Deliverable D25 (D4.4)

Nanoparticle concentration levels in the pilot studies

RI-URBANS

Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban & Industrial AreaS (GA n. 101036245)

By

UHEL, UoB & CSIC

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Deliverable D25 (D4.4): Nanoparticle concentration levels in pilot cities

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Comments	This report describes the nanoparticle size distribution measurements with a mobility particle size spectrometer (MPSS) at the selected pilot cities (Helsinki of Finland, Barcelona of Spain and Birmingham of UK) and initial results (size distributions and nanoparticle concentration levels) obtained so far in the project.

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Table of Contents

1. About this document

WP4 of RI-URBANS deals with the demonstration of Service Tools (STs) in 5 major pilots, which are a number of cities measuring specific advanced air parameters with the STs previously devised and supplied by WP1-3.

T4.2 is one of these pilot cases focusing on the demonstration of Near-real time (NRT) provision of nanoparticle-particle snubber size distributions (PNSD) data. This task provides PNSD from the urban supersites and ensures their compliance with PNSD CEN and ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure) requirements to foster harmonization. The instrument setups will be checked with regards to their performance, sampling protocols, best practices, sample drying, instrument maintenance, size classification and standard operating procedures based on the operational ACTRIS standardized NRT data provision tool for sub-micron PNSD developed in Copernicus project CAMS-21a. We apply this ST to the existing urban PNSD systems from different cities in Europe, harmonizing measurements and providing NRT-data (D25, D4.4) to the end-users enabling contrasting data analysis between city environments and background sites. The NRT-PNSD-STs is deployed at the Barcelona and Birmingham urban background supersites and Helsinki road-side and urban background supersites.

This D25 (D4.4) of the RI-URBANS project describes the nanoparticle size distribution measurements with a mobility particle size spectrometer (MPSS) at the selected pilot cities (Helsinki of Finland, Barcelona of Spain and Birmingham of UK) and initial results (PNSD levels) obtained so far in the project.

This is a public document that will be distributed to all RI-URBANS partners for their use and submitted to European Commission as a RI-URBANS deliverable D25 (D4.4). This document can be downloaded at https://riurbans.eu/work-package-4/#deliverables-wp4.

2. Measurements and data coverage

2.1 Helsinki, Finland

PNSD measurements started at the SMEAR-3 (Station for Measuring Ecosystem–Atmosphere Relations) urban background station (located on the Kumpula campus of the University of Helsinki, Helsinki, Finland) in 2004. The inverted PNSD from the beginning of Jan 2022 until the end of Jul 2023 is shown in Figure 1. The MPSS at this station is a Twin-DMPS system consisting of a Hauke-type DMA (differential mobility analyser) with a TSI Model 3756 CPC and a second Hauke-type DMA with a TSI Model 3772 CPC (condensation particle counter). The sample is dried using a Permapure drier. The total diameter range for the instrument is 3 – 820 nm and one of the two parallel DMPS systems follows the ACTRIS measurement protocols for sampling with a diameter range of 10 – 800 nm. Sample flows are checked on a weekly basis and relative humidity is kept at below 40%. Note, gaps in obtained data are related to instrument breakdowns.

The PNSD measurements at Mäkelänkatu street canyon site (Helsinki urban area) were started in 2015 with a size range of 6-800 nm with 26 size bins. The inverted PNSD from beginning of Jan 2022 until beginning of Oct 2023 is shown in Figure 2. Note, on 31/8/2022 the measurement range and number of bins was extended to 6-820 nm with 28 size bins. The MPSS at this station is a DMPS system consisting of a Vienna-type DMA with an Airmodus A20 CPC and the sample air is dried with a Topas silica-gel dryer. The system also measures samples with 10 – 800 nm size range following ACTRIS standards. Sample flows are checked on a weekly basis. University of Helsinki performs a

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yearly maintenance for the instrument. This includes e.g., cleaning the DMA, voltage check, maintenance, and calibration of the CPC and finally, size calibration of the entire instrument and comparison with University of Helsinki DMPS.

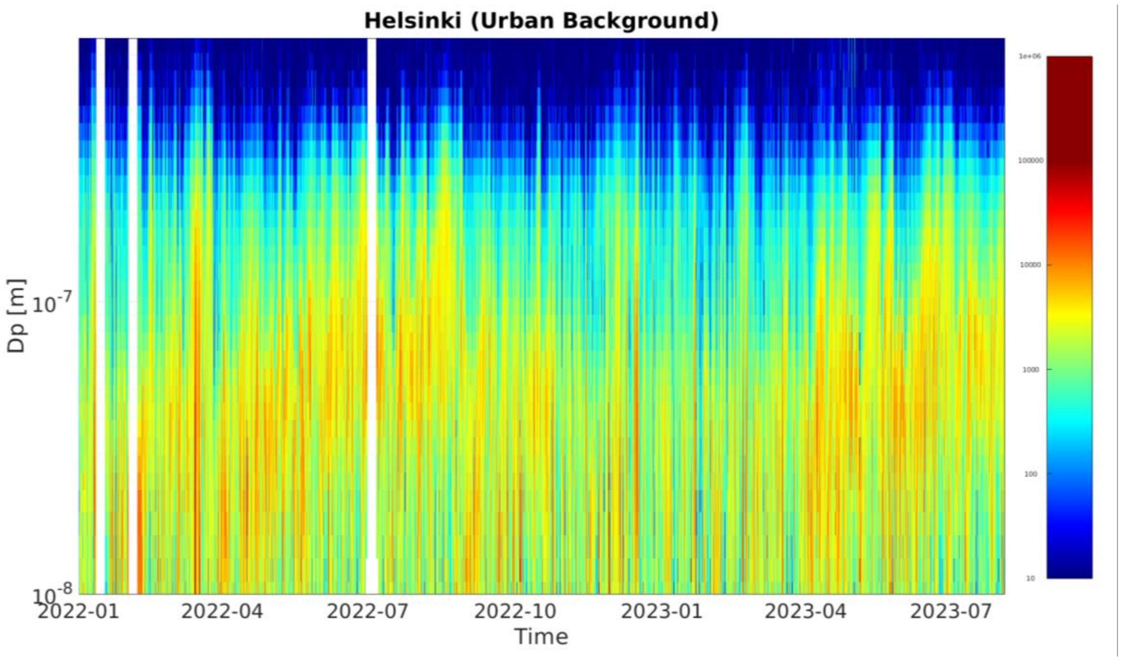

Figure 1. *Time-series of the particle number size distribution between 10 and 800 nm from the Helsinki urban background site (SMEAR-3) from 01/01/2022 to 31/07/2023.*

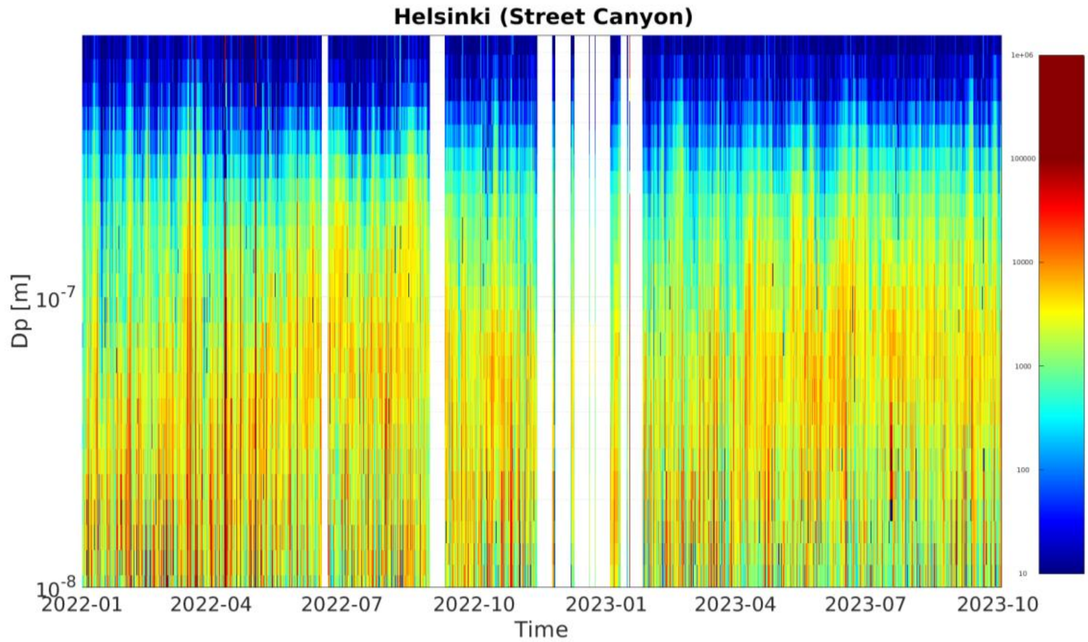

Figure 2. *Time-series of particle number size distribution between 10 and 800 nm from the Mäkelänkatu street canyon site (Helsinki urban area) from 01/01/2022 to 01/10/2023.*

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2.2. Barcelona, Spain

The measurements of PNSD started in 2013 at the Barcelona urban background station. The MPSS comprised of a TSI 3080 classifier, operated with a TSI 3081 DMA and a TSI 3772 CPC. The MPSS was operated in conjunction with a stand-alone TSI 3785/3787 WCPC (water CPC). These instruments were connected to a sampling system consisting of a PM_{10} inlet, with a total flow rate of 38.3 l/min.

We have recently upgraded the MPSS system and stand-alone CPC to ACTRIS and CEN standards. The Barcelona site is now running a TSI3938 SMPS comprising of a TSI 3082 classifier, a wide range DMA TSI 3083 (10-800 nm) and a TSI 3750 CPC. The classifier was upgraded to be able to work with positive voltage. The stand-alone CPC was replaced with a TSI 3750 CPC, and this instrument was also upgraded to meet ACTRIS standards. Therefore, the lower detection efficiency diameter (DP50) has been changed from 7 to 10 nm. All these instruments have recently been calibrated following ACTRIS standards at the December 2022 Calibration Workshop held at TROPOS, Germany.

We have recently added a UCPC (TSI 3756) for parallel particle concentration measurements from 3 nm.

From the end of the year 2020 we use a BGI $PM_{2.5}$ inlet, with a total flow rate of 5 l/min, exclusively dedicated to ultrafine particle (UFP) measurements. The aerosol is dried before the splitter using a TROPOS Nafion dryer operated with a compressor and a membrane dryer, trying to reach lower than 40% RH.

The TSI software was upgraded to the latest TSI AIM11.5 (monitoring version). In addition, we have been exporting data continuously from our station using the CAMS system. The near-real-time (NRT) upgraded software was installed and set up on the logging computer at the December 2022 Calibration Workshop held at TROPOS, Germany. This software is being checked at the moment due to compatibility problems with the TSI software upgraded versions.

The breaks in the data along the measurement period are related to the calibration workshop in Leipzig (end of 2022), electricity power cuts, problems with the computer or instrument breakdown (pumps, CPCs, etc.). The inverted PNSD from Barcelona urban background site is shown in Figure 3.

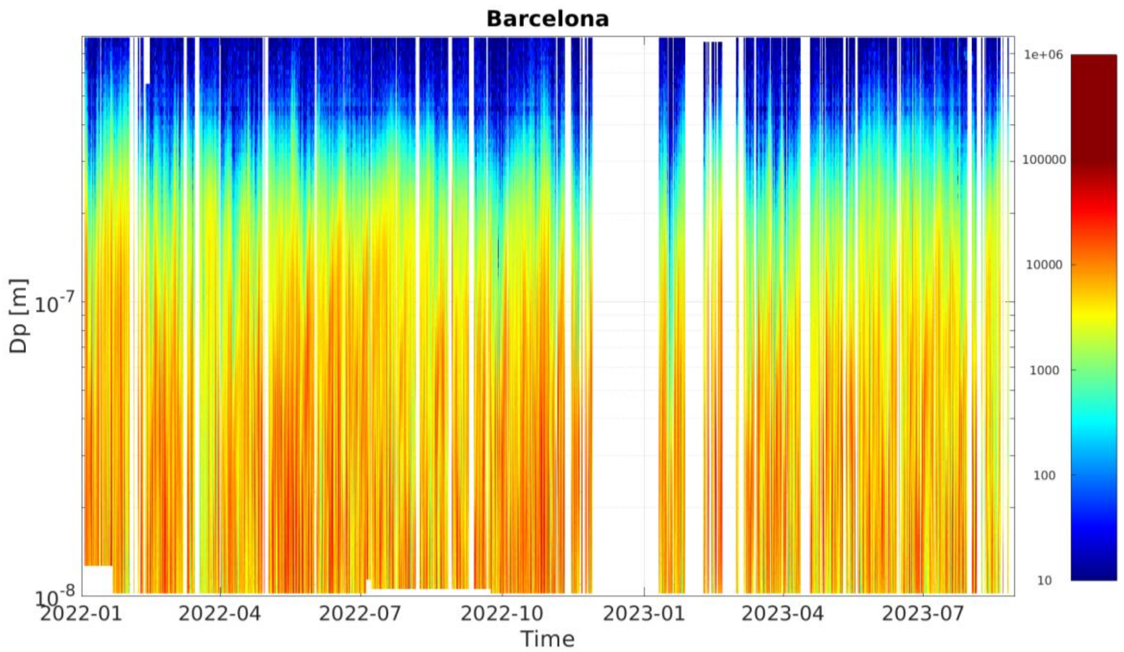

Figure 3. *Time-series of particle number size distribution between 10 and 800 nm from the Barcelona urban background site from 01/01/2022 to 30/09/2023.*

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2.3 Birmingham, UK

The MPSS operated in Birmingham comprises of a TSI SMPS system comprising of a TSI3082 classifier (upgraded to be able to work with positive voltage), operating with a wide range DMA TSI 3083 (10-800 nm) and a TSI 3750 CPC with DP50 at 10 nm. The aerosol sample was sampled and dried using a TSI 3750200 system. In this, the aerosol enters through a PM_{10} head, passes through an optional $PM_{2.5}$ cyclone, and is then dried to relative humidity of less than 40%. An isokinetic flow splitter distributes particles to one or multiple attached instruments (CPC and/or SMPS). The breaks in the data were either due instrument calibration workshops or due to instrument break down due to instrument breakdown, e.g., pump breakdown, computer issues, power cuts, etc. The instrument system was upgraded to meet the ACTRIS standards towards the end of August 2022 although the initial measurements were started in 2019. The inverted PNSD from the Birmingham measurement site is shown in Figure 4. Inversion was carried out using TSI AIM11.5 (monitoring version). In addition, the NRT software was installed and set up on the logging computer at the December 2022 Calibration Workshop held at TROPOS, Germany.

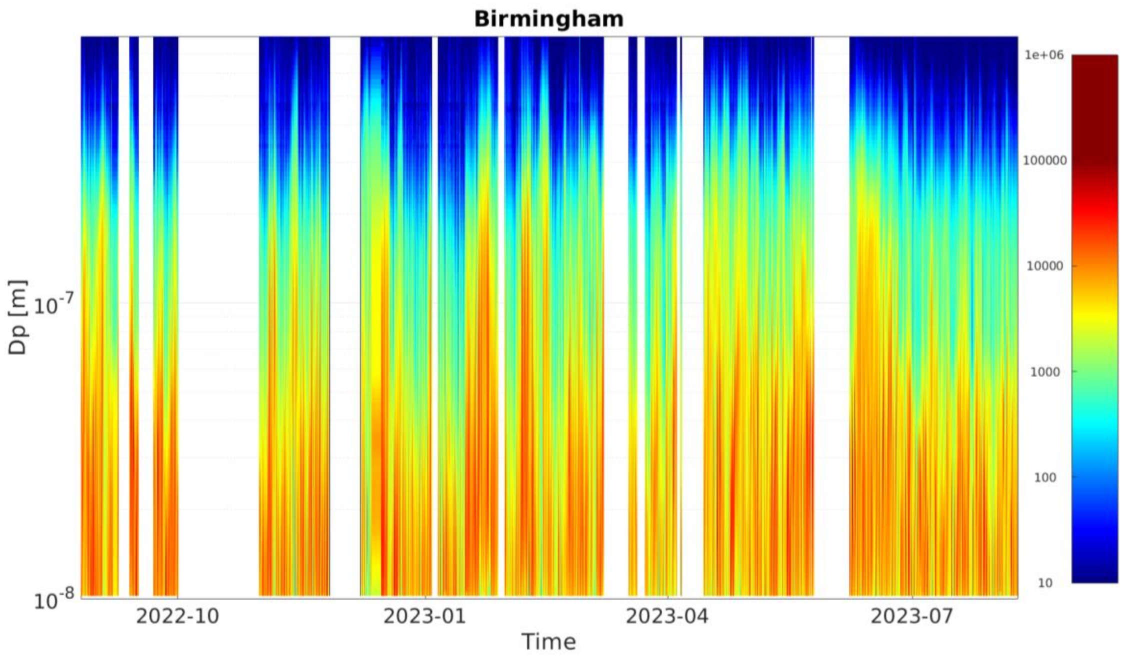

Figure 4. *Time-series of particle number size distribution between 10 and 800 nm from the Birmingham urban background site from 01/08/2022 to 30/09/ 2023.*

3. Comparison of the concentration levels in the pilot cities

Nanoparticle concentrations in the above mentioned three pilot cities were calculated for the total concentration (10 – 800 nm) as well as for the nucleation (10 – 25 nm), Aitken (25 – 100 nm) and accumulation (100 – 800 nm) modes. The five-point summary statistics for each site is presented in Table 1. The Helsinki urban background (UB) site has the lowest concentrations across all modes, with median total concentration at 2950 cm-3 and even the largest concentrations (95 percentile) not exceeding 10 000 cm^{-3}. The Mäkelänkatu street canyon (SC) site in the Helsinki urban area has the second lowest median concentrations across all modes except accumulation mode. It has also the largest variance, with largest total concentrations exceeding or comparable to Birmingham and Barcelona sites, and the smallest total concentrations comparable to the Helsinki UB site. The Birmingham site has the second largest median total concentrations as well as nucleation and Aitken mode concentrations, but the accumulation mode concentrations are typically lower or comparable than the Helsinki SC site. The Barcelona site has the largest overall median concentrations across all modes.

Figure 5 demonstrates the distribution of total concentrations at each of the measurement sites during selected periods of 2022-2023 (wherever data was available). The data follows a lognormal distribution, as expected for particle number concentration (PNC). It is clearly seen from the shown distributions that the Barcelona site has the highest average PNCs, followed by Birmingham, Helsinki (SC), and Helsinki (UB) sites.

Table 1. *Five-point summary statistics of the particle number concentrations from 3 selected pilot cities for the total concentration as well as for the nucleation, Aitken and accumulation modes.*

		5th percentile (cm^{-3})	25th percentile (cm^{-3})	Median (cm^{-3})	75th percentile (cm^{-3})	95th percentile (cm^{-3})
Helsinki (UB)						
10 – 800 nm	Total	830	1930	2950	4370	7890
10 – 25 nm	Nucleation mode	164	450	858	1640	4050
25 – 100 nm	Aitken mode	331	848	1470	2320	4290
100 – 800 nm	Accumulation mode	83	177	317	626	1300
Helsinki (SC)						
10 – 800 nm	Total	1340	2760	4170	6310	12100
10 – 25 nm	Nucleation mode	204	597	1300	3000	11700
25 – 100 nm	Aitken mode	535	1250	2000	3090	6380
100 – 800 nm	Accumulation mode	142	313	557	960	1760
Birmingham						
10 – 800 nm	Total	1760	3920	6080	9280	16700
10 – 25 nm	Nucleation mode	737	1720	2870	4510	8740
25 – 100 nm	Aitken mode	576	1350	2290	3890	7980
100 – 800 nm	Accumulation mode	131	273	470	885	2010
Barcelona						
10 – 800 nm	Total	3060	4860	7190	11000	19700
10 – 25 nm	Nucleation mode	699	1510	2680	4840	11300
25 – 100 nm	Aitken mode	1270	2150	3210	5030	9740
100 – 800 nm	Accumulation mode	306	681	1010	1390	2300

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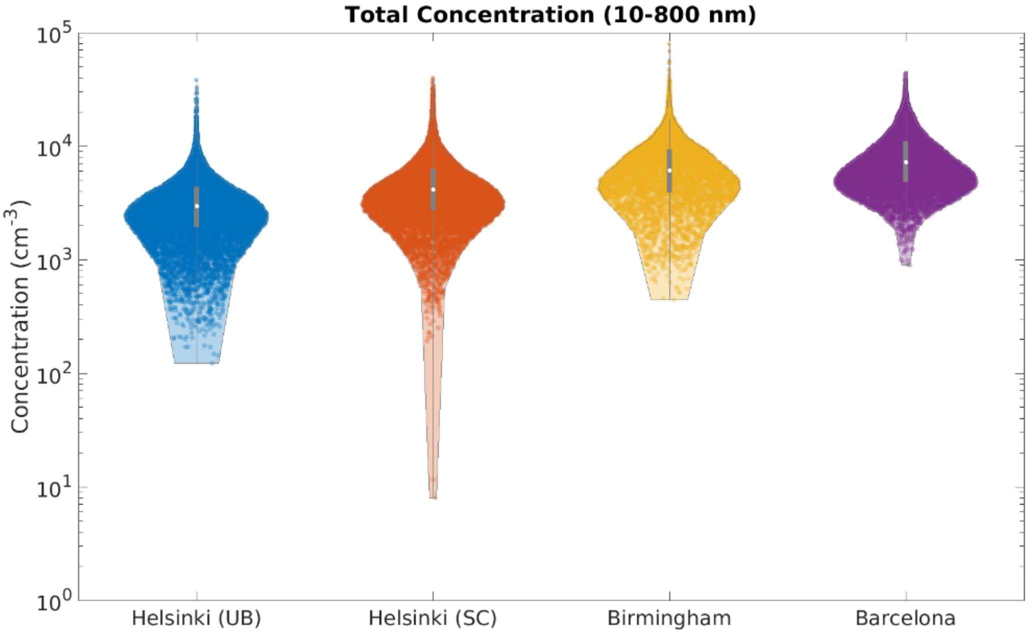

Figure 5. *Violin plots of the total particle number concentration between 10 and 800 nm from each of the pilot sites demonstrating the variability in total concentration of fine particles.*

The effect of human activities is particularly visible in the median diurnal cycles for each season (as seen in Figure 6). A peak in total PNC can be observed in each of the pilot cities around 7 am of local standard time. This peak is typically associated with morning traffic rush hour, and it is often seen in urban measurements. A noontime peak is observed in each of the sites other than Helsinki (SC). These midday peaks are typically associated with photochemistry and secondary particles formed though new particle formation processes. This is supported by the fact that the midday peak is much stronger in spring and summer compared to autumn and winter periods. Furthermore, a third local maximum is observed in Birmingham and Barcelona around 20 pm. This could be related to evening traffic and/or shallowing of the atmospheric boundary layer due to the formation of the shallow stable layer around sunset, which can increase pollutant concentrations.

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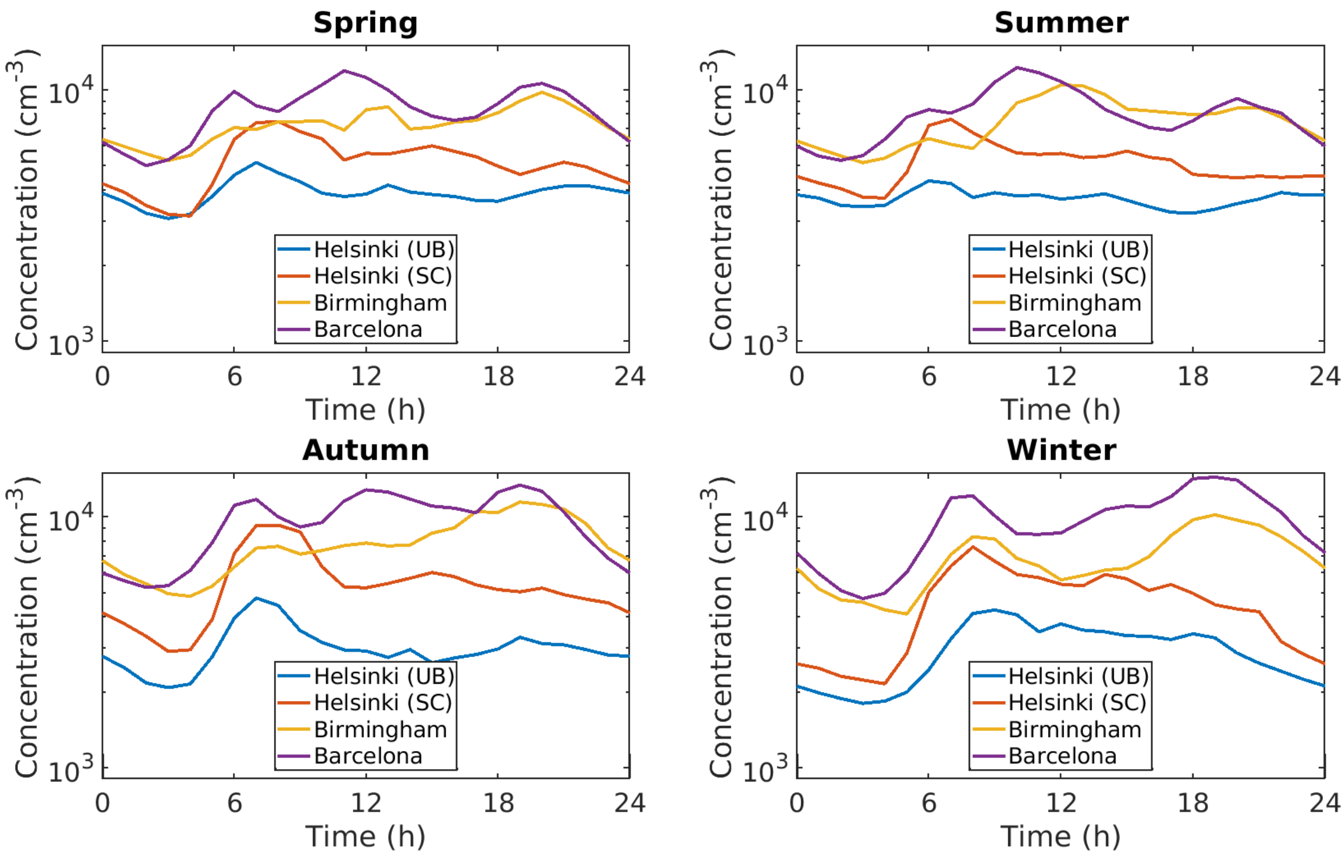

Figure 6. *The diurnal variation (by seasons) for total particle number concentration between 10 and 800 nm in each of the pilot cities. Spring (M,A,M) in the top left, summer (J,J,A) in the top right, autumn (S,O,N) in the bottom left, and winter (D,J,F) in the bottom right.*

4. Conclusions

Measurements of particle number size distribution, PNSD, between 10-800 nm are ongoing in all of the RI-URBANS pilot cities and the near-real-time data delivery has been started.

The first analysis of the number concentrations and size distributions based on measurements from years of 2022-2023 revealed common features between all of these urban locations, but also some differences in the concentration levels and diurnal variation related to the unique location of each site. The results are in general consistent with earlier analyses of particle size distributions in urban sites (e.g., Trechera et al. 2023). The harmonization of measurement protocols and instrumentation within RI-URBANS and ACTRIS will make future comparison studies more straightforward.

5. Further work

The measurements on the aerosol number concentrations and aerosol number size distributions in the pilot cities will continue as their operation and maintenance is connected to the long-term functions of the institutes. The data will be delivered in Near Real Time and the involved WP 4 teams will tackle the problems and challenges regarding instrument failures, data collection and data flow issues as they appear. The expertise and lessons learned gathered in Task 4.2 will be conveyed to WP5 for upscaling and inclusion of new cities and environments providing harmonized aerosol number concentrations and aerosol number size distribution data.

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The consolidated summary of Task 4.2 is provided in Deliverable D26 (D4.5), which summarizes the nanoparticle aerosol pilots, sustainability, associated benefits for Air Quality Monitoring Networks (AQMNs) and AQ policy.

6. References

Trechera, P., Garcia-Marlès, M., Reche, C., Pérez, N., Savadkoohi, M., Beddows, D., Salma, I., Vörösmarty, M., Casans, A., Casquero-Vera, J.A., Hueglin, C., Marchand, N., Chazeau, B., Gille, G., Kalkavouras, P., Mihalopoulos, N., Ondracek, J., Zikova, N., Niemi, J.V., Manninen, H.E., Green, D.C., Tremper, A.H., Norman, M., Vratolis, S., Eleftheriadis, K., Gómez-Moreno, F.J., Alonzo-Blanco, E., Gerwig, H., Wiedensohler, A., Weinhold, K., Merkel, M., Bastian, S., Petit, J.-E., Favez, O., Crumeyrolle, S., Ferlay, N., Dos Santos, S.M., Putaud, J.-P., Timonen, H., Lampilahti, J., Asbach, C., Wolf, C., Kaminski, H., Altug, H., Hoffmann, B., Rich, D.Q., Pandolfi, M., Harrison, R.M., Hopke, P.K., Petäjä, T., Alastuey, A. and Querol, X. (2023) Phenomenology of ultrafine particle concentrations and size distribution across urban Europe, Environ. Int. 172, 107744, https://doi.org/10.1016/j.envint.2023.107744

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