HAQT deliverable 4-1: Evaluation of current Kumpula AQ observations and benefits from two close-by supersites in Kumpula and in Mäkelänkatu

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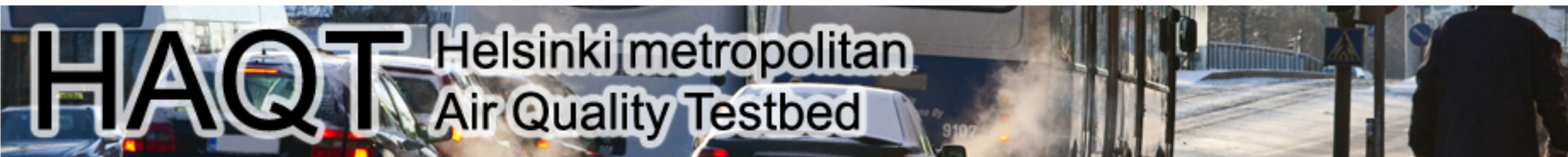
30/04/2018



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1. Introduction

A holistic scientific understanding on the atmospheric phenomena associated with air quality as a whole, as well as on the connection between air quality and climate, is lacking at the moment (Fiore et al., 2012; Fuzzi et al., 2015; Kulmala 2015). Together with emission reductions, the key way to get forward is to make long-term, continuous and comprehensive observations on aerosol particles (mass, number, chemical composition, optical properties), trace gases (SO_2, NO_x, CO, Volatile Organic Compounds, sulfuric acid, HONO, HNO_3, NH_3, etc.) and atmospheric oxidants (O_3, HO_x, RO_x, NO_3, Criegee intermediates etc.) as well as greenhouse gases (Kulmala et al., 2015). With a network of such observation stations (Hari et al. 2016), we will be able to understand the interactions and feedbacks associated with the urban pollution mixture and, ultimately, be ready to make targeted strategies for the pollution control (Kulmala, 2018).

As examples of the complex interactions and feedbacks in heavily-polluted environments, we have shown, based on the measurements performed at SORPES station in Nanjing (Ding et al. 2013a), that lowering NOx concentrations tends to increase ozone and secondary particle concentrations in summertime and that poor air quality decreases daily surface temperatures and is able to change precipitation patterns on the regional scale (Ding et al., 2013b). Recent advances in our theoretical understanding have made it possible to explain how enhanced pollution decreases atmospheric turbulence and mixing, reducing the boundary layer height and causing further enhancement of pollution levels (Petäjä et al., 2016). To take into account these interconnections and feedbacks, comprehensive observations are required.

In the Helsinki metropolitan area, air quality observations are performed in 11 locations by Helsinki Region Environmental Services Authority (HSY). A particular supersite measurement station is located in Mäkelänkatu street canyon in Helsinki (Kaski et al., 2017). In addition, extensive air quality observations by the University of Helsinki and Finnish Meteorological Institute (FMI) are performed at the Station for Measuring Ecosystem-Atmosphere Relations (SMEAR) III (Järvi et al. 2009) operated in Kumpula, Helsinki. The distance between SMEAR III and Mäkelänkatu supersite stations is 900 meters. The measurements of SMEAR III station and Mäkelänkatu supersite were started in 2007 and 2015, respectively.

The aim of this report is to 1) describe the current observation capacity of SMEAR III station in Kumpula and HSY observation site in Mäkelänkatu, and 2) explore the potential and benefits arising from the data from these two observation sites.

2. Description of observation capacity

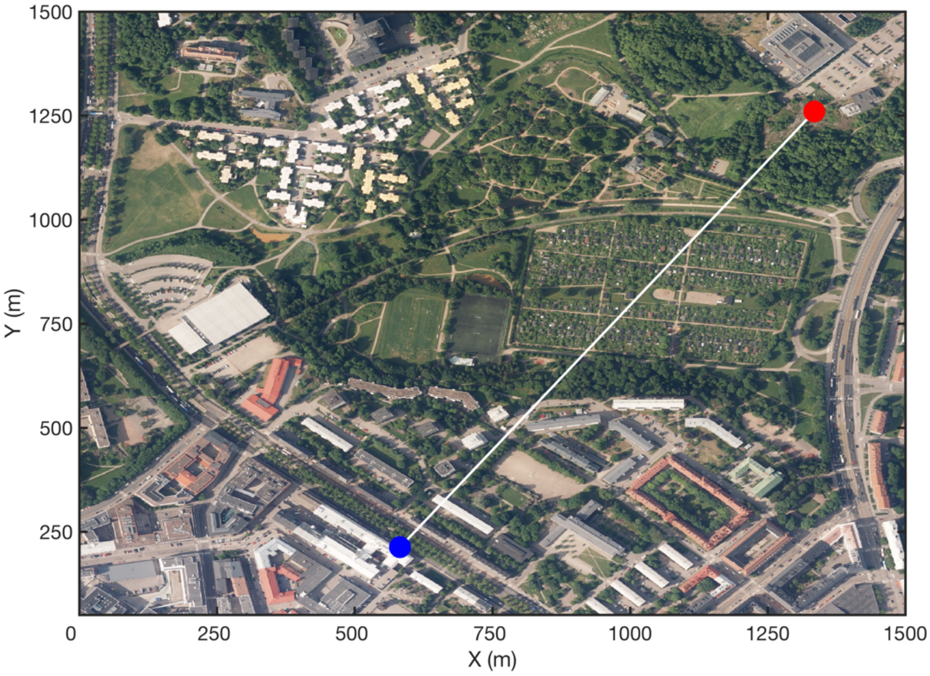

Figure 1. Map of the observation sites, with red point indicating the SMEAR III station and blue point the Mäkelänkatu supersite. The distance between the sites is ca. 900 m. (Figure from Pääkaupunkiseudun ortokuva, 2017)

2.1 SMEAR III station in Kumpula

The SMEAR III station is one of four SMEAR stations in Finland. The acronym SMEAR stands for Station for Measuring Ecosystem-Atmosphere Relations and the stations measure how the momentum, energy and matter are exchanged between the different ecosystems/surfaces and the atmosphere in different types of environments. One of the main aims of the SMEAR stations is to conduct versatile and continuous long-term measurements on different atmospheric properties, such as the physical and chemical properties of aerosol particles, gas concentrations and meteorological parameters.

The station was established in Kumpula, Helsinki, in the autumn of 2004 to study how different air pollutants and meteorological variables behave in different types of urban environments. The station is divided between three different locations. The main station in Kumpula is located 5 km northeast of the city center (60° 12´ N, 24° 58´ E, 26 m.a.s.l.) and it is classified as an urban background site. The other two locations for the SMEAR III station (so called satellite stations) are in Viikki and in the city center (Nordbo et al. 2013, Kurppa et al. 2015; Riikonen et al. 2016). Multidisciplinary ecosystem research is conducted at the Viikki site and the city center measurements represent urban conditions. The University of Helsinki runs the SMEAR III station in cooperation with the Finnish Meteorological Institute (FMI). GHG concentrations calibrated by WMO CCL traceable calibration gas cylinders were measured on the roof level of the FMI building (30m above ground level)

In this report we concentrate only on the main station in Kumpula, where the most versatile measurements covering air quality, turbulent fluxes and meteorology are conducted. Most of the measurements concentrate to a 31 meters tall measurement tower and container located next to the tower. The area around them is rather heterogeneous and the surrounding area is divided into three different types of sectors according to their land use (see Fig. 2): built (320° – 40°), road (40° – 180°) and vegetation (180° – 320°) (Järvi *et al.*, 2009). The built sector consists of the university campus area and of a family housing area located behind the campus. In the road section the pollutants and greenhouse gas emissions are dominated by a busy road (Hämeentie), where the traffic count is around 40 000 vehicles per workday (statistics from the City of Helsinki). The station is located 150 m away from the road and the area between the station and the road is covered with deciduous forest. In the vegetation sector, there is the University Botanical garden, an allotment garden and a lightly forested park. A more detailed description on the surrounding area can be found in Järvi *et al*. (2009) and Karsisto *et al.* (2015).

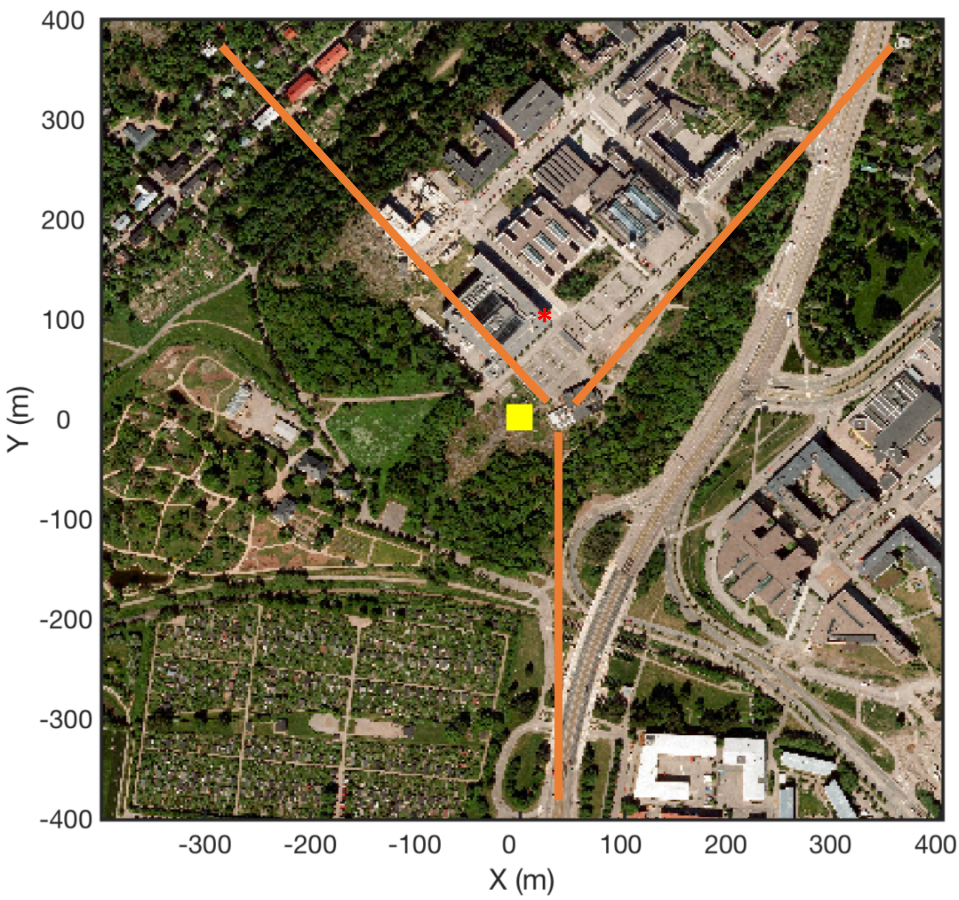

Figure 2: Map of SMEAR III site, with different land-use sectors indicated: built sector to the North, road sector to the East and vegetation sector to the West (see text for more details). Red star denotes the location of GHG measurements. (Figure from Pääkaupunkiseudun ortokuva, 2017)

The measurement capacity in Kumpula includes aerosol number size distribution from 1 nm to 10 µm, particle mass, comprehensive trace gas characterization, optical properties (absorption/black carbon, scattering), aerosol chemical composition, turbulent flux measurements (aerosols, CO_2, H_2O), urban meteorology and boundary layer characterization with Lidar. The full list of different measurements is given in Table 1. The flux measurements are conducted on top of the measurement tower, which is shown in Figure 3. Most of the measurements of particulate matter and trace gases are conducted in the container, which can be seen immediately on the left side of the tower in Figure 3. The meteorological variables are obtained from the tower, from close to the station (observations by FMI, fence of the small measurement area visible in lower left corner of Figure 3) and from the roof of the Physicum-building (200 m North-North-East from the station).

Figure 3: Picture of the SMEAR III station towards South-East.

Table 3. List of the measurements conducted at the SMEAR III station in Kumpula. The measurements are still ongoing if the ending time is not marked.

Measured quantity	**Instrument**	**Availability of data**
Particle size distribution in the range of 3 – 950 nm	Twin-DMPS (Twin Differential Mobility Particle Sizer, Aalto *et al*. 2001)	2004 –
Particle size distribution in the range of 0.5 – 20 µm	APS (Aerodynamic Particle Sizer, TSI 3321)	2005 – 2009, 2018 –
Particle size distribution in the range of >1 nm	PSM (Particle Size Magnifier, Airmodus A11)	2007 –
Ion size distribution in the range of 1-40 nm	NAIS (Neutral air ion spectrometer, Airel)	2016 –
Aerosol mass concentration	TEOM (Tampered Element Oscillating Microbolance, model 1405-D)	2018 –
Aerosol absorption on 637 nm and the concentration of black carbon	MAAP (Multi Angle Absorption Photometer, Thermo Scientific 5012)	2015 –
Aerosol chemistry	ACSM (Aerosol Chemical Speciation Monitor, Aerosodyne Research)	In campaigns with variable length since 2012

Flux measurements of various components (CO_2, friction velocity, H_2O, sensible and latent heat fluxes)		Eddy Covariance technique (combined 3-D ultrasonic anemometer and gas analyzers)	2005 –
CO_2, CH4 concentrations calibrated on WMO-GAW scale		Picarro (G1301, G2401) at the roof of Dynamicum	2010 –
Trace gases	NO_x and O_3	TEI42S and TEI49	2005 –
	SO_2 and CO	Horiba APMA 370 and Horiba, APSA 360	2006 –
Meteorological variables (T, p, RH, W_s, W_d,…)		Various instruments	2004 –
Weather radar		Vaisala Weather Radar prototype	2004 –
Vertical profile of aerosols in the boundary layer		Lidar (HALO Photonics Streamline)	In shorter campaigns since 2011
NO_2, SO_2, CO, O_3, T, RH, p, PM2.5 and PM10		AQT (Air Quality Transmitter, Vaisala AQT420)	2016 –
$PM_{2.5}$ and PM_{10}		FMI PAS sensor	2017 –
LDSA (Lung Deposited Surface Area of particles)		Pegasor AQ™ Urban	2017 –
NO_2, $PM_{2.5}$ and PM_{10}		Clarity sensors	2018 –
Aerosol scattering coefficient		Nephelometer (Ecotech Aurora 3000)	2017 –

2.2 Mäkelänkatu supersite

The Mäkelänkatu supersite measurement station is located in a busy street canyon (street address Mäkelänkatu 50, Helsinki). The street consists of six lanes, two rows of trees, two tramlines and two pavements, resulting in a total width of 42 m (Fig. 4). The height of buildings are about 17 meters. The traffic volume of Mäkelänkatu street was 28 000 vehicles per workday in 2016 (statistics from the City of Helsinki). The proportion of heavy duty vehicles was 11% and speed limit 50 km/h. Supersite station is operated by the HSY. Several long-term measurements are conducted in research projects in co-operation with Finnish research organizations and companies (Table 1).

Figure 4: Picture of Mäkelänkatu supersite station.

Table 1. All the measurements conducted at the Mäkelänkatu supersite station. The measurements are still ongoing if the ending time is not marked.

Measured quantity	**Instrument**	**Availability of data**	**Main operator**
Particle size distribution in the range of 6 – 800 nm	DMPS (Differential Mobility Particle Sizer; Airmodus CPC A20 with Vienna type DMA)	2015 –	HSY
Particle size distribution in the range of 0.5 – 20 µm	APS (Aerodynamic Particle Sizer, TSI 3321)	Selected periods in 2017 and 2018	FMI
Particle size distribution in the range of >1 nm	PSM (Particle Size Magnifier; Airmodus PSM A10 with Airmodus CPC A20)	2015 –	TUT
Aerosol mass concentration (PM10 and PM2.5)	TEOM (Tampered Element Oscillating Microbolance, model 1405)	2015 –	HSY
Aerosol absorption on 637 nm and the concentration of black carbon	MAAP (Multi Angle Absorption Photometer, Thermo Scientific 5012)	2015 –	HSY
Particle scattering coefficient	Nephelometer (TSI 3563)	2016 –	FMI
Aerosol absorption (7 wavelengths) and the concentration of black carbon	Aethalometer (Magee Scientific, mode AE33)	2016 –	Metropolia
Aerosol chemistry	ACSM (Aerosol Chemical Speciation Monitor, Aerodyne Research)	2015 -	FMI
PAH concentrations	Monthly mean concentrations from PM10 filters samples	2015 -	HSY
VOC concentrations	Monthly mean concentrations (passive samplers)	2015 -	HSY
CO_2 concentration	LICOR model LI-7000	2016 –	HSY
NO_x and O_3 concentration	Horiba APNA 370 and Horiba APOA-370 (or Thermo Electron Model 49C/49i)	2015 –	HSY
CO concentration	Horiba APMA-360	2017 –	HSY
Meteorological variables (T, p, RH, W_s, W_d,)	Vaisala WXT 520	2015 –	HSY
Remote Surface State Sensor (Road weather)	Vaisala DSC211	2015 –	HSY
NO_2, SO_2, CO, O_3, T, RH, p, PM2.5 and PM10	AQT (Air Quality Transmitter, Vaisala AQT420)	2017 –	Vaisala
LDSA (Lung Deposited Surface Area of particles)	Pegasor AQ™ Urban	2016 –	Pegasor

3. Potential benefits from SMEAR III and Mäkelänkatu sites

The close proximity (900 m) of the two observation sites in the urban setting provides a very good setup for detailed scientific work related to air quality. By combining the data from both sites, the following studies are under work or planned:

1) Aerosol number size distribution dynamics in the urban environment
2) Analysis of emission of nanoparticles and clusters from traffic, connecting this to co-emitted CO_2 with observations
3) Sources and chemical composition fine particles in the urban environment
4) Trend and spatio-temporal variation of black carbon
5) Analysis of local boundary layer dynamics and air quality parameters
6) Uptake of CO_2 by the near-by parks based on eddy covariance and contrasting this to the emissions from the traffic
7) Connecting data sources to regional AQ model (ENFUSER) to capture diurnal and seasonal patterns of AQ parameters and their spatial variability
8) Development of proxy variables

Concurrent measurements on aerosol chemical composition and aerosol number size distributions at these sites will provide novel insights into the diurnal and seasonal variability of aerosol emissions and the transport and transformation of air pollution in the urban environment. Based on the combination of the comprehensive observations, integrating data analysis and modeling work we will be able to provide recommendations for optimized air quality improvements.

As few examples of the on-going analysis on the comparison of the data from these two sites, we present below Figures A1 and A2.

In Fig. A1 the time series of black carbon (BC) is presented for the Kumpula and Mäkelänkatu measurement stations. Even though the concentration of the BC seems to decrease in the Mäkenlänkatu station, there was no statistically significant trend observed. Since the measurements in Kumpula have been discontinuous, it was not possible to determine a trend for Kumpula BC concentration. However, statistically significant trends were determined for two other measurement sites in Helsinki run by the HSY. The negative trends were determined for the Mannerheimintie (-8 %/year) and Kallio measurement sites, which have been measuring since 2011 and 2012 respectively. Mannerheimintie station is also located next to a busy road like the station in Mäkelänkatu. The Kallio site is also classified as an urban background station like the station in Kumpula. The trends were about -8 and -7 % per year, respectively.

The diurnal variations of the BC from the Mäkelänkatu and Kumpula sites, presented in Fig. A2, show how much the BC concentration varies during the day. Mäkelänkatu, being a busy road canyon, represents the variation mostly due to the traffic. In the urban background station, Kumpula, the morning rush hour is detected but the rush hour in the evening is not that obvious, which is probably due to more efficient mixing in the boundary layer in the afternoon. In both of the stations, the difference between the weekdays and weekends is also clear, because of the smaller amount of traffic during weekends.

4. Summary

The long-term development of the observation sites at Kumpula (SMEAR III) and Mäkelänkatu (HSY supersite) provide novel insights into urban air quality and their spatio-temporal variability.

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Annex 1: Exemplary figures on the data

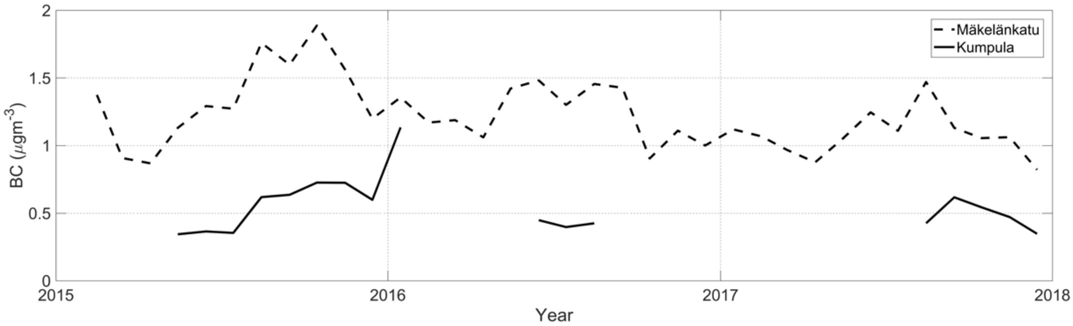

Figure A1. The time series of BC concentration for Mäkelänkatu and Kumpula measurement stations. The values presented here are monthly means. Monthly mean was calculated if there was more than 14 days of valid data.

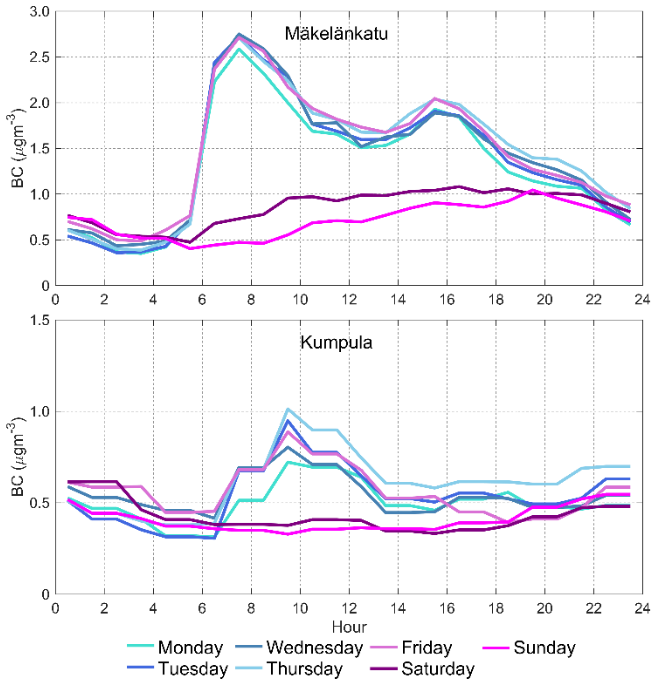

Figure A2. The hourly medians of BC concentration for different measurement stations. The different colored lines describe different weekdays. Note that the limits of the y-axis differ for the stations.