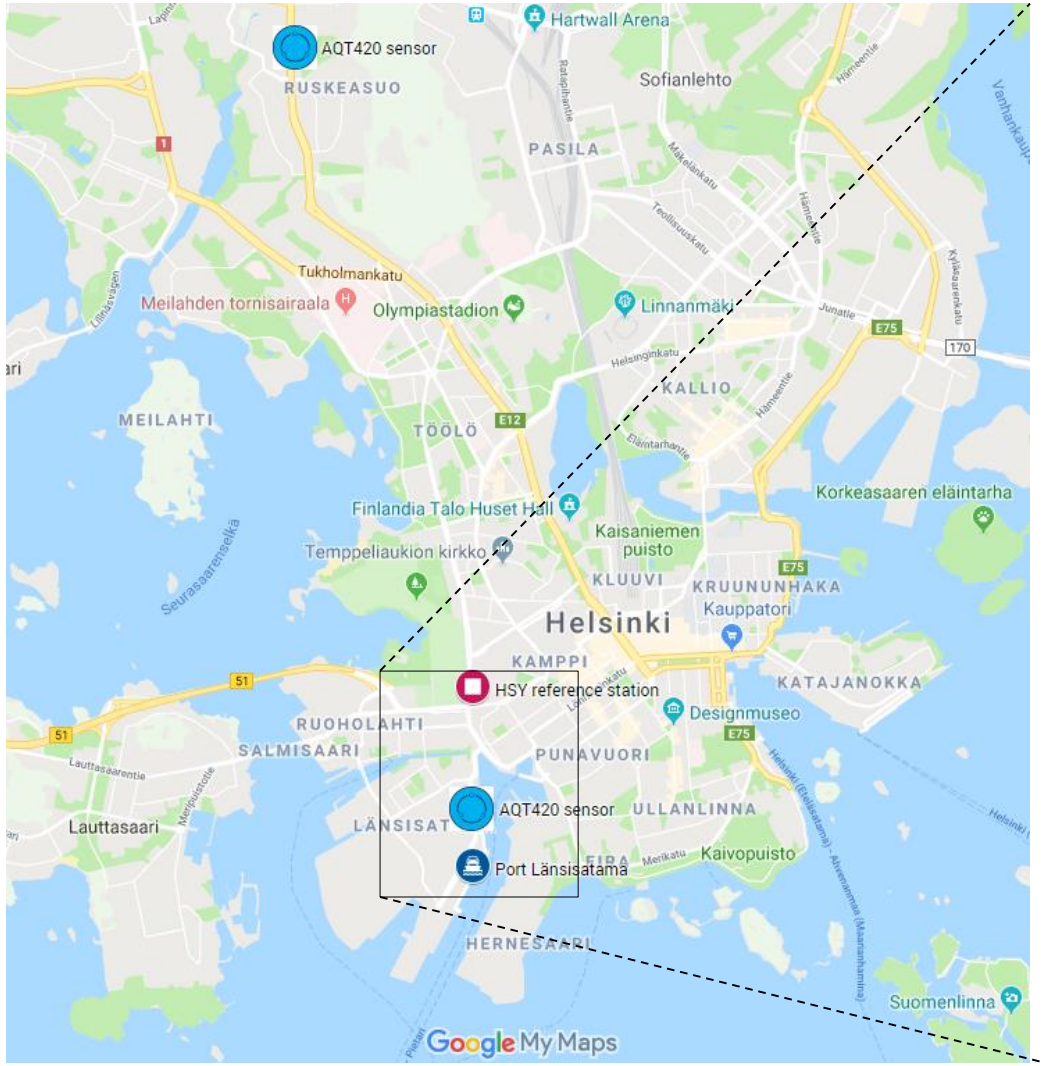
NO_2 from traffic
- downtown street canyons
- congested periods

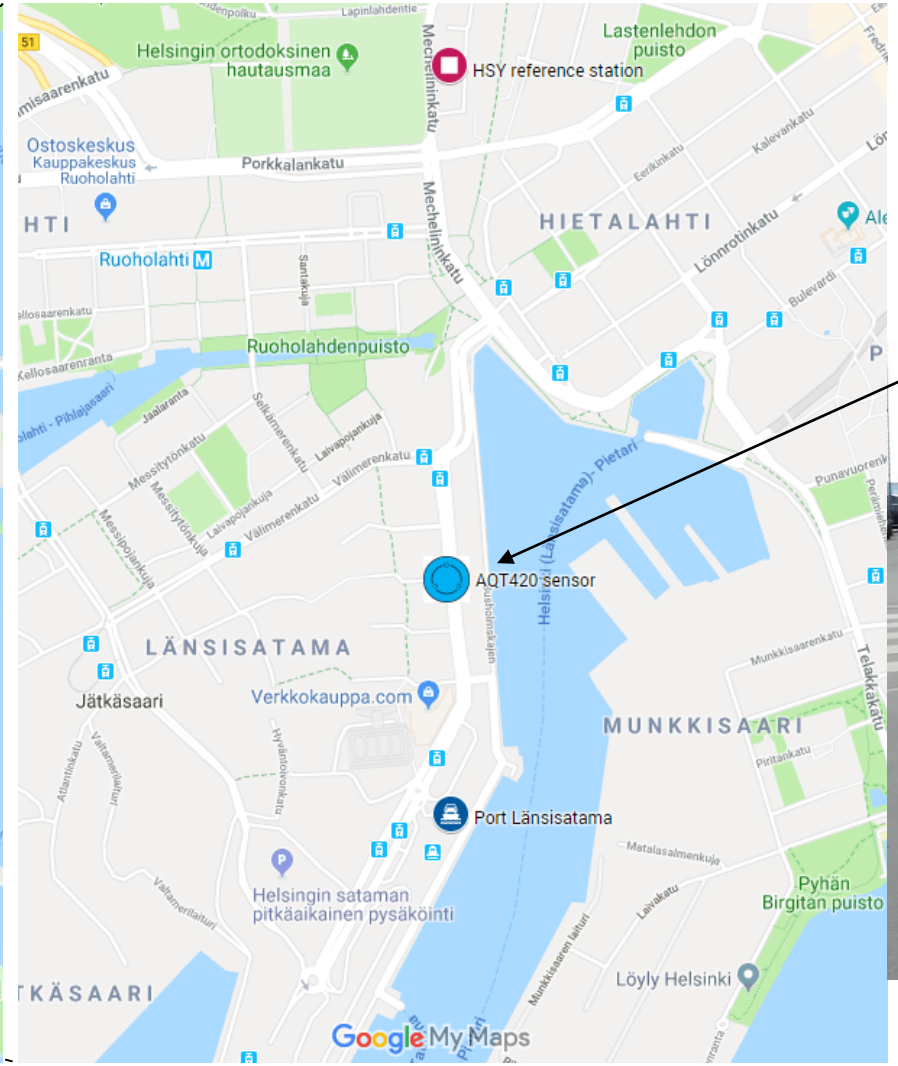
Domestic wood burning
- small house areas
- more prominent in winter time

Street dust
- spring time
- studded tires

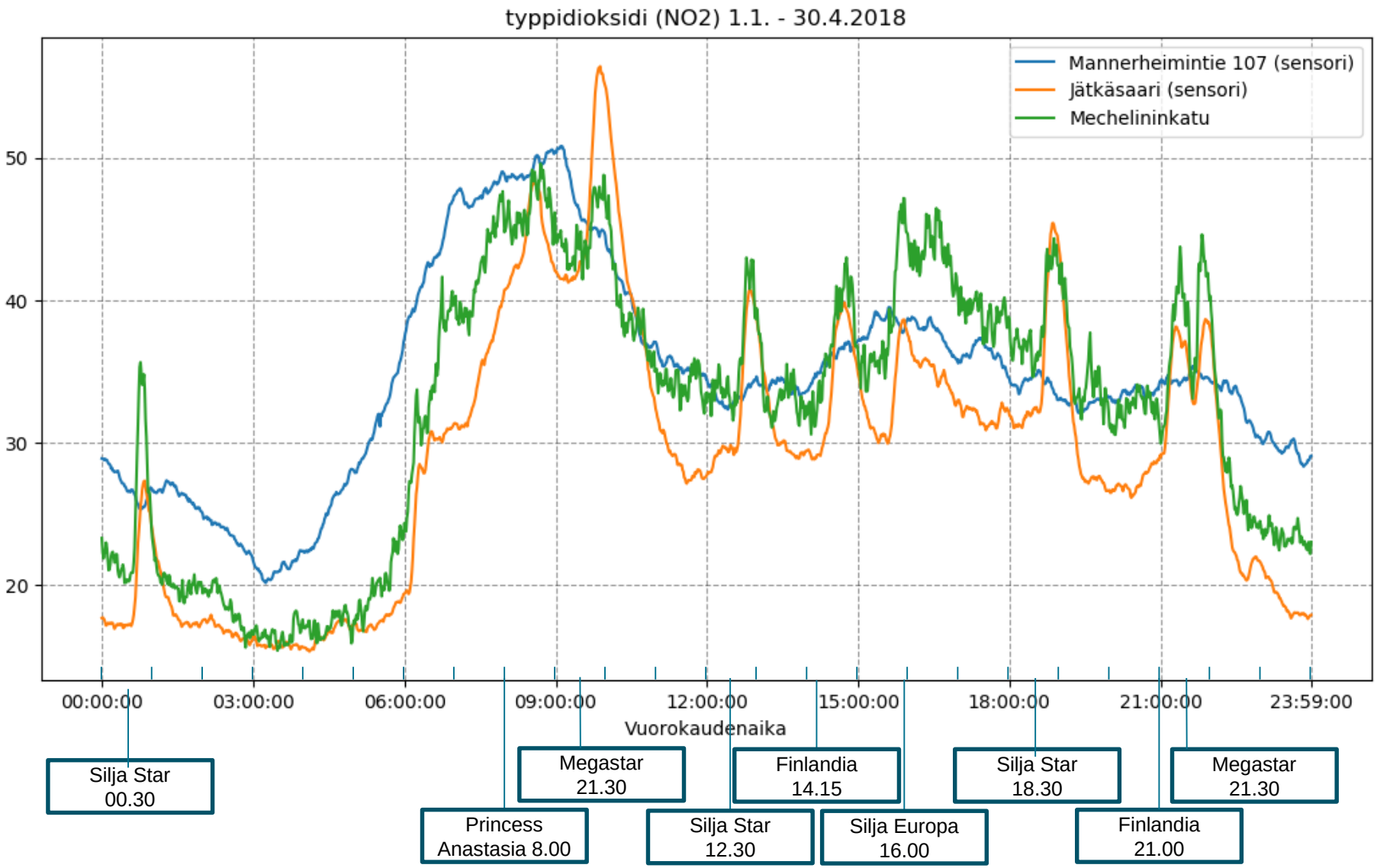
Jätkäsaari port car traffic

Case: Community monitoring, public outreach



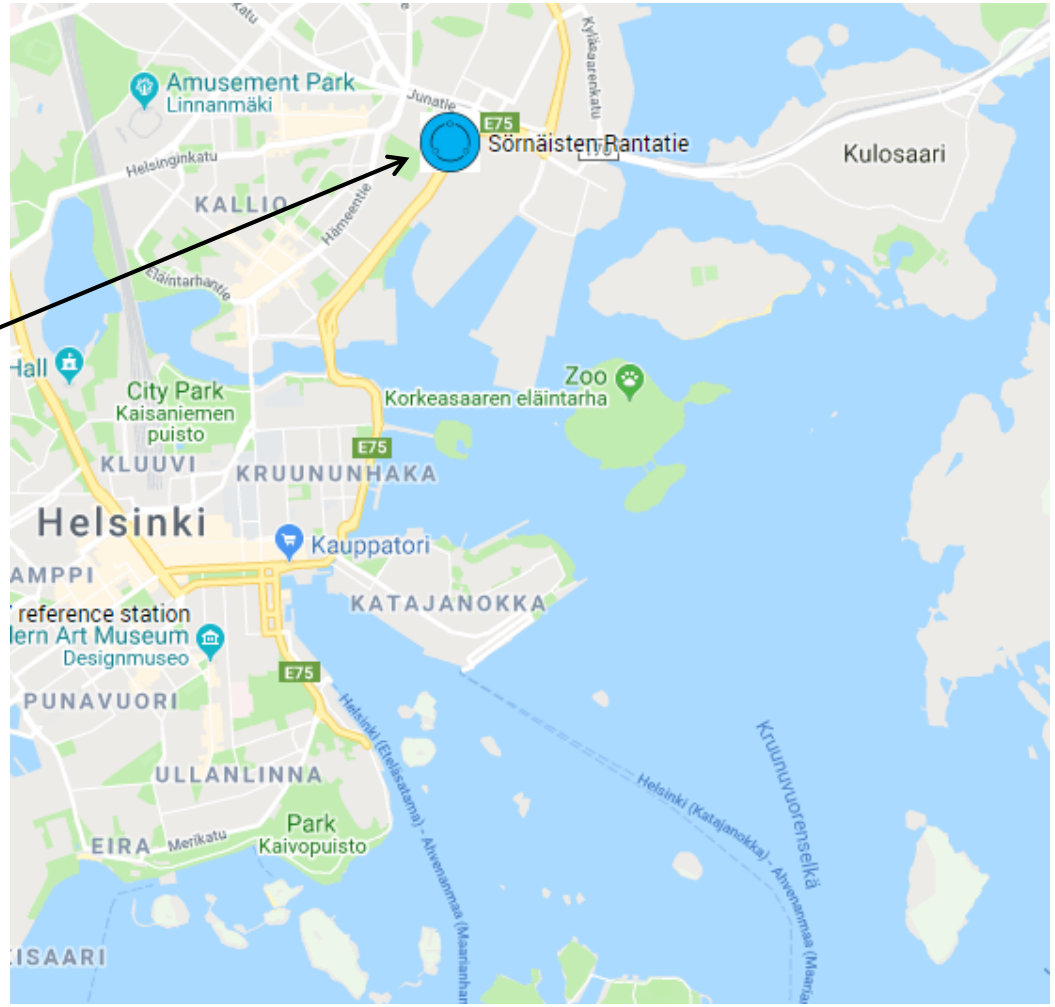


Jätkäsaari port NO_2 measurements

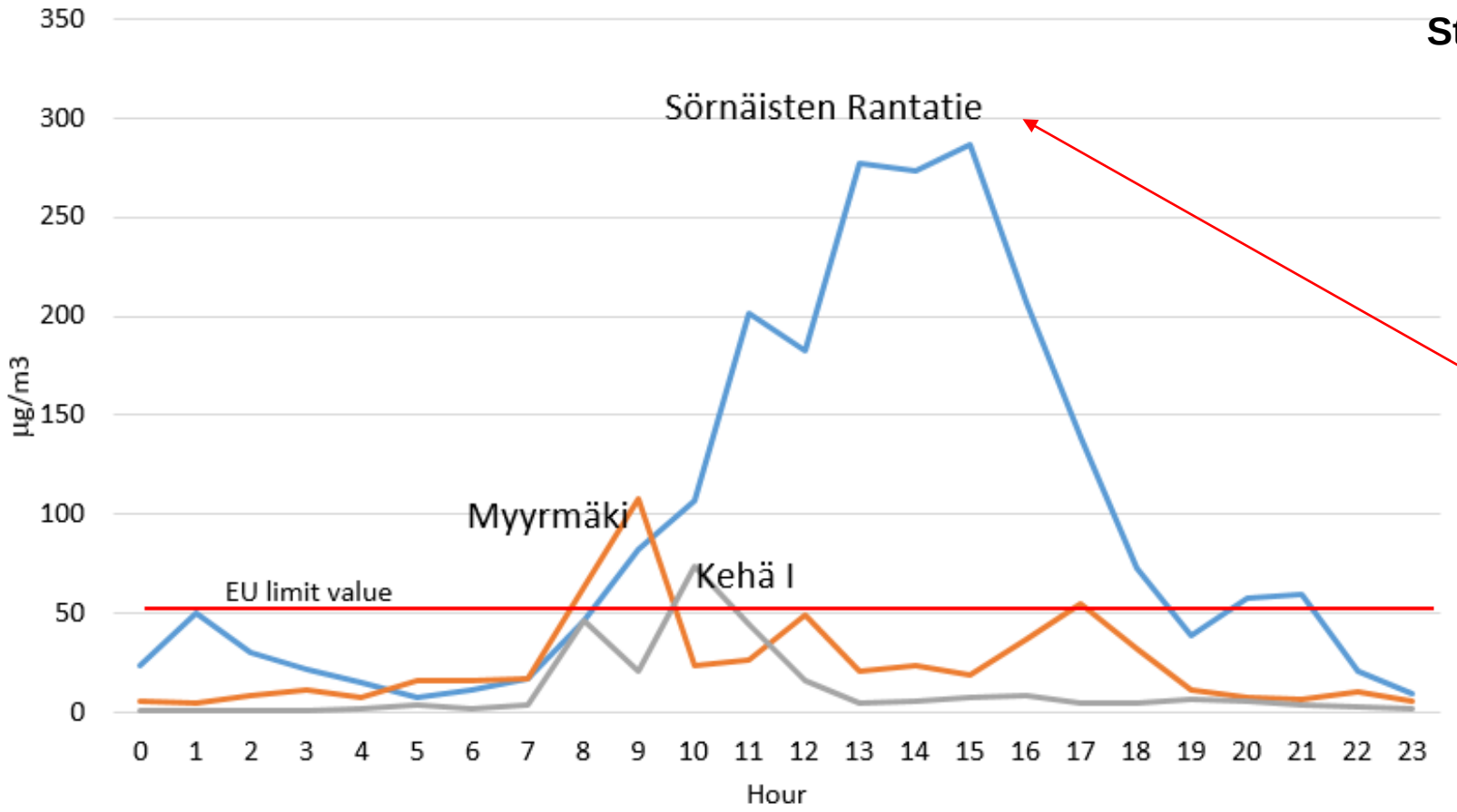


Rare mid-winter street dust event

Case: support for dust mitigation actions



Unusual winter PM10 event detected by sensor network



The familiar spring annoyance torments Helsinki in mid-winter

Studded tires dusting streets in Helsinki

Sää: Keväältä tuttu vitsaus saattaa kiusata Helsinkiä keskellä tammikuuta

Kadut pölisevät nastarenkaiden alla Helsingissä

Korkeapaineen keskus pitänee Etelä-Suomen kuivana loppuviikkoon asti.

Kaisa Hakkarainen HS

HELSINGIN sääolosuhteet näyttävät nyt siltä, että tällä viikolla voi pölistä. Luvassa saattaa olla talvista katupölyä hintana siitä, että kaupunkilaiset voivat viikon ajaksi luopua kumisaappaistaan.

"Pölyä alkaa lennellä. Kun tiet kuivuvat ja nastarenkailla jurnutetaan, niin katupöly alkaa nousta keskellä talveakin", sanoo meteorologi **Jouko Korhonen** Ilmatieteen laitokselta.

Lumikaan ei nyt sido pölinöitä itseensä.

Myös pienemmät saastehiukkaset voivat Korhosen mukaan jäädä korkeapaineessa leijumaan kaupungin ylle. Ilmanlaatu saattaa heiketä varsinkin loppuviikosta.

"Mitään erityisen pahaa en vielä osaa ennustaa. Aamu- ja iltapäiväruuhkat nostavat ilmaan kaikenlaista."

ERITYISEN paljon pölinälle altistuvat lapset.

"He kulkevat siinä metrin korkeudella ja saavat hengittää siitä parhailta paikoilta, jos joutuvat odottamaan bussipysäkillä keskustan vilkkaiden teiden varsilla."

Yleensä katupöly kuuluu kevääseen, jolloin ilmassa lentelee liikenteen ja tuulten mukana talven hiekoitushiekka. Nyt kyse on siitä, että nastarenkaat repivät pölyhiukkasia irti asfaltista.

"Viikon mittaan voi nousta esiin talvinen katupölyongelma etenkin aamuisin ja iltapäivisin. Tänään tuuli vie vielä pölyt Suomenlahdelle, mutta jatkossa ei taida olla tuultakaan."

SÄÄENNUSTEMALLIT ovat Korhosen mukaan loppuviikkoa kohden vielä erimielisiä siitä, pysyykö kaupunki kuivana vai ei.

"Päätyökalumme mukaan etelän päällä pysyisi korkeapaineen keskus viikonloppuun asti."

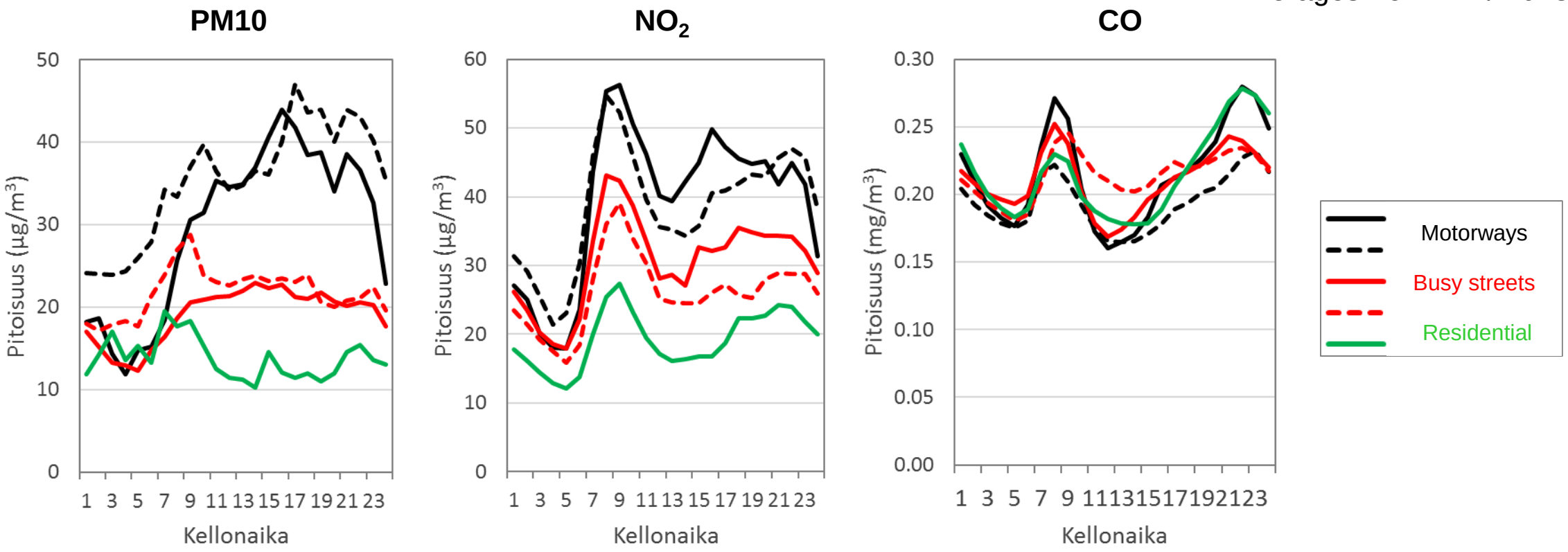
Nastarenkaat voivat raapia kuivasta asfaltista katupölyä.

Important information for Helsinki city winter maintenance to direct the cleaning activities

Sensor diurnal patterns vary by location type

Case: support for urban source apportionment

Averages from 1-7 / 2018



PM10 due to street dust
Information used to support dust mitigation activities

Dilution of traffic originated NO_2

CO affected by traffic and domestic wood burning

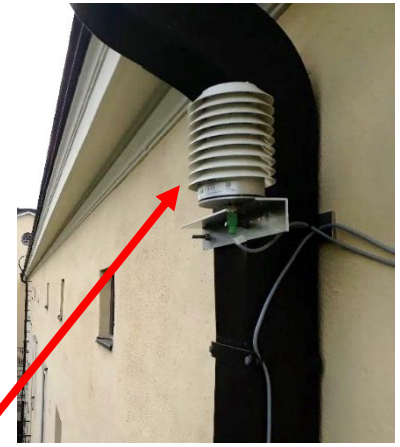
Air quality gradients in a street canyon

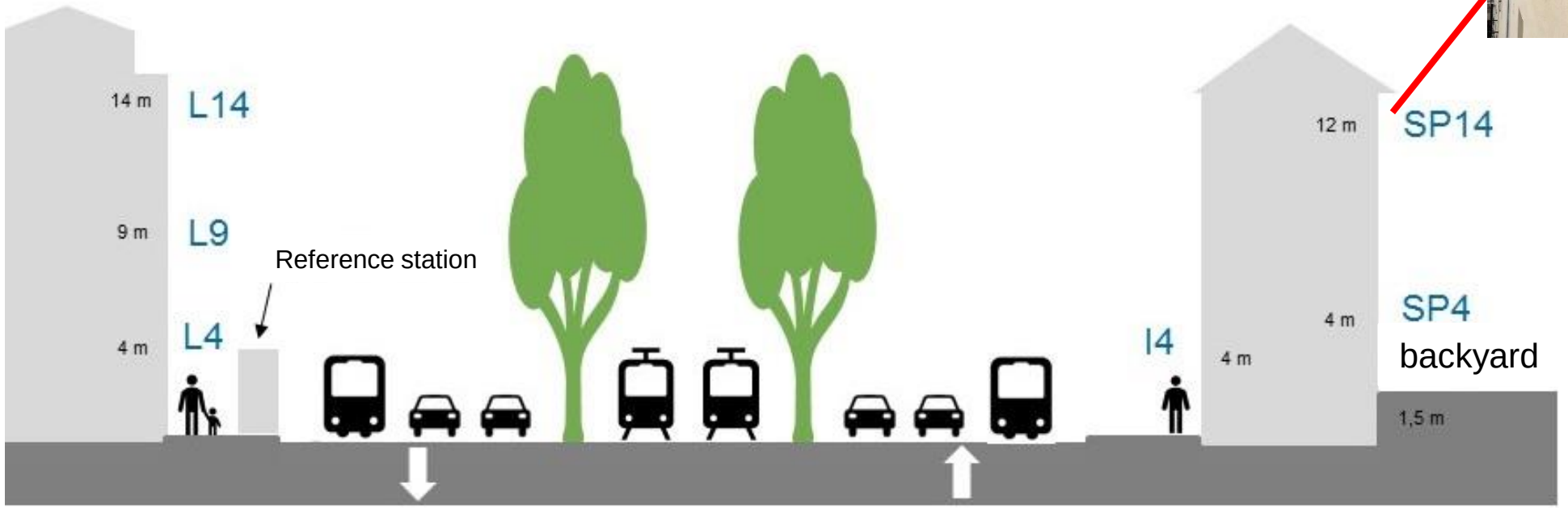
Case: Support for urban planning

Images and data courtesy:
City of Helsinki,
Helsinki Regional Environmental Services Authority HSY

Preliminary results

- Study to understand dispersion of traffic emissions surrounding residential buildings next to a busy street
- Data used to support urban city planning
- Sensors mounted on different heights on building walls on the front and back of apartment buildings



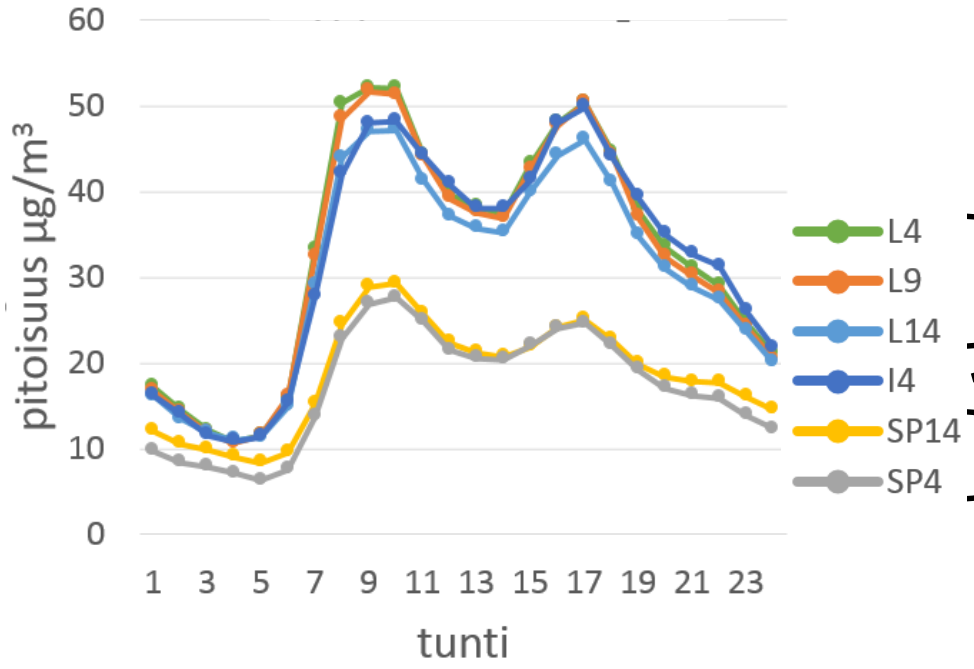


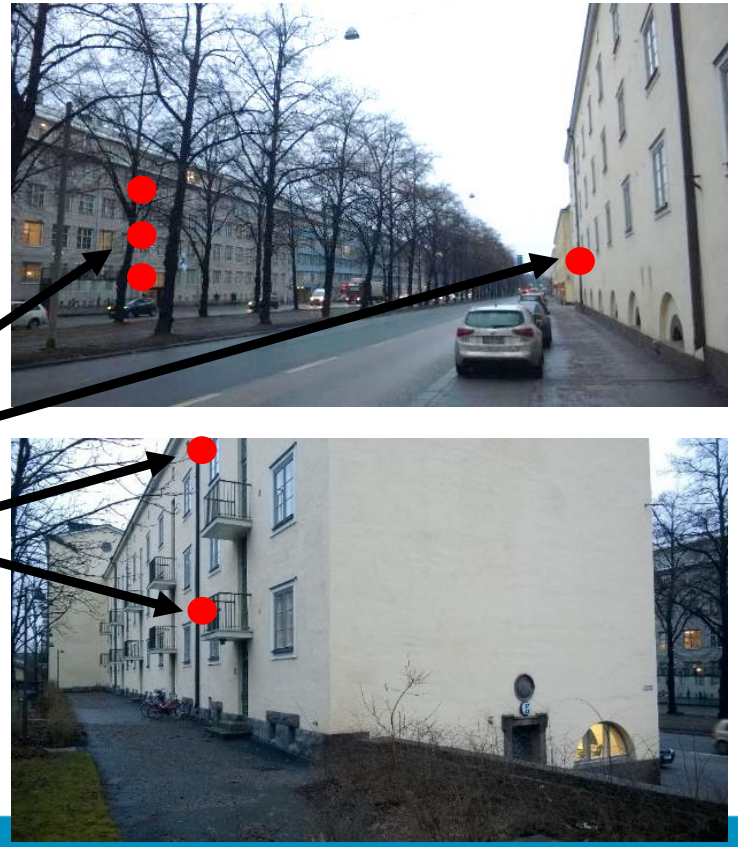
Diurnal NO_2 profiles during weekdays
09-12 / 2017

Images and data courtesy:
City of Helsinki,
Helsinki Regional Environmental Services Authority HSY

Preliminary results

- Height has relatively little effect on concentration
- Backyard concentrations low, but still clearly affected by traffic





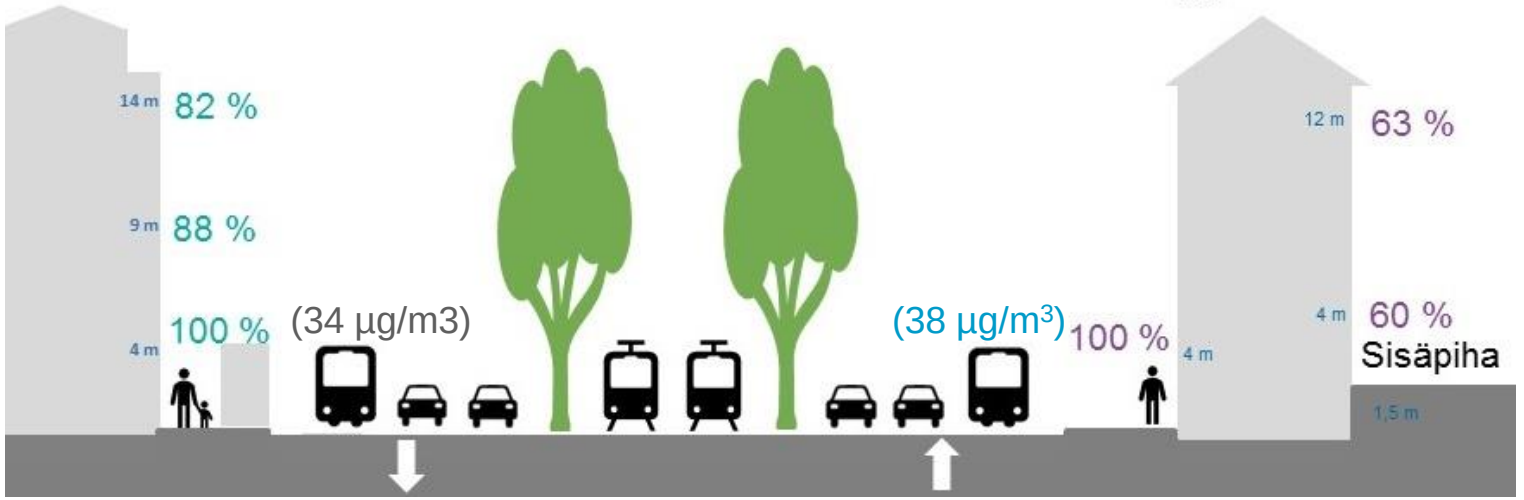
Time series analysis yields concentration gradients

5-11 months of data in different locations

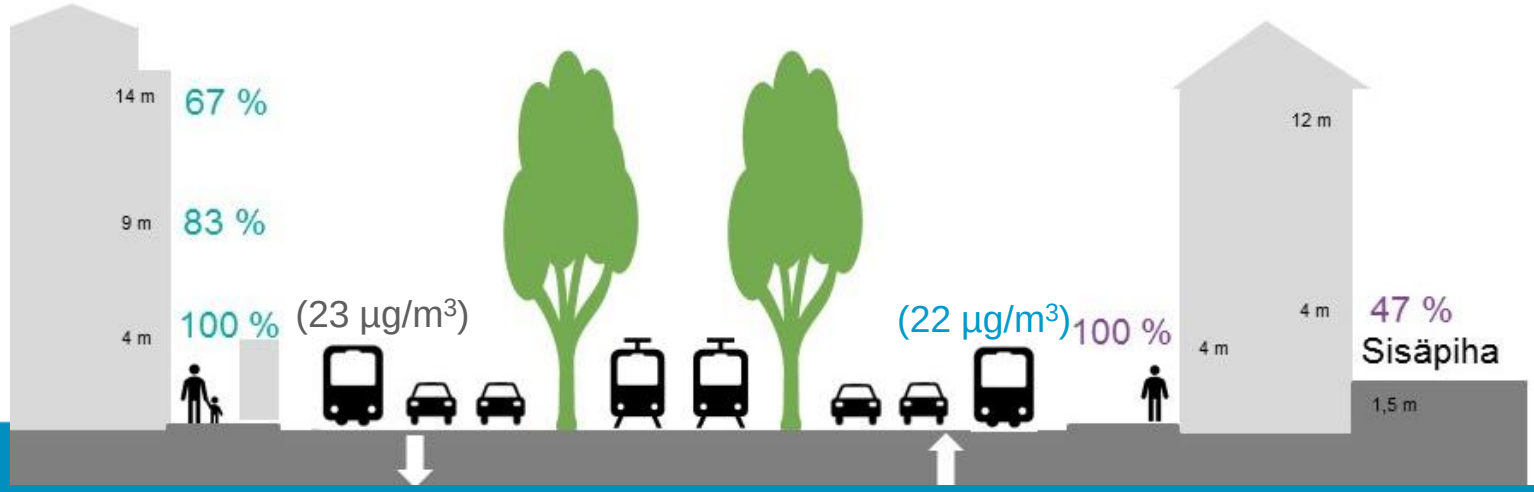
Images and data courtesy:
City of Helsinki,
Helsinki Regional Environmental Services Authority HSY

Preliminary results

NO_2 gradients



PM_{10} gradients



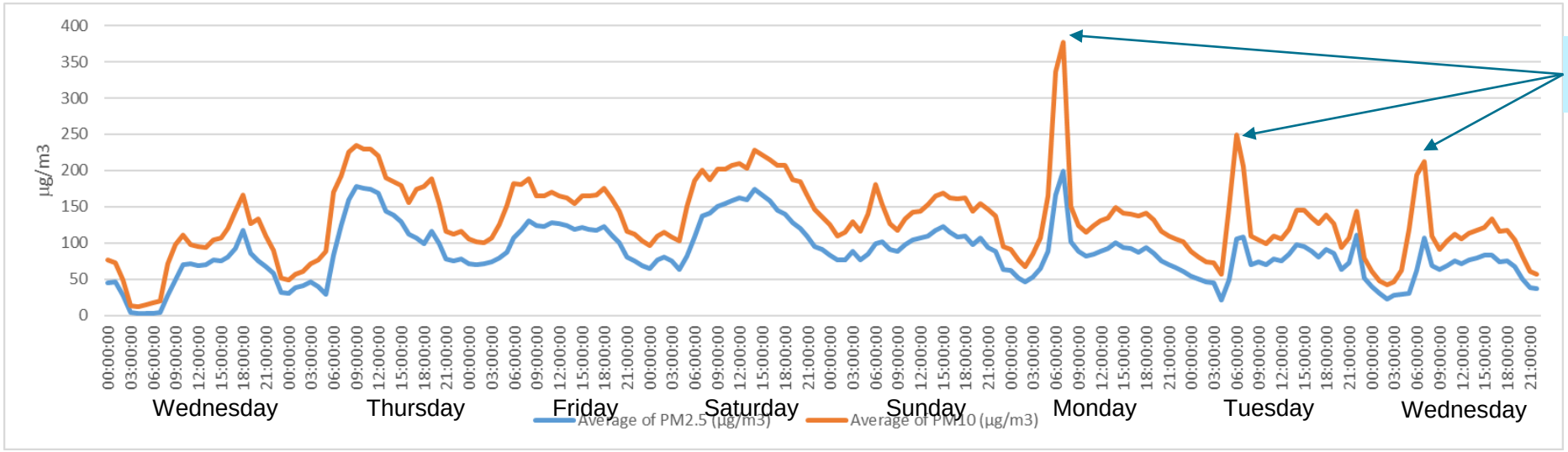
Nairobi air quality + weather monitoring

Case: Compact sensors supporting AQ monitoring in developing countries

- One environmental station with AQT420 and WXT536 set up at KMD headquarters, Nairobi
- Results from 25 days of operation
  - Daily and hourly averages for all the parameters
- Weather conditions, normal
  - Temperature between +10 to +27C
  - Humidity between 22 to 93 %RH
  - Light winds daily 0.5 to 2 m/s
  - Light precipitation event during night of 3-4.1.

Diurnal patterns Nairobi

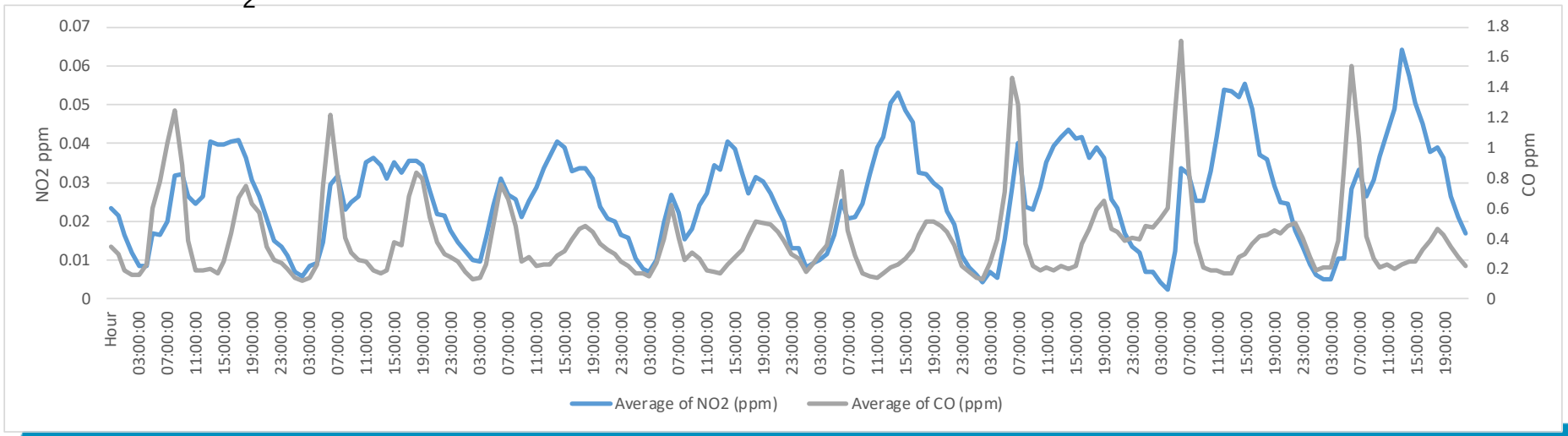
$PM_{2.5}$ and PM_{10}



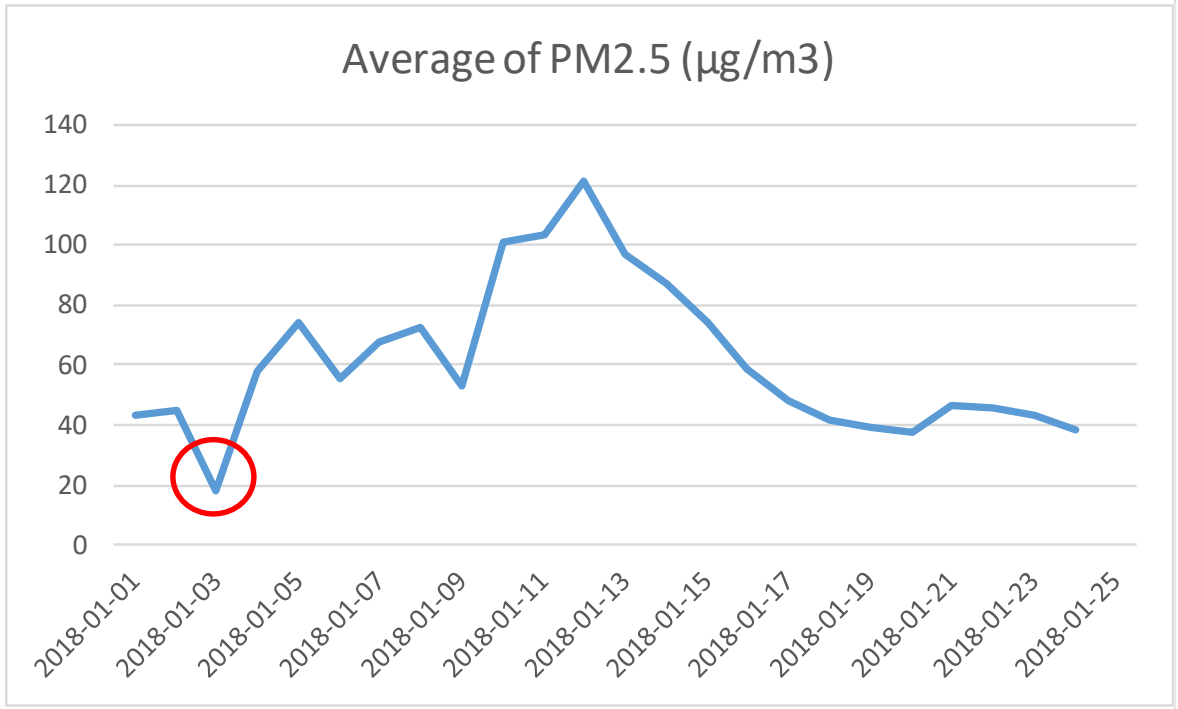
morning rush hour peaks, especially Monday

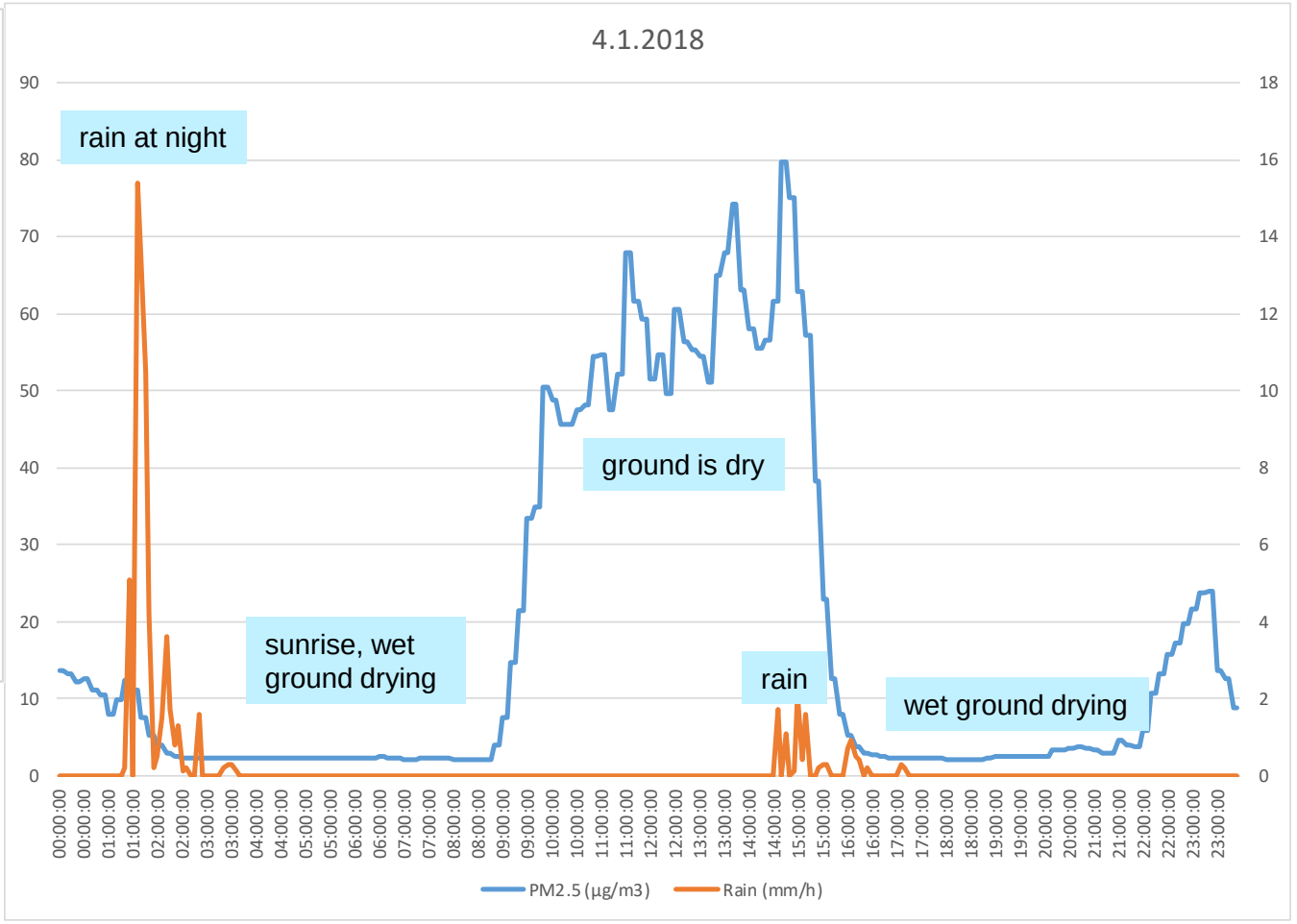
PM2.5 levels in good agreement with previous studies

CO and NO_2



Low $PM_{2.5}$ levels on 4.1.2018





Conclusions

- Compact sensors may find many uses in local air quality management thanks to their
  - Compact size
  - Easy installation
  - Low cost, making monitoring network expansion to new areas possible
- Examples of sensor usage have been presented for
  - Community monitoring and outreach
  - Support for mitigation activities
  - Urban source apportionment
  - Urban planning support
  - Use in developing countries
- When used in the context of high resolution AQ modelling, a whole new set of applications opens up for the high resolution air quality data

Acknowledgements

The active and open communication and collaboration in the HAQT (Helsinki Metropolitan Air Quality testbed) project is acknowledged!

Financial support from Helsinki – Uusimaa Regional council is gratefully acknowledged

Special thanks to the Air Protection Group personnel from Helsinki Region Environmental Services Authority HSY: Jarkko Niemi, Taneli Mäkelä, Anssi Julkunen, Maria Myllynen for valuable discussions, network management and data manipulation and analysis