NPL National Physical Laboratory

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AIRBORNE PARTICLE CONCENTRATIONS, PARTICLE NUMBERS AND BLACK CARBON IN THE UNITED KINGDOM - ANNUAL REPORT 2024

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Airborne Particle Concentrations, Particle Numbers and Black Carbon in the United Kingdom - Annual report 2024

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EXECUTIVE SUMMARY

The National Physical Laboratory (NPL) is contracted to manage the UK Particle Concentrations and Numbers (PCN) and Black Carbon (BC) Network. The PCN&BC Network measures and reports concentrations and chemical composition of particles in ambient air across the UK, with a focus on $PM_{2.5}$ (particulate matter with an aerodynamic diameter < 2.5 µm).

This report was prepared by NPL and the Environmental Research Group at Imperial College London as part of the PCN&BC Network contract. The contract is managed by the Environment Agency on behalf of the Department for the Environment, Food and Rural Affairs and the Devolved Administrations: the Scottish Government, the Welsh Government, and the Department of Agriculture, Environment and Rural Affairs in Northern Ireland (DAERA).

This 2024 annual report contains:

- A summary of the Network structure, its operation, and quality procedures.
- Descriptions of the instruments used on the Network.
- The data capture recorded for each instrument.
- Time series plots of all ratified Network data in 2024.

And, where applicable:

- Plots of the diurnal, weekly, and monthly variations in ratified Network data in 2024.
- Plots of the long-term trends in ratified Network data.
- Comparisons between pollutants measured by the Network.
- Activities associated with the UK $PM_{2.5}$ monitoring expansion programme (MEP), to provide additional particulate matter (PM) speciation data to enhance the measurement evidence base associated with the $PM_{2.5}$ targets from the Environmental Targets (Fine Particulate Matter) (England) Regulations 2023[1].

In 2024, the Network operated at 27 UK monitoring sites with a mixture of site classifications: rural background, urban background, and urban roadside. The number of sites where each instrument was deployed is shown in Table 1.

Table 1 - Summary of analytes and instruments across the PCN&BC Network in 2024.

Analyte	Instrument(s)	Interval	Sites
Particle number concentrations in $PM_{2.5}$	Condensation particle counter (CPC)	Hourly	3
Particle size distribution in the range 10 – 1000 nm mobility diameter	Scanning mobility particle sizer (SMPS)	15 min	4
Mass concentrations of ammonium, nitrate, sulfate, and organic compounds in $PM_{2.5}$ or PM_1*	Aerosol Chemical Speciation Monitor (ACSM)	Hourly	3
40 elements in $PM_{2.5}$ and PM_{10}*	X-ray fluorescence instrument (XRF)	Hourly	2
Mass concentrations of organic carbon and elemental carbon (OC/EC) in $PM_{2.5}$	Ambient air sampler and thermal/optical carbon analyser	Weekly or daily	4
Mass concentrations of BC and ultraviolet particulate matter (UVPM) in $PM_{2.5}$	Aethalometer	Hourly	26

* PM_1 and PM_{10} are particulate matter with an aerodynamic diameter < 1 µm and <10 µm respectively.

Fully ratified data from the Network can be downloaded from the Defra UK AIR website[2].

Some notable features from the Network data in 2024 are:

- The annual average particle number concentrations for 2024 at London Marylebone Road, London Honor Oak Park and Chilbolton Observatory showed a decrease from the 2023 annual average. The particle number concentrations at all three sites continue to remain lower than the pre-pandemic values, supporting the hypothesis that there has been a sustained reduction in local emissions compared to the 2019 annual average values.

- The peak shift in the SMPS particle size distributions, seen in the 2023 data at London Marylebone Road and London Honor Oak Park, has been observed again in the 2024 data at those sites and also at Chilbolton Observatory. This supports the hypothesis that the peak shift is due to a change in monitoring equipment and not a change in the ambient aerosol[3].

- The two months of data from the Horley SMPS were not submitted to the DDU. Due to the complexities of data ratification, these will be ratified and submitted with next year's data, when more data is available.

- The annual average chemical mass concentration of secondary particles (nitrate, sulfate, and ammonium) and organic mass measured at London Marylebone Road and London Honor Oak Park remained similar to those in 2023.

- Of the 40 elements measured *via* XRF at London Honor Oak Park and London Marylebone Road, the elements that reported the highest annual average concentrations in PM_{10} were chlorine, iron, and sulfur at both sites.

- The annual average mass concentrations of OC, EC and total carbon (TC) mass concentrations for all sites decreased relative to 2023. The most significant decrease was observed at rural background sites (up to 26 %) and at London sites (by around 20 %), except for EC mass concentration at London Marylebone Road, which decreased by 7 % relative to 2023.

- Annual average mass concentrations of BC and UVPM were measured at all 26 sites in 2024, and both were broadly lower than in 2023 (excluding 12 sites opened in 2024, where this comparison is not possible). The largest decrease in UVPM was observed at the Cardiff Centre site from 0.11 µg m^{-3} in 2023 to 0.01 µg m^{-3} in 2024, whereas the largest decrease in BC was observed at the London Marylebone Road site from 0.93 µg m^{-3} in 2023 to 0.73 µg m^{-3} in 2024.

- The significant downward trend in measured BC mass concentrations, observed at all the long-running sites in the Network (apart from Strabane 2) since 2009, continued into 2024. The relative decrease in BC measured at London Marylebone Road remains much larger than that at other sites, whereas the highest concentration of BC among roadside sites is measured at Birmingham A4540 Roadside.

- Out of the 12 new BC Network sites opened in 2024, only two sites (Blackburn Audley Park and Derby Stockbrook Park) were operational for whole year. Thus, comparison with other sites should be treated with caution, e.g. the highest annual mean of BC mass concentration was obtained for Bradford Shipley Airedale Road site (1.87 µg m^{-3}) opened in December 2024, which is not representative of whole year.

The annual average data capture across all Network sites was:

- 70 % for particle number concentration measurements
- 78 % for particle size distribution measurements
- 95 % for aerosol mass and chemical composition measurements
- 87 % for elemental measurements
- 99 % for OC/EC measurements
- 90 % for BC measurements

1 INTRODUCTION

1.1 OVERVIEW

The National Physical Laboratory (NPL) is contracted to manage the UK Particle Concentrations and Numbers (PCN) and Black Carbon (BC) Network. This report was prepared by NPL and the Environmental Research Group (ERG) at Imperial College London as part of the PCN&BC Network contract with the Environment Agency, on behalf of the Department for Environment, Food and Rural Affairs (Defra) and the Devolved Administrations: the Welsh Government; the Northern Ireland Executive, Department of Agriculture, Environment and Rural Affairs in Northern Ireland (DAERA); and the Scottish Government.

The PCN&BC Network measures and reports concentrations and chemical composition of particles in ambient air across the UK, with a focus on $PM_{2.5}$ (particulate matter with an aerodynamic diameter < 2.5 µm). A summary of the analytes measured and the types of instruments used on the PCN&BC Network is given in Table 2. The PCN&BC Network sites are located to maximise the benefit of the measurements made, in terms of drawing conclusions about the concentrations and chemical composition of particles in ambient air at these locations and understanding more fully the sources of pollution. Details of site locations are given in section 2.2.

Table 2 - Summary of analytes measured and instruments used on the PCN&BC Network in 2024.

Analyte(s)	Instrument(s)
Particle number concentrations in $PM_{2.5}$	Condensation particle counter (CPC)
Particle size distribution in the range 10 – 1000 nm mobility diameter	Scanning mobility particle sizer (SMPS)
Mass concentrations of ammonium, nitrate, sulfate, and organic compounds in $PM_{2.5}$ or PM_1*	Aerosol chemical speciation monitor (ACSM)
40 elements in $PM_{2.5}$ and PM_{10}* (Ag, Al, As, Ba, Bi, Br, Ca, Cd, Ce, Cl, Co, Cr, Cu, Fe, Ga, Ge, Hg, In, K, La, Mn, Mo, Ni, P, Pb, Pd, Pt, S, Sb, Se, Si, Sn, Sr, Te, Ti, Tl, V, Y, Zn, and Zr)	X-ray fluorescence instrument (XRF)
Mass concentrations of organic carbon and elemental carbon (OC/EC) in $PM_{2.5}$	Ambient air sampler and thermal/optical carbon analyser
Mass concentrations of BC and ultraviolet particulate matter (UVPM) in $PM_{2.5}$	Aethalometer

* PM_1 and PM_{10} are particulate matter with an aerodynamic diameter < 1 µm and < 10 µm respectively.

This 2024 annual report contains:

- A summary of the Network structure, its operation, and quality procedures.
- Descriptions of the instruments used on the Network.
- The data capture recorded for each instrument.
- Time series plots of all ratified Network data in 2024.
- And, where applicable:
    - Plots of the diurnal, weekly, and monthly variations in ratified Network data in 2024.
    - Plots of the long-term trends in ratified Network data.
    - Comparisons between pollutants measured by the Network.
    - Activities associated with the UK $PM_{2.5}$ monitoring expansion programme, to provide additional particulate matter (PM) speciation data to enhance the measurement evidence base associated with the $PM_{2.5}$ targets from the Environmental Targets (Fine Particulate Matter) (England) Regulations 2023[1].

1.2 BACKGROUND

Prior to 2020, these data were reported in two separate annual reports, one for the PCN Network and one for the BC Network. As these two Networks are closely linked, they are now reported in one annual report to provide administrative cost savings to the Environment Agency and Defra.

The PCN Network began operation in November 2001. Since then, the number and location of sites, and monitoring methodologies have transitioned through several iterations. NPL, supported by ERG, have operated the PCN Network contract since 2005. In 2024, it comprised five sites (Auchencorth Moss, Chilbolton Observatory, Horley, London Marylebone Road, and London Honor Oak Park). Multiple instruments are operated at most sites under this Network, with the purpose of providing data to improve understanding of airborne PM, with a focus on $PM_{2.5}$ and monitoring compliance with limits set out in the UK's Air Quality Standards regulations (AQSR) 2010[4,5,6,7], and all associated amendments, which reference the EU Ambient Air Quality Directive 2008[8,9], and support objectives set out in the UK's Clean Air Strategy 2019[10] and Environmental Improvement Plan 2023[11].

The purpose of the BC Network is to continue a historical dataset on black smoke (which dates back to the 1920s) and monitor BC concentrations. NPL, supported by ERG, was awarded the contract to restructure and run this Network in September 2006. By the end of 2024, the BC Network comprised 26 sites (listed in Table 4).

Following the Environment Act 2021[12] and the new legally binding $PM_{2.5}$ targets published through the Environmental Targets (Fine Particulate Matter) (England) Regulations 2023[1], Defra requested an expansion of the PCN&BC Network to provide additional PM speciation data to enhance the measurement evidence base associated with the $PM_{2.5}$ environmental targets. This is referred to as the $PM_{2.5}$ monitoring expansion programme ($PM_{2.5}$ MEP) throughout this report. In 2024, the PCN&BC Network team were involved in various activities for expanding the Network.

2 NETWORK INFRASTRUCTURE AND OPERATION

2.1 OVERVIEW

In 2024, the PCN&BC Network was managed in the same way as the previous year; no sites were decommissioned, but several new sites were added as part of the $PM_{2.5}$ MEP. Further details are given in the sections below.

2.2 NETWORK SITES

At the start of 2024, the PCN&BC Network comprised 15 sites (three PCN&BC, one PCN-only, and 11 BC-only). By the end of 2024, there were 27 sites, including one new PCN-only site, and 11 new BC-only sites.

A map of all the sites is given in Figure 1. The list of PCN sites and instruments operating during 2024 is shown in Table 3. The site locations for the BC Network are given Table 4. Site details are available through Defra's UK AIR website[2].

The four sites that previously comprised the PCN Network (Auchencorth Moss, Chilbolton Observatory, London Marylebone Road, and London Honor Oak Park) are located to provide $PM_{2.5}$ OC/EC mass concentration data to assist in requirements of AQSR 2010[4,5,6,7] (and all associated amendments). They also allow the benefit of the measurements made to be maximised, both in terms of drawing conclusions about the concentrations and chemical composition of particles in ambient air at these locations and understanding more fully the key pollutant sources. A fifth site was incorporated into the PCN network in 2024: an SMPS was installed at the Horley site on 1 November 2024, in collaboration with the Local Authority, Reigate and Barnstead Borough Council, to provide additional data at the site near Gatwick airport.

The 14 sites that previously constituted the BC Network are located to target the measurement of traffic emissions of BC in urban areas, and of solid fuel and biomass burning emissions in Northern Ireland and Cardiff. Urban and traffic increments are targeted by combining an urban roadside (UR), an urban background (UB), and a rural background (RB) site across each conurbation. Chilbolton Observatory site is used as an RB site for both Birmingham and London. A list of these 14 BC sites is given below:

- **Glasgow urban area:** Glasgow High Street (UR); Glasgow Townhead (UB); Auchencorth Moss (RB)
- **Birmingham urban area**: Birmingham A4540 Roadside (UR); Birmingham Ladywood (UB); Chilbolton Observatory (RB)
- **London urban area**: London Marylebone Road (UR); London North Kensington (UB); Chilbolton Observatory (RB); Detling (RB)
- **Solid fuel use / domestic emissions in Northern Ireland and Cardiff:** Ballymena Ballykeel; Belfast Centre; Kilmakee Leisure Centre; Strabane 2; Cardiff Centre

Ten new Aethalometers (excluding London Teddington Bushy Park and London Honor Oak Park) were installed at sites in England during 2024 as part of the $PM_{2.5}$ MEP. Installation dates have been specified in Table 4.

The Aethalometer at London Honor Oak Park, previously funded by the Natural Environment Research Council (NERC) for the Observation System for Clean Air (OSCA) research project, became affiliated with the BC Network as of 1 November 2024.

A new Aethalometer was installed at London Teddington Bushy Park on 1 December 2024 as part of an equivalence measurement campaign associated with the $PM_{2.5}$ MEP.

Figure 1 - Map of monitoring sites comprising the PCN&BC Network during 2024. Key: orange = PCN&BC; black = BC; yellow = new PCN (SMPS only); blue = new BC; number = multiple sites within region.

Table 3 - List of sites comprising the PCN Network in 2024, including name, region, UK AIR ID, and type and frequency of measurements.

Site Name	Region	UK AIR ID	Site Type [1]	Particle number concentration in $PM_{2.5}$	Particle size distribution (mobility diameter range 10 – 1000 nm)	Aerosol mass and speciation	40 elements in $PM_{2.5}$ and PM_{10} [2]	OC/EC in $PM_{2.5}$
Auchencorth Moss	Scotland - Central	UKA00451	RB	-	-	-	-	Weekly
Chilbolton Observatory	England - Southeast	UKA00614	RB	Hourly	15-minute	Hourly, $PM_{2.5}$	-	Daily
Horley [3]	England - Southeast	UKA00511	SI	-	15-minute	-	-	-
London Marylebone Road	England - London	UKA00315	UT	Hourly	15-minute	Hourly, PM_1	Alternating hourly	Daily
London Honor Oak Park	England - London	UKA00656	UB	Hourly	15-minute	Hourly, $PM_{2.5}$	Alternating hourly	Daily

[1] Site Type: RB = Rural Background; UB = Urban Background; UT = Urban Traffic; IS = Suburban Industrial.
[2] The XRFs have a switching size fraction sampling inlet, measuring $PM_{2.5}$ and PM_{10} on alternate hours.
[3] New PCN site in 2024; particle size distribution measurements commenced at Horley on 1 November 2024.

Table 4 - List of sites comprising the hourly Aethalometer measurements on the BC Network in 2024, including name, region, UK AIR ID, site type, and installation date for new sites in 2024.

Site Name	Region	UK AIR ID	Site Type	Installation date for new sites in 2024
Auchencorth Moss	Scotland - Central	UKA00451	RB	-
Ballymena Ballykeel	Northern Ireland	UKA00503	UB	-
Barnsley Gawber	England - Yorkshire & Humberside	UKA00353	UB	15/04/2024
Belfast Centre	Northern Ireland	UKA00212	UB	-
Birmingham A4540 Roadside	England - West Midlands	UKA00626	UR	-
Birmingham Ladywood	England - West Midlands	UKA00655	UB	-
Blackburn Audley Park	England - North-west & Merseyside	UKA01025	UB	01/01/2024
Bradford Shipley Airedale Road	England - Yorkshire & Humberside	UKA01090	UT	01/12/2024
Cardiff Centre	Wales - South	UKA00217	UB	-
Chilbolton Observatory	England - South-east	UKA00614	RB	-
Derby Stockbrook	England - East Midlands	UKA01027	UB	01/01/2024
Detling	England - South-east	UKA00481	RB	-
Glasgow High Street	Scotland - Central	UKA00602	UR	-
Glasgow Townhead	Scotland - Central	UKA00576	UB	-
Glazebury	England - North-west & Merseyside	UKA00170	RB	14/04/2024

Site Name	Region	UK AIR ID	Site Type	Installation date for new sites in 2024
Kilmakee Leisure Centre	Northern Ireland	UKA00570	UB	-
Ladybower	England - East Midlands	UKA00171	RB	15/06/2024
London Honor Oak Park	England - London	UKA00656	UB	01/11/2024
London Marylebone Road	England - London	UKA00315	UR	-
London North Kensington	England - London	UKA00253	UB	-
London Teddington Bushy Park	England - Greater London	UKA00572	UB	01/12/2024
Newcastle Centre	England – North-east	UKA00213	UB	04/07/2024
Shrewsbury Underdale	England - West Midlands	UKA01055	UB	15/05/2024
St Osyth	England - Eastern	UKA00445	RB	16/04/2024
Strabane 2	Northern Ireland	UKA00393	UB	-
Wicken Fen	England - Eastern	UKA00362	RB	13/04/2024

2.3 NETWORK MANAGEMENT

The day-to-day operation of the PCN&BC Network is set up to mirror that of the Automatic Urban and Rural Network (AURN), which includes a central management and control unit (CMCU) and a quality assurance and quality control (QA/QC) unit. In 2024, NPL continued its role as the CMCU and QA/QC unit, with significant support from ERG.

CMCU activities include management of equipment, consumables, and health and safety; management of subcontractors such as local site operators (LSOs) and equipment support units (ESUs); collection and storage of data; reporting; and providing technical advice to the Environment Agency. QA/QC activities include ensuring adherence to the appropriate technical standards; training and auditing LSOs; managing equipment services and calibrations; and data ratification and submission to the data dissemination unit (DDU).

For CPC, SMPS, OC/EC, and Aethalometers, NPL perform the majority of the CMCU and QA/QC duties, with support from ERG, who are responsible for collecting and storing the CPC, SMPS, and BC data; and manage the ESU emergency callouts and scheduled services and calibration for Aethalometers. NPL have continued to undertake OC/EC analyses in-house, including associated QA/QC activities.

ERG have continued to undertake the majority of the CMCU and QA/QC activities for the ACSM and XRF equipment, with support from NPL.

Further details of the operation of the instruments on the Network are given in section 2.5 and section 3.

2.4 NOTABLE CHANGES AND ACTIVTIES

2.4.1 Overview

Further to the significant increase in the number of sites on the PCN&BC Network, there are a few other notable changes and activities detailed below.

2.4.2 Particle number concentration

The Network CPC at Birmingham Ladywood continued to not be operational during 2024. Discussions about preparing the site for installation of the equipment are currently on hold.

With regards to the calibration of Network CPCs, in 2024 a silver nanoparticle generator facility was set up at NPL ahead of the 2025 annual calibration round. In 2025, there will be two changes to the Network CPCs and their calibrations in order to align with the standard EN 16976:2024[13]: the “d50” size cut-off for the CPCs will be changed from 7 nm to 10 nm; and the linearity calibration will be carried out using silver aerosols (rather than soot). The CPC calibration checks relevant to the 2024 data were carried out using soot-like particles following the same method as previous years.

2.4.3 Particle size distribution

As part of the $PM_{2.5}$ MEP, the Environment Agency procured five new SMPSs (GRIMM, model 5416/5420-TR-CEN). These were delivered to and checked by NPL during 2024, ahead of installation at Horley and in preparation for installation at other new $PM_{2.5}$ MEP sites.

2.4.4 Aerosol mass speciation and composition

Following the delivery of two new Aerodyne time-of-flight (ToF)-ACSMs as part of the $PM_{2.5}$ MEP in 2023, the testing and commissioning were completed in ERG's laboratories during 2024.

Further to this, in order to support the increased number of ACSMs on the PCN Network, and in alignment with best practice and the recommendations of ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure), in 2024 the Environment Agency procured a portable, water-based CPC and X-ray source SMPS for the sole purpose of Network ACSM calibrations. This was received in December 2024 and was commissioned by ERG for use in 2025.

2.4.5 Elemental analysis

No notable changes were implemented in 2024.

2.4.6 OC/EC

No notable changes were implemented in 2024.

2.4.7 BC and UVPM

In addition to the 11 $PM_{2.5}$ MEP sites added in 2024, preparations were also made for further sites to be added in future years.

2.5 INSTRUMENTATION

2.5.1 Particle number concentration

Particle number concentrations are measured using a TSI 3750-CEN-7 CPC (Figure 2) or a 3772-CEN-7 CPC depending on the monitoring site.

The CPCs operate by drawing a continuous airborne particle sample through a heated saturator, in which butanol is vapourised and diffuses into the sample stream. The particle sample and butanol vapour pass into a cooled condenser, where the butanol vapour becomes supersaturated. Under these conditions, the butanol vapour condenses on the particles (down to 7 nm in size), growing quickly into larger droplets and enabling them to be counted optically *via* an optical detector. These CPCs are sensitive to particles from 7 nm up to a few micrometres in size and have a concentration measurement range from zero to 50,000 cm^{-3}.

The TSI 3772-CEN-7 CPC was developed to comply with the requirements of the Technical Specification CEN/TS 16976:2016[14], which has since been superseded by EN 16976:2024[13]. The CPC operates in single particle counting mode with continuous real-time coincidence correction for particle concentrations up to 50,000 cm^{-3}. EN 16976:2024[13] outlines the measurement criteria for the control of humidity in the sampled aerosol.

The TSI 3750200 sampling system (Figure 2), shared between the SMPS and stand-alone CPC, is operating at London Marylebone Road, London Honor Oak Park, and Chilbolton Observatory.

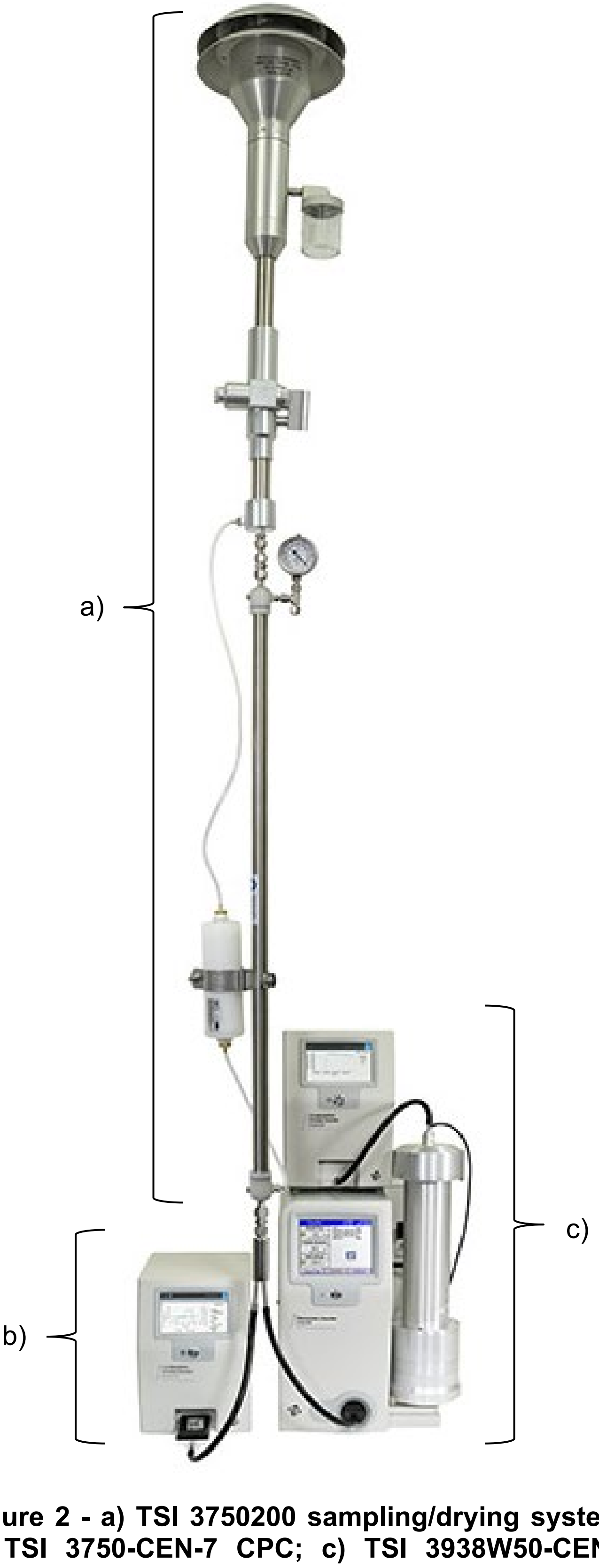


Figure 2 - a) TSI 3750200 sampling/drying system; b) TSI 3750-CEN-7 CPC; c) TSI 3938W50-CEN-7 SMPS, consisting of TSI 3750-CEN-7 CPC (top) and TSI 3082 electrostatic classifier and TSI 3083 DMA (bottom). Photograph courtesy of TSI Incorporated.

2.5.2 Particle size distribution

Particle size distributions were measured using a TSI 3938W50-CEN-7 SMPS (Figure 2) at all sites.

A TSI 3938W50-CEN-7 SMPS system was purchased and trialled in 2022 for use across the Network starting in 2023. This has a larger size range (nominally 10 - 800 nm) than the older TSI 3936 model (nominally 16 - 600 nm). It consists of a TSI 3750-CEN-7 CPC combined with a TSI 3082 electrostatic classifier and a new TSI 3083 Vienna-type differential mobility analyser (DMA). The charge neutraliser in the electrostatic classifier brings the airborne particles in the sample to a known steady state charge distribution and, at a specific voltage, the DMA allows particles of a specific electrical mobility (a quantity related to particle diameter) to pass to the CPC. By varying the operating voltage of the DMA, the size of particles sent to the CPC can be changed and a size distribution of particles in the sample is obtained. The new 3083 DMA is designed to cover a particle size range from 10 - 800 nm. This SMPS is compliant with Technical Specification CEN/TS 17434:2020[15].

Using the TSI 3938W50-CEN-7 SMPSs on the network, it is possible to reliably determine the total particle number concentration from the weighted combination of the concentrations from all SMPS size bins (TNC-SMPS). This therefore allows TNC-SMPS to be reported to UK AIR[2]. Previously, the only TNC data reported was for TNC-CPC (using data from the standalone CPCs). It should be noted that the EN 16976:2024[13] standard method for determining TNC stipulates the use of a CPC. Variations between TNC-SMPS and TNC-CPC may be due to the effects of differing proportions of sub-20 nm particles in the sample – this is currently under further investigation in CEN TC264 WG32 (Air quality - Determination of the particle number concentration).

Figure 2 shows the new configuration of the SMPS, CPC, and sampling system typically found at Network sites. Note that instead of a TSI 3772-CEN-7 CPC, a TSI 3750-CEN-7 CPC is shown in the figure.

A GRIMM 5420-TR-CEN (Figure 3) was installed at the Horley site in October 2024. The GRIMM 5420-TR-CEN is a 19” rack-mounted CPC, with an integrated DMA voltage controller, so it can be operated as fully equipped SMPS system. Integrated pumps allow for an aerosol inlet flow rate of 0.6 L min^{-1} and a sheath-air flow rate of 3.0 L min^{-1}. The GRIMM 5420-TR-CEN is fully compliant with CEN/TS 17434:2020.

Figure 3 - GRIMM 5420-TR-CEN SMPS system.
Photograph copyright of © DURAG GROUP.

2.5.3 Aerosol mass and chemical composition

The Aerodyne Research Inc. (ARI) quadrupole Q-ACSM measures in real-time the mass and chemical composition of non-refractory sub-micrometre aerosol particles in ambient air. It uses established aerosol mass spectroscopy technology to provide quantitative chemical composition measurements for particulate ammonium, nitrate, sulfate, and organics. It is designed for continuous monitoring of aerosol composition with long-term (many weeks) unattended operation.

The instrument operates by sampling air into a high vacuum system through a size-selective particle aerodynamic lens at either PM_1 or $PM_{2.5}$. The aerodynamic lens focuses particles into a narrow beam which is directed to a resistively heated particle vaporiser, typically operated at 600 °C, mounted inside the electron impact ionisation chamber of a mass spectrometer, where non-refractory components in/on the particle flash vaporise. The vaporised constituents are ionised by electron impact and subsequently analysed with a quadrupole mass spectrometer which reports aerosol mass spectra (< 200 amu). These spectra are used to extract the chemically speciated aerosol mass loadings. Figure 4 shows a schematic diagram of the set up.

A Q-ACSM instrument was installed at London North Kensington in 2013 with a standard vaporiser and PM_1 aerodynamic lens. It was moved to London Honor Oak Park in November 2018 and the standard vaporiser was changed to a capture vaporiser and the aerodynamic lens changed to $PM_{2.5}$. The Q-ACSM instrument installed at London Marylebone Road in July 2020 has a capture vaporiser and PM_1 aerodynamic lens. At Chilbolton Observatory, a Q-ACSM with a capture vaporiser and $PM_{2.5}$ aerodynamic lens was installed in April 2022.

Following the acquisition of two ToF (Time of Flight) ACSMs with standard vaporisers, due to be installed at two new rural supersites in 2025 and 2026 as part of the $PM_{2.5}$ MEP, the decision was made to harmonise vaporiser types across the Network and thereby mitigate fragmentation anomalies in the organic mass fraction and improve source apportionment. The ToF-ACSM is very similar to the Q-ACSM except it uses a time-of-flight detector with the additional advantages of increased mass resolution and lower detection limits. In 2023, all the capture vaporisers were replaced with standard vaporisers (London Marylebone Road and London Honor Oak Park in April 2023, and Chilbolton Observatory in December 2023).

Table 5 summarises the configuration of the three current Network ACSMs in 2024.

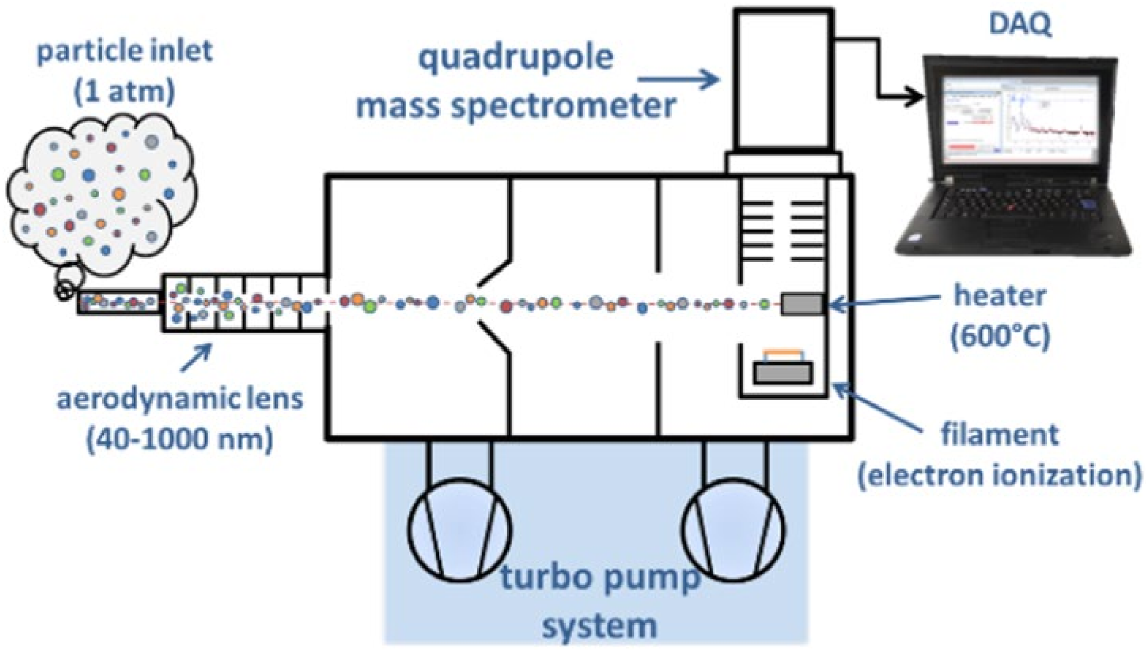


Figure 4 - ARI Q-ACSM schematic diagram (DAQ = Data acquisition [control]). Image copyright of Deutscher Wetterdienst (DWD).

Table 5 - Configuration of Network ACSM instruments in 2024

Site	Installation year	Vaporiser	Lens size fraction
Chilbolton Observatory	2022	Standard	$PM_{2.5}$
London Honor Oak Park	2018	Standard	$PM_{2.5}$
London Marylebone Road	2020	Standard	PM_1

2.5.4 Elemental analysis

The Cooper Environmental Xact® 625i XRF analyser (Figure 5) continuously and simultaneously measures the ambient concentration of 40 elements: Ag, Al, As, Ba, Bi, Br, Ca, Cd, Ce, Cl, Co, Cr, Cu, Fe, Ga, Ge, Hg, In, K, La, Mn, Mo, Ni, P, Pb, Pd, Pt, S, Sb, Se, Si, Sn, Sr, Te, Ti, Tl, V, Y, Zn, and Zr. The instrument collects PM samples on filter tape, which are then analysed by non-destructive XRF. The reel-to-reel filter tape sampling and subsequent analysis is engineered in a way that enables near real-time and continuous monitoring of the elemental composition of PM.

The instrument uses a flow rate of 16.7 L min^{-1} and draws air through a size selective inlet and across a filter tape. The sample that collects on the filter tape is automatically moved into the analysis area and analysed while the next sample is being collected. Measurements of one hour time resolution are achieved by conducting continuous sampling and analysis simultaneously. The sampling is only interrupted during tape advances and during internal QA/QC checks at midnight daily.

At both sites, the instrument uses a switching valve, which alternates between sampling PM_{10} and $PM_{2.5}$ on an hourly basis. The switching valve starts randomly on either PM_{10} or $PM_{2.5}$ after an intervention, such as a tape change. An analysis of the start times and the PM_{10} / $PM_{2.5}$ allocation has confirmed that no bias results from this approach.

Detailed information about the instrumentation can be found in Furger *et al.*, 2017[16] and Tremper *et al.*, 2018[17].

The XRF instrument installed at London Honor Oak Park was incorporated into the PCN Network in February 2022. At London Marylebone Road, the instrument was installed in March 2022 and was fully operational from April 2022.

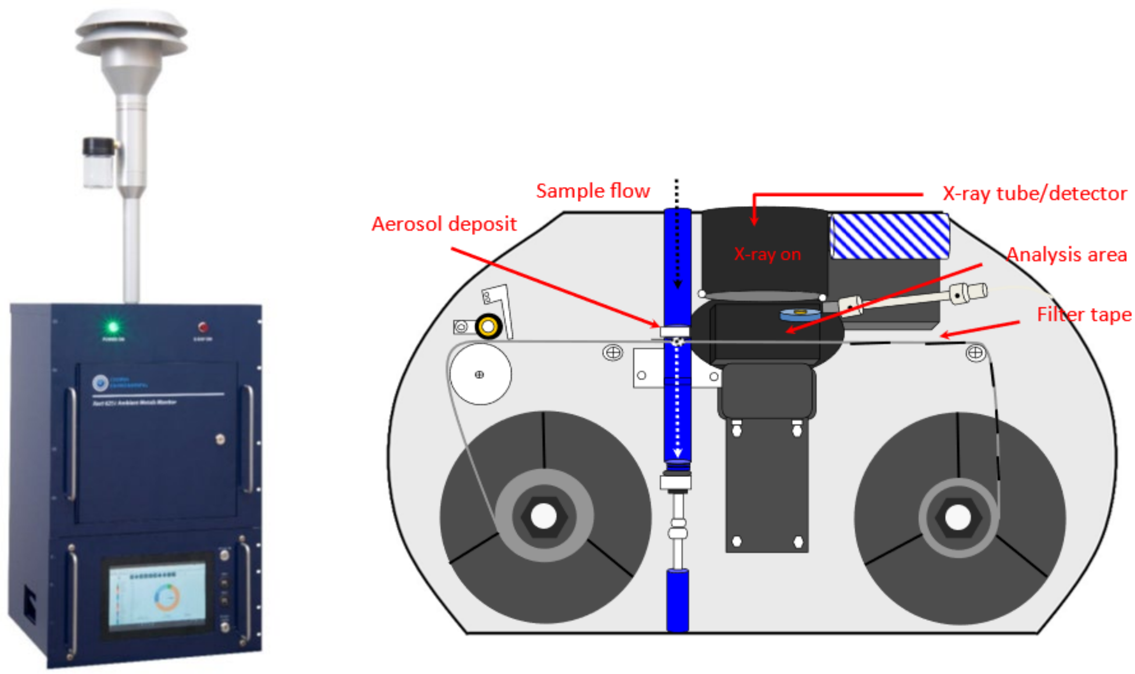


Figure 5 - Xact 625i instrument (left) and sampling schematic (right). Images courtesy of Cooper Environmental Services.

2.5.5 OC/EC

OC and EC samples were collected on filters at four sites: Auchencorth Moss and Chilbolton Observatory (rural background); London Honor Oak Park (urban background); and London Marylebone Road (urban roadside). Ultrapure quartz filters (Pallflex Tissuquartz 2500QAT-UP) were used for sampling. In 2024, sampling of $PM_{2.5}$ continued at all four sites using Digitel DPA14 samplers (Figure 6).

OC/EC analysis was carried out using the Sunset Laboratory Inc. L5 thermal/optical carbon analyser (Figure 7). In the laboratory, a 1.5 cm^2 punch is taken from each filter and analysed. The procedure involves heating the sample to remove PM from the filter, conversion of carbonaceous material to methane, followed by detection by flame ionisation. In a helium atmosphere, the sample is gradually heated to 650 °C to remove organic carbon collected on the filter. During this first phase, organic compounds in the sample are pyrolytically converted to EC. Measuring the transmission of a laser beam through the filter continuously monitors this pyrolytic conversion and allows a correction to be made for it. EC is detected in the same way after heating to 850 °C in the presence of oxygen and helium. The analysis protocol used is termed EUSAAR2, as specified in EN 16909:2017[18]. The protocol also specifies that a transmittance correction must be used to determine concentrations for OC and EC. Data are reported as the mass of carbon per volume of air (µg m^{-3}).

Figure 6 - Digitel DPA14 sampler, photograph courtesy of Digitel AG.

Figure 7 - Sunset Laboratory Inc. L5 thermal/optical carbon analyser, photograph courtesy of Sunset Laboratory Inc.

2.5.6 BC and UVPM

BC is a measure of the mass concentration of airborne soot-like carbon, based on the optical absorption of light at a specific wavelength (880 nm) by particulates collected on a filter.

It is often assumed that BC and EC, a measure of soot-like carbon determined by thermo-optical techniques, are the same, however in practice the measured concentration of the EC fraction of TC depends strongly on the method chosen. The term “equivalent black carbon (eBC)” is formally recommended for data which simply converts an aerosol absorption coefficient to a mass concentration as described in section 2.5.6.

Aethalometers measure BC on filter samples based on the transmission of light through a sample. In 2024, the BC Network used the Aerosol Magee Scientific AE33 instrument (Figure 8) across all sites.

This 7-wavelength AE33 instrument operates at 950 nm, 880 nm, 660 nm, 590 nm, 520 nm, 470 nm, and 370 nm, and samples $PM_{2.5}$ using an inlet flow of 5 L min^{-1}. The sample is collected onto a Teflon tape (M8060 type), and the optical attenuation is measured at a time resolution of 1 min. Two spots with different sample flows (approximately 1.5 and 3.5 L min^{-1}) together with the reference spot (without flow), are used to calculate the attenuation. The rate of change of the attenuation of light, together with flow rate, spot area, and volume of the sample are mathematically converted to the compensated particle light absorption and a BC mass concentration. A mass absorption cross-section of 7.77 m^2 g^{-1} was used at 880 nm and one of 18.47 m^2 g^{-1} at 370 nm, as described in Drinovec *et al.*[19]. The results from the 880 nm channel (BC) give the quantitative concentration of 'black' carbon, and those from 370 nm channel (UV) indicate the presence of aromatic organic compounds such as those found in wood smoke, biomass-burning smoke, and tobacco smoke.

At all sites, ambient air is drawn into the sampling system through a standard rain cap mounted on the end of a vertical tube. Size selection of the sampled aerosol was made by a $PM_{2.5}$ cyclone placed close to the inlet of the Aethalometer. All the tubing upstream of the cyclone is constructed from stainless steel.

In this report, the term BC concentration refers to the mass concentration of particulate matter measured at the 880 nm wavelength also within the infrared range. For this Network, the parameter UVPM is calculated by subtracting the BC mass concentration from the UV mass concentration. UVPM can, in principle, be used as an indicator of organic compounds present in the sample, *e.g.* from wood or solid fuel emissions.

Figure 8 - Aerosol Magee Scientific AE33 Aethalometer.

3 DATA QUALITY

3.1 QA/QC PROCEDURES

3.1.1 General

NPL operates under a Quality Management System certified for scientific research and development and the provision of internal services by Lloyd's Register Quality Assurance (LRQA) according to ISO 9001:2015[20]. NPL is accredited to ISO 17025:2017[21] for the general requirements for the competence of testing and calibration laboratories for OC/EC measurements (UKAS accredited testing laboratory No. 0002), and CPC calibration (UKAS accredited calibration laboratory No. 0478).

A summary of the general QA/QC procedures used during the measurement and ratification process is given below:

- A Technical Lead (supported by expert consultants) is appointed for each instrument type to manage data collection and ratification.
- LSOs are trained and audited on an ongoing basis to carry out routine maintenance and report issues. All LSO maintenance activities are recorded.
- Each instrument type has an appointed ESU who is responsible for routine servicing and emergency repairs.
- An annual audit of all sites, LSOs, and instruments (including flow checks) is conducted by an independent NPL audit team.
- Calibrations and checks are carried out at regular intervals throughout the year.
- Data collection is performed manually for Digitel samplers by NPL and automated by the MONNET data handling system at ERG for all other instruments. All data are stored securely and backed up.
- The quarterly Network reports include data capture values from the verified data of the previous quarter.
- Automatic and manual data validation is followed by rigorous ratification procedures.
- Data quality circle meetings are held at least annually to review and validate the data. Other measurements made in this monitoring programme and in other EA monitoring programmes are also used to check the validity of the measurements.

The key additional measurement-specific QA/QC procedures are summarised below:

3.1.2 Particle number concentration

- The manufacturer's software is set up to automatically perform repeat measurements every 15 minutes, providing verified data.
- NPL is accredited by UKAS to ISO 17025 to perform the calibration of CPCs directly against the UK primary reference electrometer. The primary calibration of CPC instruments is by comparison with a Faraday Cup Electrometer (FCE) which NPL have ISO 17025 UKAS accreditation to calibrate. The reference FCE and the test CPC simultaneously measure the particle number concentration of a test sample being produced by a well-characterised aerosol generator. The results obtained are corrected for any multiple charges on the test particles. The calibration factors are then applied during ratification to give the best estimate of the particle number concentrations.
- The CPC instruments undergo annual servicing: replacing the saturator wick, cleaning the critical orifice, and replacing any discoloured or damaged tubing. The CPC firmware is also checked at this stage and updated to the latest version if required.

3.1.3 Particle size distribution

- The LSO confirms that the radioactive source is present and makes a radiation measurement monthly.
- The manufacturer's software is set up to automatically repeat 140-second scans every 3 minutes. This is then combined into 15-minute measurements by ERG software providing verified numerical data.
- The CPC part of the SMPS is calibrated at NPL (see section 3.1.2).
- For the SMPS calibration process carried out by NPL, an aerosol containing a single size of polystyrene latex nanospheres is used to check the sizing accuracy. This aerosol is generated using a nebuliser and conditioned with a diffusion dryer.
- The SMPS instruments undergo annual servicing of the CPC component instrument: replacing the saturator wick, cleaning the critical orifice, and replacing any discoloured or damaged tubing. The CPC firmware is also checked at this stage and updated to the latest version if required.
- The DMA column sent to the manufacturer for cleaning and maintenance if a shift in particle size distribution outside of acceptance criteria of the NPL DMA calibration is observed).

3.1.4 Aerosol mass and chemical composition

- The LSO attends the instruments every fortnight to perform checks on the instrument and software. These include flow rate checks, pinhole and inlet cleaning and instrument tuning using ACTRIS standard operating procedures (SOPs) developed for the ACSM[22].
- Calibrations are scheduled to be performed every six months by trained technical users. Particles of ammonium sulfate and ammonium nitrate are generated from solution and then size-selected by passing through the DMA of the SMPS. Particles are then counted by the CPC to produce a particle stream of known concentration before entering the ACSM. The stream is diluted with different ratios of particle-free air to produce a calibration curve.
- Ratification is performed by the proprietary software. Data are scaled and corrected for pressure, flow and temperature using ACSM ACTRIS SOPs[22]. Sensibility checks are performed by mass closure comparison to co-located PM mass measurements.

3.1.5 Elemental analysis

- During daily data checking, the results from the internal standards and automated overnight standards are checked for deviations.
- The LSO attends the instruments every fortnight to perform checks on the instrument and software. These include inlet cleaning and tape changes (as required).
- Flow rate checks and calibration checks are performed every quarter by trained technical users. For the calibration checks, five thin film standards covering different analysis conditions of the instrument are used to verify the instrument operates within its parameters.
- Annual services are carried out by trained engineers from the ESU.
- A full calibration of the instrument is performed after any change of the X-ray tube.
- Ratification is performed using ERG owned software. Data are scaled and corrected for flow. Sensibility checks are performed by comparison to co-located PM and chemical speciation instrument measurements.

3.1.6 OC/EC

- The Digitel DPA14 sampler is compliant with EN 12341:2023[23]. The four flow calibrations and flow checks carried out during the year are used to calculate and apply a flow correction to the data.
- Sampled filters received at NPL Teddington are recorded, handled, stored, and analysed following NPL's UKAS accredited in-house procedure for OC/EC samples.
- NPL's analysis procedure describes a method for the accurate measurement of the collected Total Carbon (TC) on ambient air monitoring filters, subdivided into OC and EC. As part of this procedure, field blank filters are analysed to evaluate the contamination due to the transport of the filters to the sites and back to the laboratory.

3.1.7 BC and UVPM

- Measurements of BC, UVPM, flow rate, tape life and data from the other five channels are remotely downloaded by ERG's data handling system (MONNET). A range of checks are undertaken at this point to ensure measurements are within threshold value range; the flow data are also checked to ensure it is 5 L min^{-1} (± 10 %).
- Issues raised during the manual data checking are noted in the database. This information is retained and passed to NPL to inform the ratification process. Occasionally, issues raised during data checking require an intervention from either the LSO or ESU. In this case, a visit request is sent to either the LSO or ESU.
- The validated 1 min measurements are averaged to 15 min means in accordance with measurements made using gaseous and particulate monitors in the AURN. A valid 15 min measurement is only calculated where at least ten valid 1 min measurements exist in that 15 min period. Hourly averages are calculated if there are at least three valid 15 min averages in that period.

3.2 MEASUREMENT UNCERTAINTY

3.2.1 Particle number concentration

The expanded (k = 2) uncertainty of these measurements is currently 5 %, in accordance with NPL's ISO 17025 UKAS accreditation. However, NPL's Calibration and Measurement Capabilities have recently improved to an expanded (k = 2) uncertainty of 3.5 %, which were agreed internationally by the Gas Analysis Working Group of CCQM, in support of the Mutual Recognition Arrangement of the CIPM. This value is based on the results of the International Comparison CCQM-K150[24].

3.2.2 Particle size distribution

The expanded uncertainty of these size measurements is 4.1 %. The main component of this measurement uncertainty, as determined by NPL, is due to the uncertainty in the mobility diameter of polystyrene latex beads used in the calibration.

3.2.3 Aerosol mass and chemical composition

ACSM uncertainty is obtained by comparison of the sum of measured concentrations with a regulatory measurement of time-resolved mass concentration of particulate matter, by a Tapered Element Oscillating Microbalance Filter Dynamics Measurement System (TEOM FDMS), Beta Attenuation Monitor (BAM) or Fine Dust Analysis System (FIDAS) aerosol spectrometer. The correlation between measurements obtained by ACSM and particle mass measurements is taken into account in this process.

According to the results of the European ACTRIS interlaboratory comparison campaign[25] in 2013, the expanded uncertainties of the ACSM concentration from hourly measurements are equal to 9 % for the sum of the five measured compounds in non-refractory sub-micron aerosols. Uncertainties for individual species are 15 % for nitrate, 19 % for organics, 28 % for sulfate and 36 % for chloride.

3.2.4 Elemental analysis

The XRF calculates and reports an uncertainty with each hourly concentration measurement. These calculated uncertainties vary depending on the concentration and element being measured, with the relative uncertainty of each hourly measurement typically being larger at lower concentrations.

The dominant uncertainty contribution is typically from the spectral deconvolution process applied by the instrument (*i.e.*, the process of resolving the signal from the detector into individual peaks that can be quantified).

As examples of the magnitude of the estimated uncertainties reported by the XRF, the average relative uncertainties from an hourly measurement of iron (one of the most abundant elements) and zinc (an element of lower abundance, but still above the limit of detection in almost all measurements) in 2024 are shown in Table 6.

Table 6 - Average relative expanded uncertainties of highest and lowest abundance elements from hourly XRF measurements in 2024

	Average relative expanded uncertainties / %			
	London Marylebone Road		London Honor Oak Park	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Fe	9.5	9.1	9.3	8.0
Zn	15.5	11.9	16.9	14.0

3.2.5 OC/EC

The uncertainty in the measured TC concentrations is a combination of the analytical uncertainty and the uncertainty in the measured sample volume. The expanded analytical relative uncertainty for TC has been found to be 6 %. EN 12341:2023[23] requires the consistency of the average volumetric flow rate for $PM_{2.5}$ and PM_{10} samplers to be ≤ 2 % over the sampling period. The uncertainty of the measurement of OC and EC is therefore dominated by the analytical uncertainty.

3.2.6 BC and UVPM

A standardised method for the determination of the uncertainty in BC mass concentration has not been formulated yet. This is however one of the deliverables in the European Partnership of Metrology project STANBC[26]. NPL's current uncertainty budget estimates the expanded uncertainty for the annual concentration of BC measured using the AE33 Aethalometer to be 9 %, with the dominant contribution arising from the uncertainty in the measurement of the flow rate. Uncertainties related to the default parameters used in the Aethalometer algorithm are not yet taken into account.

The Aethalometer measurement of BC does not depend on the absolute calibrated response of the detectors, but relies instead upon their ability to determine very small relative changes in optical transmission. The repeatability of the Aethalometer when sampling zero air has been assessed to be < 0.2 % relative to typical Network concentrations over a period of a year, and therefore it is a negligible contribution to the overall uncertainty.

The uncertainty in the annual concentration of UVPM is expected to be of the same magnitude as that in the annual concentration of BC, as both are dominated by the uncertainty in the flow rate.

3.3 SCHEDULED INSTRUMENT SERVICE AND CALIBRATION

3.3.1 CPC

NPL holds ISO 17025[21] accreditation for CPC calibration. The Network CPCs are serviced (replacing the saturator wick, cleaning the critical orifice, and replacing any discoloured or damaged tubing) and calibrated at NPL on an annual basis. Details of the calibration and servicing are provided in section 3.1.2.

3.3.2 SMPS

The SMPS instruments have been serviced (CPC component serviced by replacing the saturator wick, cleaning the critical orifice, and replacing any discoloured or damaged tubing) and calibrated at NPL on an annual basis. Details of the calibration are provided in section 3.1.3.

3.3.3 ACSM

The ACSMs are managed by ERG staff who perform monthly flow checks and *ad hoc* instrument tuning, pinhole cleaning, and inlet cleaning. Repairs are carried out by the ERG operator following manufacturer (Aerodyne) advice and procedures. The instruments are calibrated at least once annually using laboratory ammonium sulfate and ammonium nitrate standards.

3.3.4 XRF

The XRF instruments are managed by ERG and ACOEM UK Ltd. ERG carry out tape changes and *ad hoc* checks, as well as routine flow checks and three-monthly calibration checks. Annual services are carried out by ACOEM UK Ltd. These services can include a full instrument calibration if the x-ray tube has been changed. ACOEM UK Ltd also carries out *ad hoc* callouts and repairs.

3.3.5 Digitel samplers and OC/EC analyser

In 2024, the Digitel DPA14 samplers were serviced by the Environment Agency's Ambient Air Monitoring (AAM) Team, with the exception of the first six-monthly service in 2024 at Auchencorth Moss, which was carried out by Enviro Technology Services. These 6-monthly services include replacing old or worn parts, cleaning, sensor and flow checks and calibrations, leak tests, and time and date checks.

The Sunset Laboratory Inc. L5 thermal/optical carbon analyser is serviced annually by a Sunset Laboratory Inc. service engineer, as per manufacturer's guidelines. The service involves replacing worn parts, and a full test and calibration. NPL run a daily calibration check prior to sample analysis using a laboratory blank filter and a filter spiked with a traceable standard solution.

3.3.6 Aethalometers

The AE33 Aethalometers were serviced by ACOEM UK Ltd. These 6-monthly service visits include replacing old or worn parts, cleaning cyclones/optics, flow calibrations, leak tests and tape mechanism check. Service visits are either scheduled or carried out during a callout visit.

3.4 DATA CAPTURE

3.4.1 Overview

Data capture is calculated as the percentage of time for which valid measurements exist across the intended measurement period (*e.g.*, excluding downtime for planned calibrations).

The tables below show the annual data capture for 2024 for each instrument at each site. In the cases where an instrument measures more than one analyte, an average has been calculated for each site. All values are stated to the nearest whole percentage.

3.4.2 Particle number concentration

The data capture loss at London Honor Oak Park (37 %) was due to a laser fault in the CPC. This fault was repaired by the manufacturer and the instrument returned to site after recalibration at NPL.

Table 7 - Data capture for particle number concentration measurements

Site Name	Data capture / %
Chilbolton Observatory	74
London Marylebone Road	73
London Honor Oak Park	63
Average	**70**

3.4.3 Particle size distribution

The data capture loss at Chilbolton Observatory (44 %) was due to an electrical fault in the electrostatic classifier. This fault was repaired by the manufacturer and the instrument returned to site after recalibration at NPL.

Due to the complexities of data ratification, the two months of data available for the Horley SMPS (November and December 2024) were not submitted to the DDU. These will be ratified and submitted the next year, when more data is available.

Table 8 - Data capture for particle size distribution measurements

Site Name	Data capture / %
Chilbolton Observatory	56
London Marylebone Road	89
London Honor Oak Park	90
Average	**78**

3.4.4 Aerosol mass and chemical composition

All three ACSMs operated without any major issues throughout 2024. At London Honor Oak Park the main cause of data loss occurred due to PC connection issues and software crashes, and there was a further loss of five days due to a power cut.

Table 9 - Data capture for aerosol mass and chemical composition measurements

Site Name	Data capture / %
Chilbolton Observatory	98
London Marylebone Road	98
London Honor Oak Park	88
Average	**95**

3.4.5 Elemental analysis

Minor non-scheduled data losses occurred at both sites due to the tape running out outside of scheduled tape changes and unexpected errors, such as x-ray tube failure, USB port failure for licence key, tape wheel loosening and power cuts.

Table 10 - Data capture for elemental measurements

Site Name	Data capture / %
London Marylebone Road	85
London Honor Oak Park	89
Average	**87**

3.4.6 OC/EC

All the samplers functioned without any major issues in 2024.

Table 11 - Data capture for OC/EC measurements

Site Name	Data capture / %
Auchencorth Moss	98
Chilbolton Observatory	100
London Marylebone Road	99
London Honor Oak Park	100
Average	**99**

3.4.7 BC and UVPM

Causes of data capture less than 80 %:

- Birmingham Ladywood: wrong tape installed from September 2023 to March 2024, thus data from this period were not valid.
- Strabane 2: wrong tape installed from January to August 2024, thus data from this period were not valid.
- Bradford Shipley Airedale Road: instrument stopped measuring two weeks after installation, in December 2024, but was rebooted in January 2025.
- Wicken Fen: reoccurring issue with insects in the sampling line during hot weather. This impacted the optics and data quality; data from June to August 2024 were not valid.

Table 12 - Data capture for BC measurements (value in brackets denotes annual data capture, where the measurement period does not cover the whole year)

Site Name	Data capture / %
Auchencorth Moss	95
Ballymena Ballykeel	87
Barnsley Gawber	99 (70)
Belfast Centre	93
Birmingham A4540 Roadside	93
Birmingham Ladywood	71
Blackburn Audley Park	96
Bradford Shipley Airedale Road	58 (5)
Cardiff Centre	92
Chilbolton Observatory	87
Derby Stockbrook Park	97
Detling	86
Glasgow High Street	91
Glasgow Townhead	96
Glazebury	99 (70)
Kilmakee Leisure Centre	94
Ladybower	99 (55)
London Honor Oak Park	96 (16)
London Marylebone Road	100
London North Kensington	96
London Teddington Bushy Park	94 (9)
Newcastle Centre	100 (49)
Shrewsbury Underdale	99 (62)
St Osyth	98 (69)
Strabane 2	37
Wicken Fen	75 (53)
Average	**90 (72)**

4 NETWORK DATA

4.1 PARTICLE NUMBER CONCENTRATION

4.1.1 2024 time series

Time series of hourly particle number concentrations (between approximately 7 nm and 2.5 µm in diameter) measured at Network sites during 2024 are shown in Figure 9 to Figure 11. In 2024, for the first time, NPL submitted SMPS total particle number concentration (TNC-SMPS) values to UK AIR as more accurate measurements were available from these instruments. This was due to the implementation of improved processing software which was better able to correct for particle losses at smaller particle sizes (below 20 nm). It should be noted, however, that the CPC is the only CEN compliant instrument for measuring total particle number concentration.

4.1.2 2024 diurnal, weekly, and monthly profiles

The diurnal, weekly, and monthly profiles for particle number concentrations in 2024 are shown for the Chilbolton Observatory, London Honor Oak Park, and London Marylebone Road sites in Figure 12 to Figure 14 (plots generated using the OpenAir Tools run on the R software platform[27,28]).

At all three monitoring sites higher concentrations were observed during the working week and lower concentrations on a Sunday. There was a clear increase in particle number concentration at both the Chilbolton Observatory and London Honor Oak Park sites after midday. This increase was not seen at London Marylebone Road where the particle number concentrations remained at nominally the same level from 6 am onwards.

4.1.3 Long-term trends

Figure 15 and Figure 16 show long-term annual trends for CPC measurements at all sites. The 2017 data are omitted due to the installation of new CPCs in that year. There was insufficient data capture to generate a datapoint for Chilbolton Observatory in 2023.

The London Ultra Low Emission Zone (ULEZ) was introduced in April 2019 and encompassed the London Marylebone Road Site. The ULEZ was expanded to also cover the London Honor Oak Park site in October 2021. The effect of the ULEZ on measured annual particle number concentrations at London Marylebone for 2020 and 2021 was difficult to determine, predominantly due to the potential influence of the Covid-19 lockdowns in those years. The 2022-24 data at London Marylebone Road provides strong evidence that the annual particle concentrations are not returning to pre-lockdown levels, which may represent the changing emissions profile of the vehicle fleet. This could be driven by the completion of the upgrade of old diesel buses to meet EURO VI legislation in 2021[29,30,31].

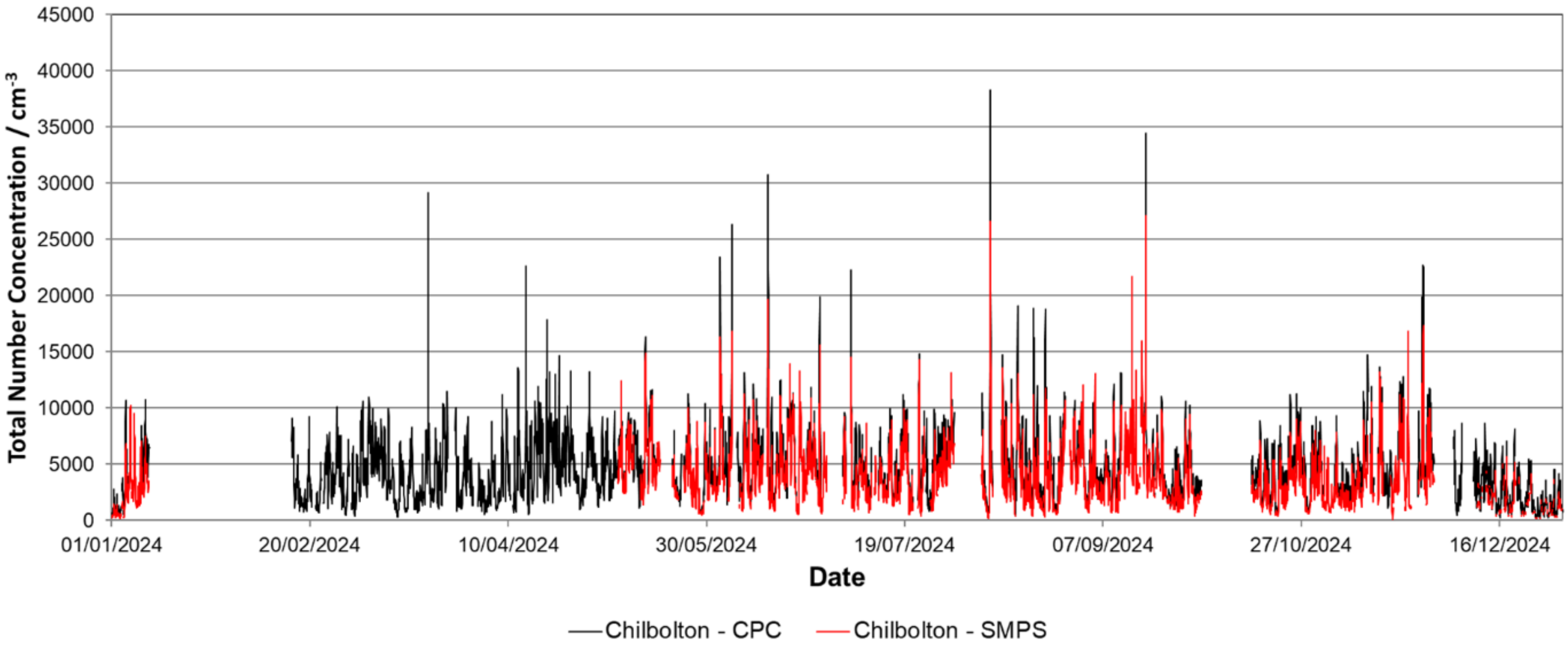


Figure 9 - Hourly particle number concentrations from both CPC and SMPS instruments at Chilbolton Observatory in 2024.

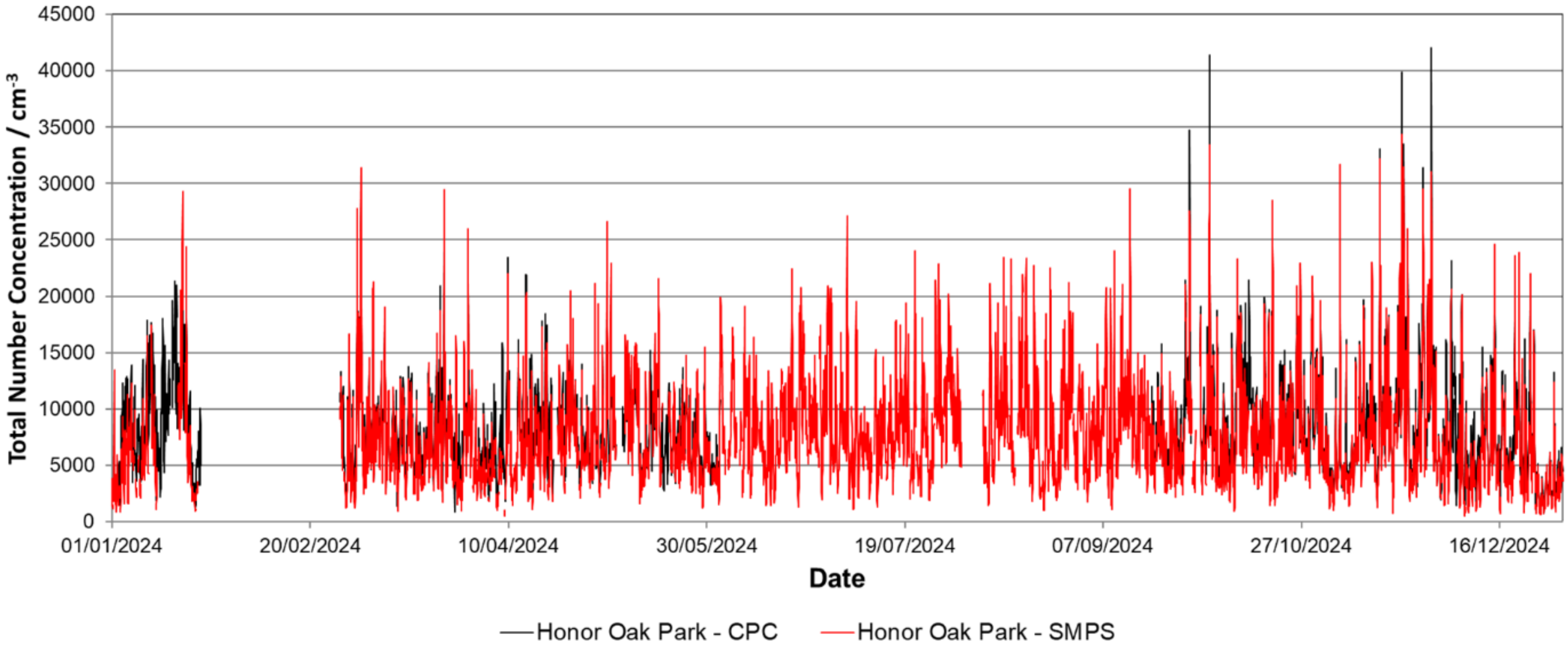


Figure 10 - Hourly particle number concentrations from both CPC and SMPS instruments at London Honor Oak Park in 2024.

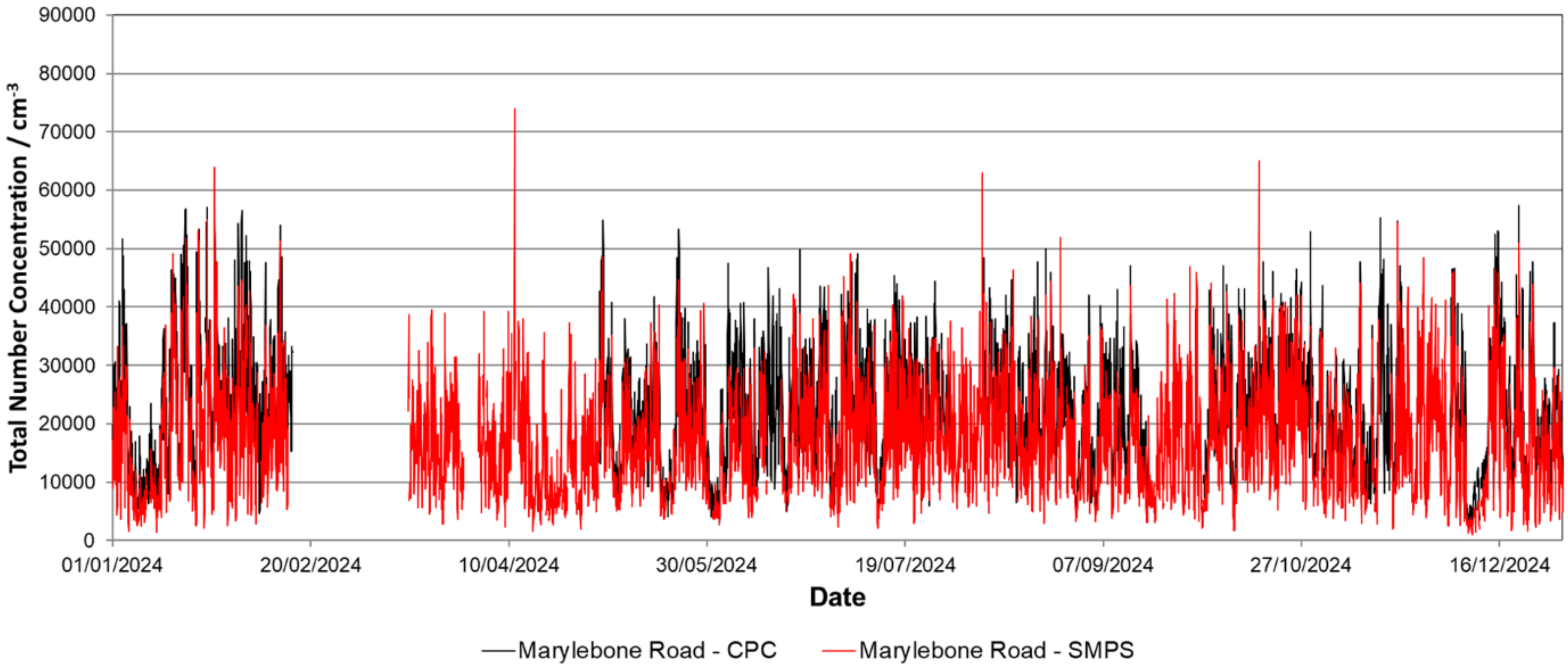


Figure 11 - Hourly particle number concentrations from both CPC and SMPS instruments at London Marylebone Road in 2024.

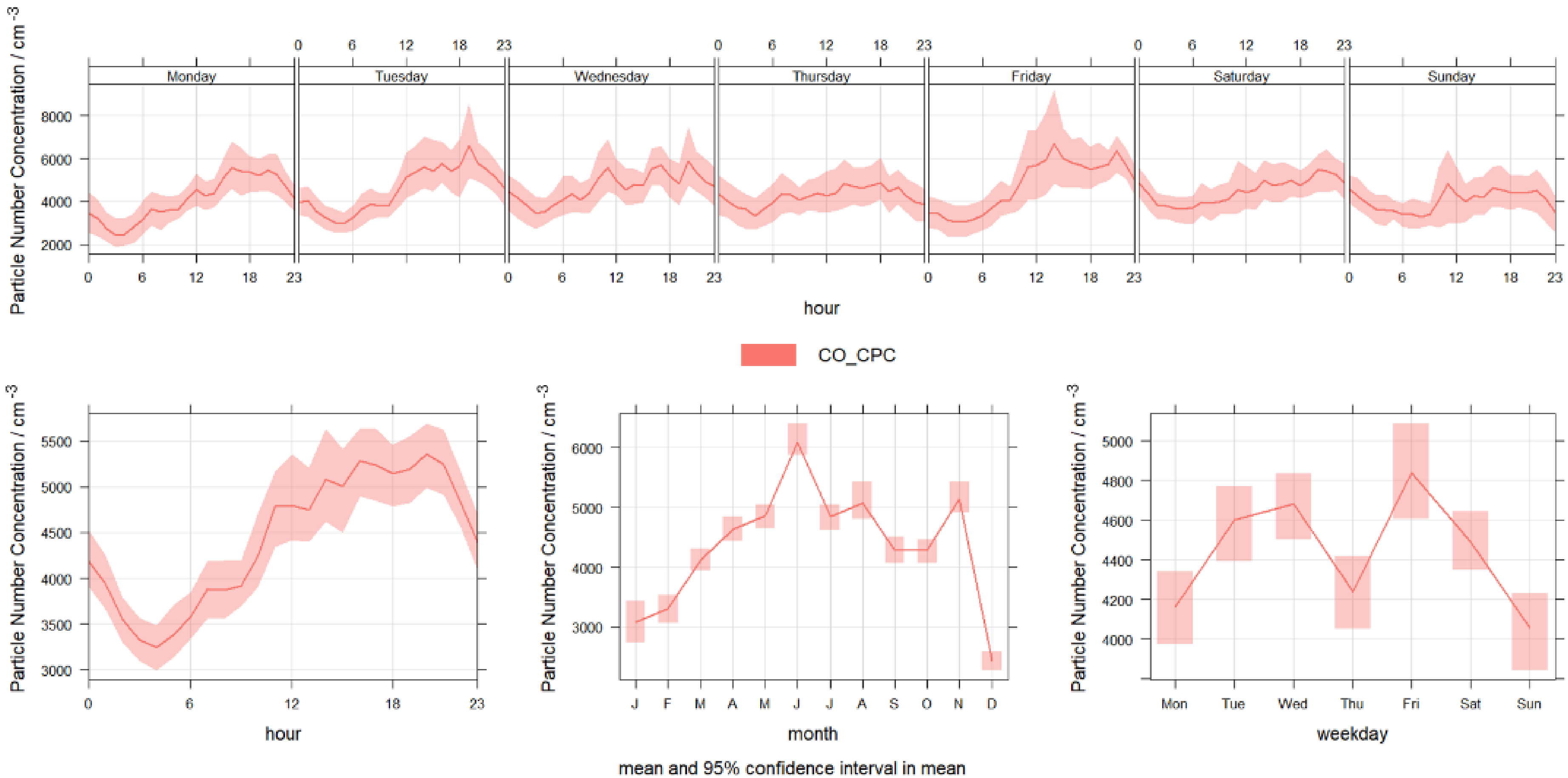


Figure 12 – Diurnal, weekly and monthly variations in particle number concentrations in 2024 at Chilbolton Observatory. The solid lines represent the mean particle number concentration, and the shaded areas represent the 95 % confidence interval in the mean.

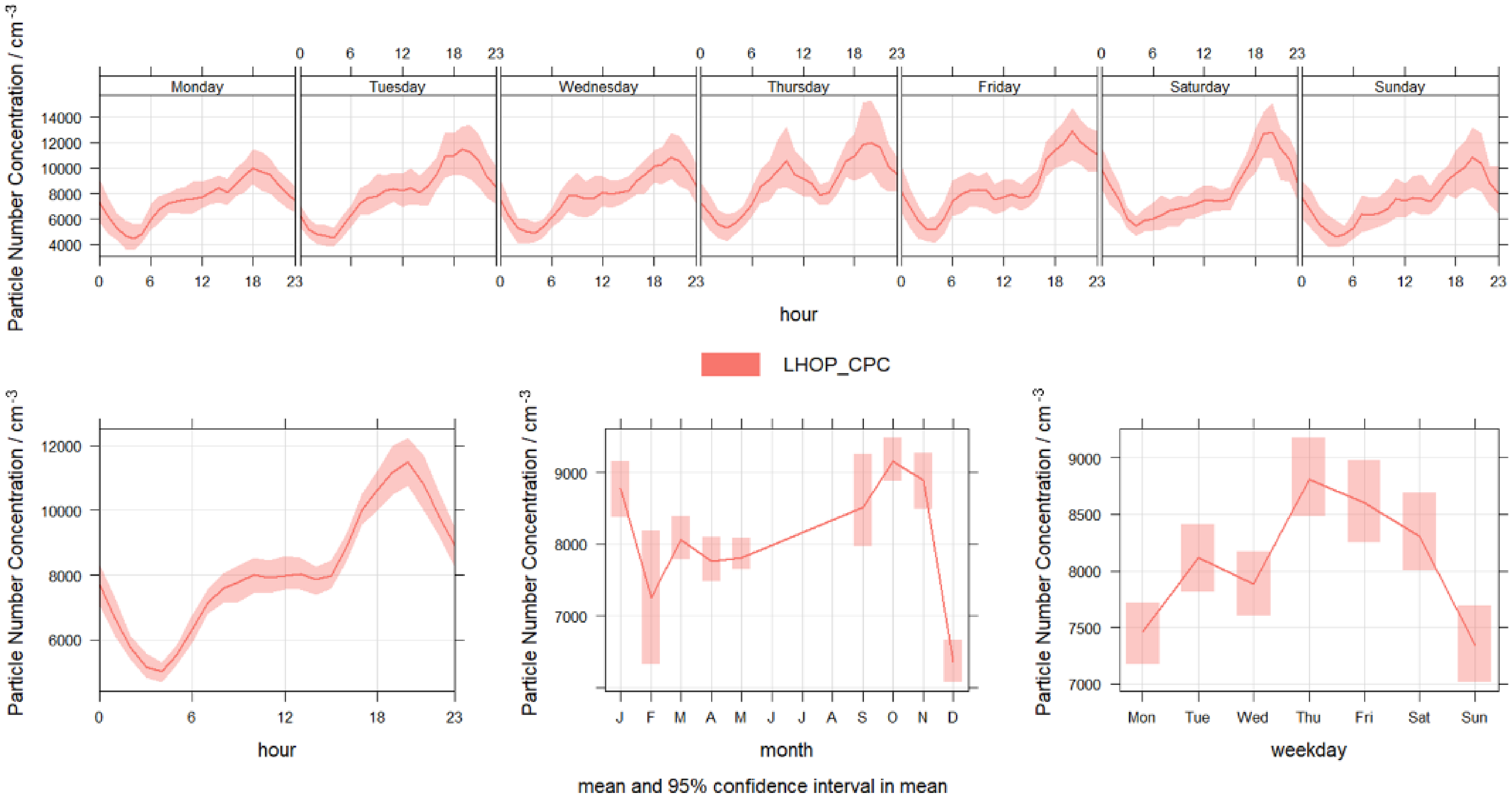


Figure 13 – Diurnal, weekly and monthly variations in particle number concentrations in 2024 at London Honor Oak Park. The solid lines represent the mean particle number concentration, and the shaded areas represent the 95 % confidence interval in the mean. Note that any line joining non-consecutive months in the monthly plot is automatically produced by the software used to generate the plot and is not intended to represent the particle number concentration of the 'missing' month(s).

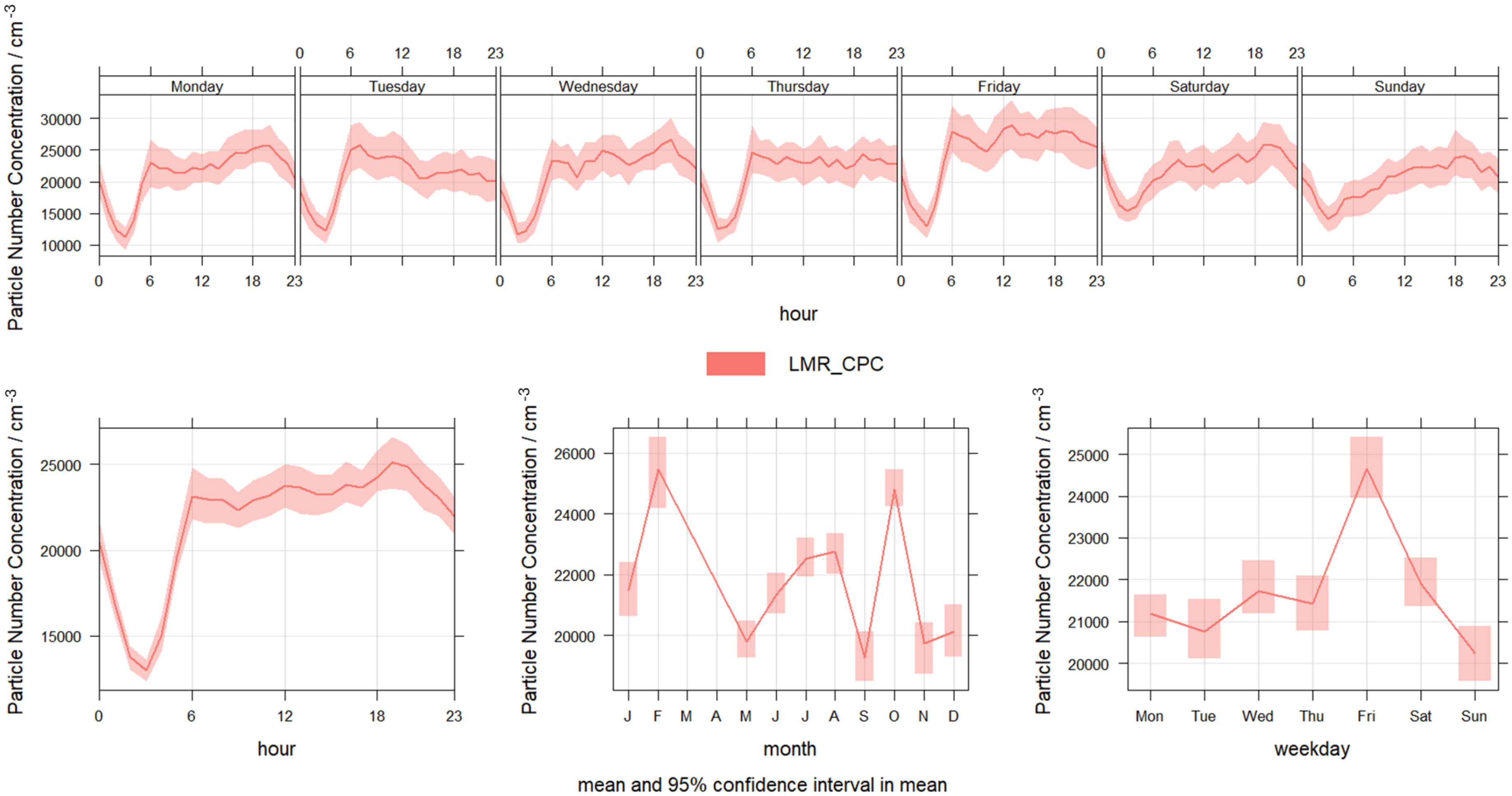


Figure 14 – Diurnal, weekly and monthly variations in particle number concentrations in 2024 at London Marylebone Road. The solid lines represent the mean particle number concentration, and the shaded areas represent the 95 % confidence interval in the mean. Note that any line joining non-consecutive months in the monthly plot is automatically produced by the software used to generate the plot and is not intended to represent the particle number concentration of the 'missing' month(s).

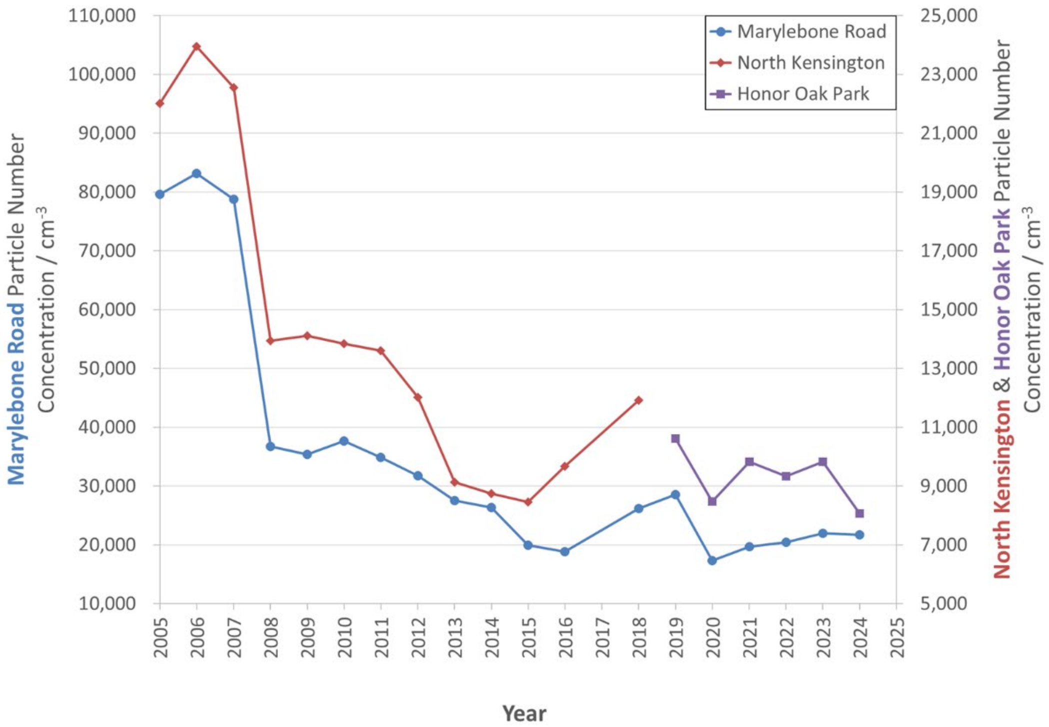


Figure 15 - Long-term particle number concentrations annual trends at all London sites. The London North Kensington site moved to London Honor Oak Park in November 2018.

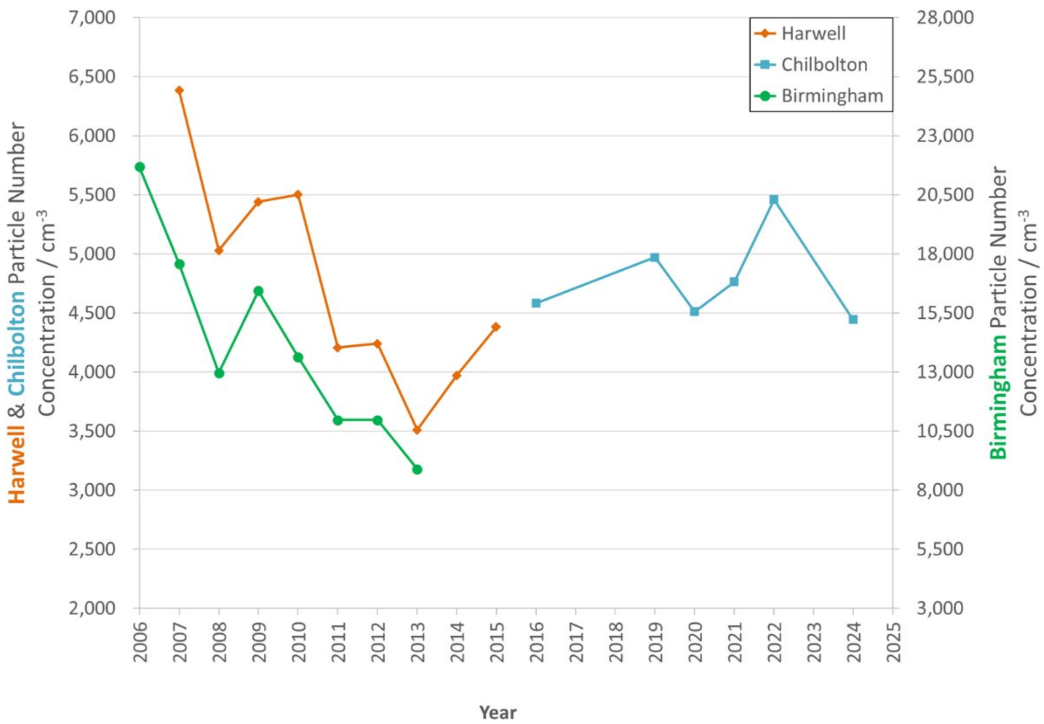


Figure 16 - Long-term particle number concentrations annual trends at all sites outside London. The Harwell site moved to Chilbolton Observatory in 2016.

4.2 PARTICLE SIZE DISTRIBUTION

4.2.1 2024 time series

Time series of monthly particle size distributions measured at Network sites during 2024 are shown in Figure 17. The plots show both the variation in particle number concentration and the shape of the particle size distribution across 2024 at each site.

4.2.2 2024 diurnal, weekly, and monthly profiles

The diurnal, weekly, and monthly profiles for particle number concentrations as an integral over the collected SMPS particle size range in 2024 are shown for the Chilbolton Observatory, London Honor Oak Park and London Marylebone Road sites in Figure 18 to Figure 20 (plots generated using the Open Air Tools run on the R software platform[27,28]).

4.2.3 Long-term trends

Time series of annual particle size distributions measured at Network sites from 2020 to 2024 are shown in Figure 21. The plots show both the variation in particle number concentration and particle size distribution. The plot for Chilbolton Observatory does not include data for 2023 due to low data capture.

The introduction of the newer model of SMPS at the sites in 2023 showed a broadening of the particle size distribution, which has been seen again in the 2024 data. The shift of the peak to larger mobility diameters at London Honor Oak Park and London Marylebone Road in 2023 is seen again in the 2024 data and is also displayed at the Chilbolton Observatory monitoring site in 2024. The fact that this peak shift is seen across all three sites and has continued from 2023 to 2024 supports the hypothesis that this is most likely an artefact of the change in instrument rather than a shift in the particle size distribution of the ambient aerosol. This will be explored further in the NPL report ‘Particle size comparison between TSI 3936 scanning mobility particle sizer and TSI 3938W50-CEN scanning mobility particle sizer conducted at NPL and London Marylebone Road monitoring sites’ which looks at the differences between the size distribution plots produced by the TSI 3936 and TSI 3938W50-CEN SMPS when challenged with the same aerosol[3].

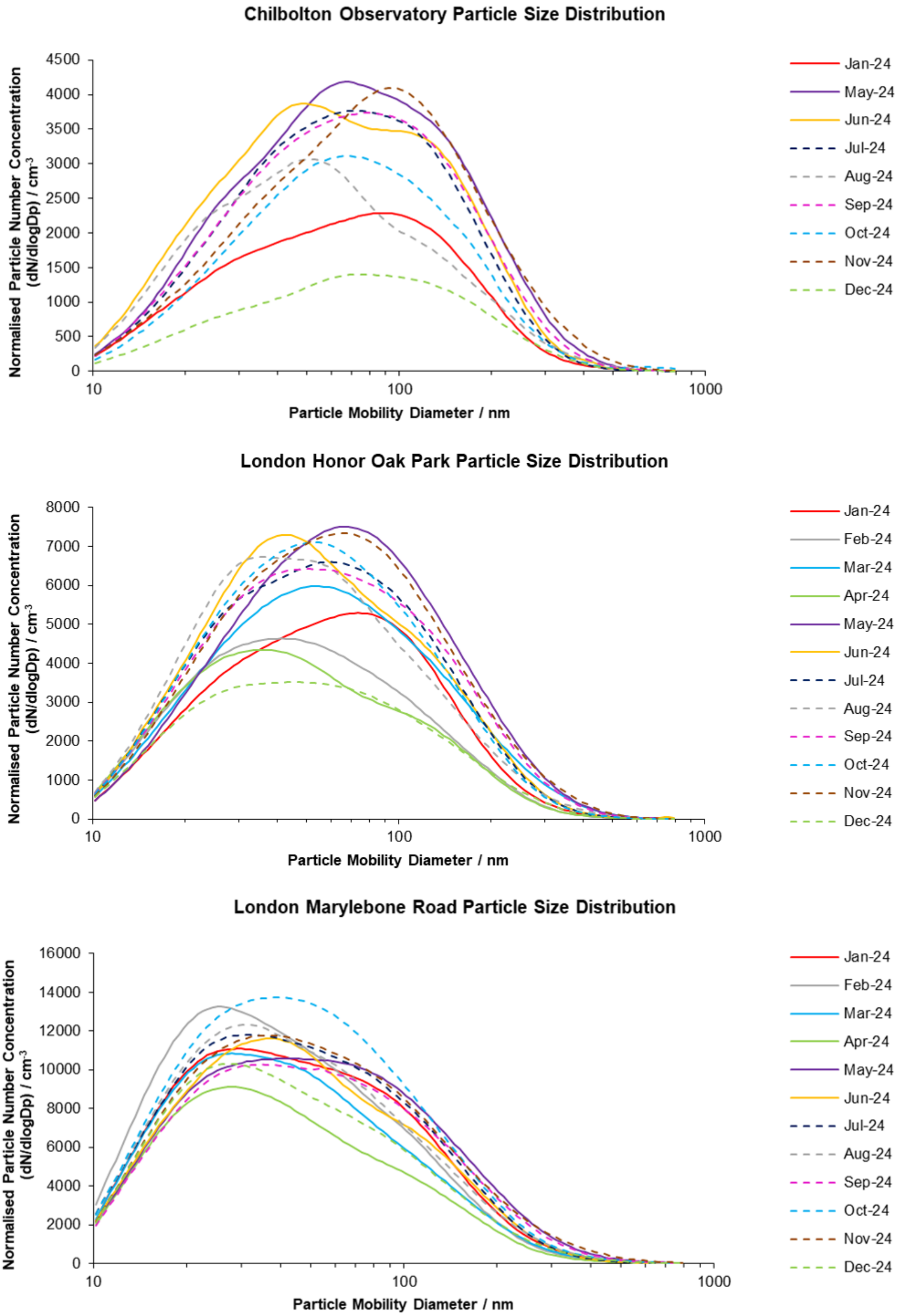


Figure 17 - Monthly averaged particle size distributions at the Network sites for each month during 2024.

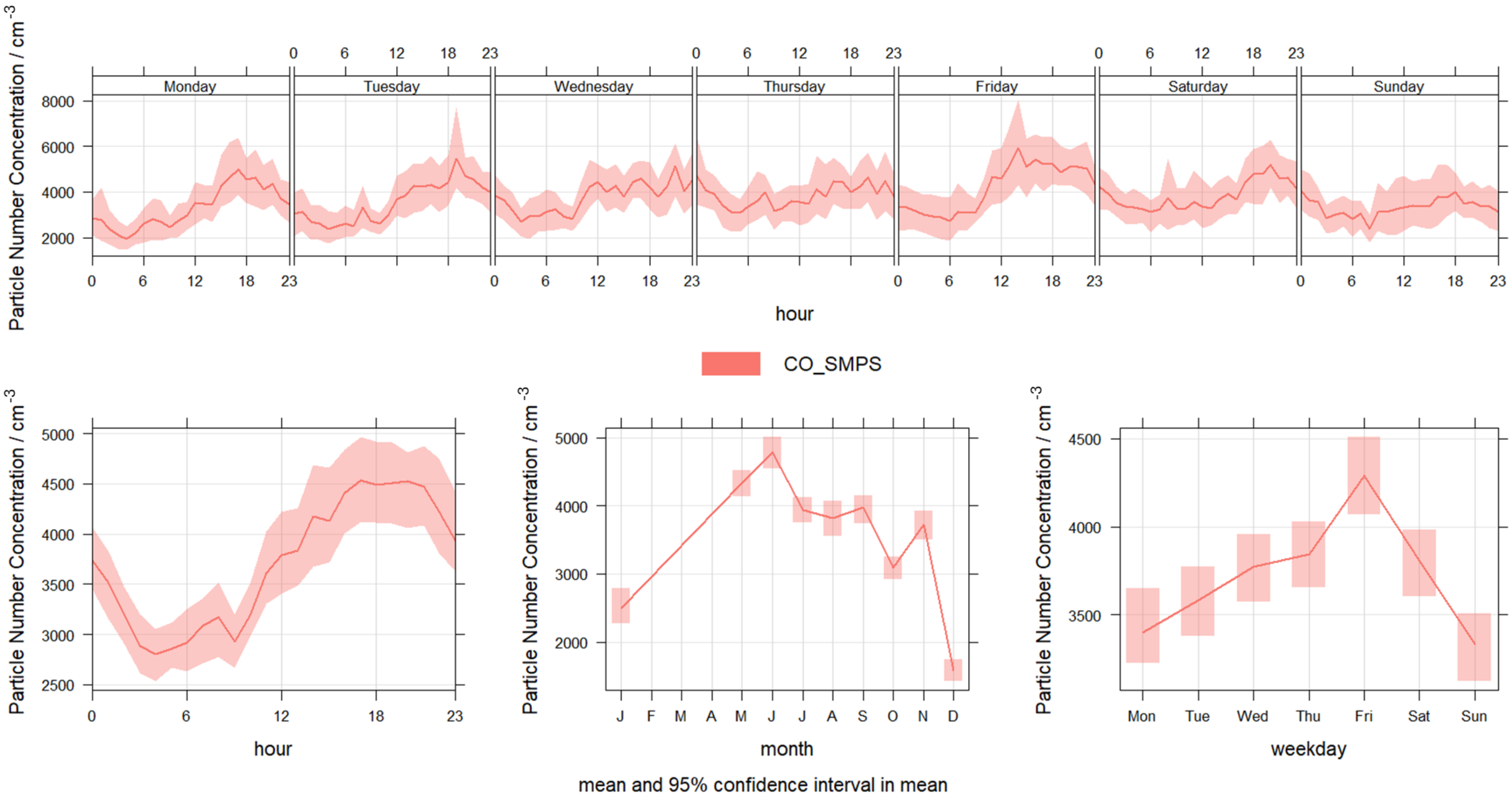


Figure 18 – Diurnal, weekly and monthly variations in total particle number concentrations from SMPS instrument in 2024 at Chilbolton Observatory. The solid lines represent the mean particle number concentration, and the shaded areas represent the 95 % confidence interval in the mean. Note that any line joining non-consecutive months in the monthly plot is automatically produced by the software used to generate the plot and is not intended to represent the particle number concentration of the 'missing' month(s).

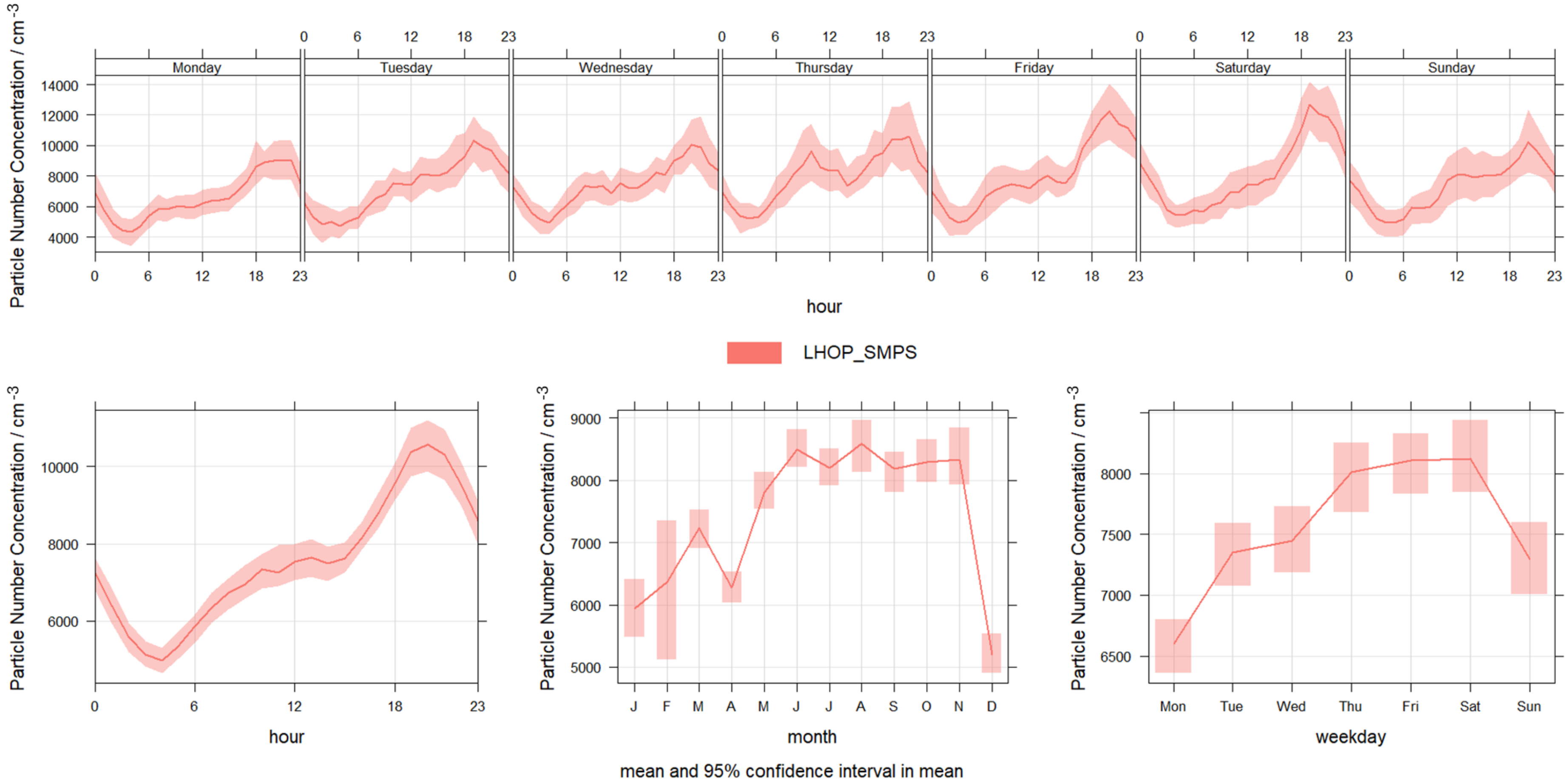


Figure 19 – Diurnal, weekly and monthly variations in total particle number concentrations from SMPS instrument in 2024 at London Honor Oak Park. The solid lines represent the mean particle number concentration, and the shaded areas represent the 95 % confidence interval in the mean. The data from June 2024 has been excluded from this plot due to low data capture meaning that the total number concentration was not representative of the month.

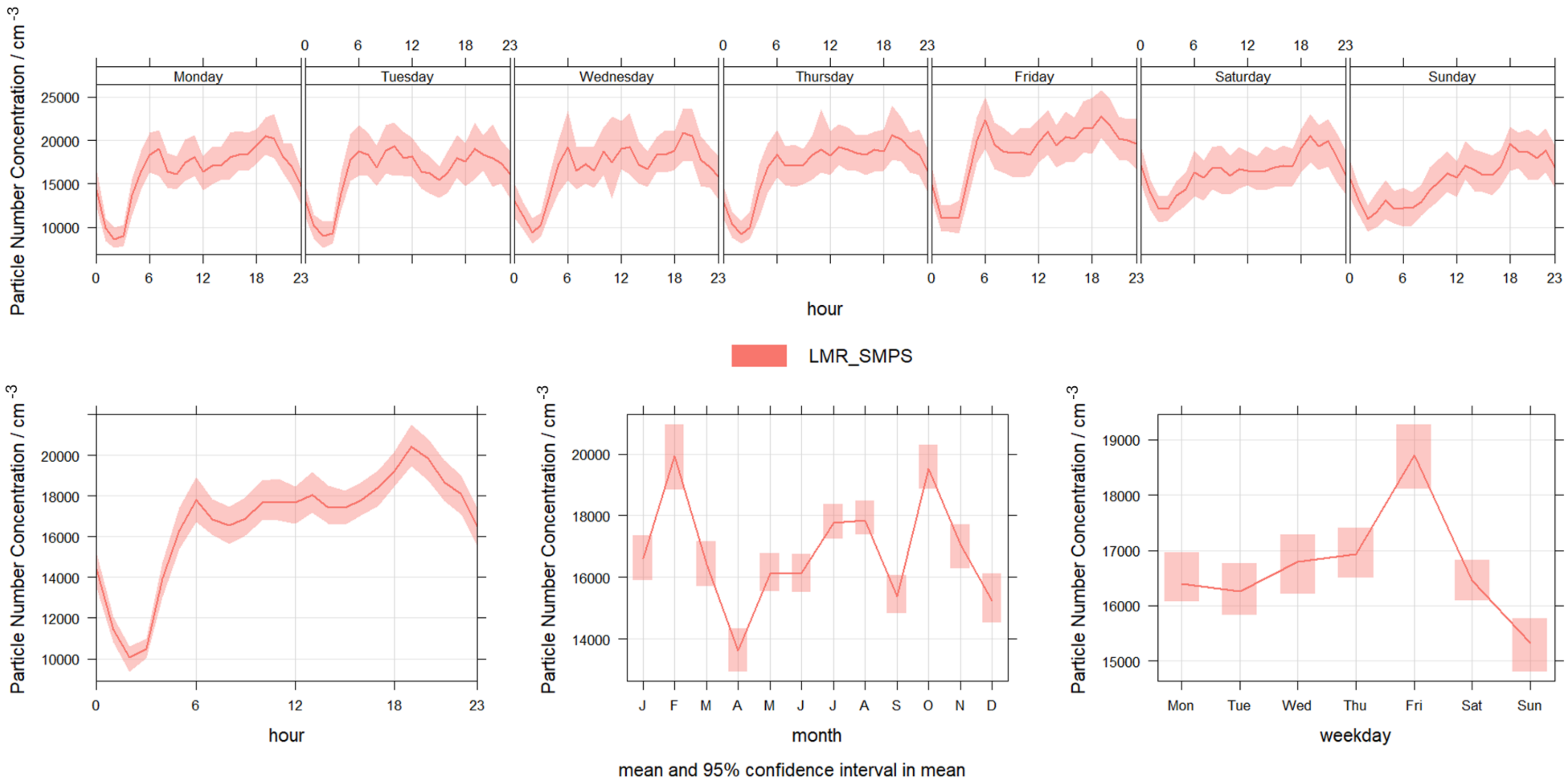


Figure 20 – Diurnal, weekly and monthly variations in total particle number concentrations from SMPS instrument in 2024 at London Marylebone Road. The solid lines represent the mean particle number concentration, and the shaded areas represent the 95 % confidence interval in the mean.

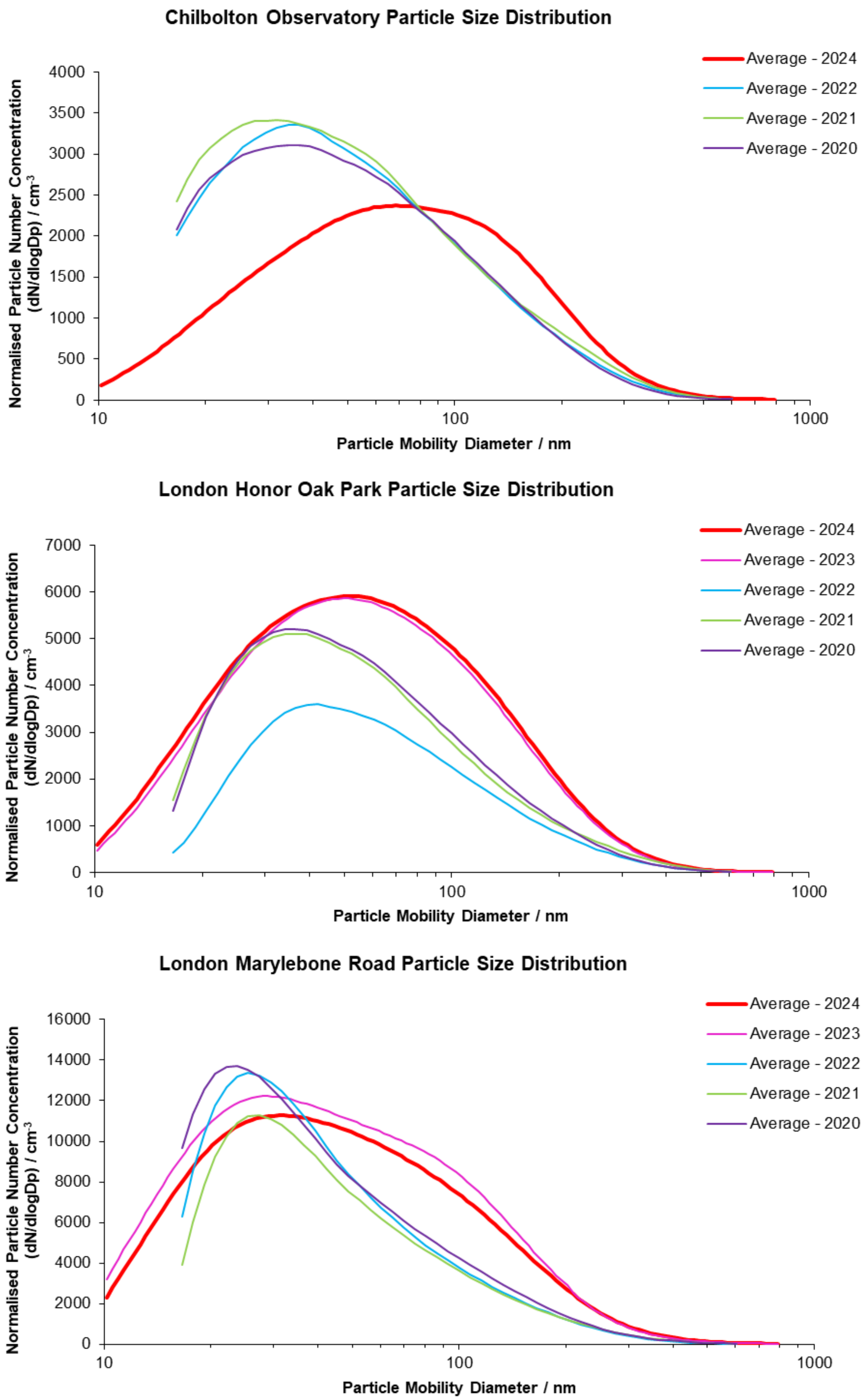


Figure 21 - Comparison of 2020 to 2024 annual average particle size distributions. Data for January and February 2023 from the old TSI 3936 SMPS at London Honor Oak Park are not included here. Data for Chilbolton Observatory in 2023 are not included due to low data capture.

4.3 AEROSOL MASS AND CHEMICAL COMPOSITION

4.3.1 2024 time series

Figure 22 to Figure 24 (plots generated using the OpenAir Tools run on the R software platform[27,28]) show the time series of monthly average mass concentrations of organics, nitrate, sulfate, and ammonium at Chilbolton Observatory, London Honor Oak Park, and London Marylebone Road during 2024.

It should be noted that although the intended measurands of the ACSM analysis are ions (*e.g.*, Cl^- and NO_3^-) in particulate matter, the ACSM also measures elements, or neutral species (*e.g.*, Cl or NO_3). For simplicity, all the results in this report are presented as if these are equivalent to ions.

4.3.2 Long-term trends

An ACSM instrument was installed at London North Kensington in 2013 measuring PM_1. It was then moved to London Honor Oak Park in November 2018. Since November 2018, the instrument has measured the hourly concentrations of organics, nitrate, sulfate, and ammonium in $PM_{2.5}$.

An ACSM instrument measuring the PM_1 size fraction was installed at London Marylebone Road in mid-July 2020. In April 2022 a new ACSM measuring $PM_{2.5}$ was installed at Chilbolton Observatory.

Figure 25 to Figure 28 (plots generated using the Open-Air Tools run on the R software platform[27,28]) show the long-term trends (using monthly averages) of the four components measured using the ACSM instrument at London North Kensington / London Honor Oak Park, London Marylebone Road, and Chilbolton Observatory.

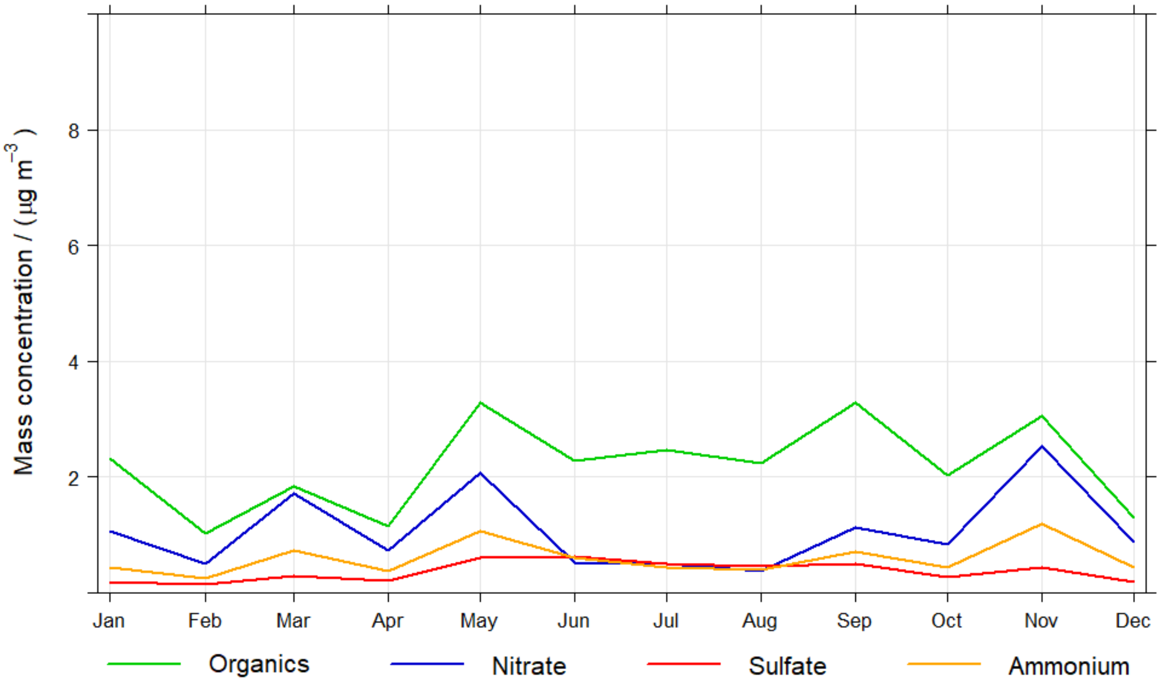


Figure 22 - Monthly average mass concentrations of organics, nitrate, sulfate, and ammonium in $PM_{2.5}$ measured by ACSM in 2024 at Chilbolton Observatory.

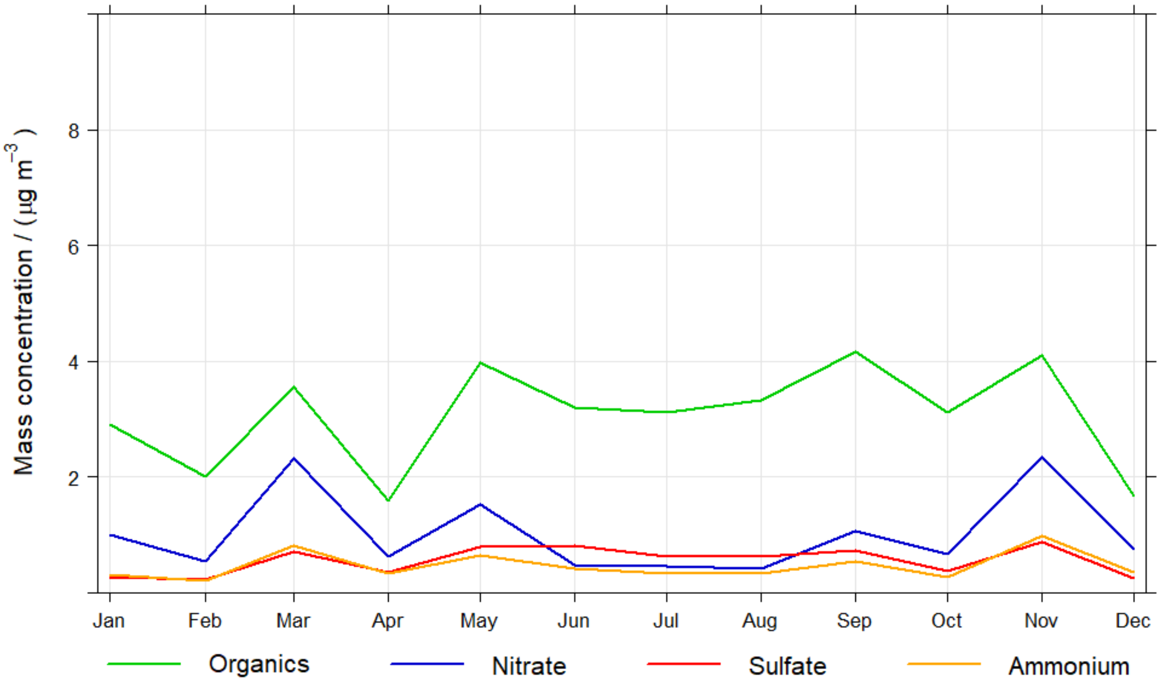


Figure 23 - Monthly average mass concentrations of organics, nitrate, sulfate, and ammonium in $PM_{2.5}$ measured by ACSM in 2024 at London Honor Oak Park.

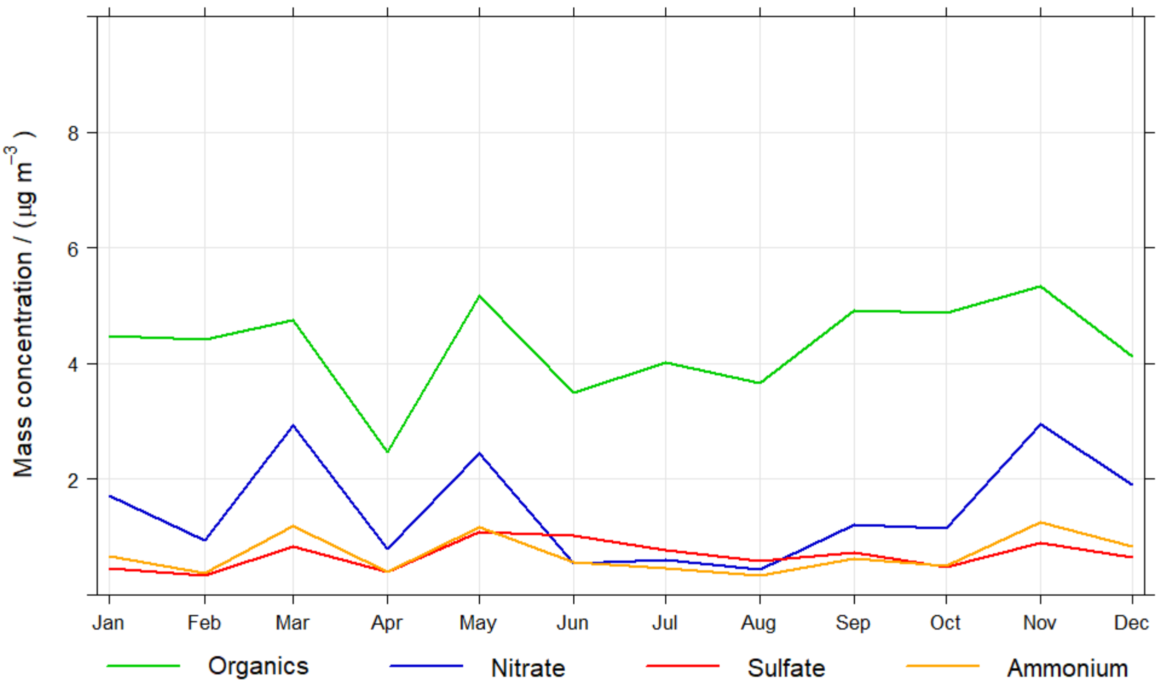


Figure 24 - Monthly average mass concentrations of organics, nitrate, sulfate, and ammonium in PM_1 measured by ACSM in 2024 at London Marylebone Road.

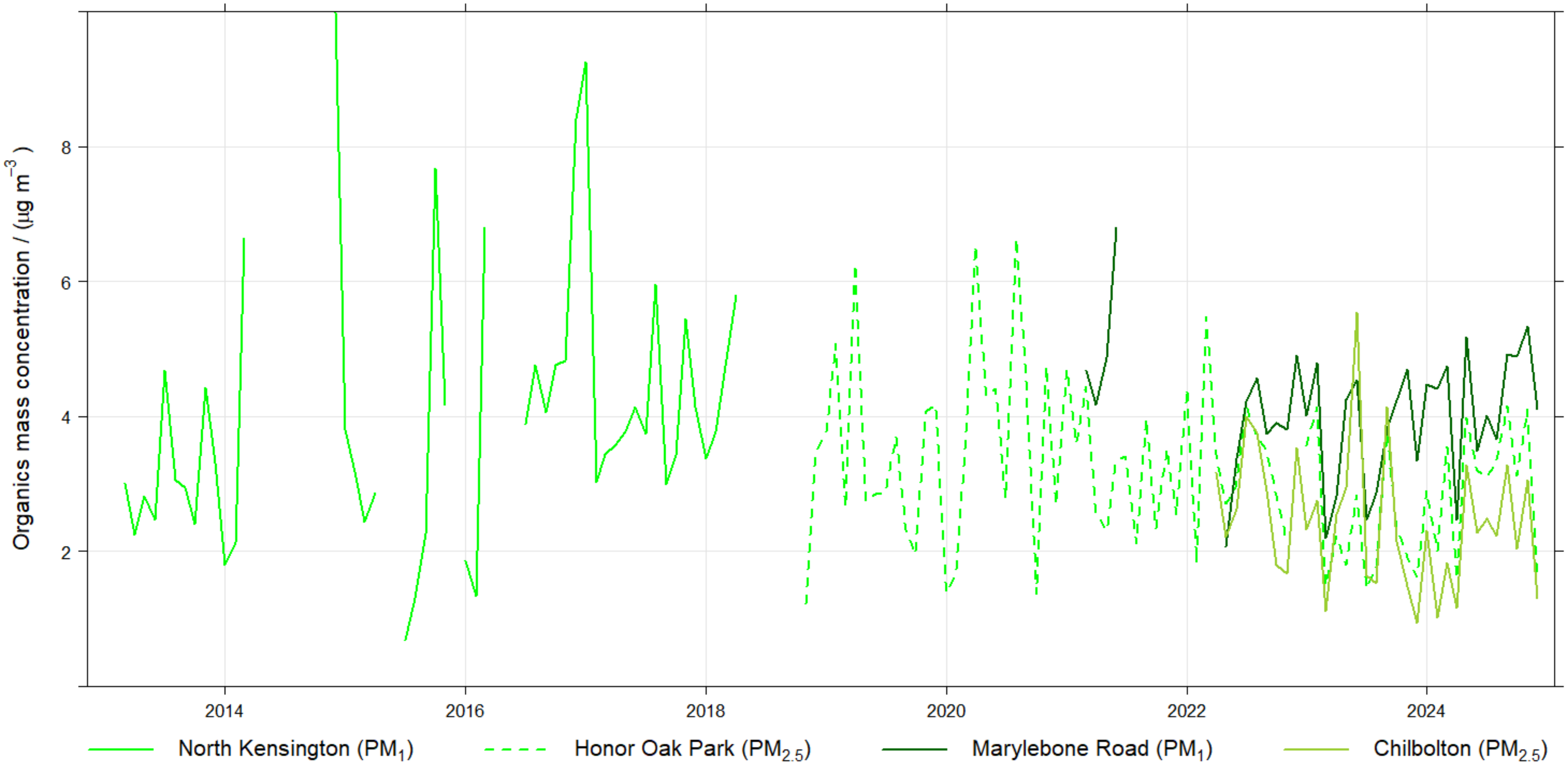


Figure 25 - Long-term mass concentration trends of organics at the rural background site Chilbolton Observatory, urban background site London Honor Oak Park (London North Kensington before 2019) and roadside site London Marylebone Road. The tick marks on the x-axis indicate the start of each year.

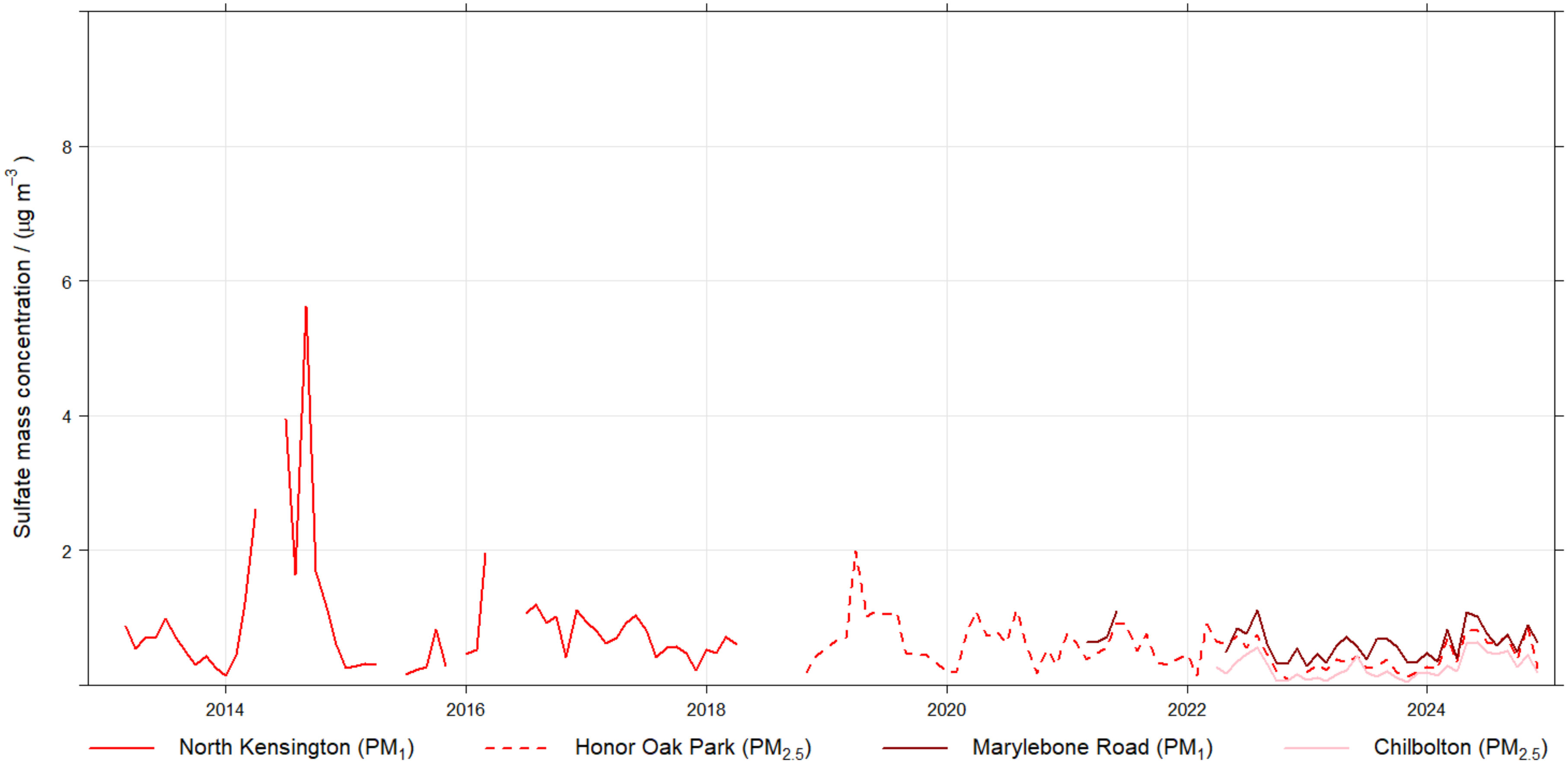


Figure 26 - Long-term mass concentration trends of sulfate at the rural background site Chilbolton Observatory, urban background site London Honor Oak Park (London North Kensington before 2019) and roadside site London Marylebone Road. The tick marks on the x-axis indicate the start of each year.

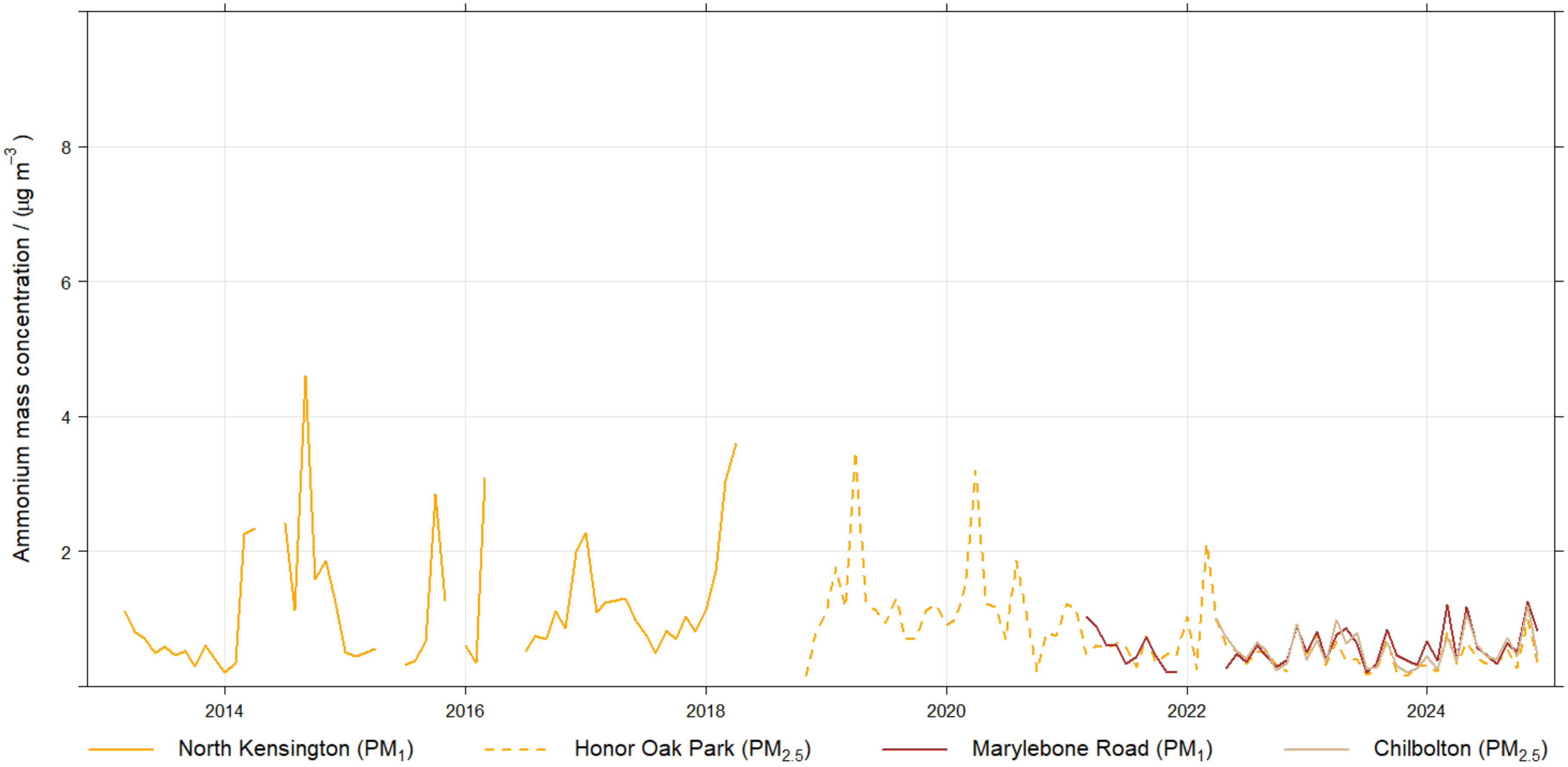


Figure 27 - Long-term mass concentration trends of ammonium at the rural background site Chilbolton Observatory, urban background site London Honor Oak Park (London North Kensington before 2019) and roadside site London Marylebone Road. The tick marks on the x-axis indicate the start of each year.

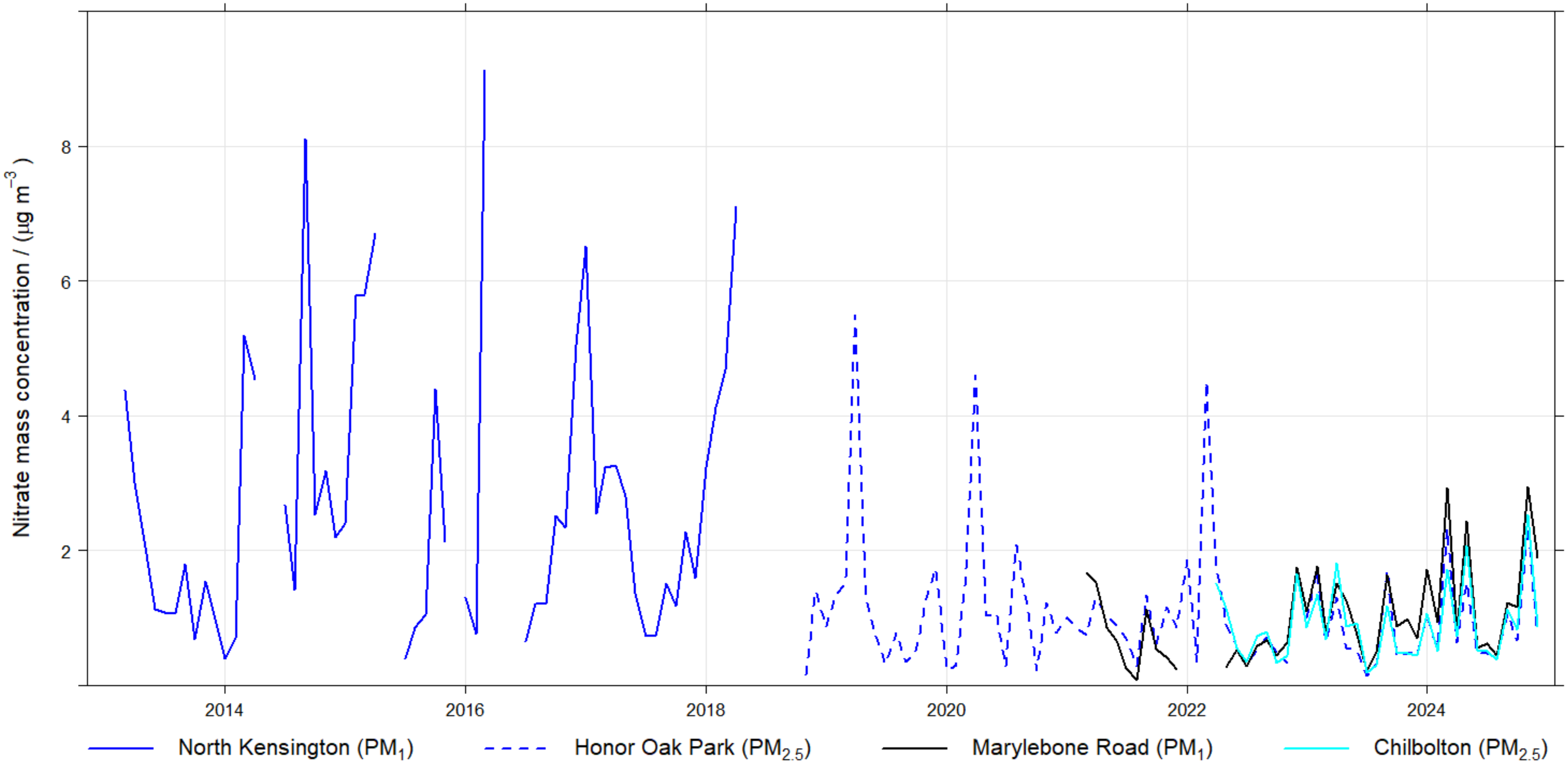


Figure 28 - Long-term mass concentration trends of nitrate at the rural background site Chilbolton Observatory, urban background site London Honor Oak Park (London North Kensington before 2019) and roadside site London Marylebone Road. The tick marks on the x-axis indicate the start of each year.

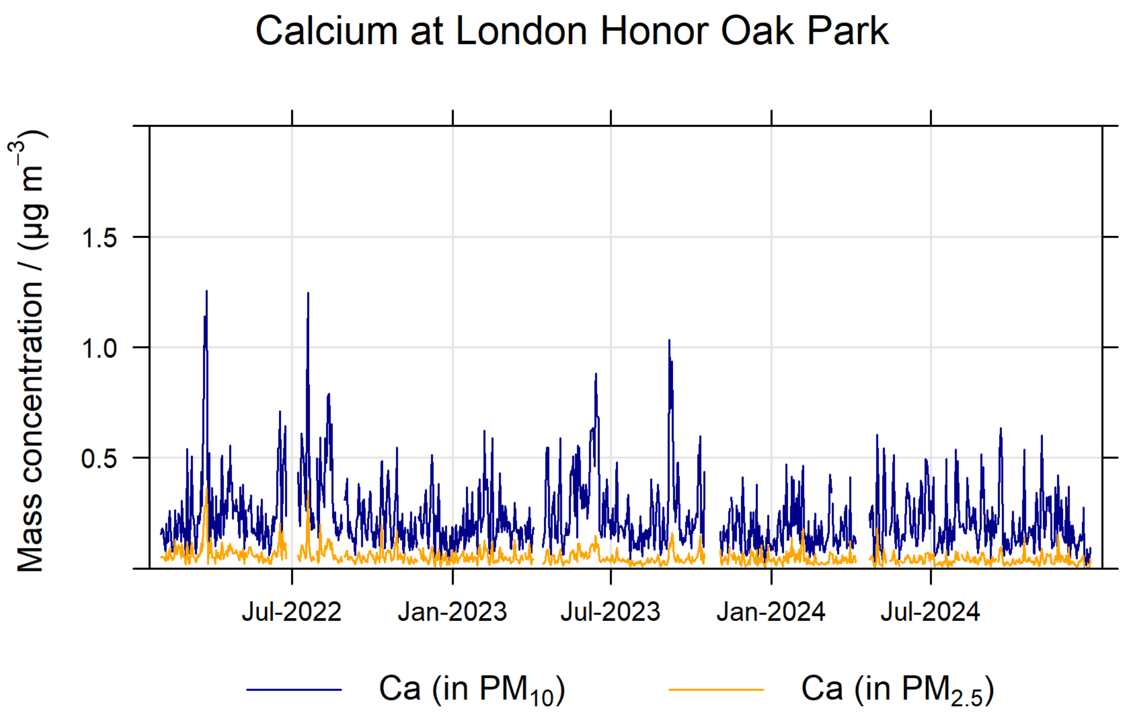
4.4 ELEMENTAL ANALYSIS

4.4.1 2022-24 time series

Data for the XRF at London Honor Oak Park has been available since February 2022, when the instrument was incorporated into the PCN&BC Network. At London Marylebone Road the XRF was installed at the end of March 2022, with the $PM_{2.5}$ / PM_{10} switching valve being operational from 5 April 2022; thus, the initial data are PM_{10} data only, and only the data obtained after the installation of the switching value are reported in this section

Figure 29 to Figure 34 show the time series of the daily concentrations of six elements (Ca, Cl, K, S, Cu and Zn) at London Honor Oak Park and London Marylebone Road from the respective start dates in 2022 to the end of 2024 for both $PM_{2.5}$ and PM_{10}. These six elements were chosen from the 40 measured as examples, because for these elements a significant proportion (more than 90 %) of the data are above the detection limit for both size fractions at both sites. Note that, as the sampled size fraction changed every hour, these graphs include extrapolated data to have a full time series.

Table 13 gives an overview of the annual mean concentration of each element at London Honor Oak Park and London Marylebone Road in 2024 calculated using the hourly mean values. It also shows the limit of detection (LoD) of the measurement, which is the same at both sites, and the percentage of data below the LoD for measurements of $PM_{2.5}$ and PM_{10}. Note that the data is based on bihourly data, which is accounted for in the data capture calculation.



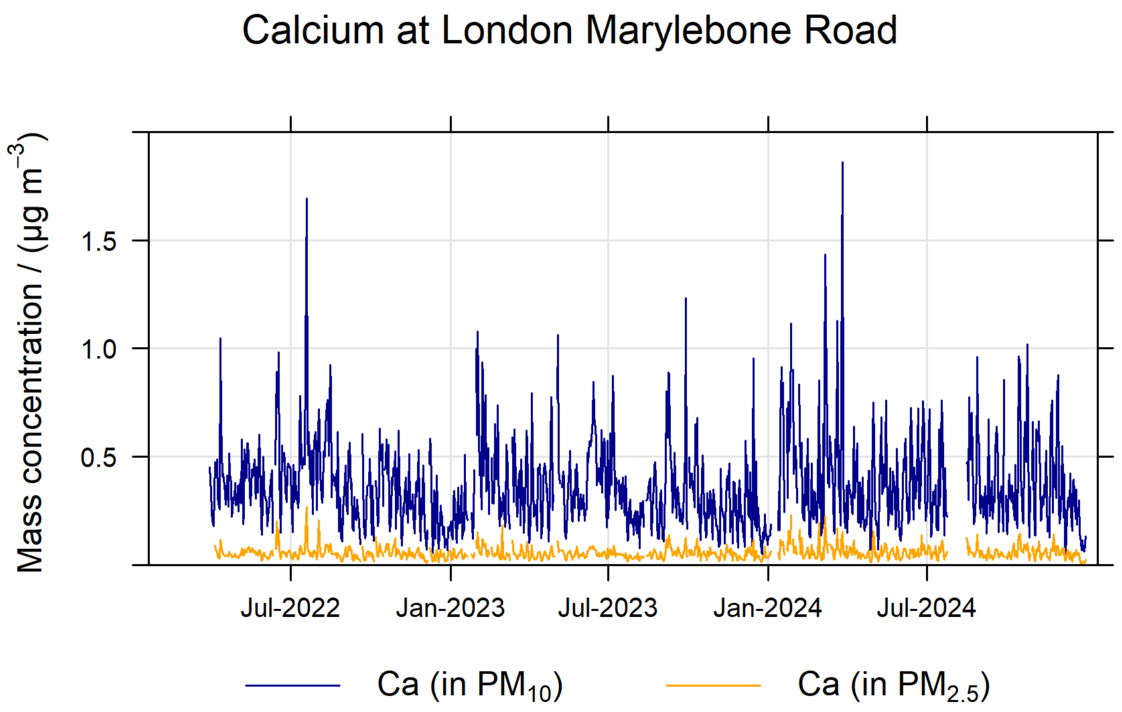


Figure 29 - Daily calcium concentrations in 2022-2024 at London Honor Oak Park and London Marylebone Road based on interpolated bihourly data. The tick marks on the x-axes indicate the start of every third month.

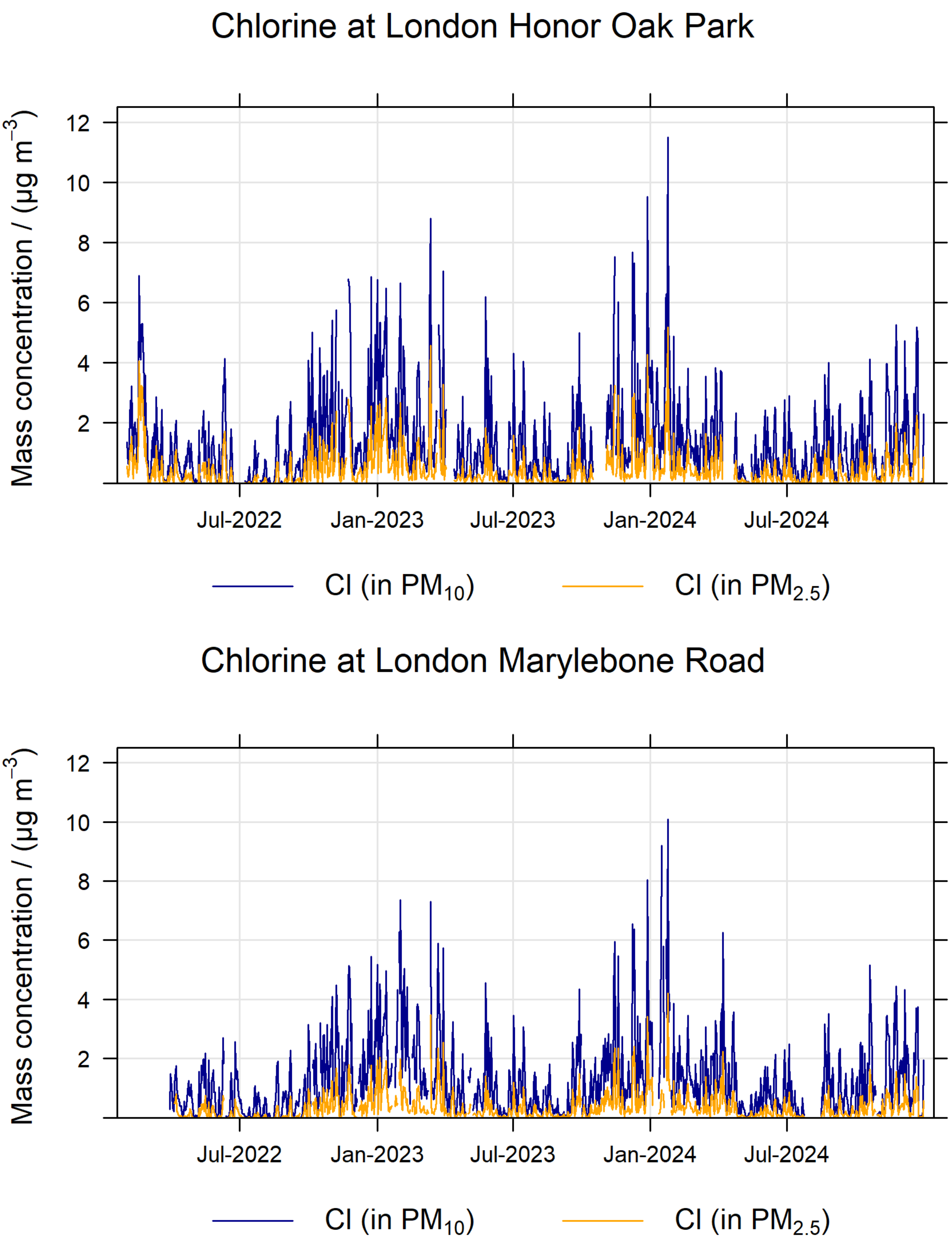
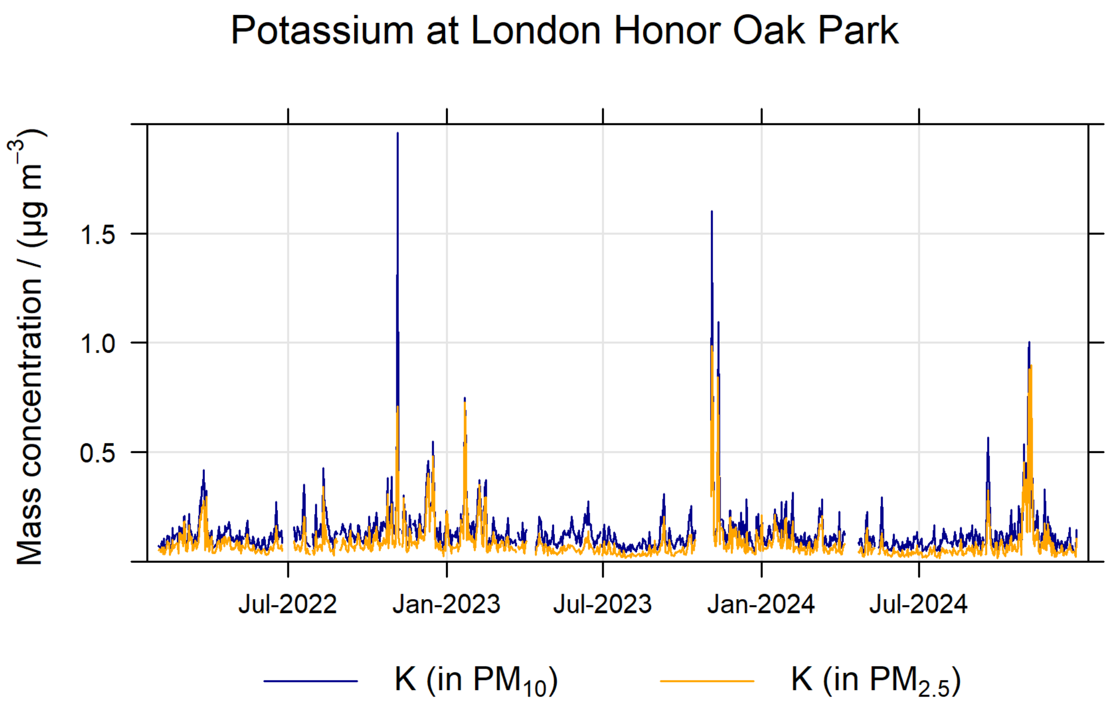


Figure 30 - Daily chlorine concentrations in 2022-2024 at London Honor Oak Park and London Marylebone Road based on interpolated bihourly data. The tick marks on the x-axes indicate the start of every third month.



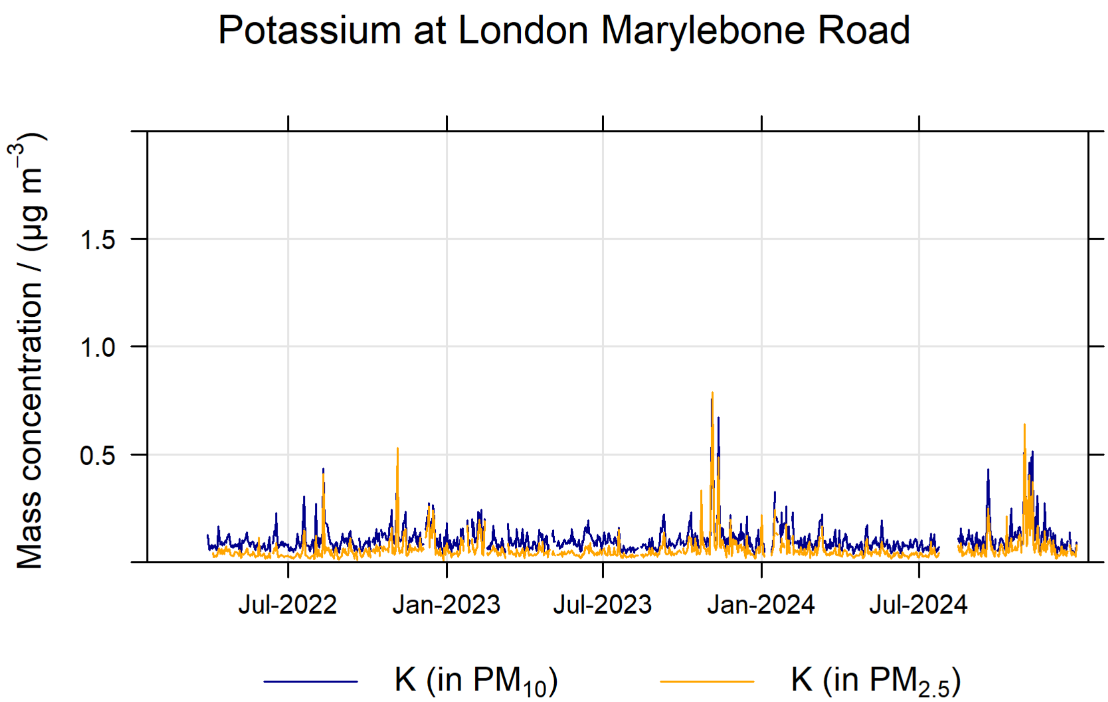
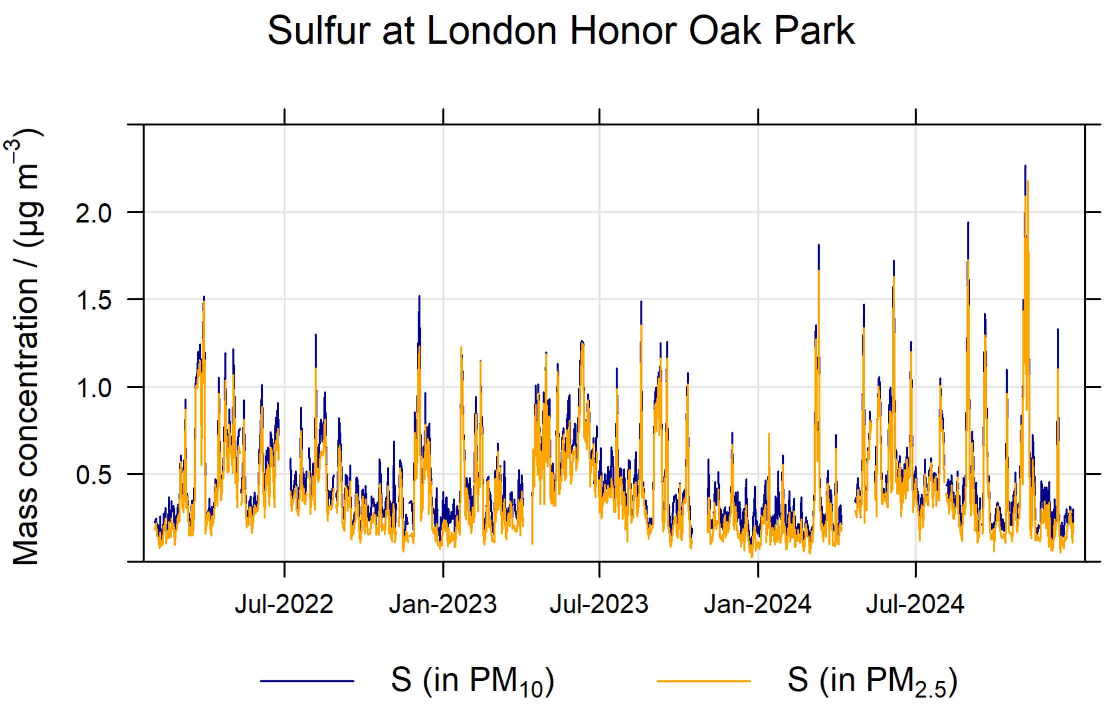


Figure 31 - Daily potassium concentrations in 2022-2024 at London Honor Oak Park and London Marylebone Road based on interpolated bihourly data. The tick marks on the x-axes indicate the start of every third month.



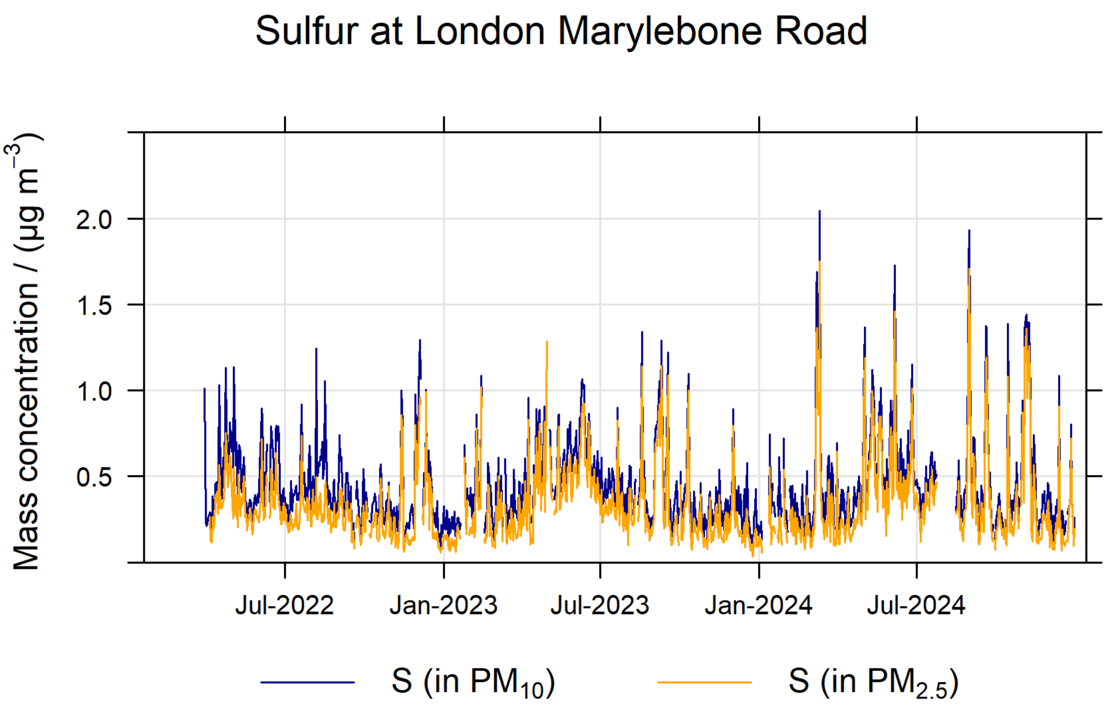
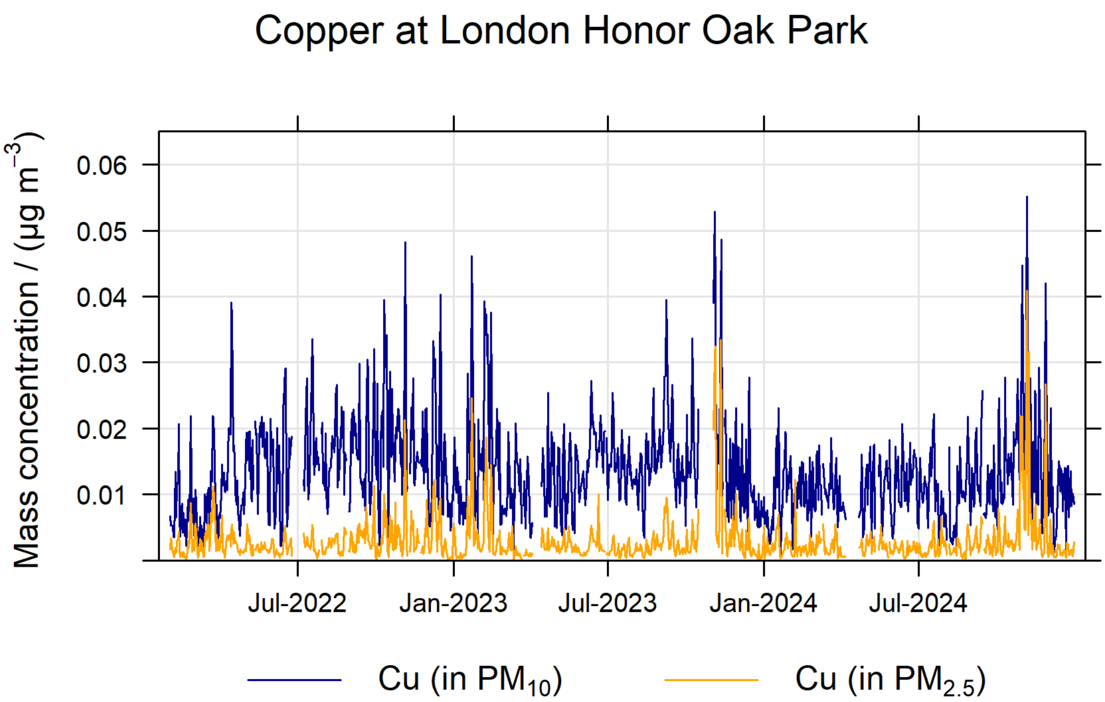


Figure 32 - Daily sulfur concentrations in 2022-2024 at London Honor Oak Park and London Marylebone Road based on interpolated bihourly data. The tick marks on the x-axes indicate the start of every third month.



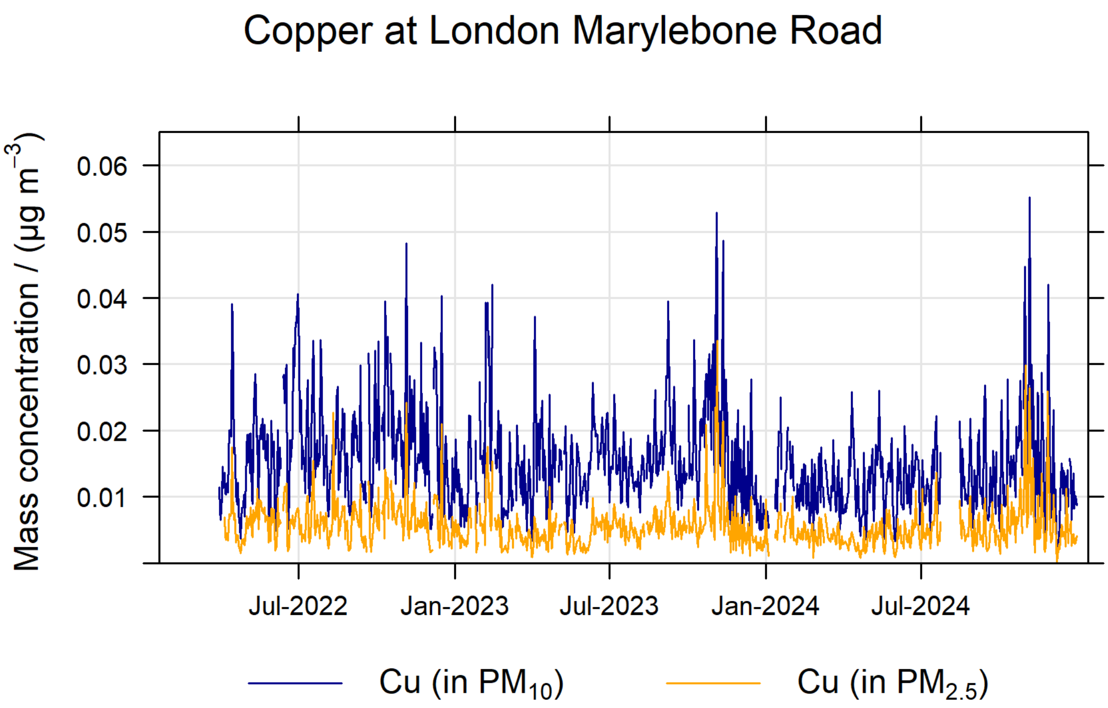
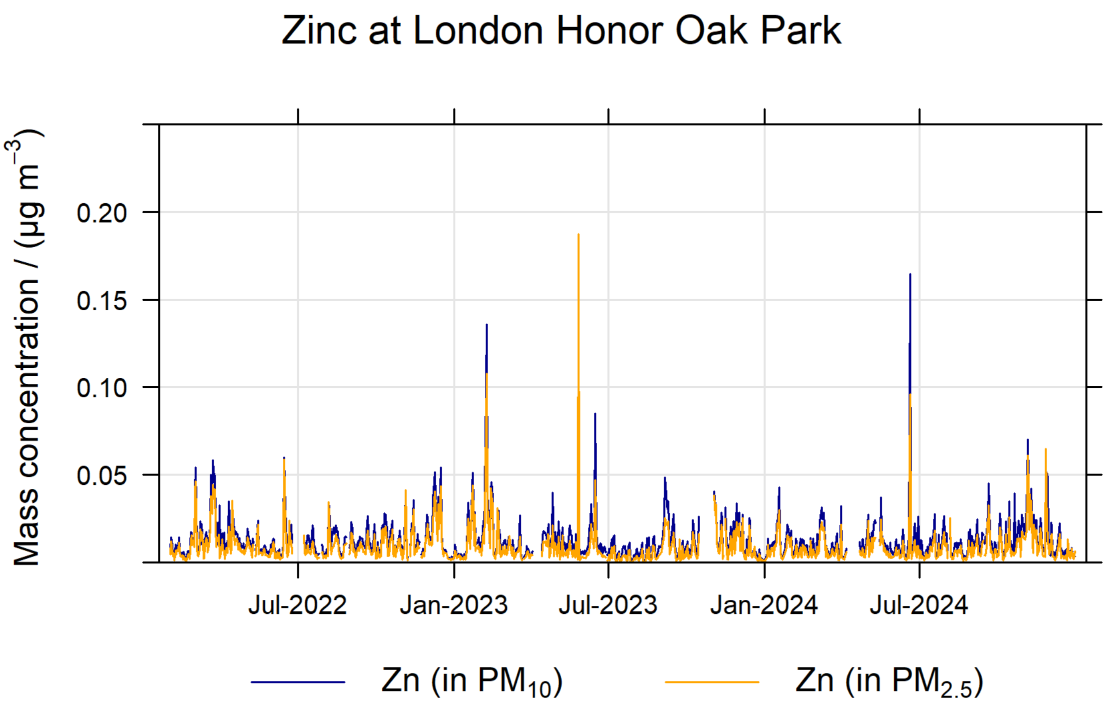


Figure 33 - Daily copper concentrations in 2022-2024 at London Honor Oak Park and London Marylebone Road based on interpolated bihourly data. The tick marks on the x-axes indicate the start of every third month.



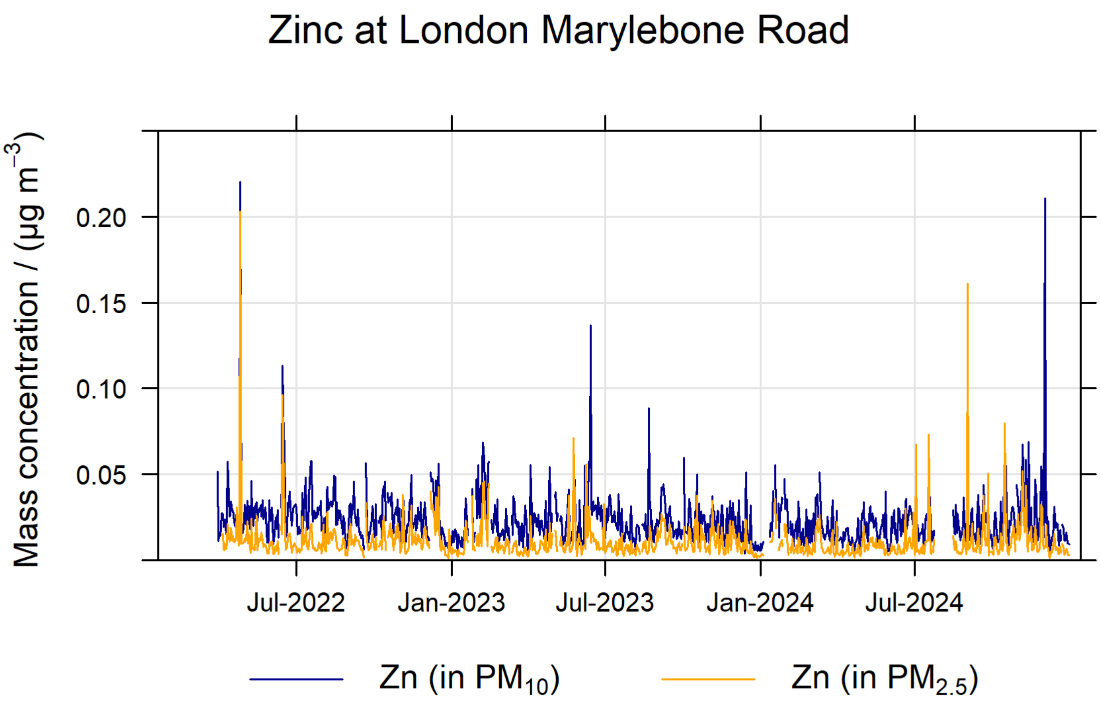


Figure 34 - Daily zinc concentrations in 2022-2024 at London Honor Oak Park and London Marylebone Road based on interpolated bihourly data. The tick marks on the x-axes indicate the start of every third month.

Table 13 – Annual mean mass concentration, LoD, and percentage of data below LoD in $PM_{2.5}$ and PM_{10} from XRF measurements at London Honor Oak Park and London Marylebone Road in 2024. The data are based on bihourly sampling, which is taken into account for the data capture calculation.

Element	LoD for metals in PM / (µg m^{-3})	London Honor Oak Park				London Marylebone Road			
		Mean $PM_{2.5}$ mass concentration / (µg m^{-3})	% of $PM_{2.5}$ data < LoD	Mean PM_{10} mass concentration / (µg m^{-3})	% of PM_{10} data < LoD	Mean $PM_{2.5}$ mass concentration / (µg m^{-3})	% of $PM_{2.5}$ data < LoD	Mean PM_{10} mass concentration / (µg m^{-3})	% of PM_{10} data < LoD
Ag	0.0033	0.00032	97	0.00029	95	0.0015	85	0.0015	85
Al	0.17	0.14	66	0.16	97	0.39	23	0.37	29
As	0.00011	0.0017	9.8	0.0019	66	0.0023	4.8	0.0028	2
Ba	0.00067	0.0012	74	0.003	7.9	0.0016	44	0.0084	8.6
Bi	0.00023	0.00023	98	0.00021	41	0.00017	98	0.00018	97
Br	0.00018	0.0032	2.8	0.0046	98	0.0033	1.7	0.0048	0.6
Ca	0.00052	0.039	2.7	0.2	1.2	0.059	0	0.38	0
Cd	0.0044	0.0018	85	0.0021	0.3	0.000043	100	0.000061	100
Ce	0.00052	0.000023	100	0.000018	83	0.0000021	100	0.0000002	100
Cl	0.003	0.42	3.7	1.3	100	0.34	6	1.2	0.9
Co	0.00024	0.000044	94	0.000034	0.7	0.0000027	100	0.0000016	100
Cr	0.0002	0.00031	61	0.00083	97	0.0007	32	0.0047	2.8
Cu	0.00014	0.0027	9.2	0.0062	25	0.005	0.7	0.019	0
Fe	0.0003	0.072	0.8	0.23	2.9	0.21	0	0.85	0
Ga	0.0001	0.0000002	100	0.0000005	0	0.0000021	100	0.0000007	100
Ge	0.0001	0.000003	99	0.0000025	100	0.0000005	100	0.0000005	100
Hg	0.00021	0.0000064	100	0.000005	100	0.0000041	100	0.0000025	100
In	0.0054	0.00071	97	0.00062	99	0.00021	100	0.00022	100
K	0.002	0.073	0.1	0.12	98	0.059	0.2	0.1	0
La	0.00063	0.0000091	100	0.000003	0	0.0000007	100	0	100
Mn	0.00025	0.00036	72	0.0017	100	0.00084	46	0.0054	3.5
Mo	0.00084	0.000047	99	0.000055	30	0.000047	99	0.00033	91

Element	LoD for metals in PM / (µg m^{-3})	London Honor Oak Park				London Marylebone Road			
		Mean $PM_{2.5}$ mass concentration / (µg m^{-3})	% of $PM_{2.5}$ data < LoD	Mean PM_{10} mass concentration / (µg m^{-3})	% of PM_{10} data < LoD	Mean $PM_{2.5}$ mass concentration / (µg m^{-3})	% of $PM_{2.5}$ data < LoD	Mean PM_{10} mass concentration / (µg m^{-3})	% of PM_{10} data < LoD
Ni	0.00017	0.00031	0	0.00036	0	0.00014	78	0.00032	55
P	0.009	0.0003	55	0.00024	51	0.00016	100	0.00035	100
Pb	0.00022	0.0014	100	0.0017	99	0.0019	47	0.0029	34
Pd	0.0038	0.0023	71	0.0022	67	0.0000004	100	0.0000038	100
Pt	0.0002	0.0000002	82	0.0000001	82	0.0000002	100	0.0000007	100
S	0.0055	0.36	100	0.43	100	0.37	0.1	0.47	0
Sb	0.009	0.0044	0.5	0.0047	0.2	0.00043	100	0.00057	99
Se	0.00014	0.00016	81	0.00018	79	0.000098	84	0.000096	83
Si	0.031	0.022	67	0.15	62	0.011	96	0.22	45
Sn	0.0071	0.00087	94	0.00086	61	0.0015	96	0.0023	91
Sr	0.00038	0.00034	97	0.00071	97	0.00036	88	0.0014	35
Te	0.001	0.0003	91	0.00027	73	0.0049	31	0.0048	33
Ti	0.00028	0.0018	96	0.0071	96	0.0023	11	0.014	0.4
Tl	0.0002	0.0000003	20	0.0000003	4.1	0.0000002	100	0.0000001	100
V	0.00021	0.00043	100	0.00047	100	0.00031	76	0.00034	73
Y	0.00048	0.000028	65	0.000027	64	0.000057	97	0.000065	97
Zn	0.00012	0.008	99	0.012	98	0.01	0.1	0.021	0
Zr	0.00057	0.000078	2.1	0.00019	0.9	0.00014	93	0.0017	31

4.5 OC AND EC

4.5.1 Introduction

OC is present in urban environments in primary PM and in secondary organic aerosol (SOA). SOA PM is dominant in rural locations, particularly during the summer, as a result of biogenic emissions, and contributes to regional episodes of high PM concentrations. EC (essentially soot) is usually formed by high temperature combustion of fossil fuels, predominantly from heavy hydrocarbons (such as diesel) and certain biofuels. Measurements of EC at urban and roadside locations are required to improve emission inventories and to determine the impacts of vehicle emissions.

$PM_{2.5}$ sampling at Chilbolton Observatory and Auchencorth Moss is carried out to comply with a statutory requirement under the AQSR[4,5,6,7] (and all associated amendments), which requires measurements of OC and EC in $PM_{2.5}$ in rural background areas.

The sampler previously stationed at Harwell (from 1 September 2011) was moved to Chilbolton Observatory and has operated there since 4 February 2016. The sampler at Auchencorth Moss has been operational since 17 November 2011.

4.5.2 2024 time series

The annual time series of OC, EC, and TC (the sum of OC and EC) for each site are displayed in Figure 35 to Figure 38. The plots for London Marylebone Road, London Honor Oak Park, and Chilbolton Observatory comprise daily data; the plot for Auchencorth Moss comprises weekly data.

4.5.3 Long-term trends

Figure 39 and Figure 40 show the long-term time series for the measurements since the installation of the samplers at Harwell / Chilbolton Observatory and Auchencorth Moss. The daily data from Chilbolton Observatory (February 2016 - December 2024) is plotted as weekly averages to provide continuity with the weekly data from the former Harwell site.

Figure 41 shows the long-term trends in annual average mass concentrations for OC, EC, and TC measurements for the daily sampling at the two London sites (London Marylebone Road and London Honor Oak Park).

The London Marylebone Road OC, EC and TC concentrations showed a downward trend over the period 2008 to 2020. The period after 2020 shows more stable concentrations for EC and an upward trend for OC and TC concentrations until 2023 and then decline at both the sites in 2024.

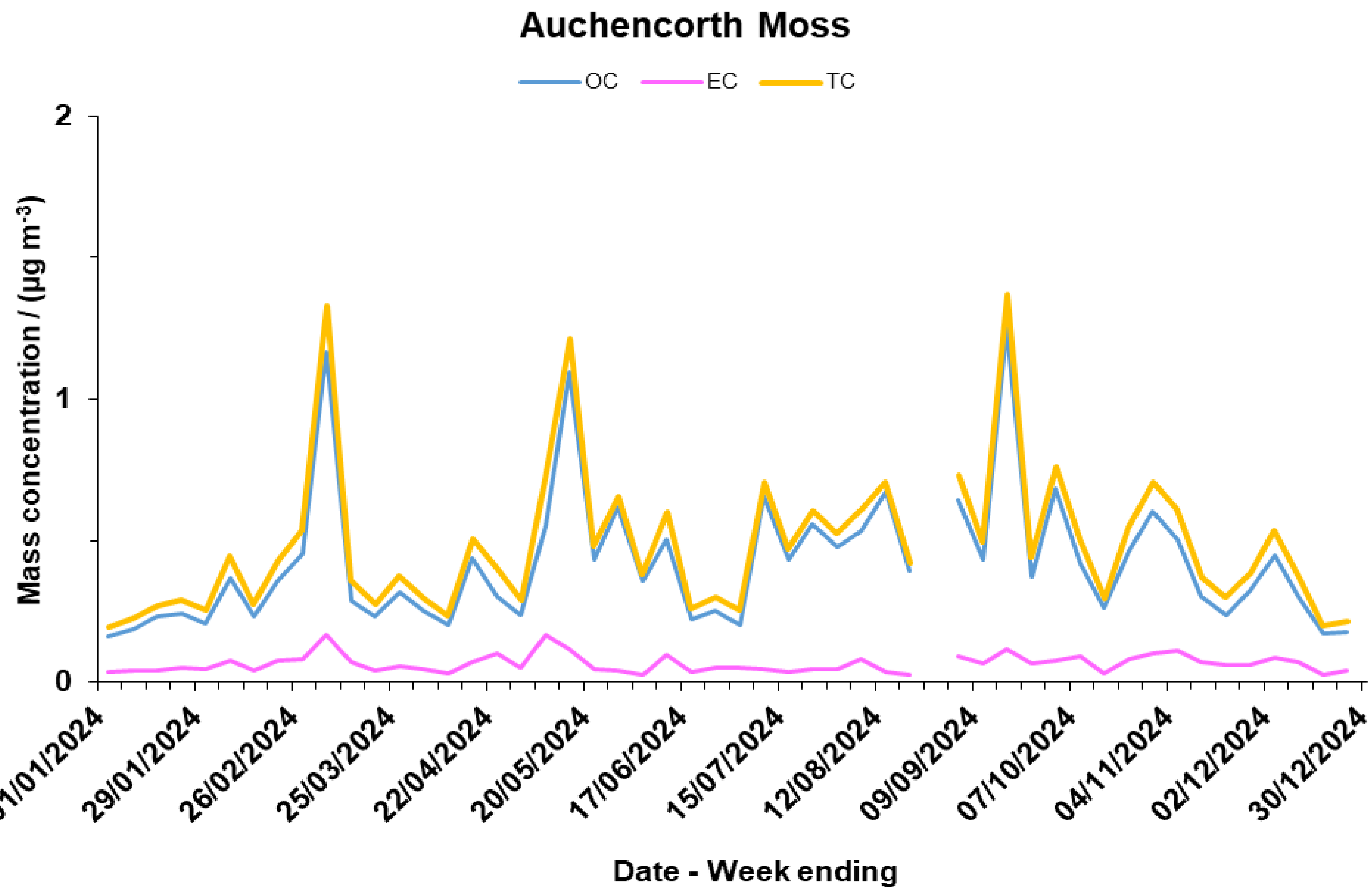


Figure 35 **- Weekly OC, EC, and TC mass concentrations in $PM_{2.5}$ measured at Auchencorth Moss during 2024.**

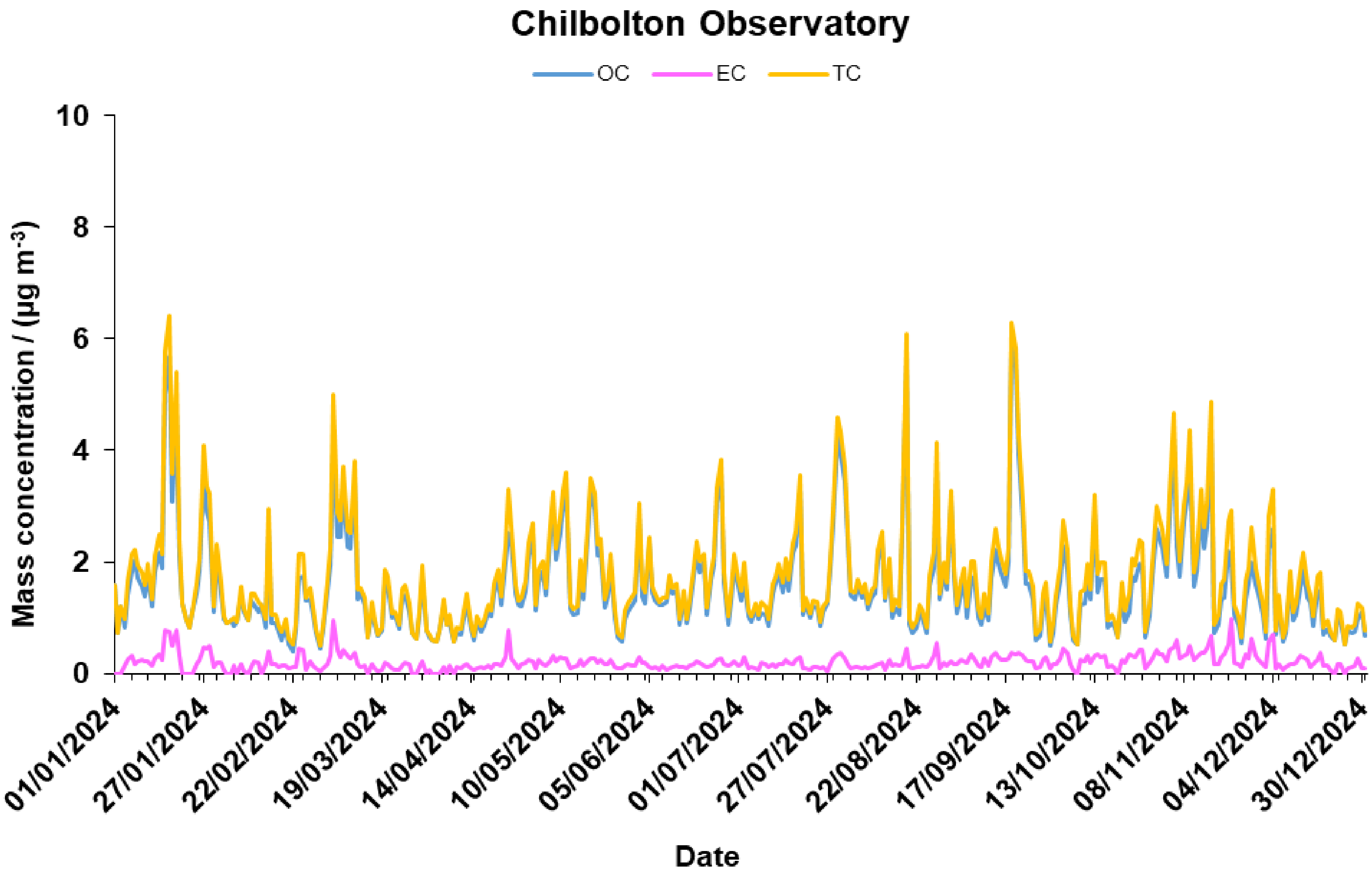


Figure 36 - Daily OC, EC, and TC mass concentrations in $PM_{2.5}$ measured at Chilbolton Observatory during 2024.

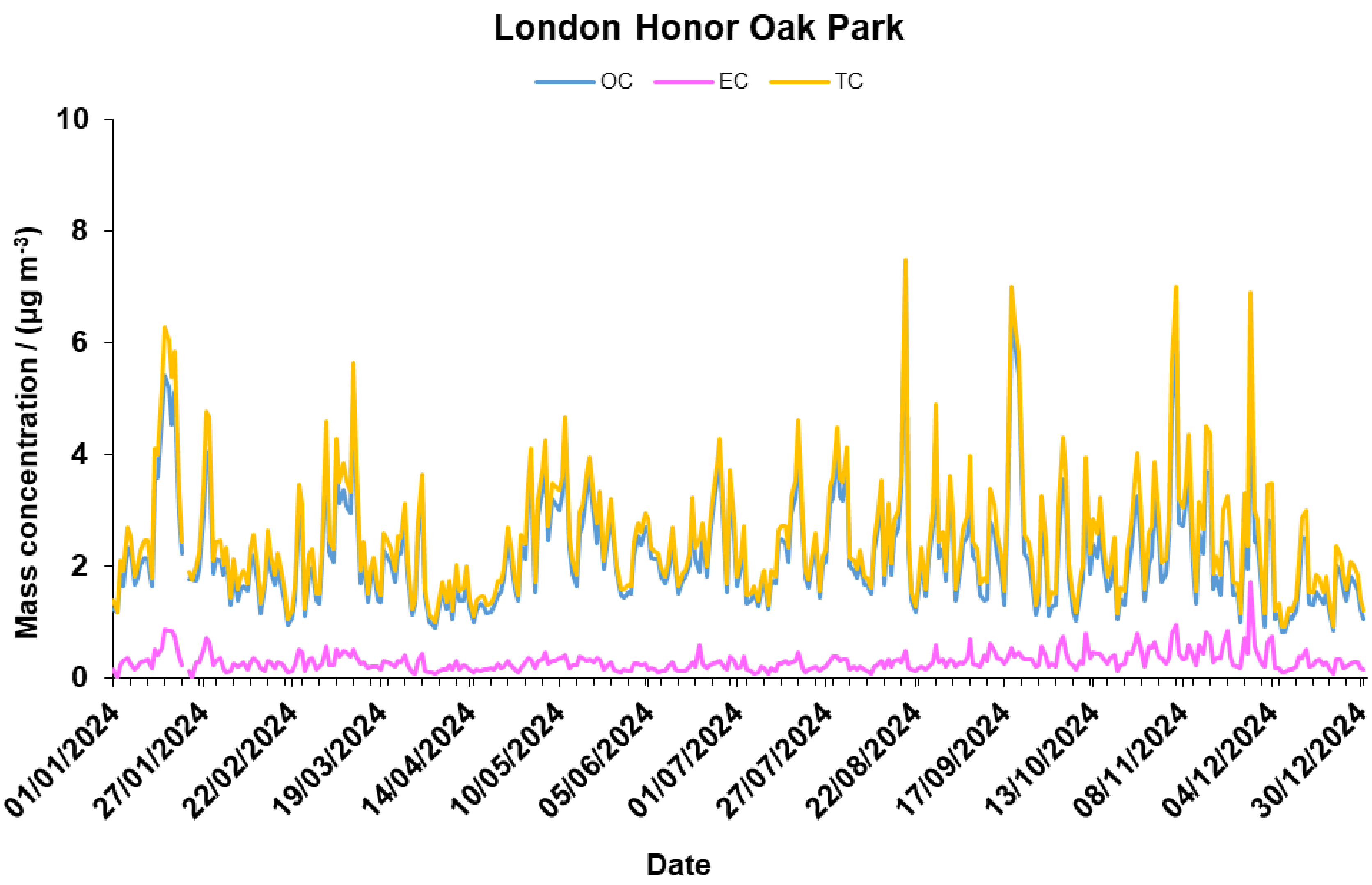


Figure 37 - Daily OC, EC, and TC mass concentrations in $PM_{2.5}$ measured at London Honor Oak Park during 2024.

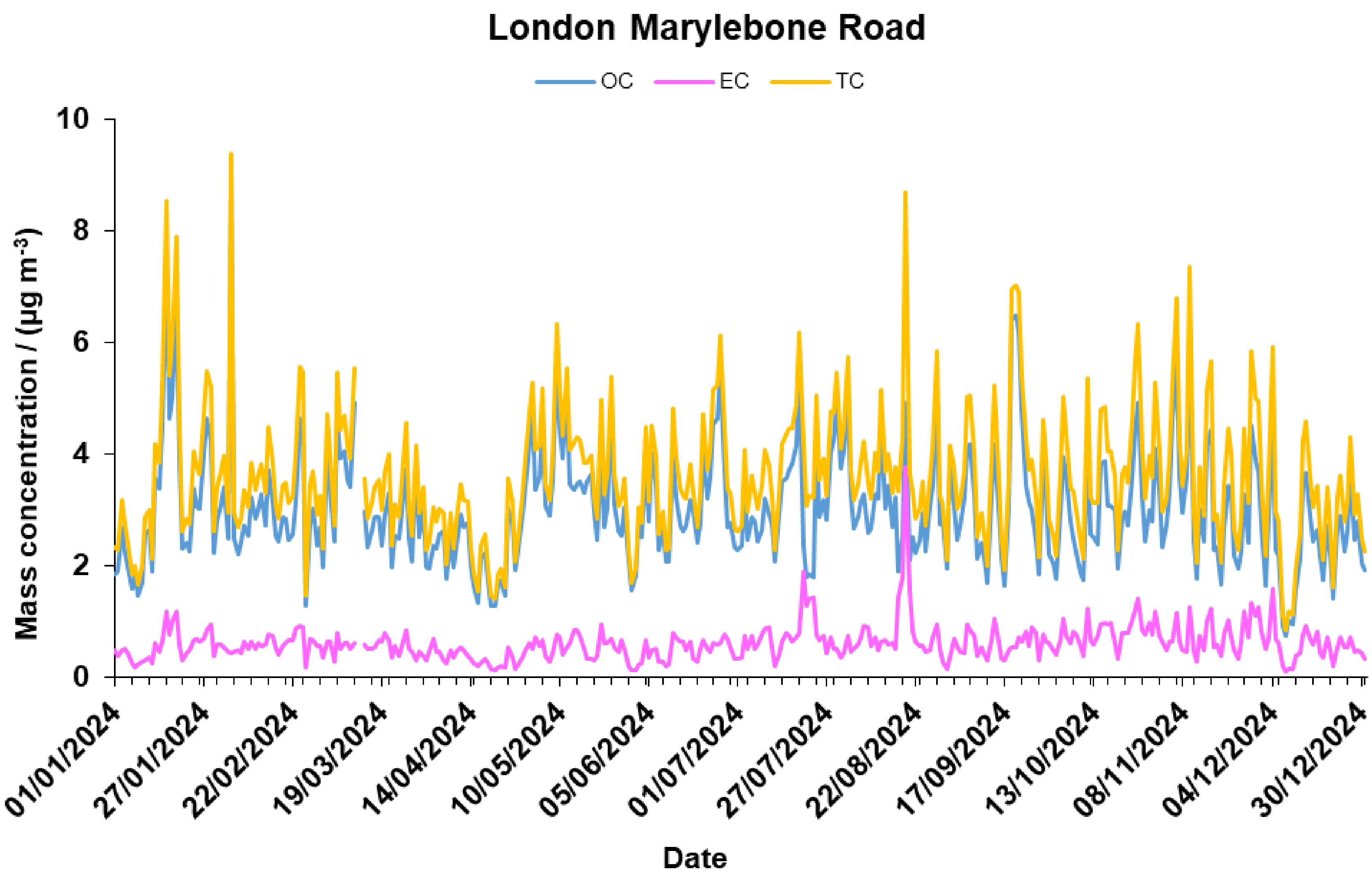


Figure 38 **- Daily OC, EC, and TC mass concentrations in $PM_{2.5}$ measured at London Marylebone Road during 2024.**

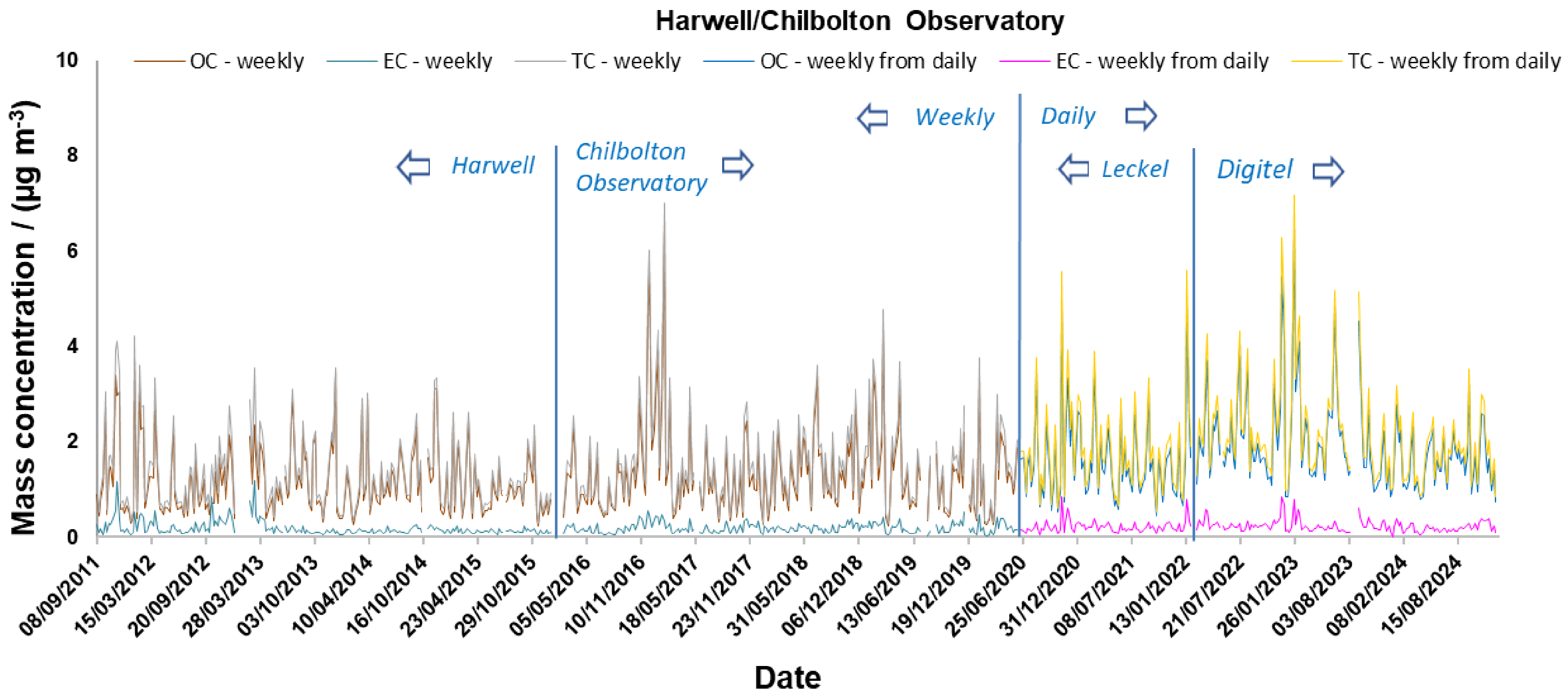


Figure 39 - Time series of the weekly OC, EC, and TC mass concentrations in the $PM_{2.5}$ fraction at Harwell/Chilbolton Observatory since the installation of the sampler up to June 2020, and daily mass concentrations from 11 June 2020. The sampler was replaced by a Digitel sampler in January 2022. The daily mass concentrations measured since June 2020 have been plotted as calculated weekly averages for consistency.

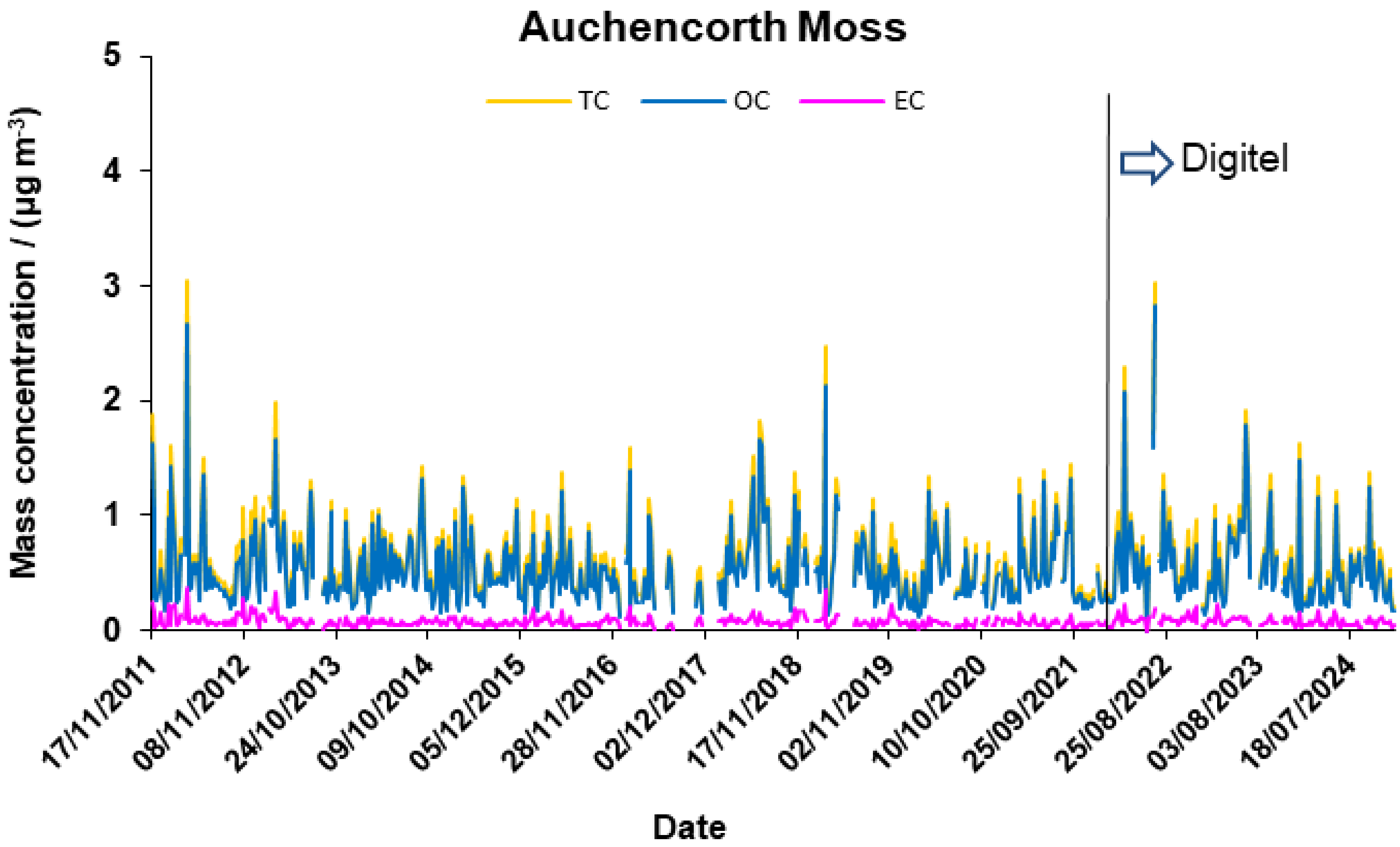


Figure 40 - Time series of weekly OC, EC, and TC in the $PM_{2.5}$ fraction at Auchencorth Moss to the end of 2024.

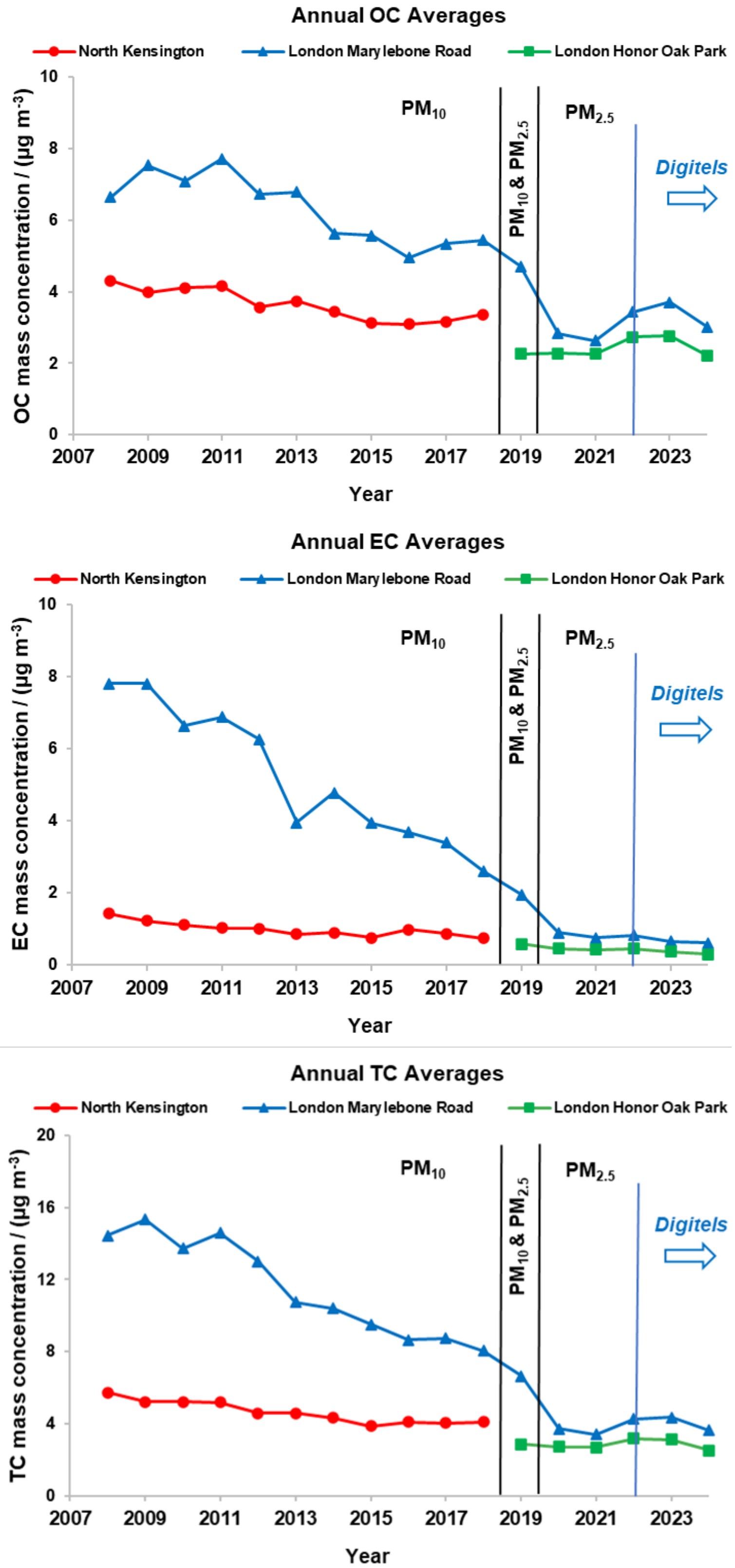


Figure 41 - Annual trends for OC, EC, and TC measurements. PM_{10} sampling heads were changed to $PM_{2.5}$ heads at London Honor Oak Park and London Marylebone Road in February 2019 and October 2019, respectively (therefore PM_{10} and $PM_{2.5}$ were both collected in 2019). Partisol samplers were replaced with Digitel samplers at London Honor Oak Park and London Marylebone Road in 2022.

4.6 BC AND UVPM (BAU)

4.6.1 Introduction

BC and UVPM concentration data for 2024 are presented and discussed in the following sections as time series graphs, summary graphs and tables. It should be noted that the Aethalometers at all sites were upgraded in November 2019 from model AE22 to model AE33. Thus, all results provided in this report should be treated with caution especially when comparing earlier years when the AE22 model was used (see details in section 2.5.6).

The AE33 Aethalometer calculates mass concentration at seven wavelengths: 950 nm (infrared, IR-2), 880 nm (BC), 660 nm (Red), 590 nm (Yellow), 520 nm (Green), 470 nm (Blue), and 370 nm (UV). Annual mean data from all channels are shown in Table 14.

Table 14 - Annual mean of particulate matter concentrations measured in $PM_{2.5}$ at specific wavelengths (indicated in nm in brackets) by AE33 Aethalometers in 2024.

	Mass concentration in $PM_{2.5}$ / (µg m^{-3})							
Site	**UV** (370)	**Blue** (470)	**Green** (520)	**Yellow** (590)	**Red** (660)	**BC** (880)	**IR-2** (950)	**UVPM**
Auchencorth Moss	0.18	0.17	0.16	0.16	0.15	0.14	0.14	0.02
Ballymena Ballykeel	0.89	0.77	0.70	0.67	0.63	0.60	0.65	0.28
Belfast Centre	0.88	0.83	0.77	0.76	0.72	0.69	0.72	0.18
Birmingham A4540 Roadside	1.60	1.62	1.53	1.50	1.44	1.42	1.43	0.17
Birmingham Ladywood	0.68	0.67	0.64	0.62	0.59	0.58	0.62	0.10
Cardiff Centre	0.84	0.84	0.85	0.86	0.84	0.83	0.77	0.01
Chilbolton Observatory	0.40	0.36	0.33	0.31	0.30	0.28	0.28	0.12
Detling	0.53	0.49	0.47	0.45	0.42	0.40	0.41	0.13
Glasgow High Street	0.66	0.66	0.63	0.61	0.58	0.58	0.59	0.08
Glasgow Townhead	0.48	0.47	0.44	0.44	0.42	0.41	0.44	0.06
Kilmakee Leisure Centre	0.72	0.65	0.60	0.58	0.55	0.52	0.55	0.19
London Honor Oak Park*	0.84	0.76	0.69	0.66	0.62	0.58	0.63	0.25
London Marylebone Road	0.88	0.84	0.81	0.78	0.75	0.73	0.74	0.15
London North Kensington	0.66	0.61	0.56	0.54	0.51	0.49	0.50	0.17
Strabane 2	1.82	1.49	1.37	1.28	1.21	1.13	1.13	0.68
Average*	**0.80**	**0.75**	**0.70**	**0.68**	**0.65**	**0.63**	**0.64**	**0.17**

* London Honor Oak Park was included in BC Network from 1 November 2024 thus results from this site are excluded from the annual average.

4.6.2 2024 time series - BC

Figure 42 to Figure 46 show the BC mass concentrations measured in 2024. The time resolution of the measurements is hourly, and the data have been split into separate figures covering different areas of the UK for clarity. As seen in previous years, Northern Ireland sites generally measured increased concentrations during the colder months from October to mid-April, indicating the contribution from domestic heating.

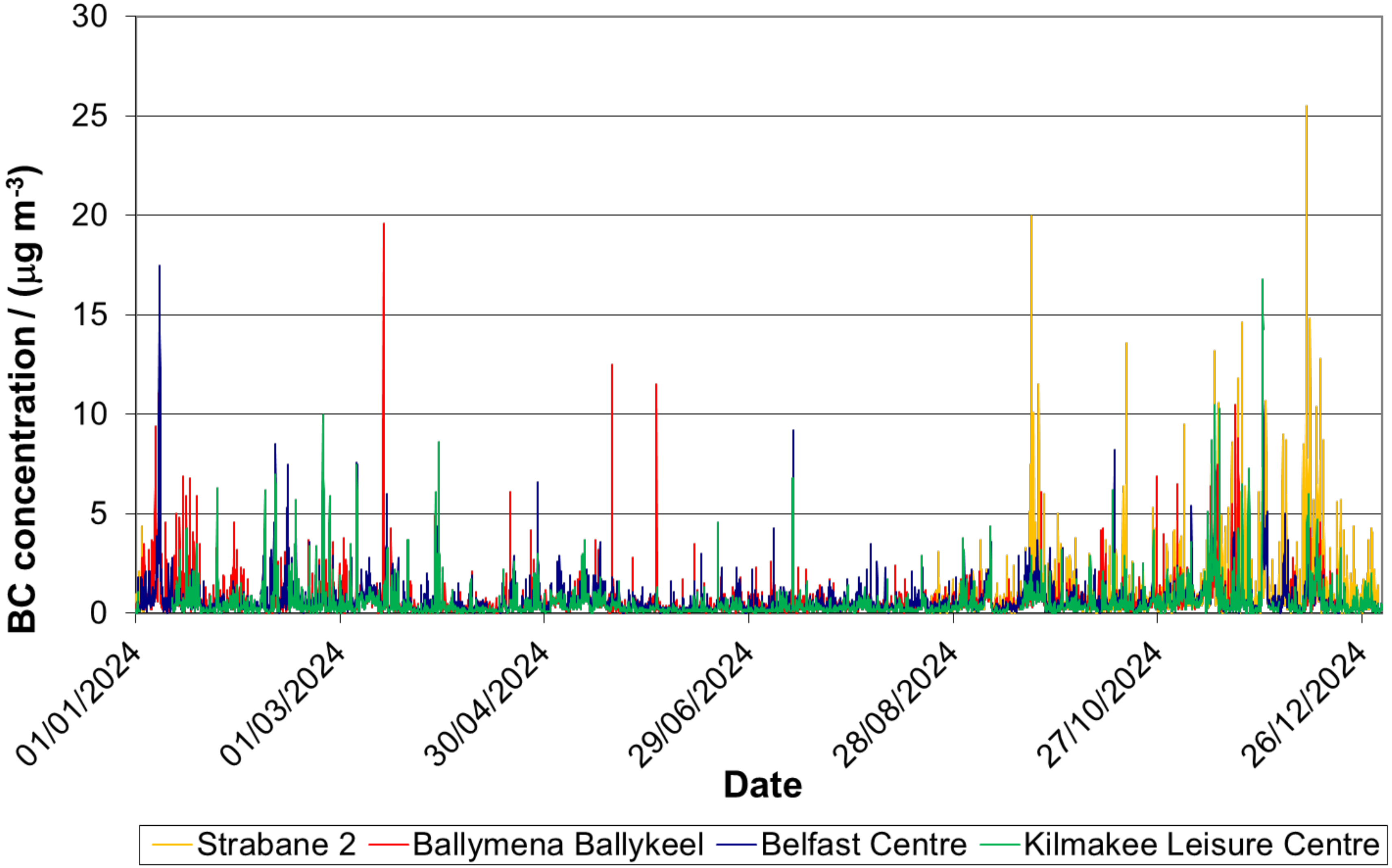


Figure 42 - BC concentrations during 2024 in Northern Ireland.

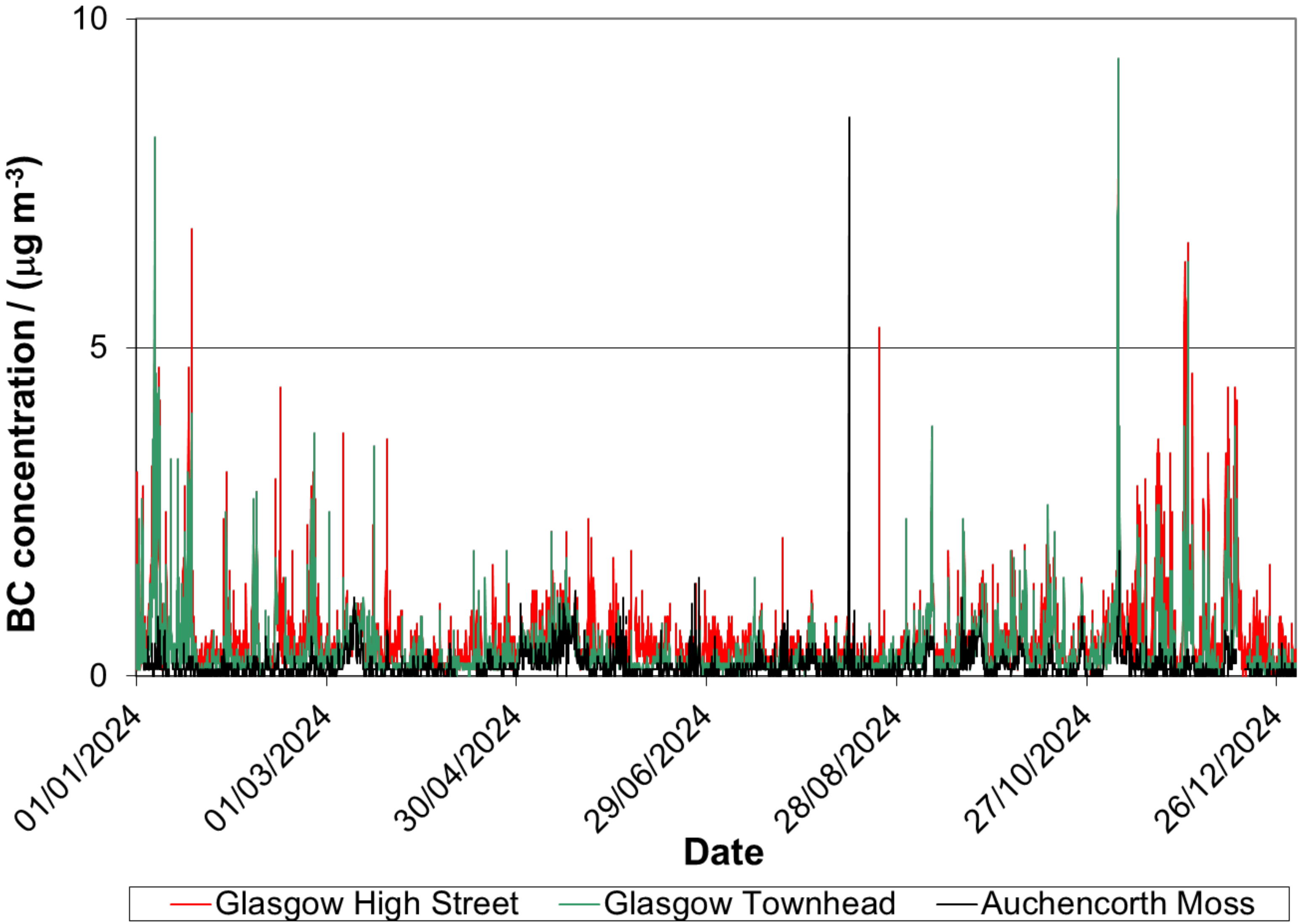


Figure 43 - BC concentrations during 2024 in Scotland.

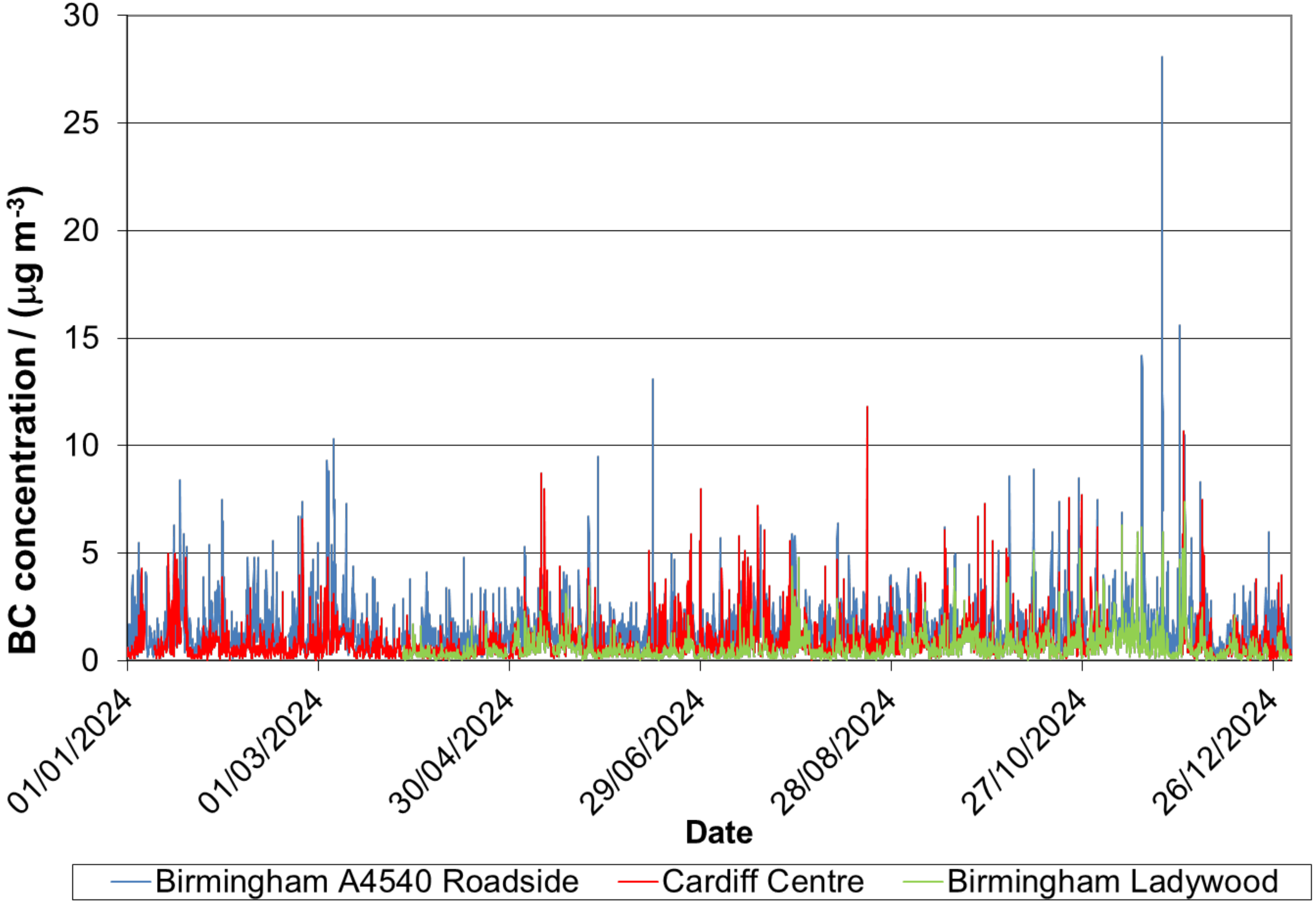


Figure 44 - BC concentrations during 2024 in Wales and the Midlands.

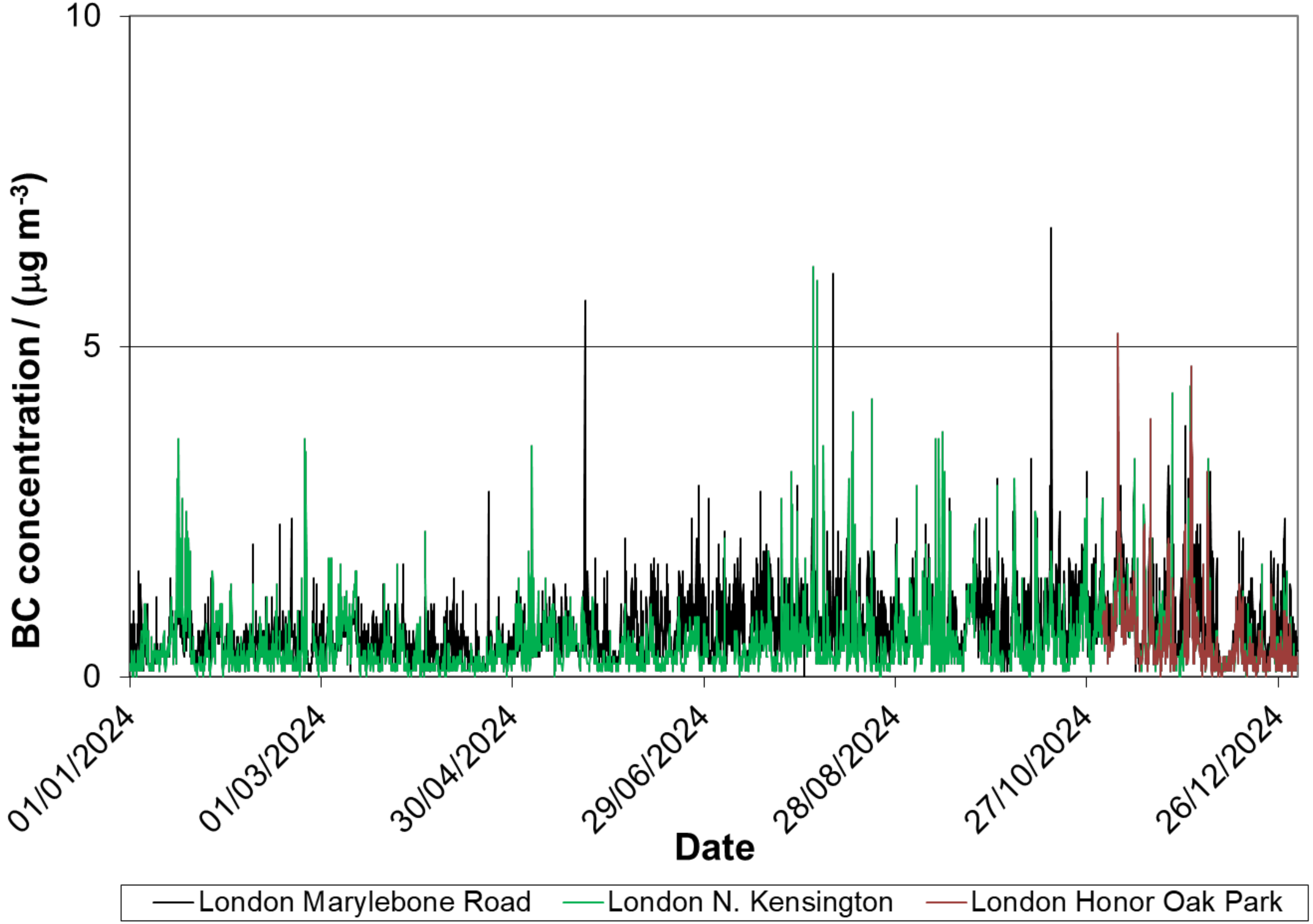


Figure 45 - BC concentrations during 2024 in London.

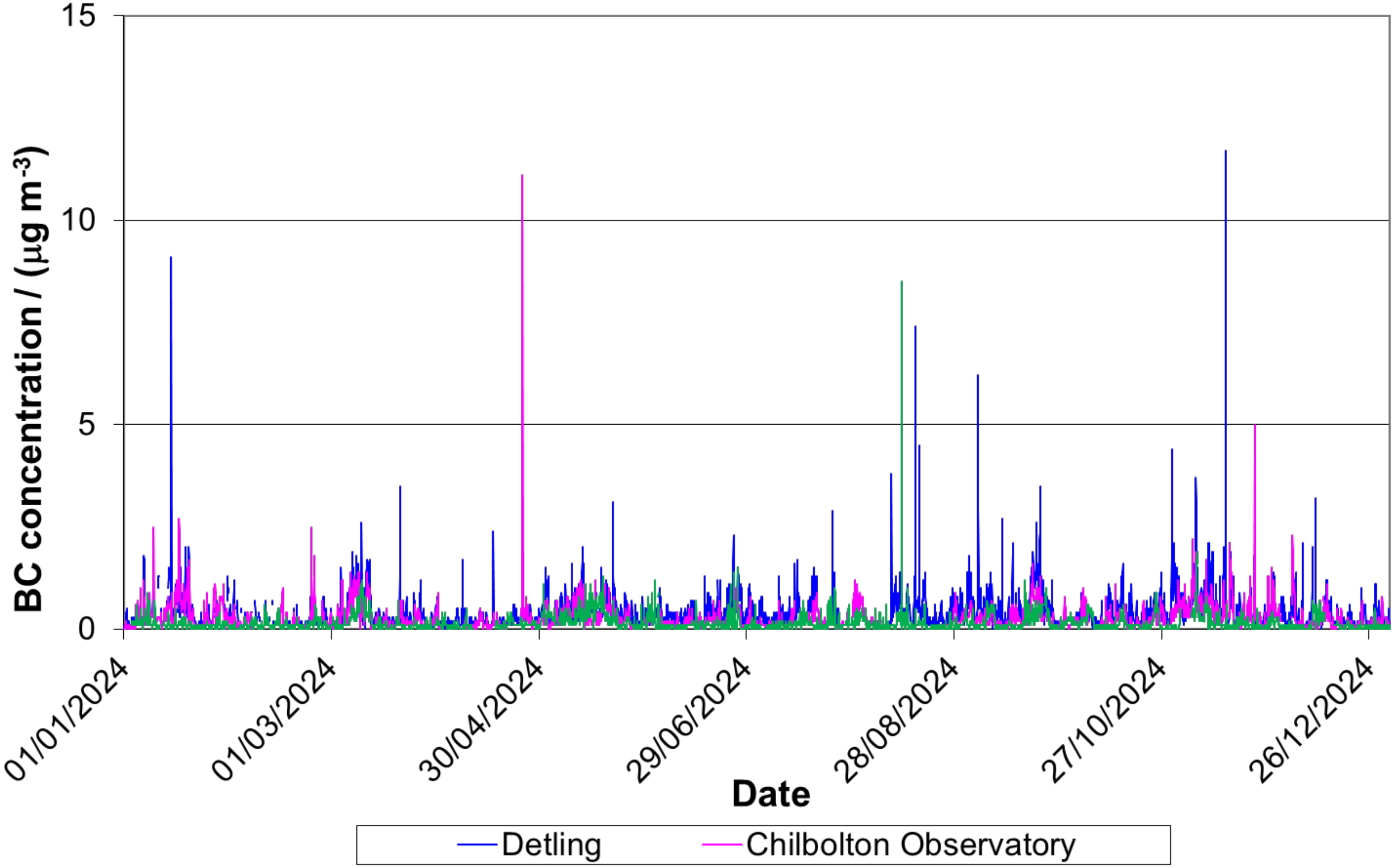


Figure 46 - BC concentrations during 2024 at rural locations.

4.6.3 2024 annual averages - BC

The annual mean concentrations are presented as a bar graph (Figure 47) to aid the comparison between sites.

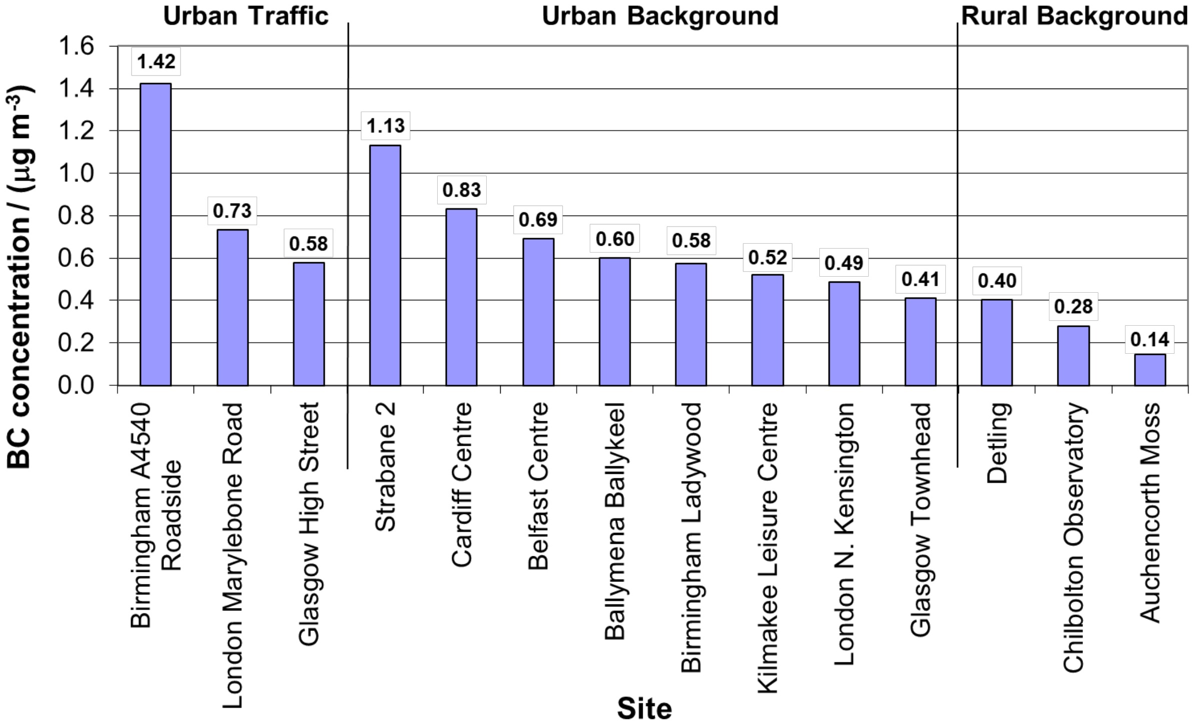


Figure 47 - Annual mean BC concentrations measured in 2024.

BC urban and roadside increments for London, Birmingham and Glasgow were calculated by subtracting the averaged rural concentrations from the averaged background concentrations. Table 15 shows these results.

The urban and roadside increments for London and Glasgow were lower in 2024 compared to 2023. The urban increment for Birmingham in 2024 was 0.32 µg m^{-3} whereas in 2023 it was 0.26 µg m^{-3}. However, the data capture for this conurbation was limited in the second half of 2023 and beginning of 2024, thus the comparison should be treated with caution. The roadside increment for Birmingham in 2024 was 0.82 µg m^{-3}, larger than those for London and Glasgow.

Figure 48 shows how the urban and roadside increments in London have changed over the period 2012 to 2024. The average urban increment (UB) is roughly stable, with increases during the cold periods indicating the contribution from domestic heating. The roadside increment (RS) for London has clearly dropped steadily over the period and is currently at similar levels as the urban increment. It should be noted that increment calculations are only possible for periods where parallel measurements are gathered from all London sites including two rural sites: Chilbolton Observatory and Detling. Both sites had issues with leaks in 2017, 2018 and 2021 which caused the gaps in Figure 48.

Table 15 - Urban and roadside increments in BC concentrations in 2024

	BC increment / (µg m^{-3})	
Conurbation	**Urban**	**Roadside**
London	0.16	0.24
Birmingham	0.32	0.82
Glasgow	0.27	0.16

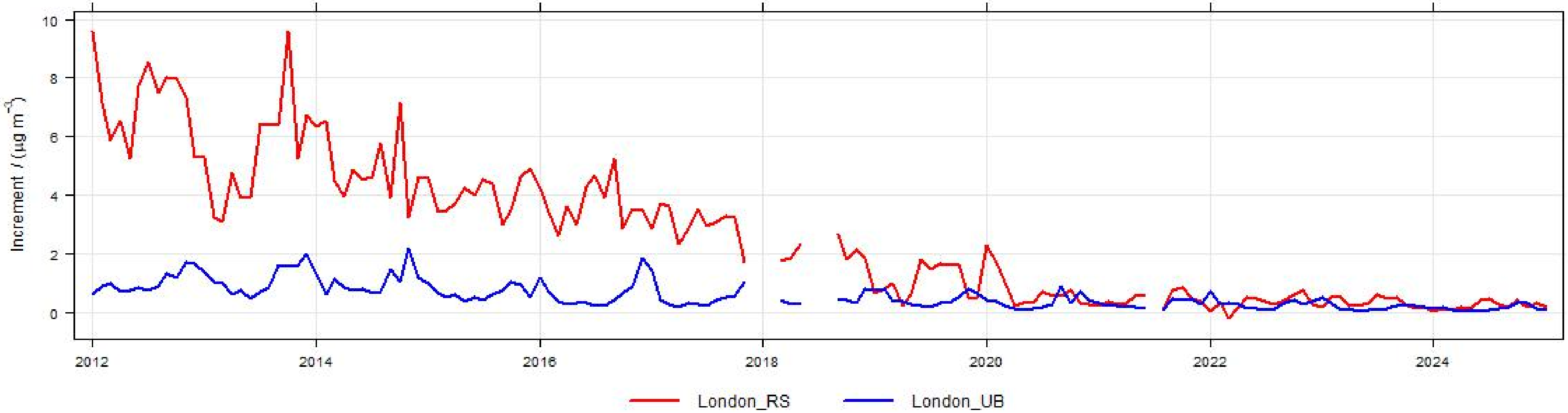


Figure 48 - Urban (UB) and roadside (RS) increments in London for the period 2012 to 2024. The tick marks on the x-axis indicate the start of the year indicated.

4.6.4 2024 annual averages - UVPM

The annual mean concentrations are presented as a bar graph (Figure 49) to aid the comparison between sites.

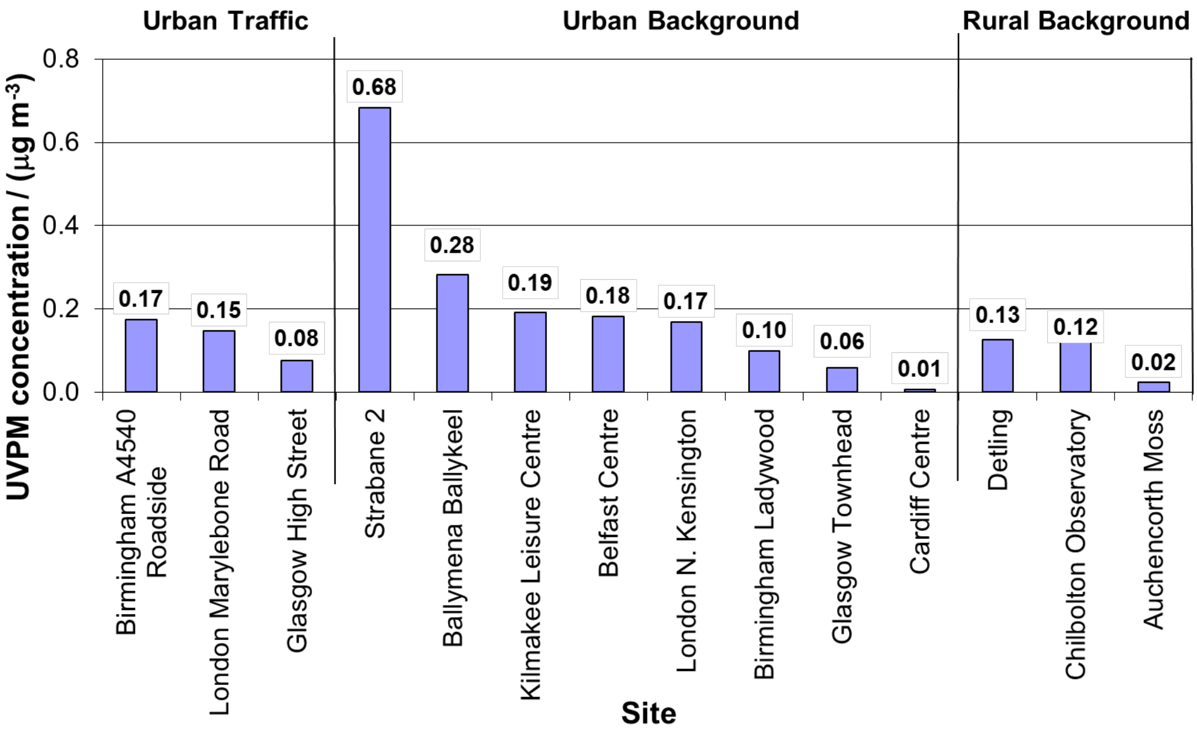


Figure 49 - Annual mean UVPM concentrations for 2024

UVPM urban and roadside increments for London, Birmingham and Glasgow have been calculated by subtracting the averaged rural concentrations from the averaged background concentrations. Table 16 shows these calculated results.

Table 16 - Urban and roadside increments in UVPM concentrations in 2024

	UVPM increment / (µg m^{-3})	
Conurbation	**Urban**	**Roadside**
London	0.05	-0.02
Birmingham	0.01	0.06
Glasgow	0.04	0.01

The urban and roadside increments at all sites were small (or slightly negative), indicating that domestic emissions or other potential sources of UVPM (such as road traffic) in the three conurbations were negligible. Only the urban increment in Birmingham changed from −0.05 µg m^{-3} in 2023 to 0.01 µg m^{-3} in 2024, whereas in London and Glasgow there was no significant difference in increments between 2023 and 2024.

Using the same method, the urban increment in UVPM concentration in Northern Ireland was calculated relative to Belfast Centre, where gas heating has largely displaced oil and coal heating since 2000. The results are shown in Table 17.

Table 17 - Increment in UVPM concentration in Northern Ireland

	Increment compared to Belfast Centre / (µg m^{-3})	Increment compared to Belfast Centre / %
Kilmakee Leisure Centre	0.03	17
Ballymena Ballykeel	0.11	60
Strabane 2	0.55	303

The increments at Kilmakee Leisure Centre, Ballymena Ballykeel and Strabane 2 are in line with a history of solid fuel usage for secondary heating in the area of Kilmakee Leisure Centre site, and a significant usage of fuel other than smokeless fuel in Strabane 2. Changes in the UVPM increment in Northern Ireland over the last ten years are summarised in Figure 50.

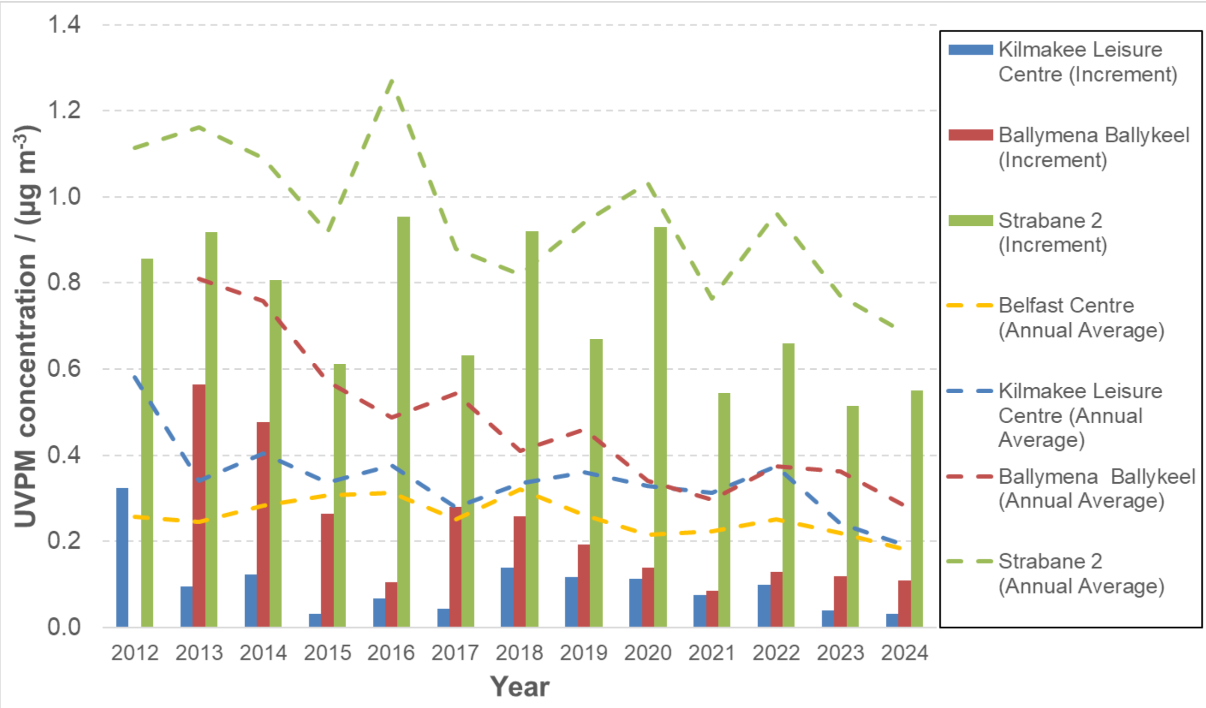


Figure 50 - Annual Mean UVPM concentrations and increments compared to Belfast Centre for 2012-2024.

4.6.5 Diurnal, weekly, and monthly profiles - BC and UVPM

This section presents analysis of the temporal variation in BC and UVPM concentrations. All results have been grouped by site classification: roadside, urban background, and rural background. The units on the y-axes are mass concentration in µg m^{-3} for BC and UVPM; the scales vary by site. The 2024 data are presented in Figure 51 to Figure 64.

Data from 2009-2024 are presented in Figure 65 to Figure 69. These 15-year average plots only include those sites which have been operating for the whole of this period. The Chilbolton Observatory site was seen to record significantly different concentrations from that at Harwell, so the latter site has been removed from the long-term time series plots. Charts of variations over the day of the week and the month using the data from 2009 - 2024, are considered to be less biased when compared to the single year (2024) measurements presented in Figure 51 to Figure 64.

Figure 51 to Figure 69 are generated using the OpenAir Tools run on the R software platform[27,28].

At roadsides on weekdays the BC concentrations followed the expected profile resulting from traffic emissions through the day, with elevated concentrations in the morning and evening rush hours. This double peak can be seen at all the roadside sites apart from London Marylebone Road, where concentrations are mostly stable during daytime. The weekend days showed slightly lower and more constant BC concentrations, particularly at London Marylebone Road. There was little UVPM observed at any of the roadside sites.

BC concentrations measured at urban background sites of Belfast Centre, Cardiff Centre, Glasgow Townhead, Kilmakee Leisure Centre, and London North Kensington showed a signature from traffic, with a peak in the morning rush hour with little corresponding increase in UVPM concentrations. Peaks related to the evening rush hour were also seen, but these often also showed an increase in UVPM concentrations. This indicates a domestic emission source, which is likely from secondary heating. Strabane 2 site is predominantly influenced by emissions from domestic heating, which can be seen during weekdays and weekends.

At rural sites the concentrations were lower than at the other site classifications, and did not exhibit morning or evening rush hour peaks. The rise in concentrations in the evening occurred at later times than would be expected for a traffic signal, and were also observed in the UVPM, suggesting a domestic heating source.

BC and UVPM data at roadside sites for 2024

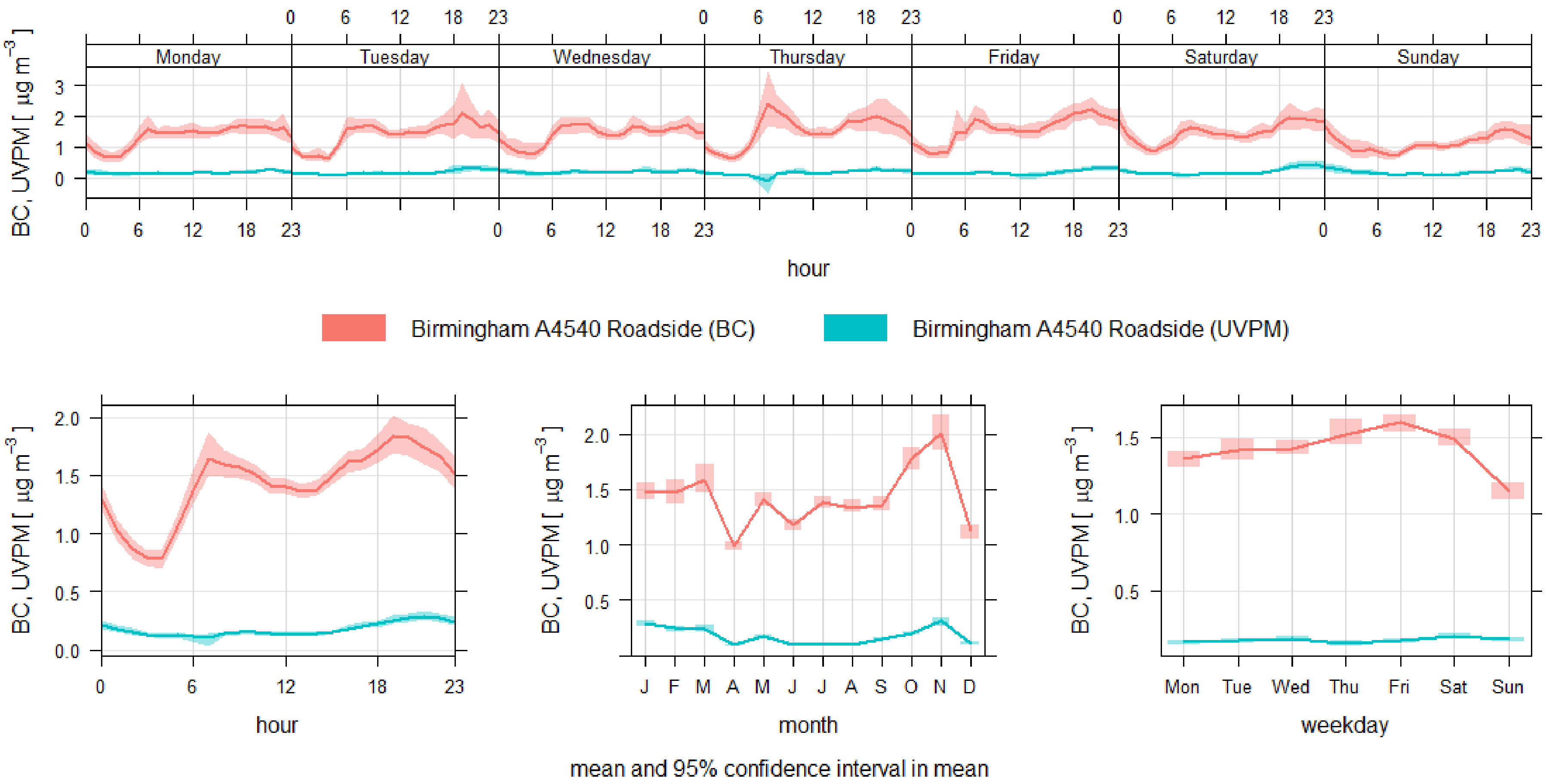


Figure 51 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Birmingham A4540 Roadside for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

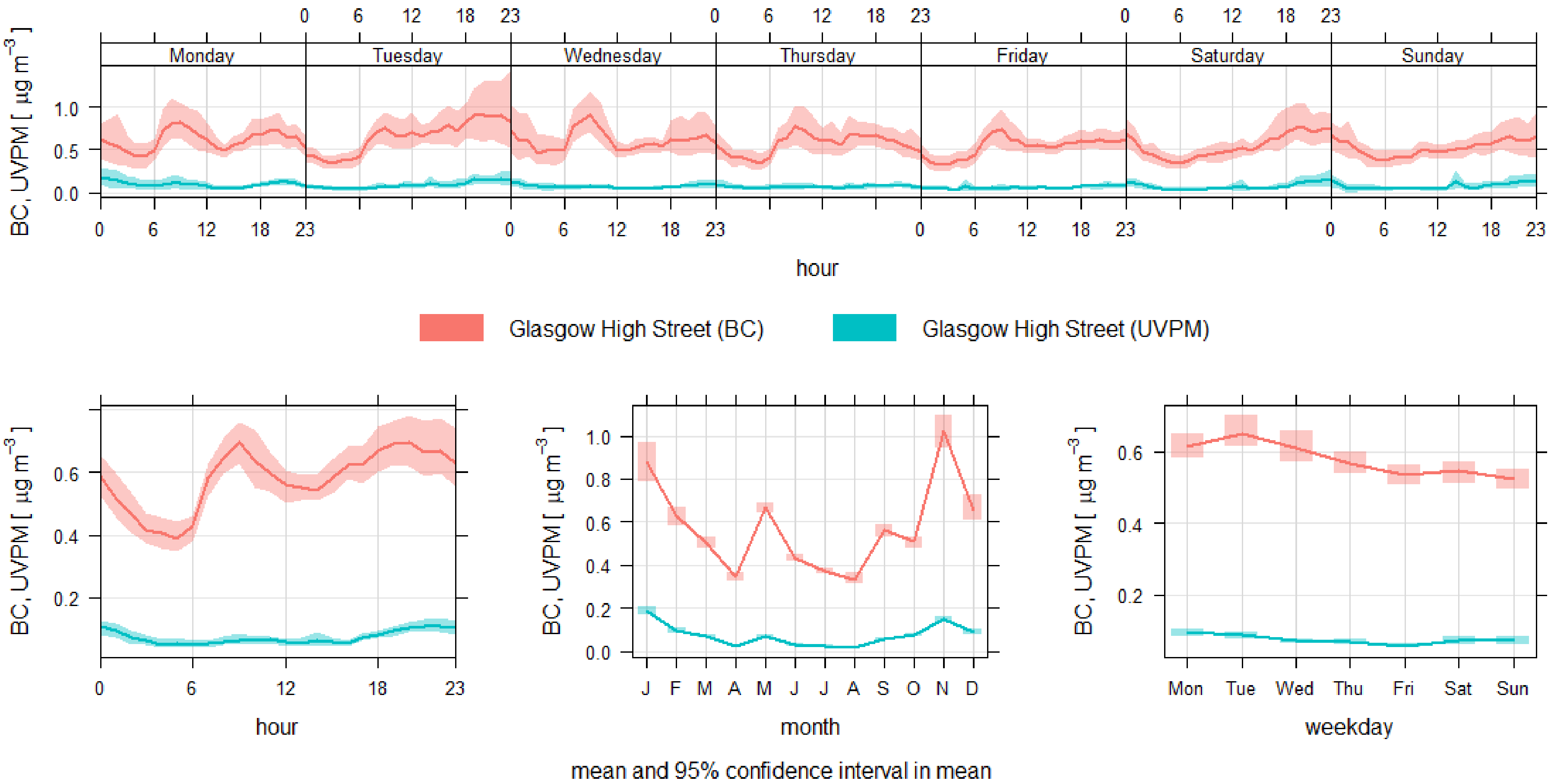


Figure 52 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Glasgow High Street for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

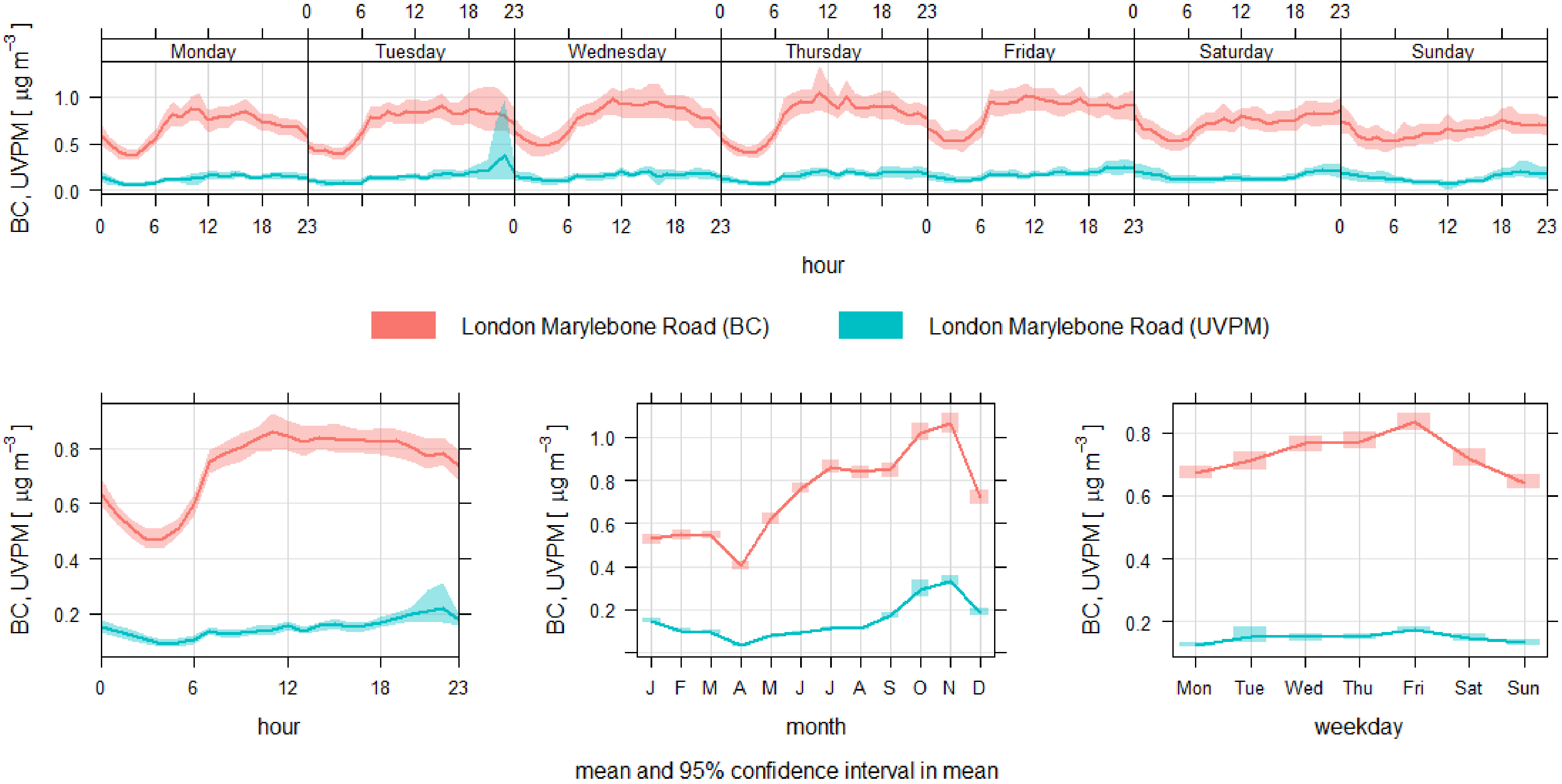


Figure 53 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at London Marylebone Road for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

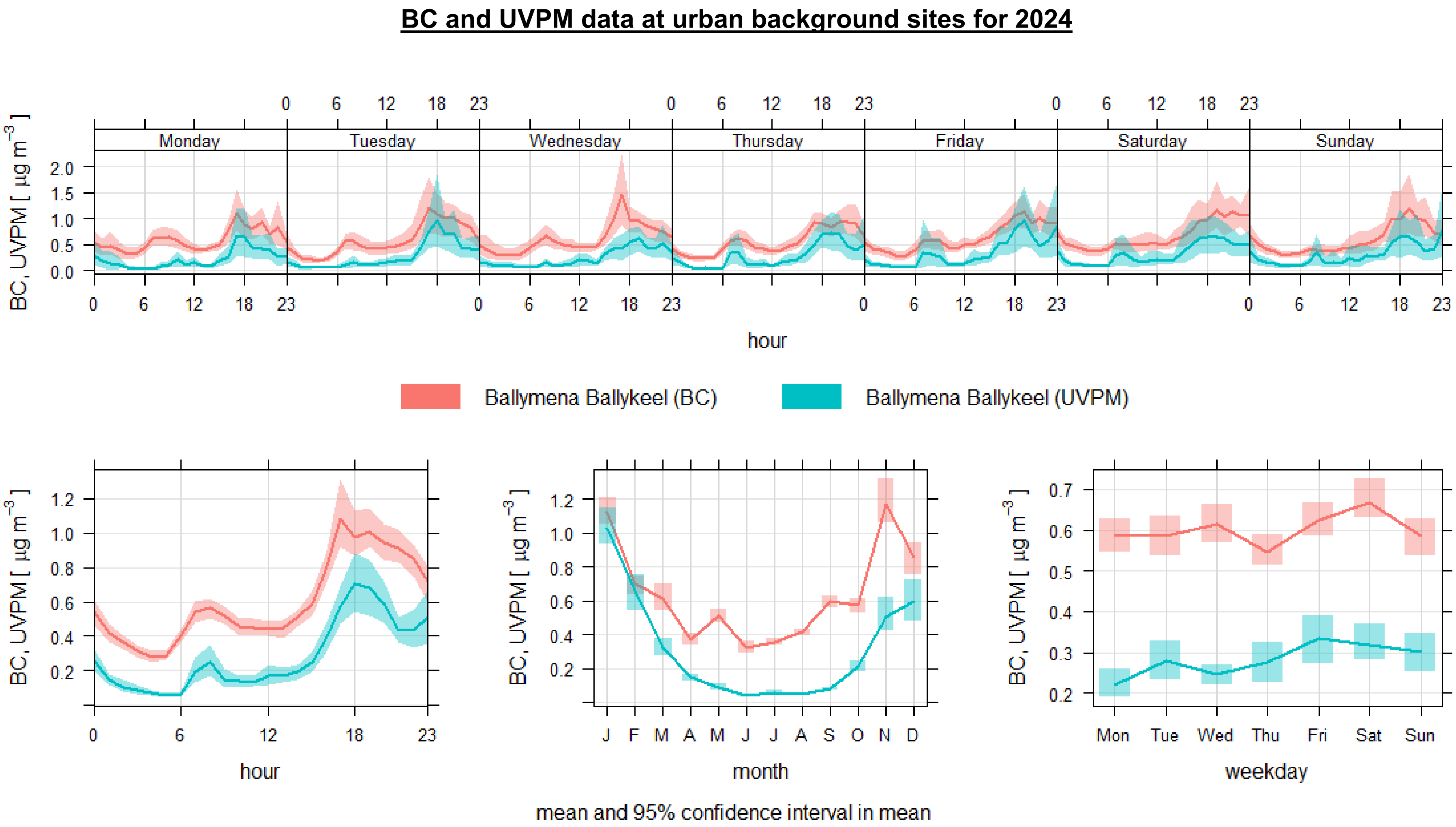


Figure 54 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Ballymena Ballykeel for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

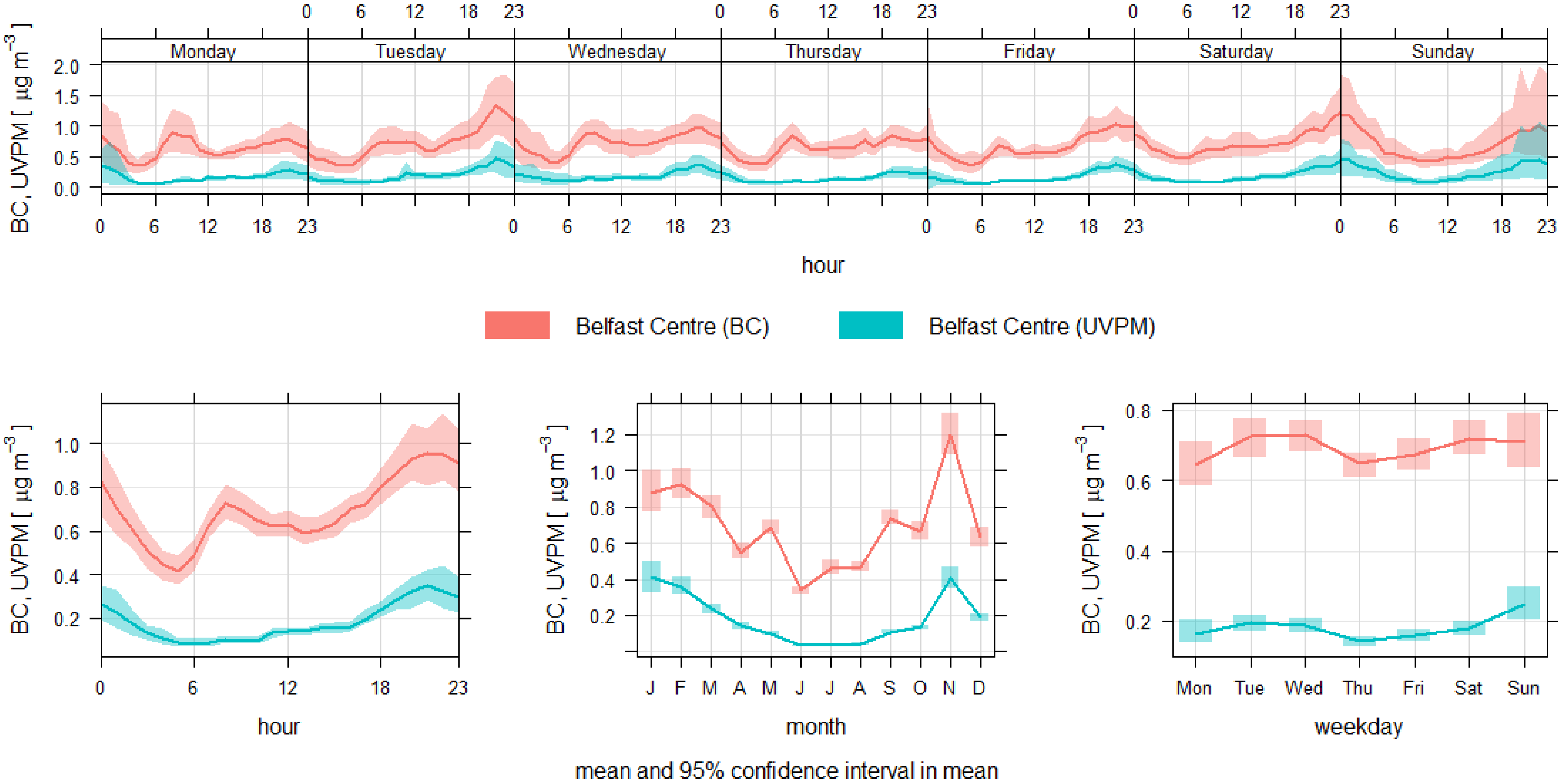


Figure 55 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Belfast Centre for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

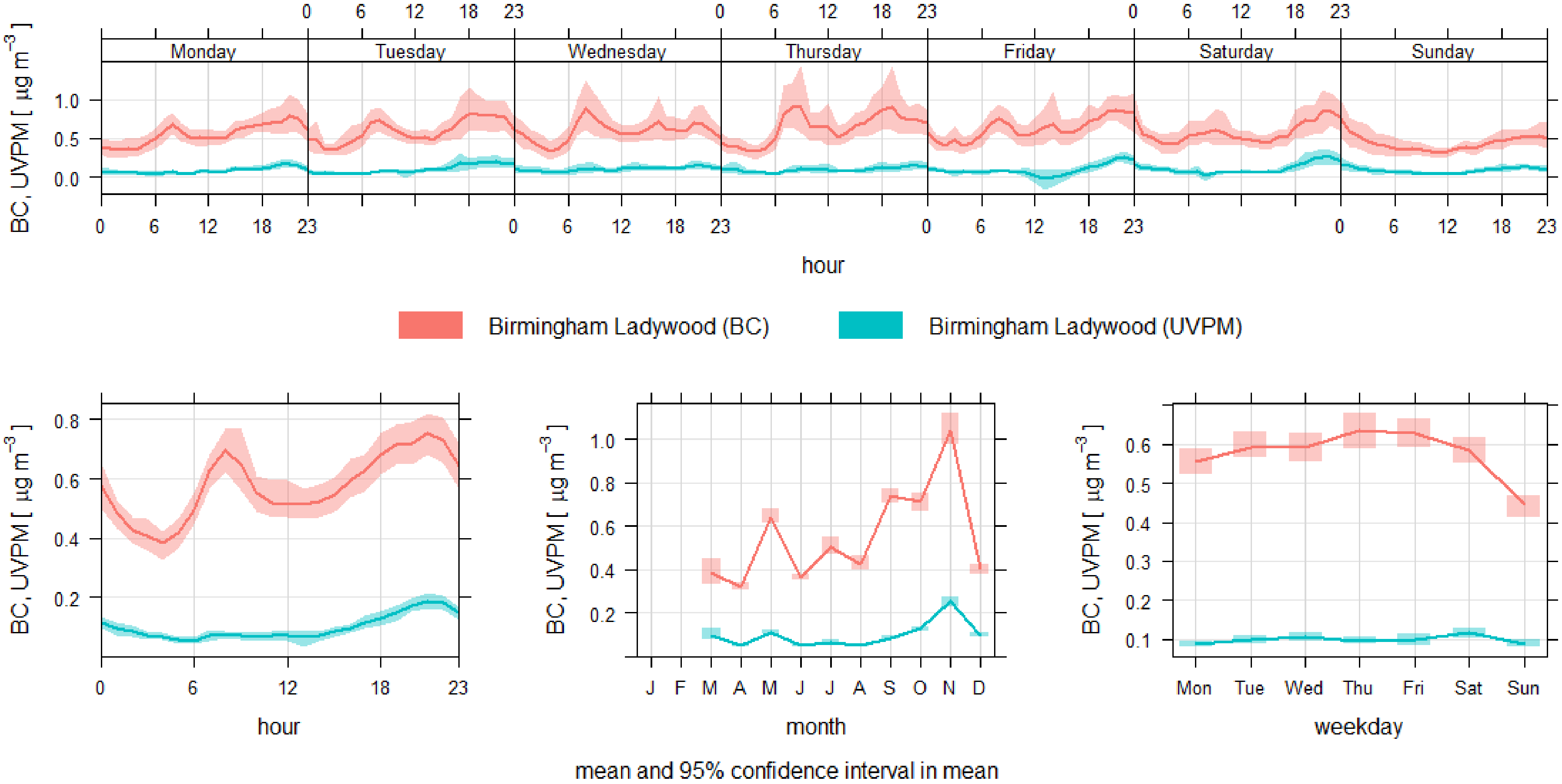


Figure 56 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Birmingham Ladywood for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean. Data from January and February 2024 was excluded from these plots as the mass concentrations were not valid, due to wrong filter tape being used in this period. Note that the March results in the monthly plot is automatically produced by the software based on limited data that might not represent the BC and UVPM mass concentrations of this month.

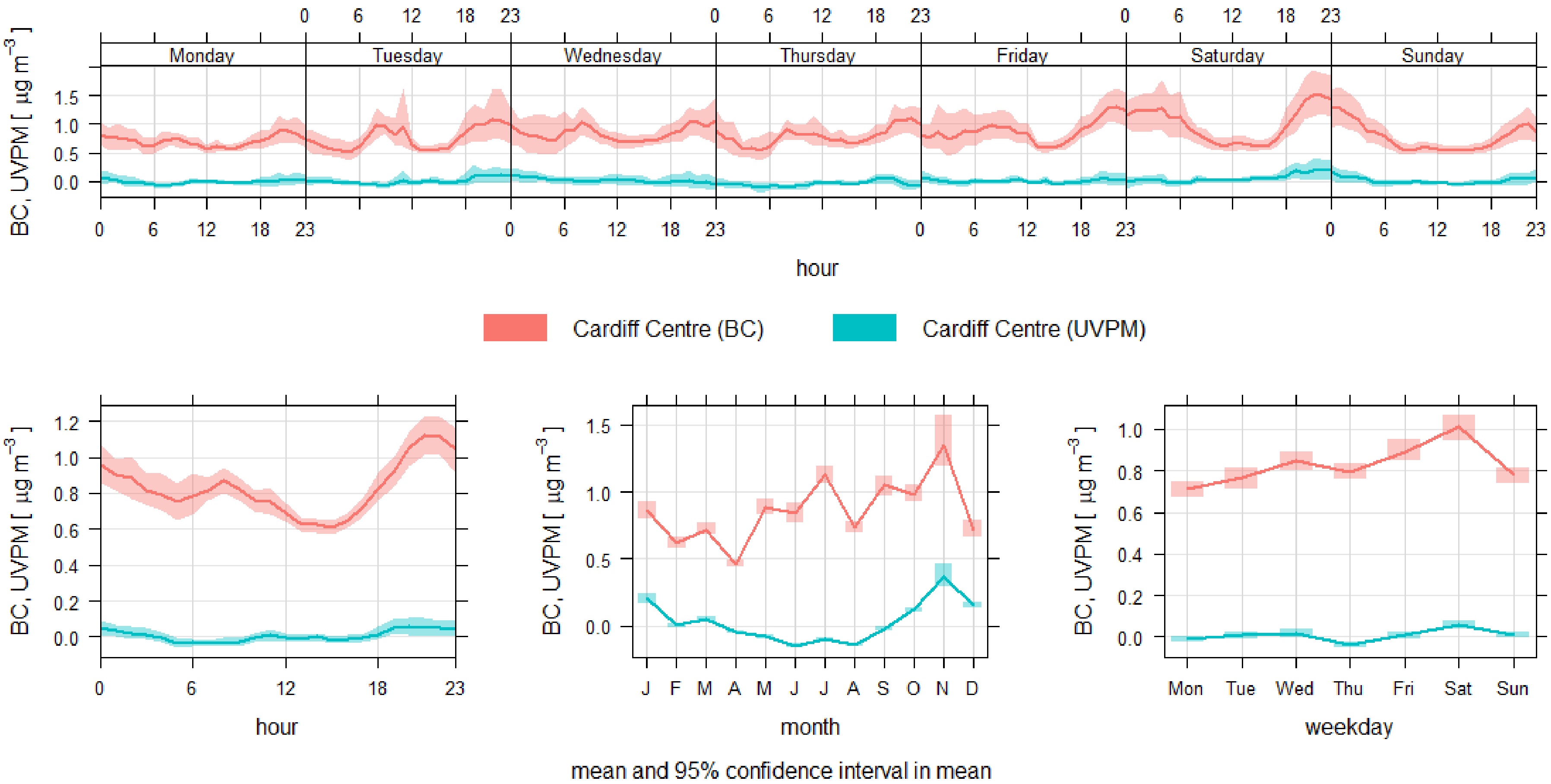


Figure 57 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Cardiff Centre for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

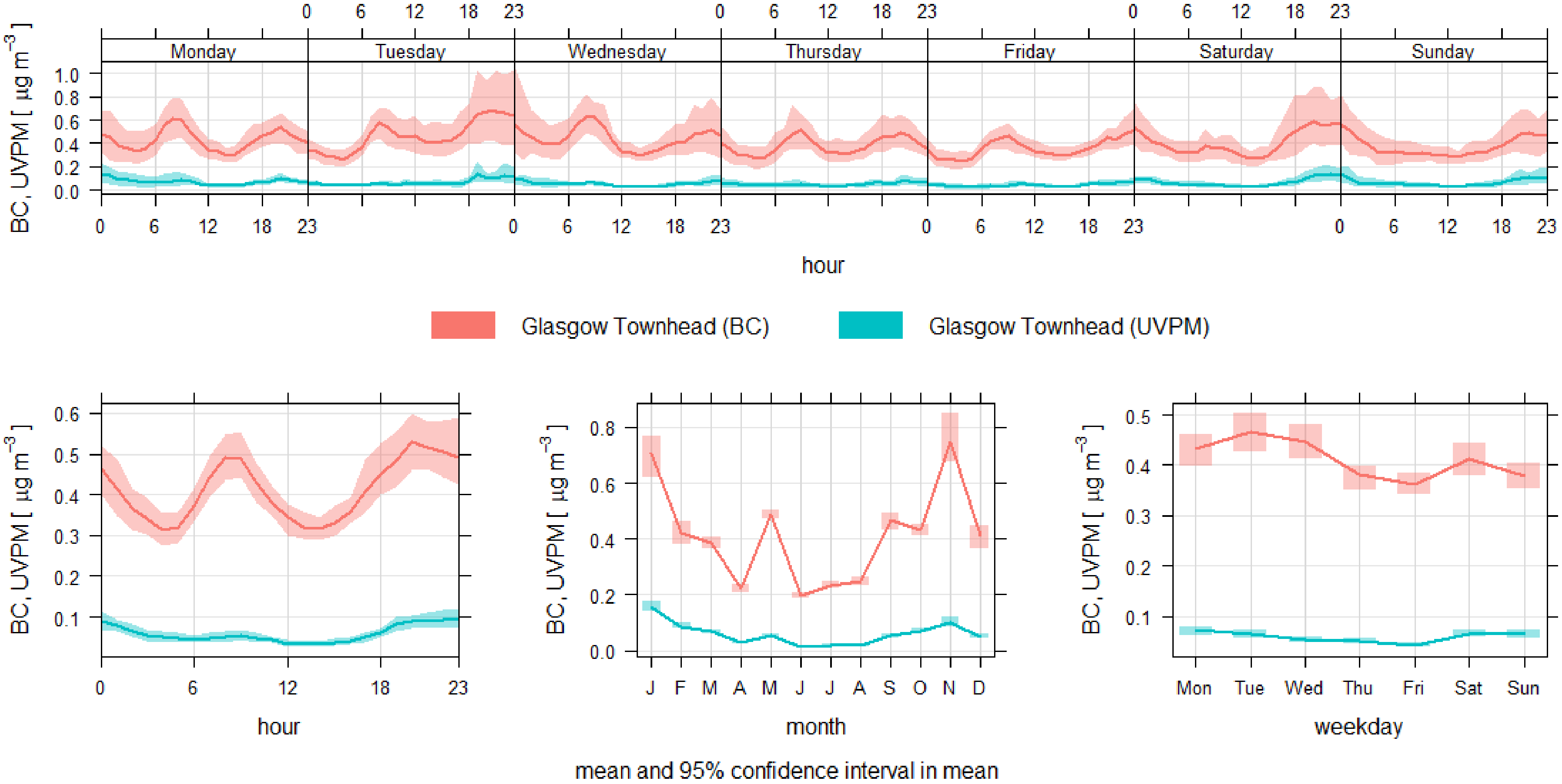


Figure 58 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Glasgow Townhead for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

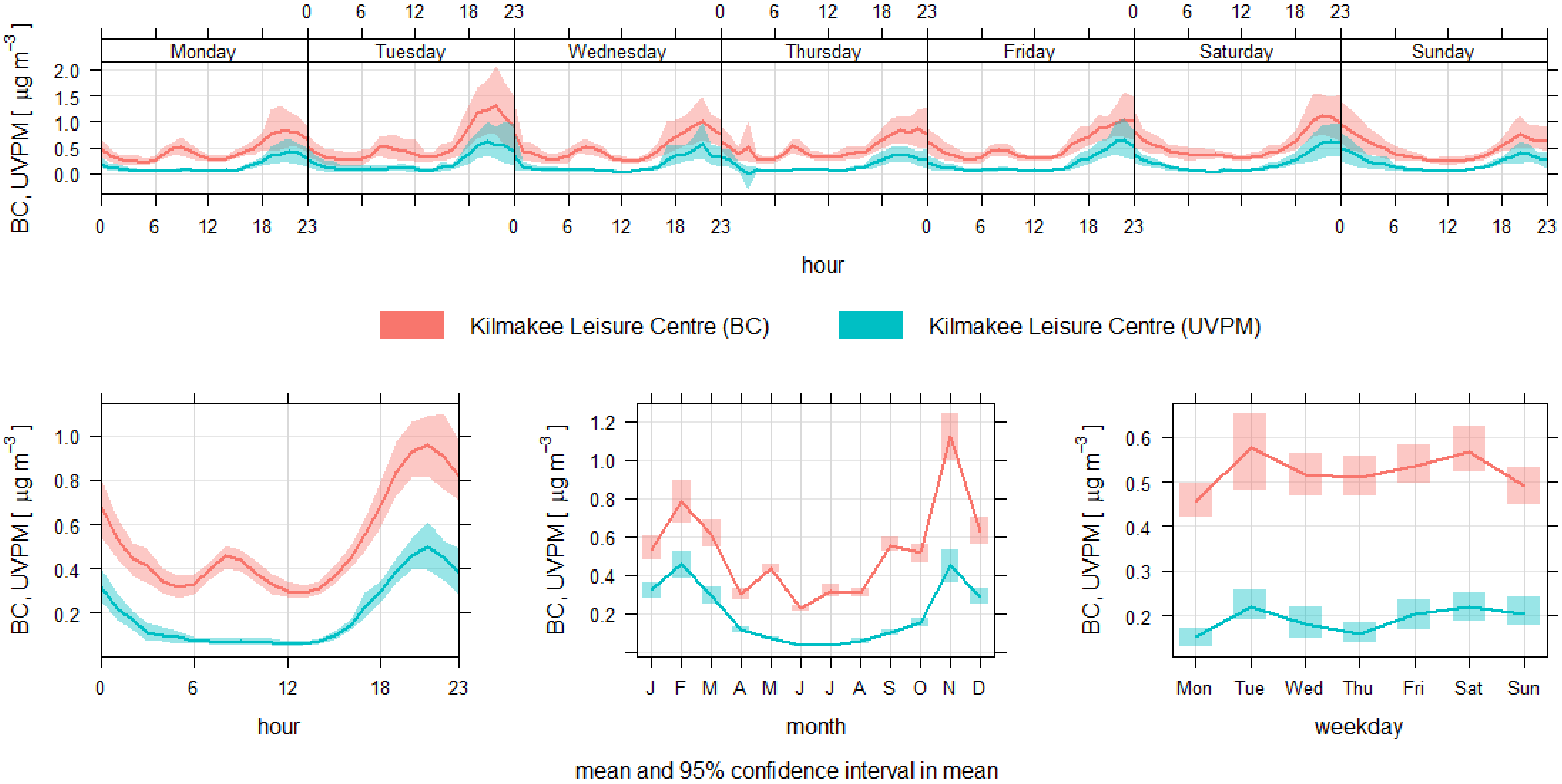


Figure 59 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Kilmakee Leisure Centre for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

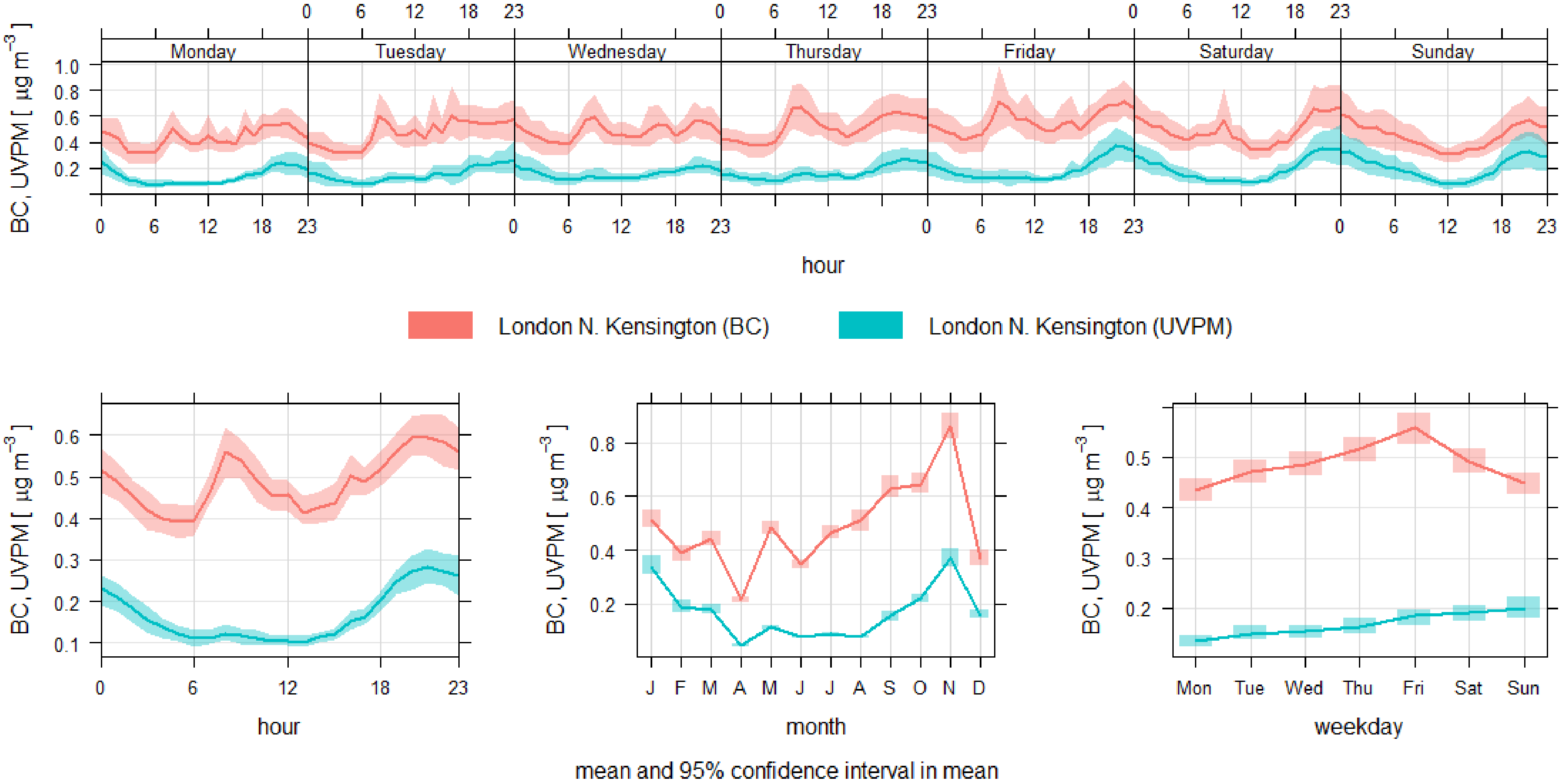


Figure 60 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at London North Kensington for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

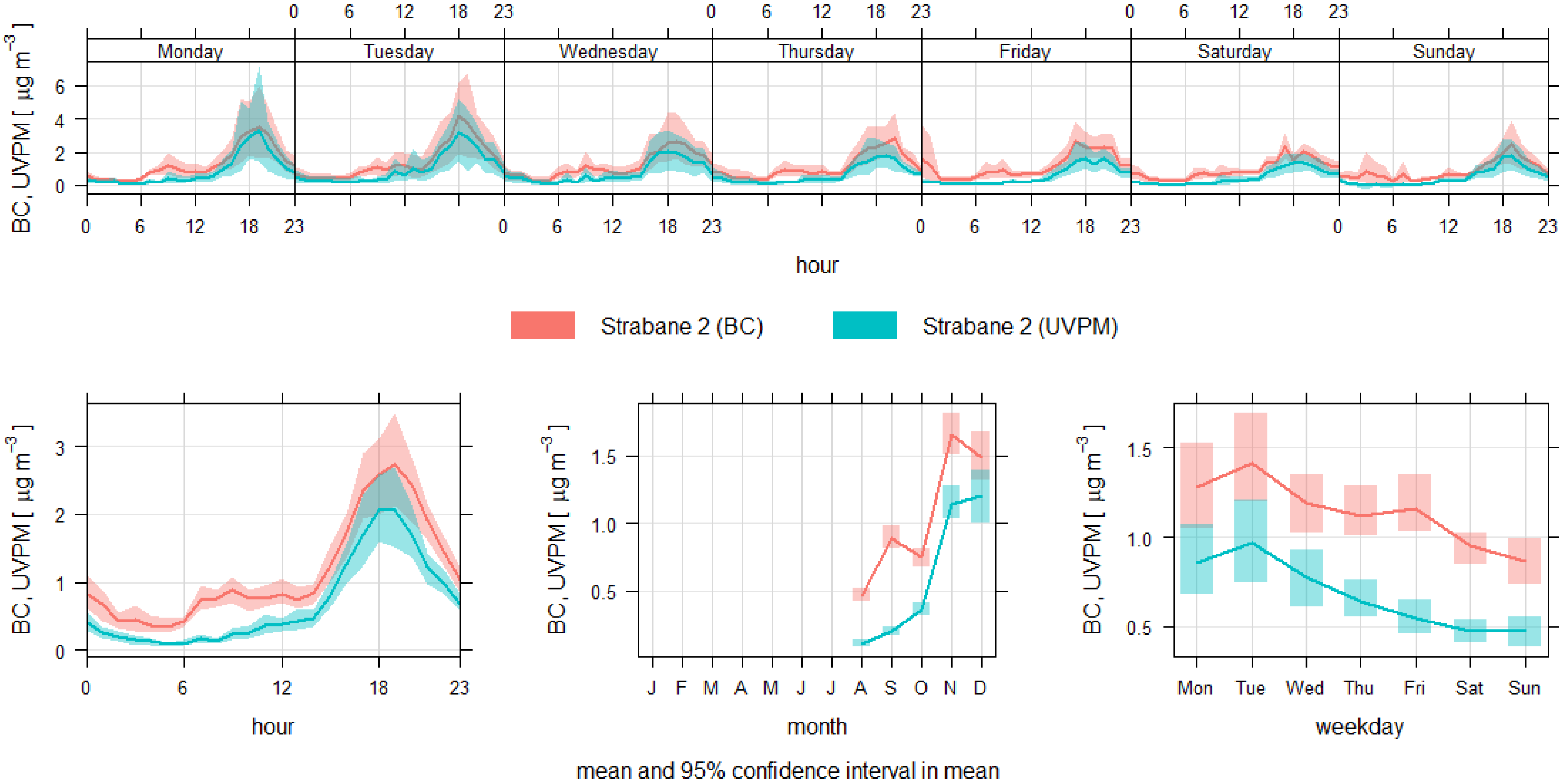


Figure 61 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Strabane 2 for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean. Data from January to July 2024 were excluded from these plots as the mass concentrations were not valid, due to wrong filter tape being used in this period. Note that the August result in the monthly plot is automatically produced by the software based on limited data that might not represent the BC and UVPM mass concentrations of this month.

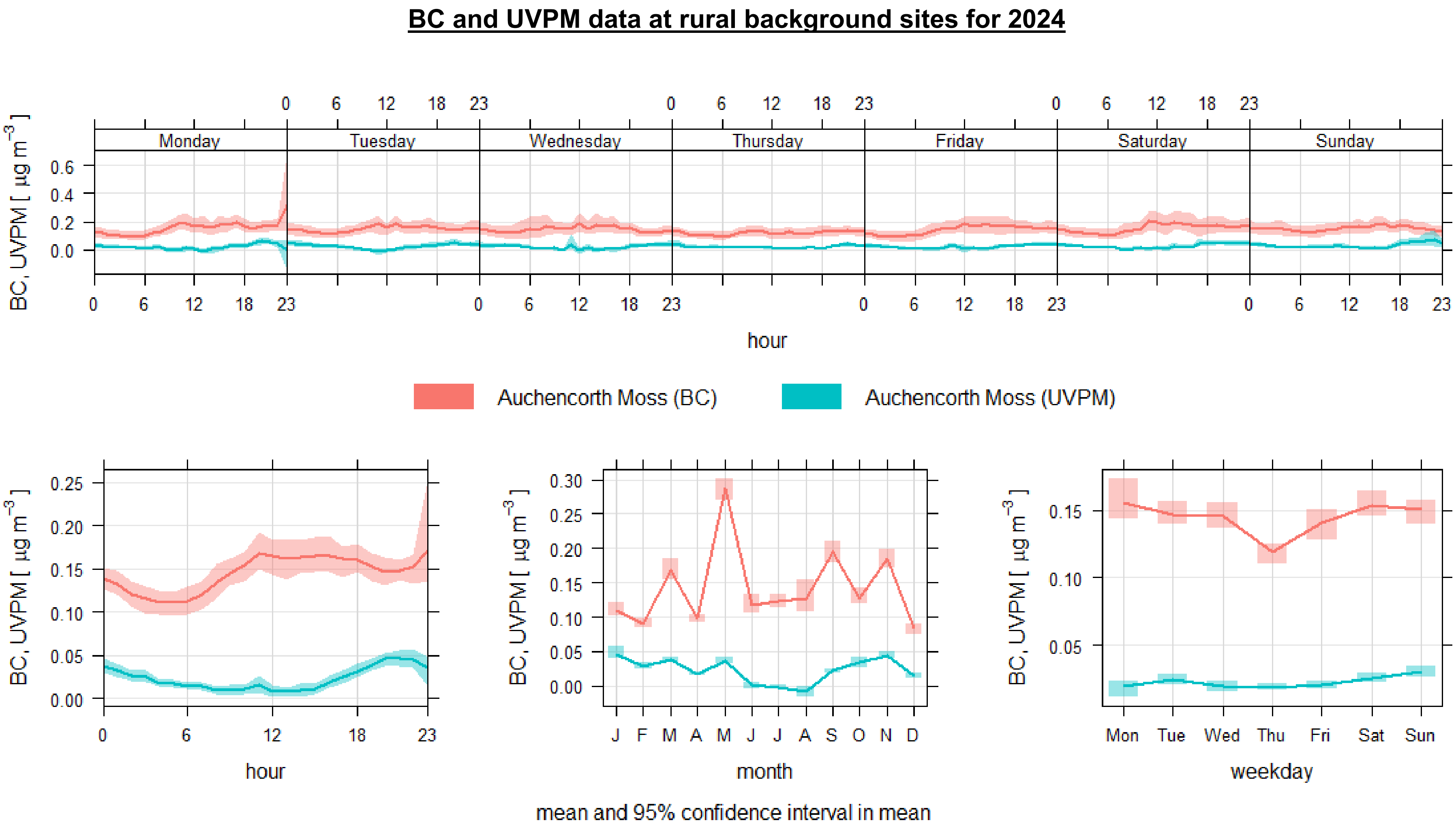


Figure 62 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Auchencorth Moss for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

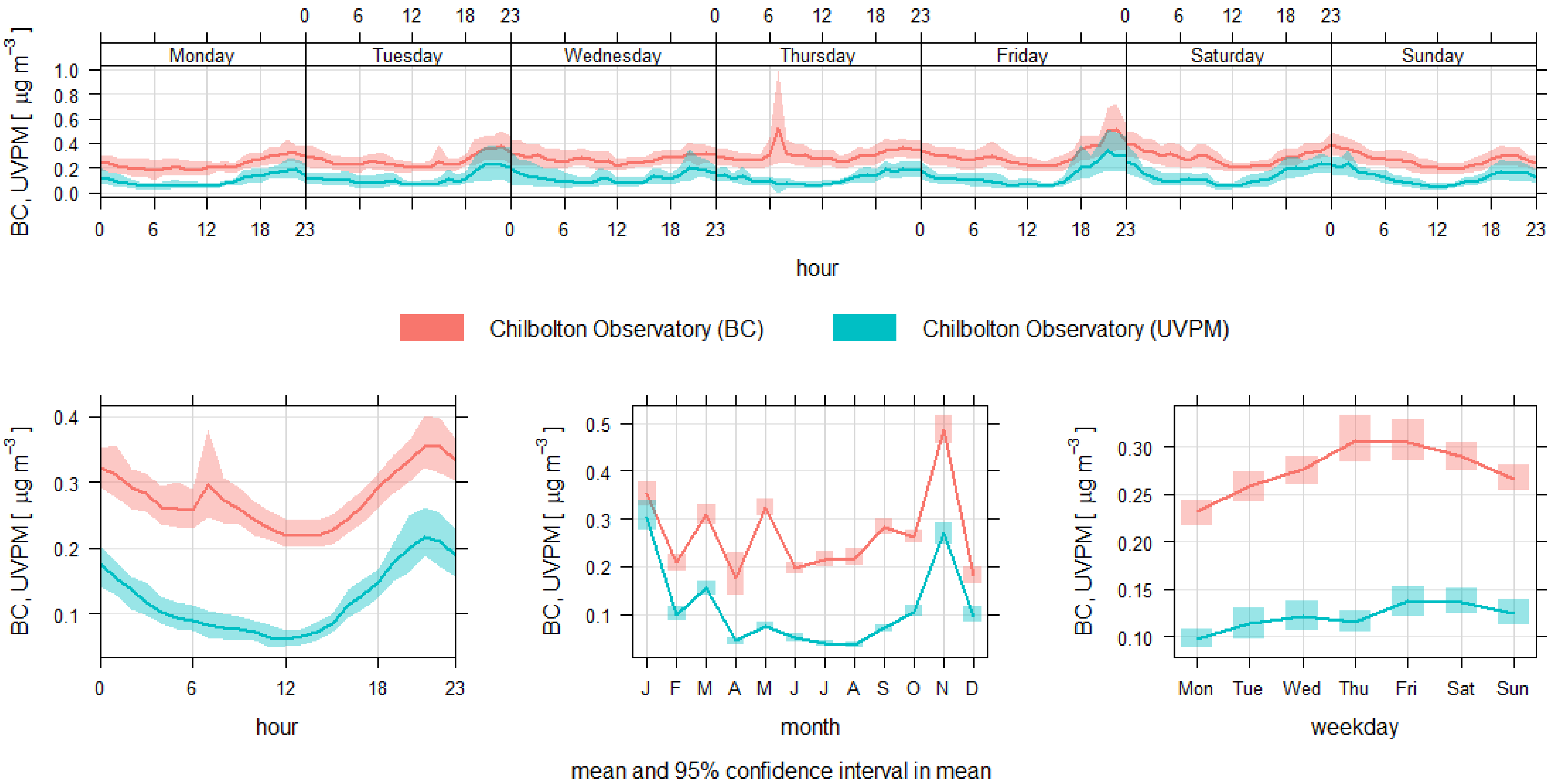


Figure 63 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Chilbolton Observatory for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

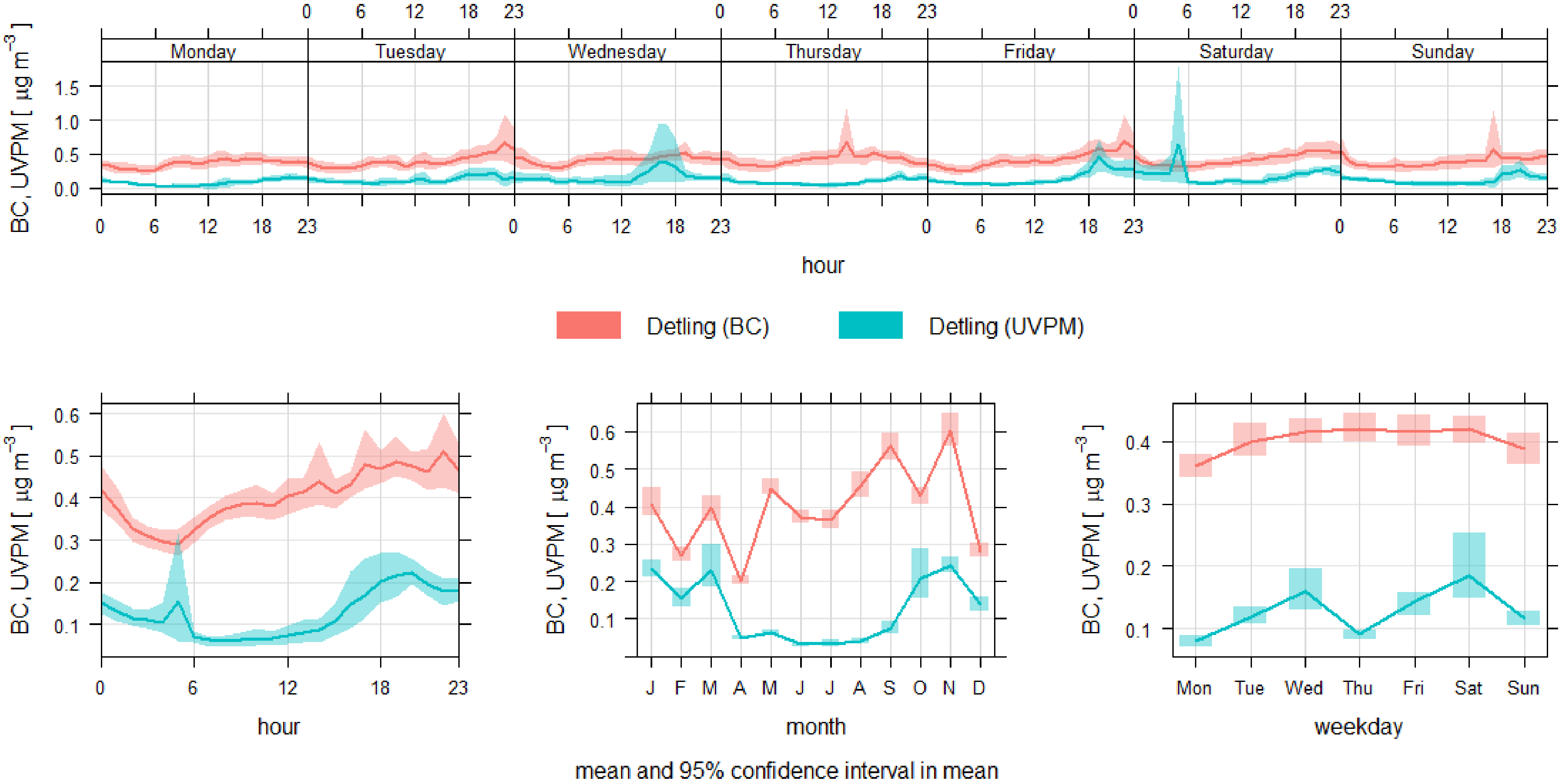


Figure 64 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Detling for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

BC and UVPM data at roadside Sites for 2009 - 2024

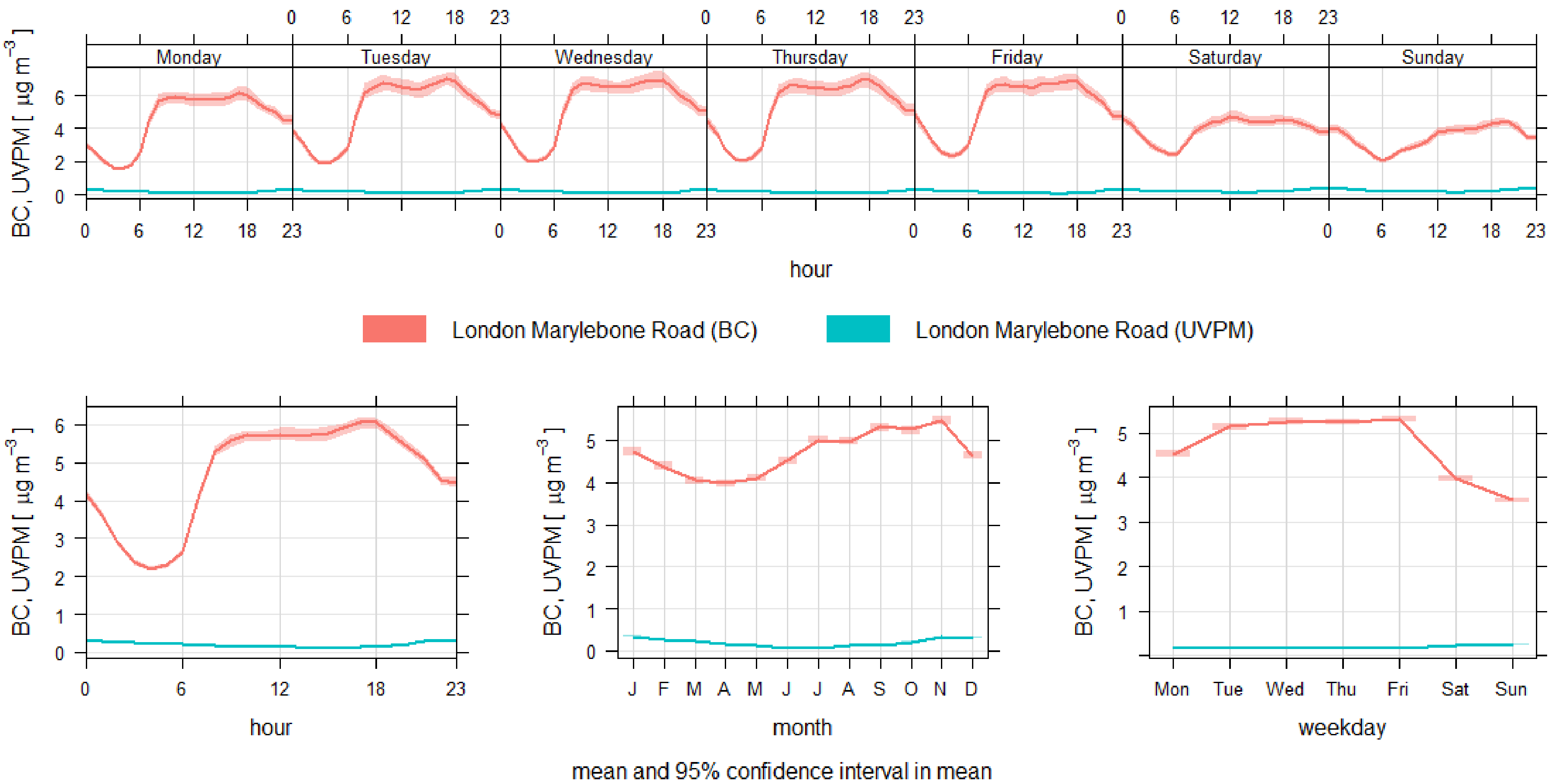


Figure 65 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at London Marylebone Road for 2009-2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

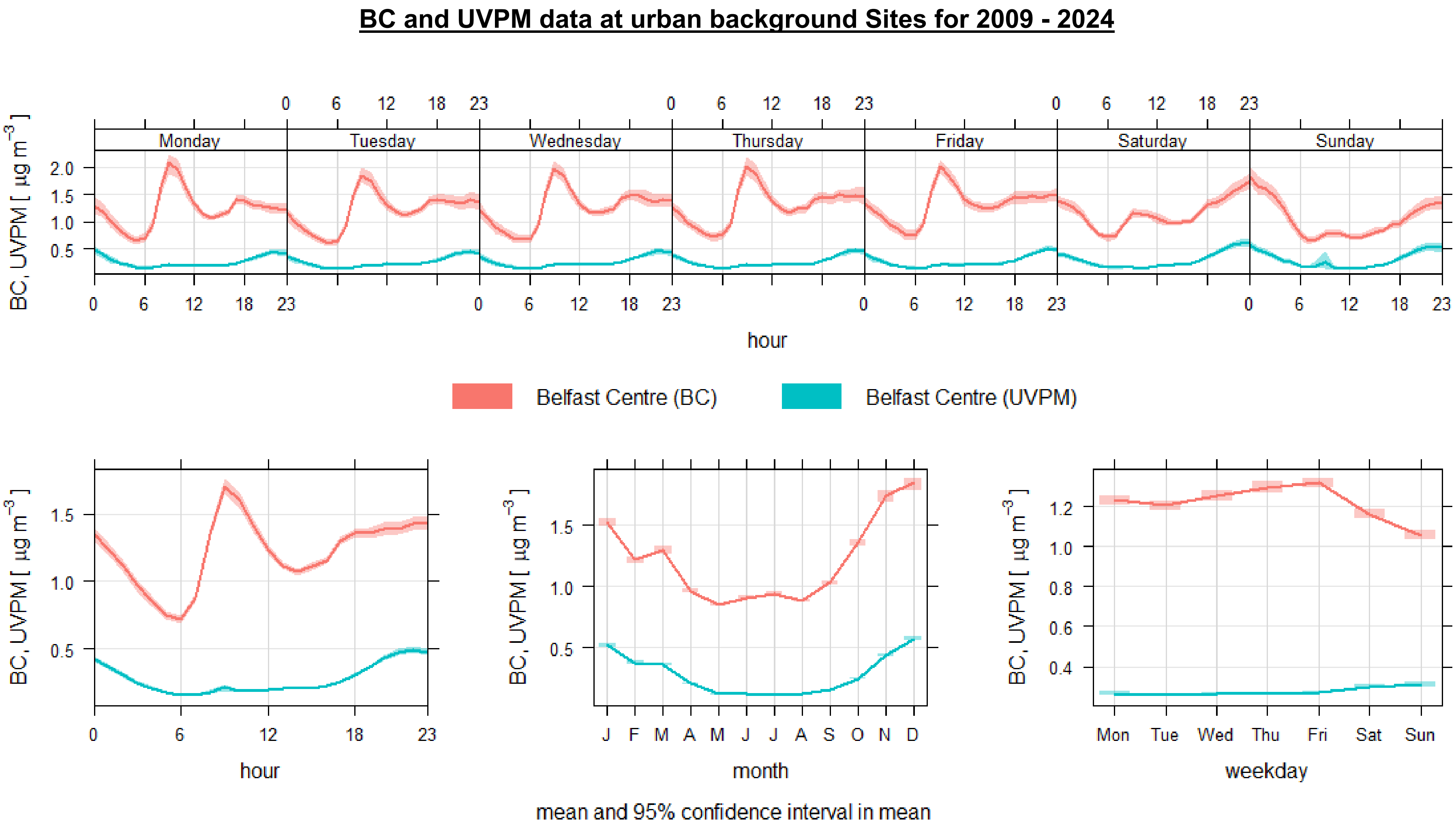


Figure 66 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Belfast Centre for 2009-2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

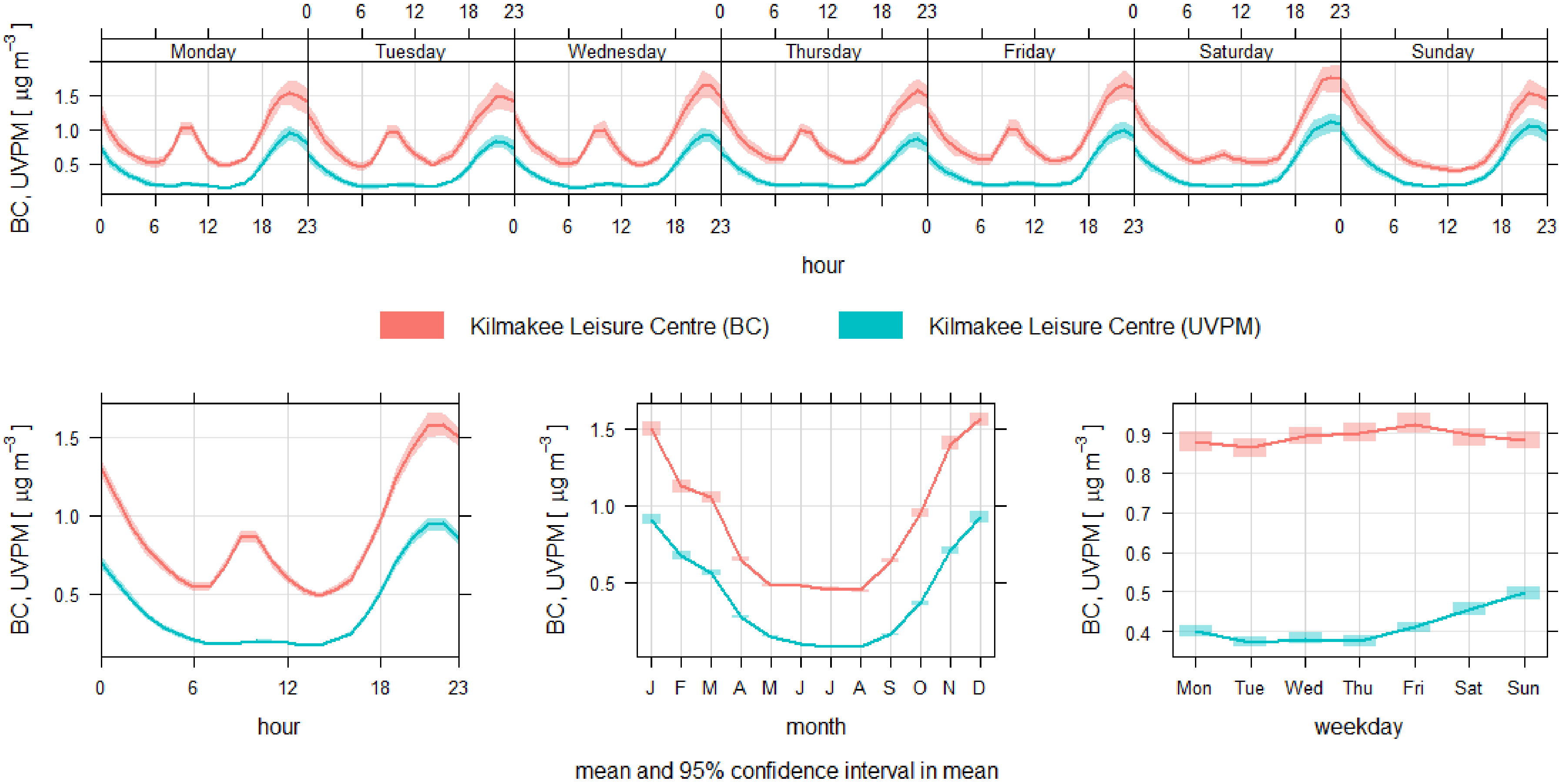


Figure 67 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Kilmakee Leisure Centre for 2009-2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

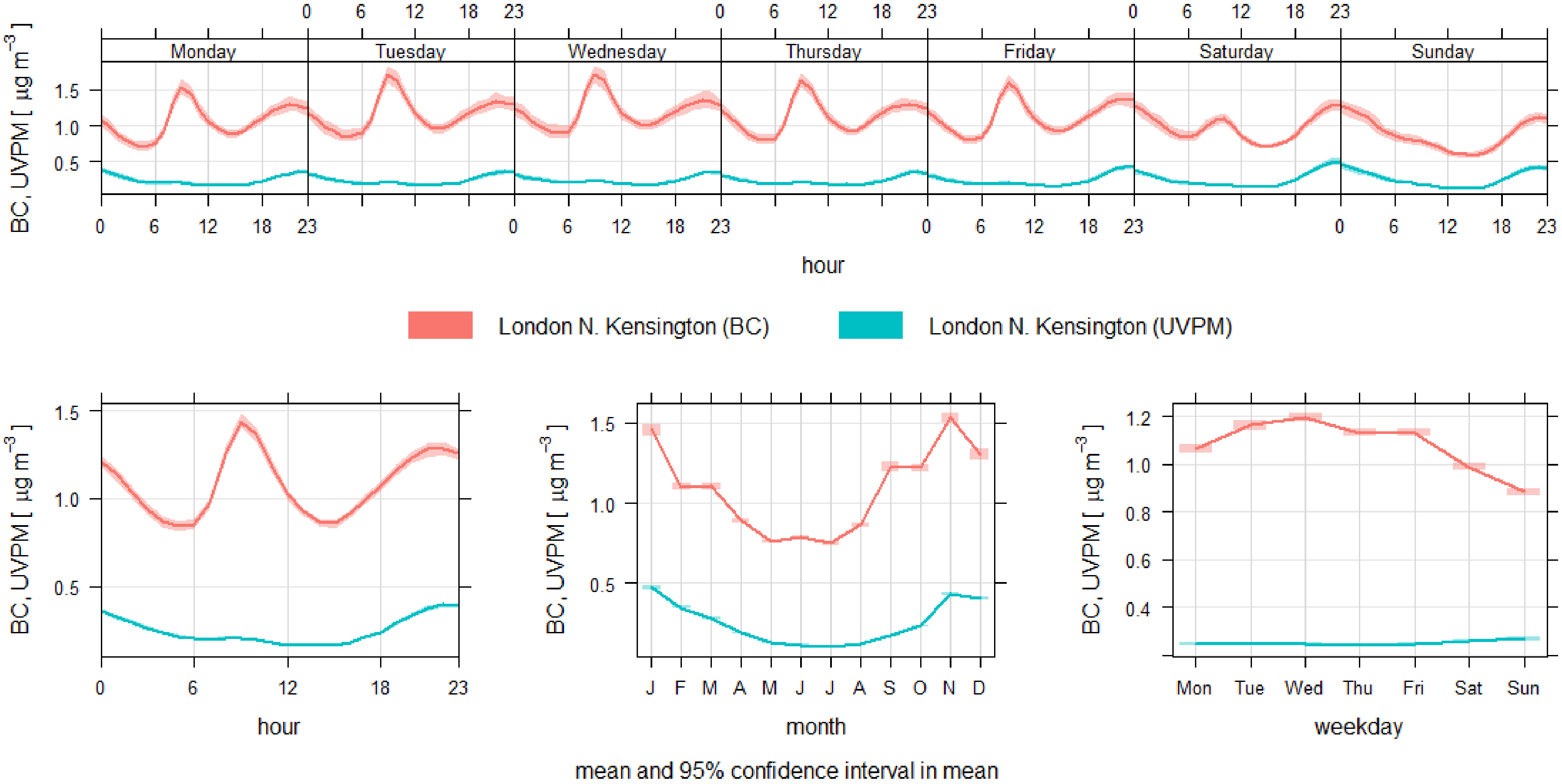


Figure 68 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at London North Kensington for 2009-2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

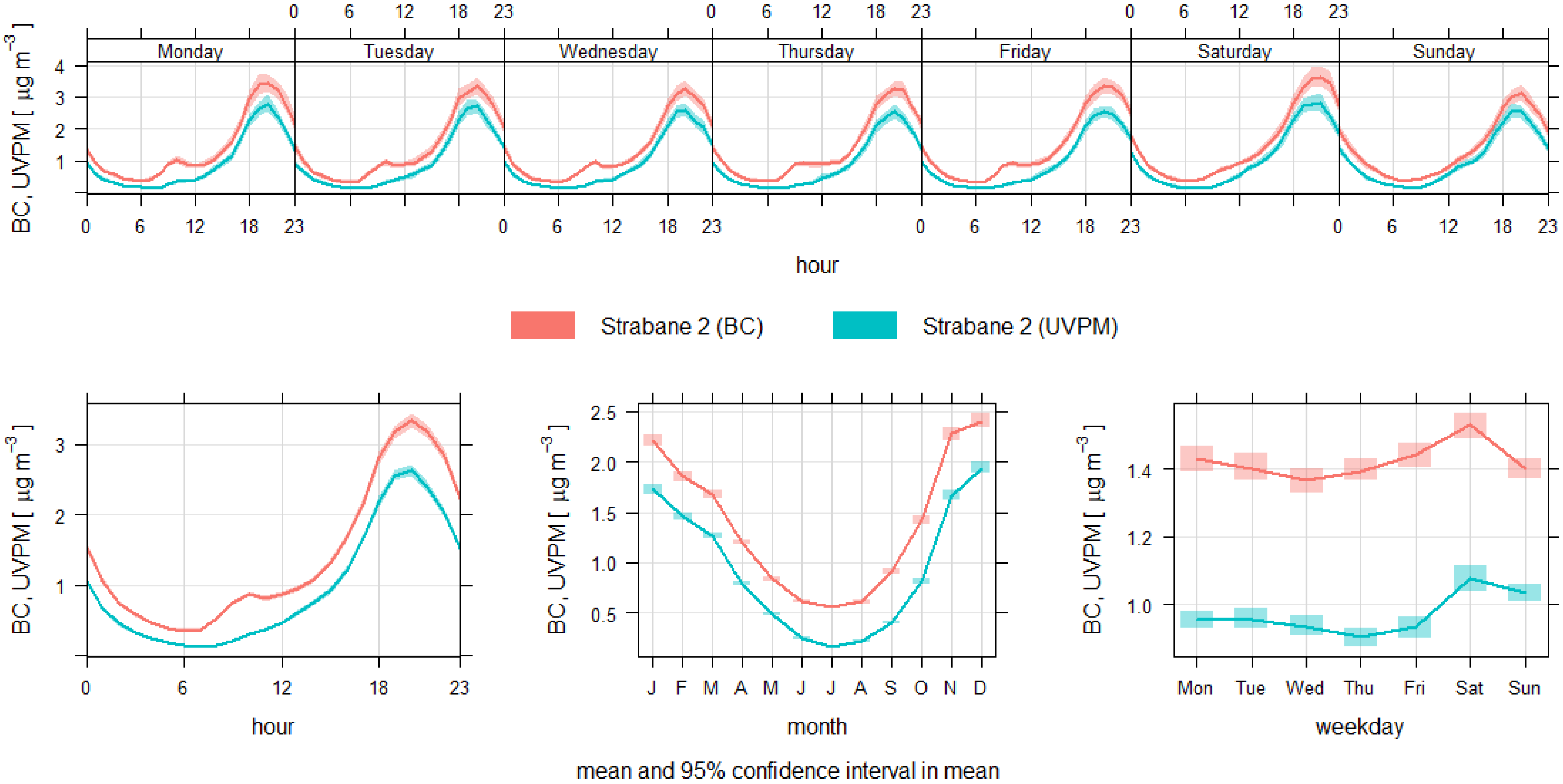


Figure 69 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Strabane 2 for 2009-2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

4.6.6 Long-term trends

Figure 70 and Figure 71 show the trend in BC concentrations from the longest running sites in the Network, as monthly averages over the full calendar years 2009 to 2024.

The Theil-Sen method in OpenAir[27,28] was used to calculate the regression parameters including slope and uncertainty in the slope. This method chooses the median slope among all lines through pairs of two-dimensional sample points. The Theil-Sen estimator tends to yield accurate confidence intervals even with non-normal data and heteroscedasticity (non-constant error variance). It is also resistant to outliers.

Bootstrap resampling provides the confidence interval for the regression slope. For these analyses the 2.5th and 97.5th percentile slopes are taken from all possible slopes shown as dashed lines with values provided in square brackets on each plot in Figure 70 and Figure 71. A statistically significant trend can be assumed when the probability value p is < 0.001 (as indicated by *** on the charts, while ** is for $p < 0.01$, * is for $p < 0.05$ and + symbol is for $p < 0.1$).

Over the period 2009 to 2023 all the long-running sites in the Network ,apart from Strabane 2, have shown a significant downward trend in BC concentrations. The decrease at London Marylebone Road is much larger than the other sites and BC concentrations have been falling consistently since 2011. However, the ratio of this change is lower since 2020, thus the long-term trend from 2009-2024 should be treated with caution.

Figure 72 and Figure 73 show the long-term trends in UVPM concentration.

The London Marylebone Road UVPM concentration showed an upward trend over the period 2009 to 2024. This was probably due to the reduced BC concentrations over the latter years, as the Aethalometer measures the UVPM as the difference between the BC and UV channels. However, these results should be treated with caution as only the trends determined for the London North Kensington and Kilmakee Leisure Centre sites are statistically significant.

The Aethalometers were upgraded in November 2019 from model AE22 to model AE33. Although the methodology of both models is, in principle, the same, they use different algorithms and factors to calculate the final BC mass concentration. Thus, all results provided in this report should be treated with caution when comparing data from the AE33 model with earlier years when the AE22 model was used. A note to this effect has been added to the BC Network page of the UK AIR website[32].

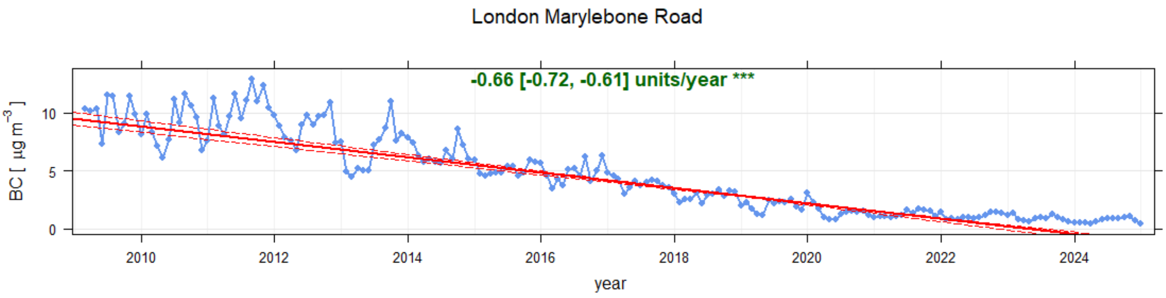


Figure 70 – Long-term trends in BC concentration measured at the London Marylebone Road roadside site, 2009 – 2024 (*p < 0.001).**

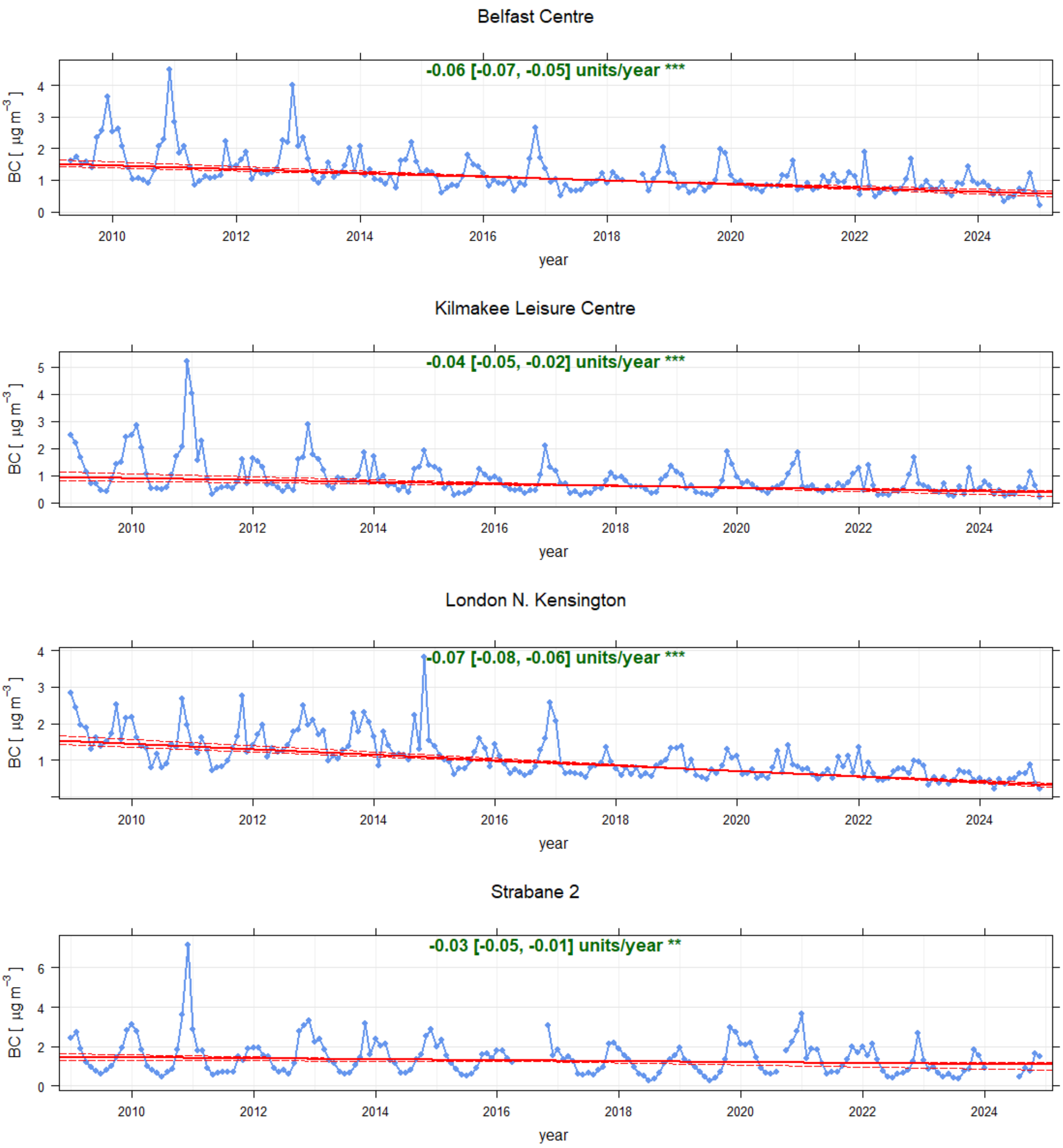


Figure 71 - Long-term trends in BC concentration measured at urban background sites, 2009 – 2024 (p < 0.01; ***p < 0.001).**

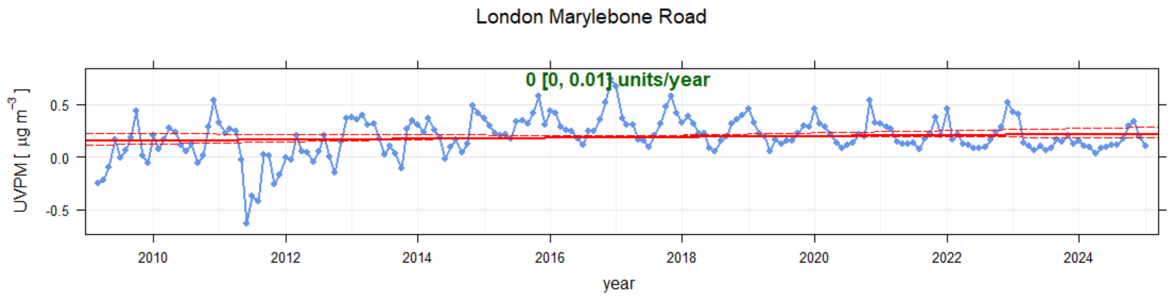


Figure 72 – Long-term trend in UVPM concentrations measured at roadside sites, 2009 – 2024 (no significant trend).

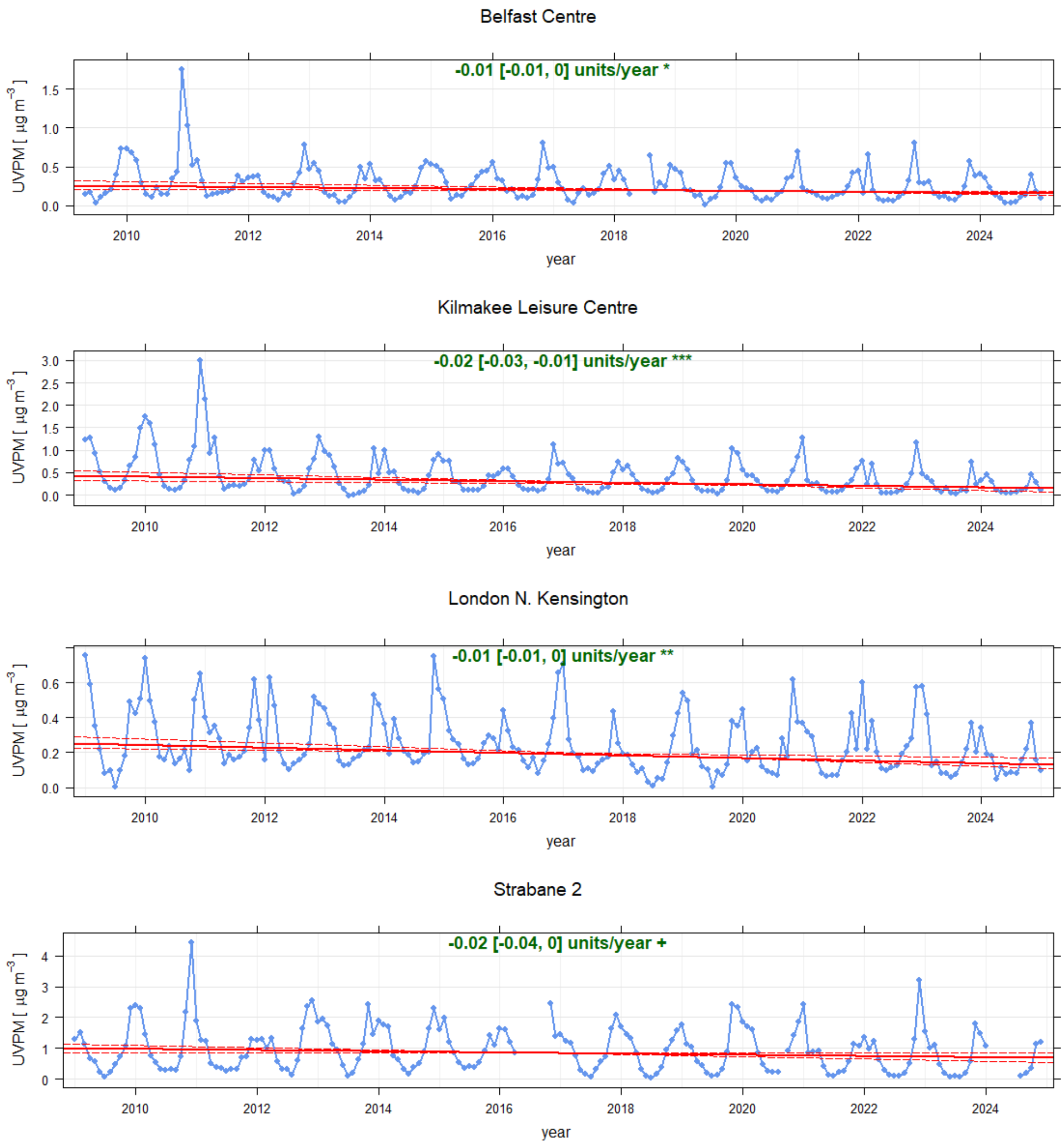


Figure 73 - Long-term trends in UVPM concentrations measured at urban background. sites, 2009 – 2024 (* $p < 0.05$, ** $p < 0.01$; *** $p < 0.001$, $^{+}$ $p < 0.1$).

4.7 BC AND UVPM ($PM_{2.5}$ MEP)

4.7.1 Introduction

In 2024, ten new sites (plus London Teddington Bushy Park) were installed as part of the expansion of the PCN&BC Network (see Table 4). As only two sites (Blackburn Audley Park and Derby Stockbrook Park) were operational for the whole year, the annual (*i.e.*, 12 month) average cannot be provided for this part of the Network. 2024 mean data from all Aethalometer channels are shown in Table 18. However, these data should be treated with caution for the remaining nine sites that were only operational for part of 2024.

Table 18 - Annual mean of particulate matter concentrations measured in $PM_{2.5}$ at specific wavelength (indicated in nm in brackets) in 2024. Grey shading indicates sites with < 10 % annual data capture.

	Mass concentration in $PM_{2.5}$ / (µg m^{-3})							
Site	**UV** (370)	**Blue** (470)	**Green** (520)	**Yellow** (590)	**Red** (660)	**BC** (880)	**IR-2** (950)	**UVPM**
Barnsley Gawber	0.76	0.70	0.67	0.64	0.61	0.58	0.58	0.18
Blackburn Audley Park	0.86	0.82	0.78	0.76	0.74	0.71	0.72	0.15
Bradford Shipley Airedale Road	1.94	2.00	1.95	1.91	1.88	1.87	1.89	0.07
Derby Stockbrook Park	0.88	0.82	0.77	0.74	0.72	0.69	0.69	0.18
Glazebury	0.64	0.61	0.59	0.56	0.54	0.52	0.52	0.11
Ladybower	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.04
London Teddington Bushy Park	0.55	0.48	0.45	0.42	0.40	0.37	0.37	0.18
Newcastle Centre	0.64	0.62	0.59	0.56	0.54	0.53	0.53	0.11
Shrewsbury Underdale	0.64	0.61	0.58	0.55	0.53	0.51	0.51	0.13
St Osyth	0.47	0.43	0.41	0.39	0.38	0.36	0.37	0.10
Wicken Fen	0.48	0.44	0.41	0.40	0.37	0.33	0.34	0.14

4.7.2 2024 time series - BC

Figure 74 and Figure 75 show the BC mass concentrations measured in 2024 at urban background and at rural locations, respectively. Time series for two sites (Bradford Shipley Airedale Road and London Teddington Bushy Park) are not presented as they were opened in November-December 2024.

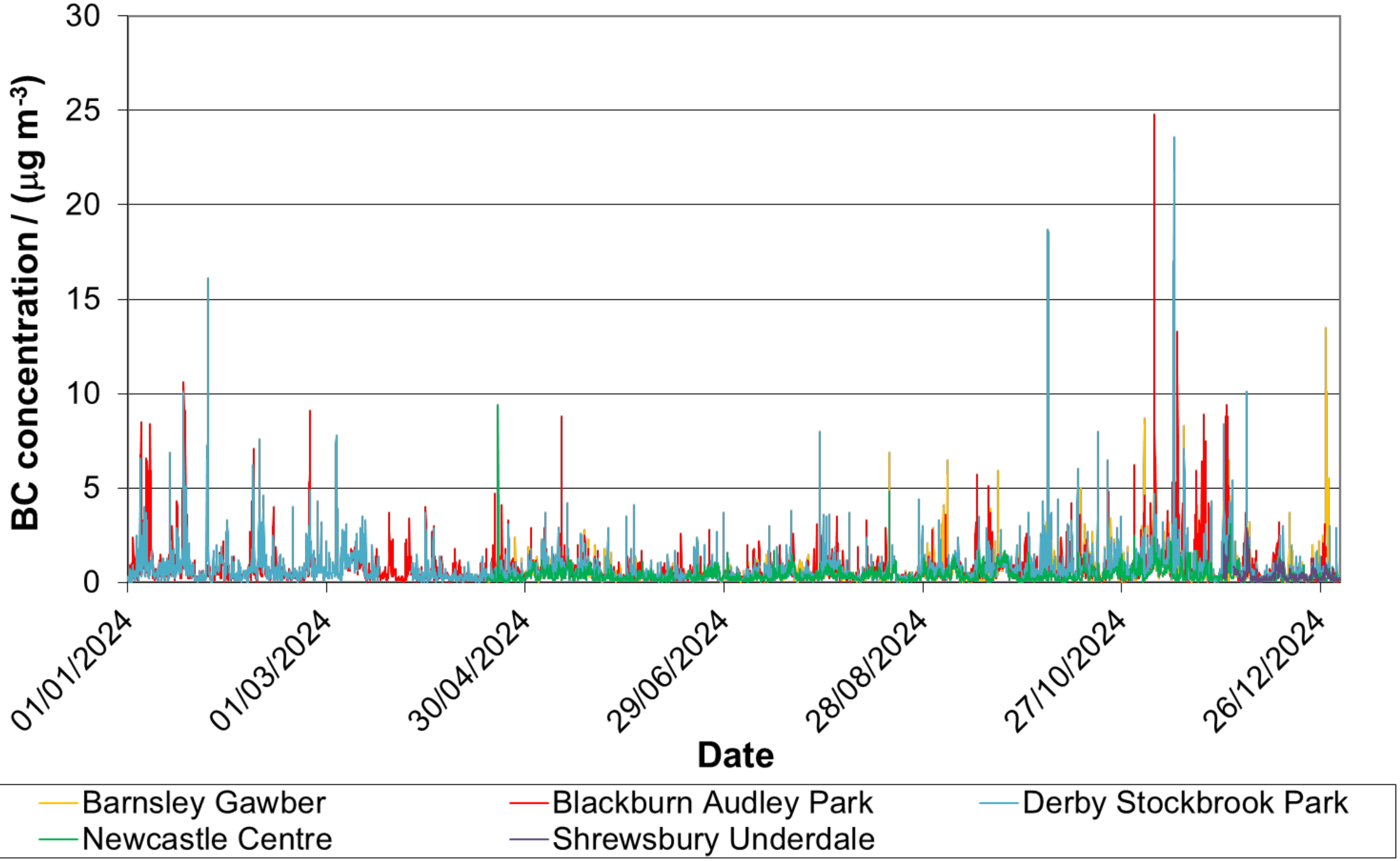


Figure 74 - BC concentrations during 2024 at urban background locations.

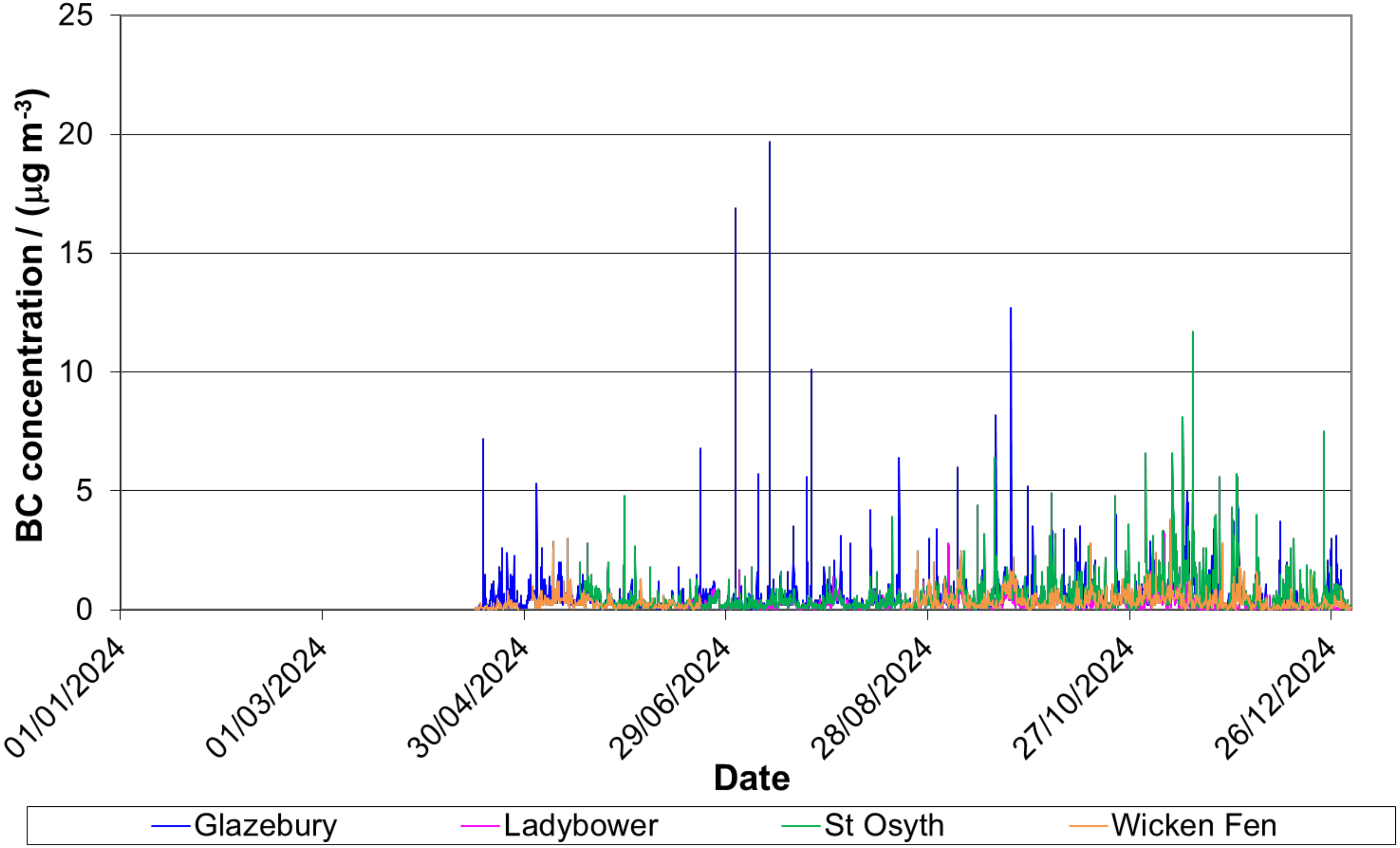


Figure 75 - BC concentrations during 2024 at rural locations.

4.7.3 Diurnal, weekly, and monthly profiles - BC and UVPM

This section presents analysis of the temporal variation in BC and UVPM concentrations at two sites: Blackburn Audley Park (Figure 76) and Derby Stockbrook Park (Figure 77) in 2024. Only these two sites were operational for the whole year; temporal variation analysis has not been provided for the sites installed during 2024. The units on the y-axes are mass concentration in μg m^{-3} for BC and UVPM; the scales vary by site (see more details in section 4.6.5).

At these two urban background sites, the measured BC concentrations showed a signature from traffic, observed as a peak in the morning rush hour with little corresponding increase in UVPM concentrations. Peaks related to the evening rush hour were also seen, but these often also showed an increase in UVPM concentrations. This indicates a domestic emission source which is likely from secondary heating. Both sites showed similar pattern and levels of BC and UVPM mass concentrations.

BC and UVPM data at urban background sites for 2024

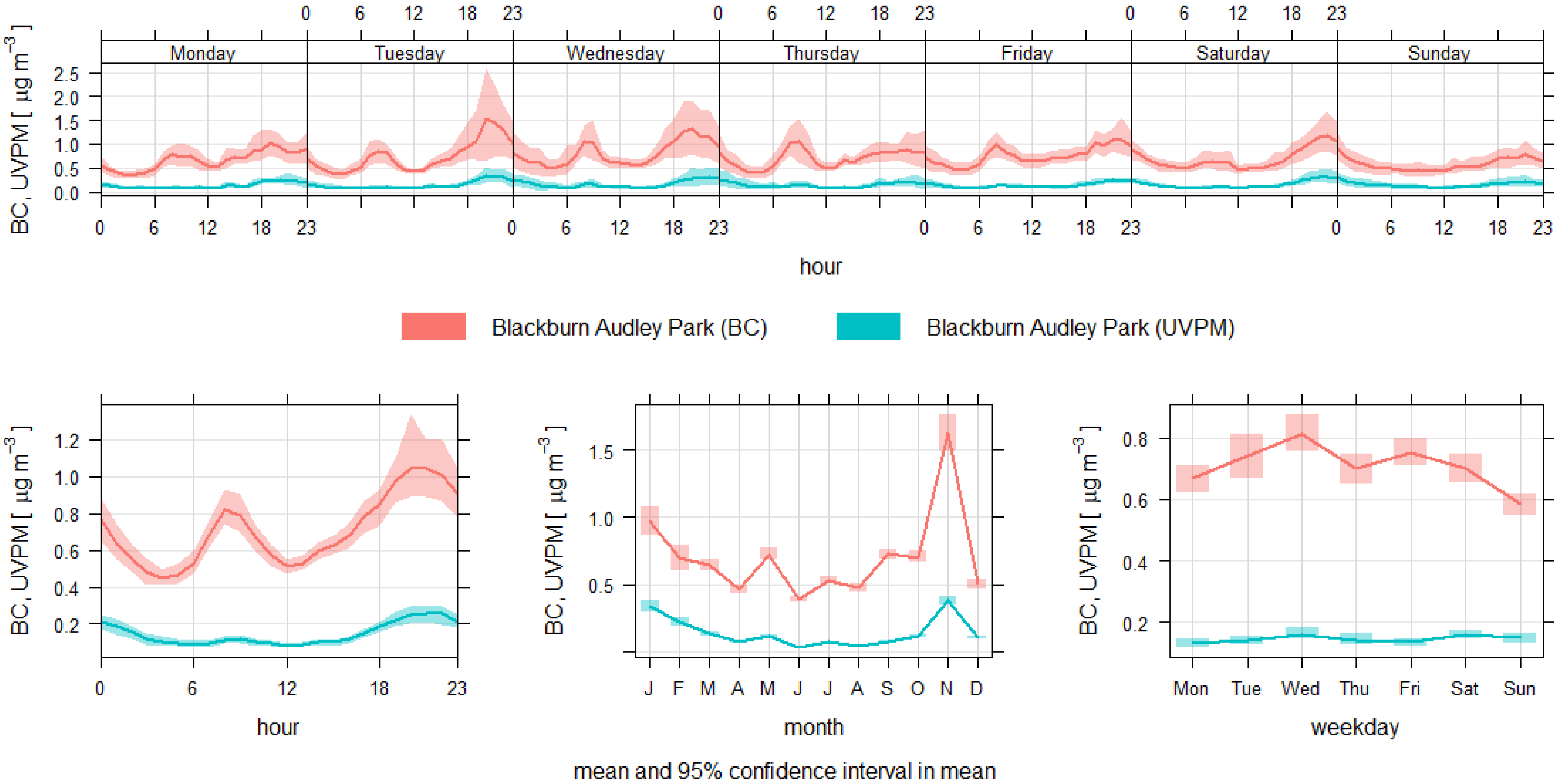


Figure 76 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Blackburn Audley Park for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

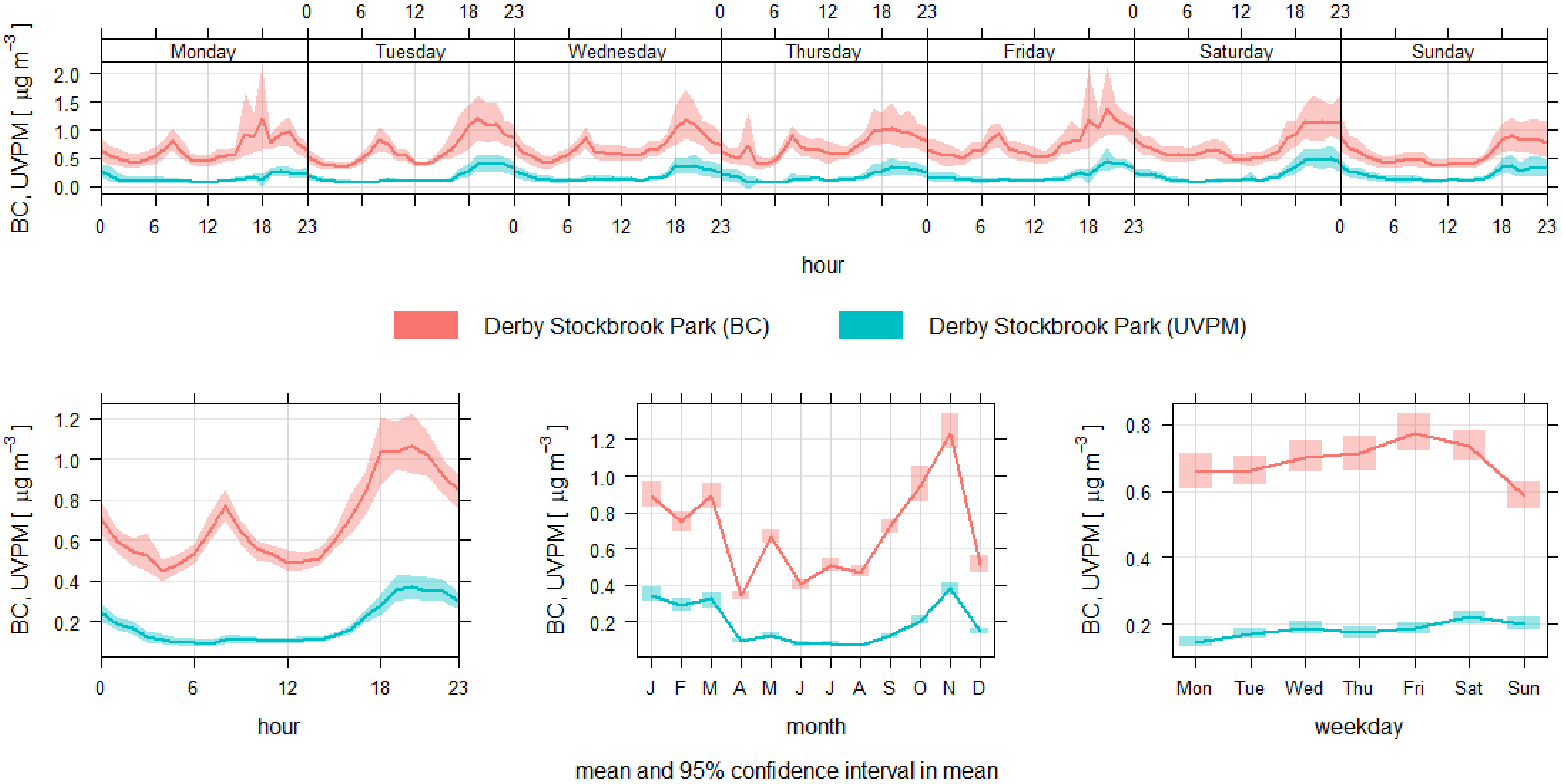


Figure 77 - Diurnal, weekly and monthly variations in BC and UVPM mass concentrations at Derby Stockbrook Park for 2024. The solid lines represent the mean black carbon or UVPM mass concentration, and the shaded areas represent the 95 % confidence interval in the mean.

5 PEER-REVIEW PUBLICATIONS

The peer-review papers that used data from the PCN&BC data published by members of the Network delivery team in 2024 are listed below. A summary of the first few sentences of the abstract of each paper is also provided for context.

1. *Source apportionment of ultrafine particles in urban Europe*[33]

Identifying sources of ultrafine particles is essential to develop abatement policies. This paper focusses on urban Europe and aims at identifying sources and quantifying their contributions to particle number size distribution using receptor modelling (Positive Matrix Factorization) and evaluating long-term trends of these source contributions using the non-parametric Theil-Sen's method.

2. *High time resolution quantification of $PM_{2.5}$ oxidative potential at a Central London roadside supersite*[34]

The oxidative potential (OP) of airborne particulate matter is gaining increasing attention as a health-relevant metric to describe the capacity of PM to promote oxidative stress and cause adverse health effects. Most OP studies have previously used filter-based approaches to sample PM and quantify OP, which have relatively poor time resolution (~24 h) and underestimate the contribution of reactive components to OP due to the time delay between sample collection and analysis. This paper develops a novel instrument which used a direct-to-reagent sampling approach, providing robust, continuous, high time resolution (5 min) OP quantification, hence overcoming analytical limitations of filter-based techniques.

3. Associations between short-term exposure to airborne carbonaceous particles and mortality: a time-series study in London during 2010-2019[35]

Exposure to ambient particulate matter (PM) has been identified as a major global health concern; however, the importance of specific chemical PM components remains uncertain. Earlier studies have suggested that carbonaceous aerosols are important detrimental components of the particle mixture; this paper uses time-series methods to investigate associations between short-term exposure to carbonaceous particles and mortality in London, UK.

4. *Air quality on UK diesel and hybrid trains*[36]

Concentrations of particulate matter (PM_{10} and $PM_{2.5}$ and ultrafine), particle number concentration, black carbon, nitrogen dioxide and nitrogen oxides were measured in train carriages on diesel and bi-mode trains on inter-city and long-distance journeys in the UK using a high-quality mobile measurement system. Air quality on 15 different routes was measured using highly-time resolved data on a total of 119 journeys during three campaigns in winter 2020 and summer 2021; this included 13 different train classes.

5. *Recommendations for reporting equivalent black carbon (eBC) mass concentrations based on long-term pan-European in-situ observations.*[37]

A reliable determination of equivalent black carbon (eBC) mass concentrations derived from filter absorption photometers measurements depends on the appropriate quantification of the mass absorption cross-section (MAC) for converting the absorption coefficient (b_{abs}) to eBC. This paper investigated the spatial–temporal variability of the MAC obtained from simultaneous elemental carbon and b_{abs} measurements performed at 22 sites. Different methodologies for retrieving eBC were compared integrating different options for calculating MAC including locally derived, median value calculated from 22 sites, and site-specific rolling MAC

6. *Inter-annual trends of ultrafine particles in urban Europe*[38]

Ultrafine particles (UFP) have been reported to potentially penetrate deeply into the respiratory system, translocate through the alveoli, and affect various organs, potentially correlating with increased mortality. This paper assessed long-term trends (5-11 years) in mostly urban UFP concentrations based on measurements of particle number size distributions.

Other peer-review papers that used data from the PCN&BC Network published in 2024, include:

1. *Insights into the sources of ultrafine particle numbers at six European urban sites obtained by investigating COVID-19 lockdowns*[39]

Lockdown restrictions in response to the COVID-19 pandemic led to the curtailment of many activities and reduced emissions of primary air pollutants. This paper applied positive matrix factorisation to particle size distribution data from six monitoring sites (three urban background and three roadside) between four European cities (Helsinki, Leipzig, Budapest, and London) to evaluate how particle number concentrations and their sources changed during the respective 2020 lockdown periods compared to the reference years 2014–2019

2. *Atmospheric new particle formation identifier using longitudinal global particle number size distribution data*[40]

Atmospheric new particle formation (NPF) is a naturally occurring phenomenon, during which high concentrations of sub-10 nm particles are created through gas to particle conversion. The NPF is observed in multiple environments around the world, but only limited epidemiological studies have investigated whether these particles are associated with adverse health effects. This paper introduces a regional NPF identifier, created using an automated, machine learning based algorithm. The regional NPF event tag was created for 65 measurement sites globally, covering the period from 1996 to 2023.

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