

# Quantifying Impacts of Local Traffic Policies on PM Concentrations Using Low Cost Sensors in Berlin

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## ABSTRACT

Urban air pollution remains a challenge in European cities, despite decades of improvement, especially with respect to recent updates to the World Health Organization's (WHO) air quality guidelines in 2021. At the same time, a new generation of small sensors for air pollution measurement have opened up new avenues for understanding air pollution in cities. In this study, we use Plantower PMS 5003 sensors to measure PM<sub>2.5</sub> alongside three local traffic policies implemented in 2020 and 2021. These measures include a new bike-lane and a temporary community space, as well as the creation of a pedestrian zone through the closure of a street to through-traffic. The measurement campaign used the sensors in both mobile and stationary deployments, utilizing their small size and lower cost to increase spatial and temporal resolution measurements. We calibrate the Plantower sensors using Schmitz *et al.*'s (2021b) methodology and test three different models: multiple linear regression (MLR), gradient-boosting machines (GBM), and support vector machines (SVM). Results show that sensors are useful for measuring PM<sub>2.5</sub>. We also find no significant effect of any of the local transport policies on local concentrations of PM<sub>2.5</sub>, despite previous studies of these policies showing reductions in local NO<sub>2</sub> concentrations. This indicates that larger-scale policies tackling urban and regional emissions of PM will be needed to improve PM concentrations and meet WHO standards.

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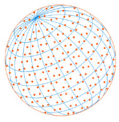
**Keywords:** Low cost, Plantower PMS 5003, Air pollution, Urban traffic policy

## 1 INTRODUCTION

In 2021, 98% of Europe's population was exposed to PM<sub>2.5</sub> concentrations above WHO recommended levels (Beloconi and Vounatsou, 2023). In Berlin in the same year, while all roadside and urban and rural background stations met the current annual EU limit-value of 25 µg m<sup>-3</sup> for PM<sub>2.5</sub>, all but two sites exceeded the WHO recommended limit-value of 5 µg m<sup>-3</sup> (SenUMVK, 2021). Despite substantial improvements in air quality over the past 30 years in Berlin, greater efforts will be needed to meet the new WHO standards and reduce negative health impacts, which occur not only at high pollution levels, but are also consistently identified with exposure to low mean PM<sub>2.5</sub> levels (< 25 µg m<sup>-3</sup>) (Chen and Hoek, 2020).

Particulate matter in eastern Germany is influenced by emissions from neighboring countries, as well as from other parts of Germany. According to a case study performed in Berlin, roughly 30% of PM<sub>10</sub> concentrations come from sources outside of Germany (mostly from Poland and the Czech Republic). The remaining 70% come from the rural background (40%), urban background (10%), and urban traffic (20%) (van Pinxteren *et al.*, 2019). A recent source attribution study of PM<sub>2.5</sub> and PM coarse (PM<sub>10</sub>-PM<sub>2.5</sub>) in Berlin found the greatest contributions to mean urban background PM<sub>2.5</sub> concentrations from household combustion, industry and energy, urban traffic, and trans-boundary emissions (Pültz *et al.*, 2023).

In the last decade, the use of small sensors for pollution measurement, also known as low-cost



sensors (LCS), has exploded. This is especially so for the measurement of PM, as the lower cost of these sensors allows for greater uptake and higher spatial resolution of measurements around the world (Giordano *et al.*, 2021). One popular such sensor is the Plantower PMS5003, which has been deployed in a variety of different sensor systems (e.g., PurpleAirs, EarthSense Zephyrs). These sensors show high inter-sensor agreeability (Ardon-Dryer *et al.*, 2020; Caseiro *et al.*, 2022; Cowell *et al.*, 2022), require correction for relative humidity and seasonality (Barkjohn *et al.*, 2021), and have a complex dependence on size distribution and composition of particles (He *et al.*, 2019). While Plantower provides proprietary-calibrated concentrations for PM<sub>1</sub>/PM<sub>2.5</sub>/PM<sub>10</sub>, these are black-box and often require re-calibration or adjustment depending on the application (Wallace, 2023). Several studies have shown this to be possible using recalibration (Aix *et al.*, 2023), linear adjustment (Barkjohn *et al.*, 2021), or using raw size distribution data from the six size bins (Wallace, 2023). These have shown promise in measuring PM<sub>2.5</sub> but are ineffective at measuring PM<sub>10</sub> (Cowell *et al.*, 2022; Kaur and Kelly, 2023).

In addition to their lower cost, small sensors also have the advantage of size. This enables them for deployment in variety of ways, including at high spatial resolution and for both mobile and stationary measurements (Schmitz *et al.*, 2021a, 2023). In the present study the PM sensors, as one component of the EarthSense Zephyrs, were deployed in two different measurement campaigns to quantify the effects of mobility policy on air quality. The policies included the creation of a pedestrian zone, the reallocation of street space for the creation of a protected bike lane, and the implementation of a temporary community space. Previous studies showed reductions in NO<sub>2</sub> resulting from these local changes to mobility infrastructure (Caseiro *et al.*, 2024; Schmitz *et al.*, 2021a). This study seeks to follow-up by assessing changes in PM concentrations due to the policies presented above to complement the NO<sub>2</sub> analysis.

## 2 METHODS

### 2.1 Instrumentation

#### 2.1.1 EarthSense Zephyrs

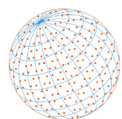
This study uses EarthSense Zephyrs®, which are sensor systems containing a variety of small sensors for measuring air pollutants and environmental parameters, among which micro-optical sensors for the measurement of PM and pressure, temperature and relative humidity monitors, which will be used for the calibration (see below, Sections 2.4 and 3.1).

The small sensors do not return concentrations of pollutants directly, but rather a raw signal of voltage (in the case of the electrochemical cells) and particle densities similar to a nephelometer (in the case of the micro-optical sensors), which need to be calibrated with reference instrumentation to estimate concentrations. This calibration was conducted by co-locating the Zephyrs with reference instrumentation from the Berlin air pollution monitoring network (BLUME) at a roadside monitoring station (MC 117) in Steglitz, Berlin, and at an urban background site (MC 042) in Neukölln, Berlin. During the study, four co-locations were performed. These were timed to account for changes in season and pollution (see Table 1 for co-location dates). Although the MC 042 and MC 117 stations are located in similar environments as the sampling sites, the occurrence of extraordinary events, such as dust intrusions or wildfires, known to influence the calibration of small sensors (e.g., Kelly *et al.*, 2021; Kaur and Kelly, 2023; Jaffe *et al.*, 2023), was not checked in this experiment.

#### 2.1.2 Plantower PMS5003

The Plantower PMS5003 sensor functions primarily by drawing in parcels of ambient air with a fan into a chamber where a beam of light is emitted. The particles present in the parcel of air scatter the light from the beam, the amount of which is translated, via a black box calibration, into particle densities in six size bins and further into particle mass concentrations (PM<sub>1</sub>, PM<sub>2.5</sub>, and PM<sub>10</sub>).

The Plantower PMS5003 is an optical particle counter (OPC). Its imperfect design does not force single particles through the focal point of the laser beam and, therefore, the energy reaching the photodiode when a particle is scattering the laser light does not depend only on the particle size (as it should under the operating principle of an OPC) but also on the position of the particle in

**Table 1.** Relevant dates regarding the sampling campaign. KD stands for Kottbusser Damm, FR stands for Friedrichstrasse.

Event	Start	End	Event	Start	End
Co-location 1	05.02.2020	18.02.2020	Co-location 3	24.07.2020	30.07.2020
Co-location 2	14.05.2020	02.06.2020	FR street closure construction	21.08.2020	28.08.2020
KD mobile measurements	06.03.2020	08.06.2020	FR without motorized traffic	28.08.2020	
KD stationary measurements	19.02.2020	19.10.2020	Co-location 4	06.11.2020	18.11.2020
1 <sup>st</sup> COVID-19 lockdown	22.03.2020	22.04.2020	2 <sup>nd</sup> COVID-19 lockdown	16.12.2020	31.03.2021
KD pop-up bike-lane constructed	23.04.2020		Co-location 5	04.03.2021	16.03.2021
FR stationary measurements	13.06.2020	01.02.2021	Co-location 6	24.06.2021	07.07.2021
FR motorized traffic allowed		21.08.2020			

the beam (Ouimette *et al.*, 2022, 2024). This shortcoming in design has implications when allocating particles to a size bin which are not uniform for all size bins (Molina Rueda *et al.*, 2023; Tryner *et al.*, 2020; Zou *et al.*, 2021), leading to poorer accuracy and precision for PM<sub>10</sub> when compared to PM<sub>2.5</sub>.

As such, another limitation arises when considering size distributions and their relationship to mass distributions. Episodes may cause significant changes in particle number and mass distributions that last hours to days in temporal scales (Li *et al.*, 2020; Viana *et al.*, 2008; Wang *et al.*, 2022) or of a few hundred metres in spatial scale. Such changes can be caused by a change in emissions (e.g., manure field application in the regional background increasing secondary inorganic aerosols (Harni *et al.*, 2023; Hristov, 2011)) or a change in atmospheric processes (partially) driven by meteorology or circulation (e.g., increase in sea salt or dust from long-range transport may shift the mass distribution for a few isolated days) (Pio *et al.*, 2020). Both the chemistry of the particles and gases and prevailing meteorological conditions can also influence the gas-particle partition regime. Such dynamism alters the number of larger particles (less efficiently counted) with respect to the number of smaller particles (more efficiently counted), amplifying the lack of accuracy and precision of PM<sub>10</sub> retrievals.

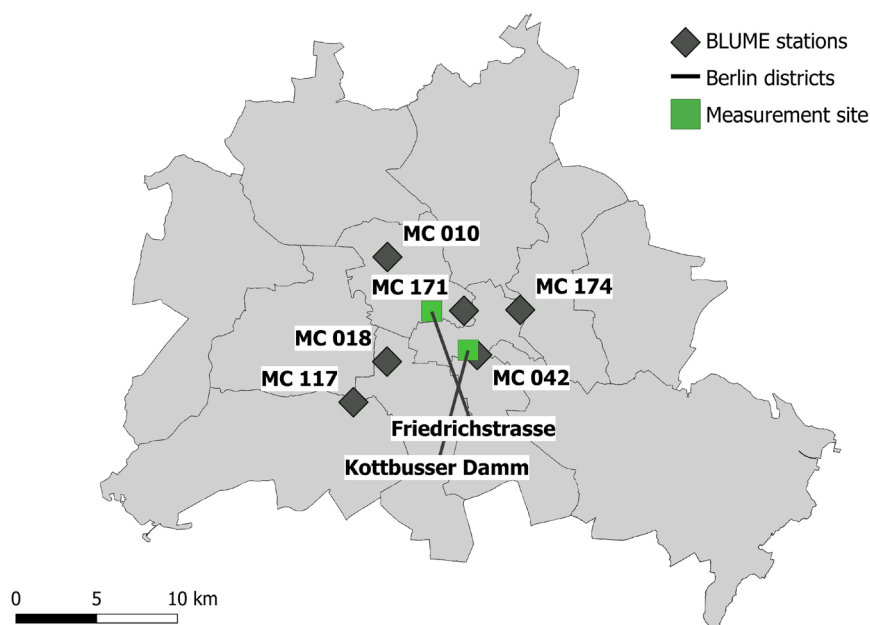
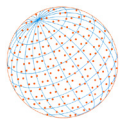
It is possible that the recalibration strategy followed in this study covers a limited set of relationships between particle number and mass distributions. These calibrations are performed on a seasonal basis at sampling sites similar to the experimental sites in terms of dominant regional and local sources, and meteorological parameters. The uncertainties presented here may therefore be underestimated. Due to the very large uncertainties computed, the calibration and subsequent results for PM<sub>10</sub> are shown in the Supplementary Information only, and the main manuscript focuses on the PM<sub>2.5</sub> results.

### 2.1.3 BLUME

We included data collected from measurement stations that are a part of the Berlin air pollution monitoring network (BLUME). Fig. 1 shows the location of four urban background stations (MC 010, MC 018, MC 042, MC 171) and one roadside station (MC 117) that were selected for use in comparison to the study area. The automatic measurement of PM<sub>2.5</sub> (and PM<sub>10</sub>, see the SI) in these measurement stations is carried out using GRIMM EDM 180 environmental dust monitors. The devices are operated in accordance with DIN EN 16450 and the equivalence to the reference method (DIN EN 12341) is verified annually. The urban background stations are located around the measurement sites and together are considered representative of urban background conditions for Berlin.

## 2.2 Study Sites

Two measurement campaigns at different sampling sites in Berlin were conducted. The first one, Kottbusser Damm (KD), was selected due to the planned occurrence of two separate policies that were to be evaluated: the construction of a new bike-lane on the street and the establishment of a community space on a side street to KD (Böckhstrasse) during the summer months on Wednesdays from 14:00–18:00 in which through-traffic was restricted. KD is a Northwest-Southeast oriented between the Berlin city districts of Friedrichshain-Kreuzberg and Neukölln and experiences



**Fig. 1.** Map of Berlin, including the locations of the four urban background BLUME stations (MC 010, MC 018, MC 042, MC 171), one roadside BLUME station (MC 117), and the location of the measurement sites.

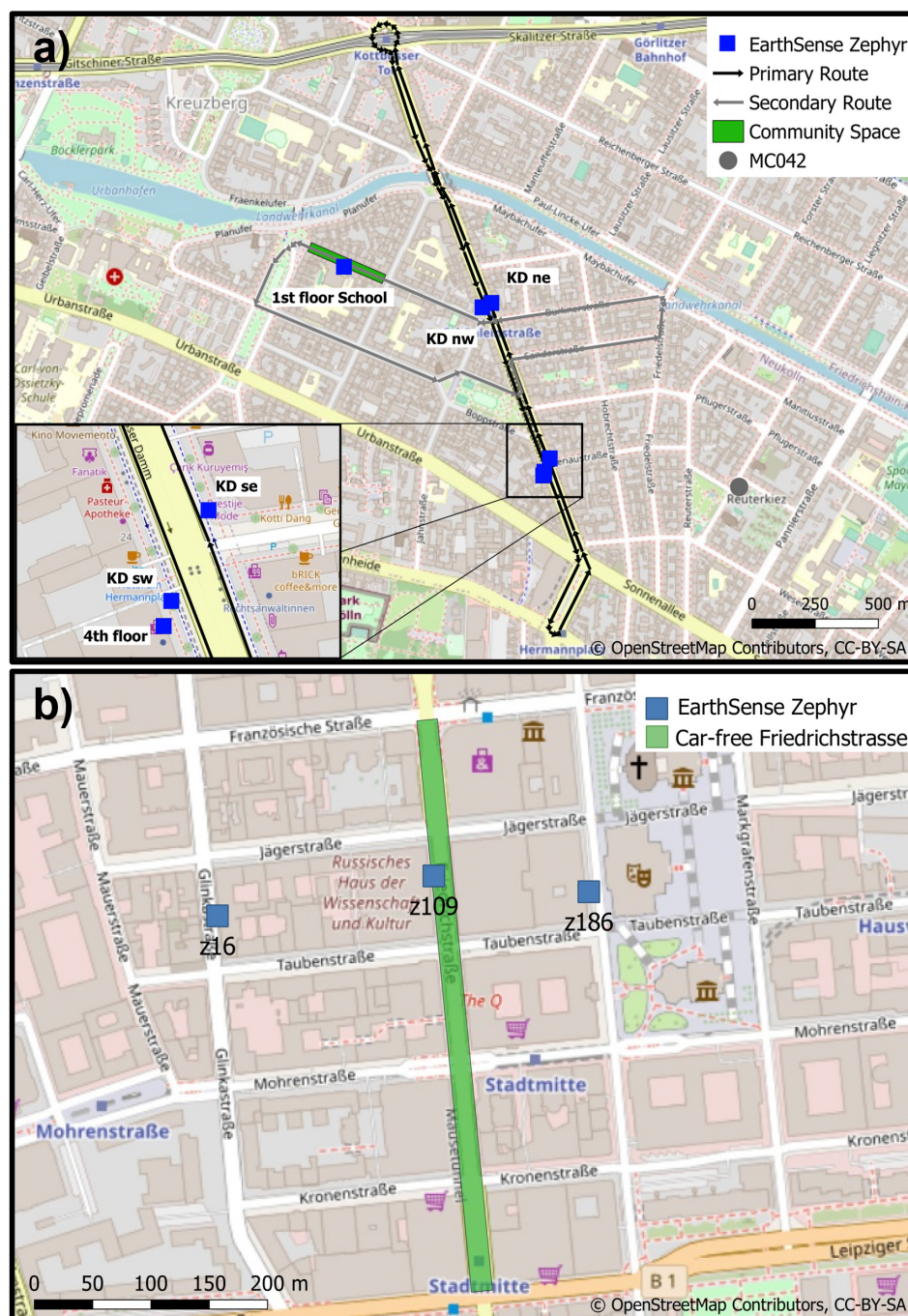
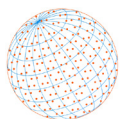
high traffic volume (23,400 cars, 660 trucks on workdays) (SenUMVK, 2019). At this site, seven Zephyrs were deployed during the measurement campaign. One was used for mobile measurements along two separate routes, one was placed on the 4<sup>th</sup> floor façade of a building facing the street, four were placed on lampposts (3.5 m above the ground) along the street, and one was placed on the 1<sup>st</sup> floor façade of a school facing the Böckhstrasse, at the location of the community space (see Fig. 2(a)).

The second sampling site, Friedrichstrasse (FR), was selected to check differences in air quality due to the restriction of traffic on a five block portion of one street (Fig. 2(b)). FR is a North-South oriented thoroughfare in the Berlin city district of Mitte, which connects the very busy streets of Leipziger Strasse and Unter den Linden and experiences medium traffic volume (11,400 cars, 520 trucks on workdays) (SenUMVK, 2019). At this site, three Zephyrs were deployed on lampposts (3.5 m above the ground). One was placed on FR and two were placed on parallel side streets (Glinkastrasse and Charlottenstrasse). Relevant dates for the campaigns at both sites are given in Table 1.

### 2.3 Calibration and Sampling Strategies

Zephyrs circulate air into the housing unit to pass over the small sensors every 10 seconds. This high time resolution was leveraged for the mobile measurements on KD, to ensure that rapid changes in PM and gas-phase pollutant concentrations were captured as accurately as possible. For stationary measurements, measurements were averaged to 5-minute resolution, so as to capture local background concentrations without being susceptible to the impact of rapid short-term changes in concentrations. During co-locations, the highest possible time resolution reference data from BLUME instruments was 5 minutes.

For the mobile measurements on KD, two separate routes were planned to capture changes associated with the bike-lane, as well as changes that occurred locally. The main route covered the full length of KD, from Kottbusser Tor to Hermannplatz; the secondary route focused on the side streets by looping on both sides of KD, as well as crossing Böckhstrasse (Fig. 2(a)). In selecting the secondary route, priority was given to paved streets to avoid cobblestones, as the potential effect of the vibrations on Zephyr performance and longevity was unclear. Each instance of mobile sampling consisted of three continuous loops of each route, conducted during the morning, afternoon, and evening.

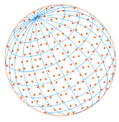


**Fig. 2.** Location of sensors at the (a) KD sampling site and (b) FR sampling site.

On KD, nine days of mobile measurements were captured before and eleven days after the implementation of the new bike-lane. On FR, three months of measurements were conducted before and six months after the closure of FR to through-traffic.

## 2.4 Statistical Methods

To calibrate the sensors, the 7-step open-source calibration methodology (Schmitz *et al.*, 2021b) was used. These steps are: 1) data cleaning; 2) analyze raw data distribution; 3) flag data; 4) model selection and tuning; 5) model validation; 6) export model predictions; 7) calculate predictive uncertainty. During calibration, models were built in steps 4–6 using multiple linear regression (MLR) were used for calibration. In this case, sensors were re-calibrated using reference data from



the BLUME stations instead of using raw size bin data. Other models, e.g., machine-learning techniques, have been used to calibrate PM small sensors (Kumar and Sahu, 2021) and therefore, models were also built and tested with gradient-boosting machines (GBM) and support vector machines using a polynomial kernel (SVM). To test model performance during the course of the campaigns, MAE and  $R^2$  were calculated for models trained on a single co-location and trained on the rest, with the approach repeated for each individual co-location. This was done for all units but results are presented only for those with the most available co-location data.

The parametric Student's t-test was used to test differences before and after policies were implemented while the non-parametric Wilcoxon Mann Whitney (WMW) u-test was used to compare distributions under the same circumstances. In addition, differences in median concentrations for the entire sampling periods before and after the implementation of each policy were calculated. Propagation of error for differences between median (not mean, to decrease the relative importance of the extremes) concentrations were calculated using the formula:

$$Q = \sqrt{(e_1)^2 + (e_2)^2} \quad (1)$$

where  $Q$  is the propagated error and  $e_1$  and  $e_2$  are the individual uncertainties of the two measurements being compared. These differences in median concentrations before and after the implementation of the measures and their propagated error are presented in the text throughout using the following syntax:

$$(\text{median conc. before} - \text{median conc. after} \pm \text{propagated uncertainty}) \quad (2)$$

In order to assess differences in extreme concentrations, the median of the 95<sup>th</sup> Percentiles were computed. For example, the 95<sup>th</sup> Percentile of the concentration for each loop of the primary route in KD before the implementation were computed, the median extracted and compared to the equivalent metric derived from concentrations measured after the implementation.

Urban background concentrations on KD were drawn from one nearby station (MC042). As there were not any urban background stations located in the close vicinity of the FR site, the urban background concentrations are an average of four urban background stations (MC010, MC018, MC042, MC171). The urban background concentrations were used to normalize the measured concentrations. By subtracting, on an hourly level, the urban background from the concentration measured at the sampling site, we are evaluating the impact of the policy against the urban background and therefore minimizing the influence of the meteorological conditions and of changes in other, less localized, sources.

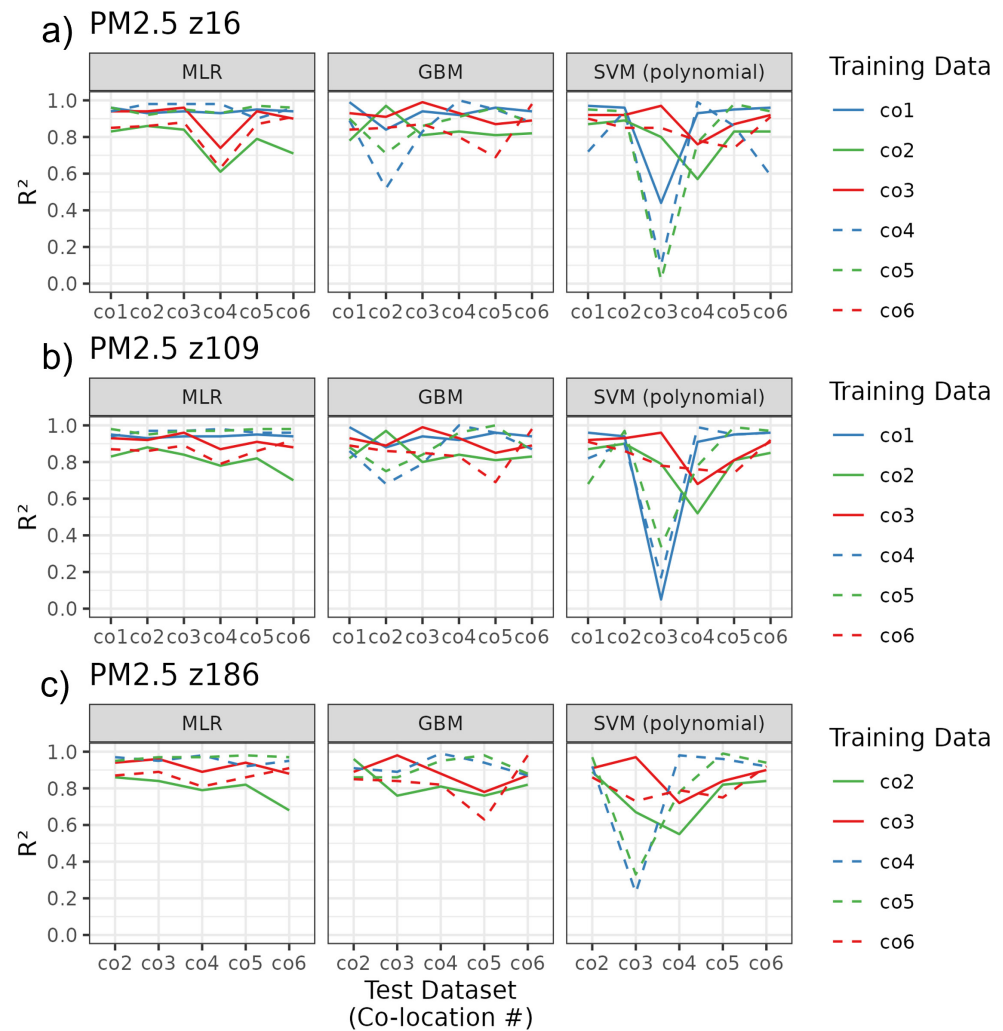
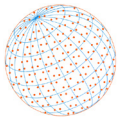
## 3 RESULTS

### 3.1 Calibration

After testing three different calibration models, MLR appears to be the best performing model. Results for the three units with the most training datasets from the co-locations are presented in Fig. 3 and Fig. S1 for  $R^2$  and MAE, respectively. Both MLR and GBM perform well ( $R^2$ : 0.6–0.95, MAE: 0.5–5  $\mu\text{g m}^{-3}$ ) with SVM performing poorly. However, MLR showed a slight impact of seasonality. Models trained with winter and the early spring co-location (Co-location 5) perform well when tested against all other co-location datasets, whereas those trained with summer co-locations or the late spring co-location (Co-location 2) perform poorly. Overall, MLR models tend to be consistent in their performance across co-locations, regardless of how well they perform and with which co-location they were trained, whereas the performance of both GBM and SVM varies substantially and has a greater dependence on the composition of the training dataset.

### 3.2 Diurnal Concentrations

An overview of the concentrations measured is given in Table 2.  $\text{PM}_{2.5}$  concentrations on KD generally match urban background concentrations well (Fig. 4), indicating only marginal contributions

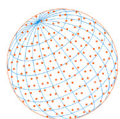


**Fig. 3.** Calibration models trained with one co-location and tested on all others for three Zephyrs (z16, z109, z186). Winter co-locations are shown in blue, spring co-locations in green, and summer co-locations in red. Solid lines represent co-locations completed in 2020, dashed lines for those in 2021. The ticks on the x-axis (co1, co2, etc.) represent the co-locations completed (see Table 1).

**Table 2.** Mean daily PM<sub>2.5</sub> concentrations for all stationary Zephyrs across the duration of each campaign, including standard deviation of daily means.

Zephyr Number	Mean PM <sub>2.5</sub> KD (± standard deviation)	Location during campaign	Mean PM <sub>2.5</sub> Fstr (± standard deviation)	Location during campaign
z13	10.66 ± 5.31	1 <sup>st</sup> floor school	–	
z16	12.34 ± 5.52	KD SE	12.4 ± 6.28	Glinkastr.
z17	9.55 ± 4.66	Bicycle	–	
z109	12.73 ± 5.69	KD SW	12.38 ± 6.28	Friedrichstr.
z115	11.48 ± 4.51	KD NW	–	
z119	11.99 ± 5.3	KD NE	–	
z186	12.77 ± 6.22	KD 4 <sup>th</sup> Floor	12.38 ± 6.5	Charlottenstr.

from local emission sources. There are marginal differences in PM<sub>2.5</sub> concentrations across the different measurement locations on weekdays. There are no differences in PM<sub>2.5</sub> concentrations across different streets at FR. There are also few differences in concentrations on weekdays versus

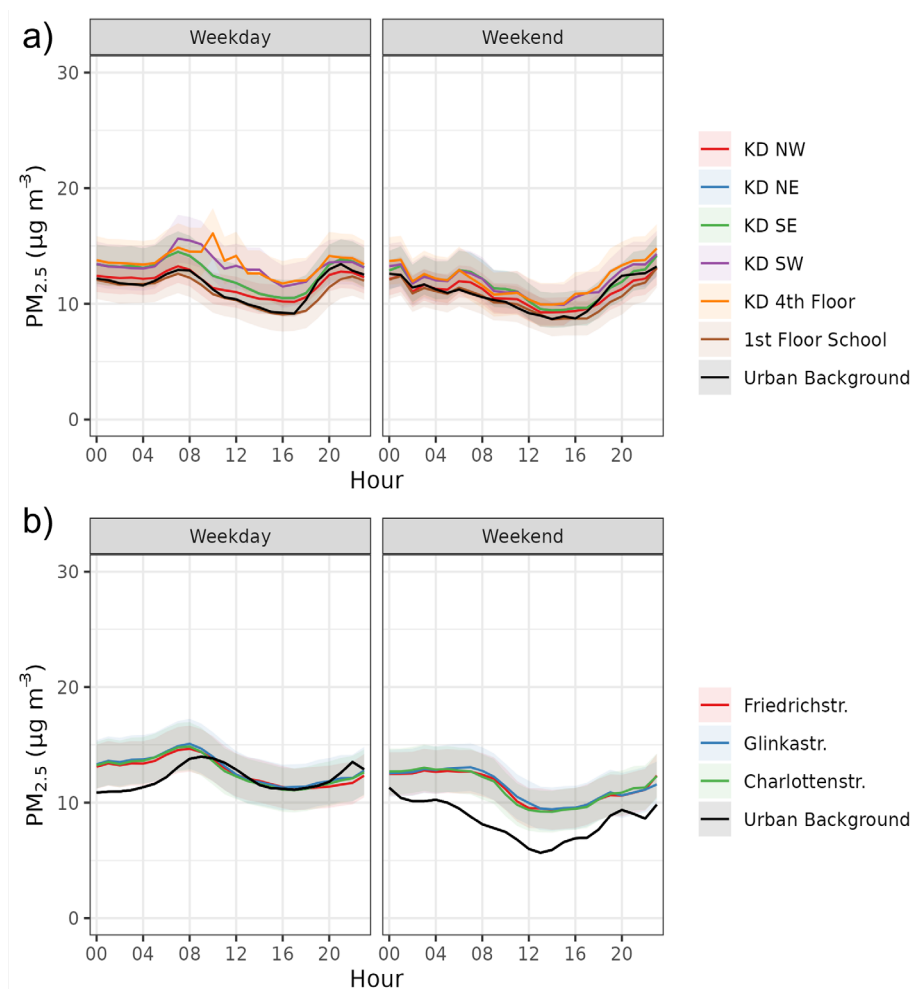


on weekends.  $PM_{2.5}$  concentrations on both streets match the pattern in the urban background of  $PM_{2.5}$ , the double peak aligning with weekday traffic patterns, especially on KD. On FR, the patterns are similar for  $PM_{2.5}$  albeit at a different concentration level.

### 3.3 Impact of Traffic Policies: Kottbuser Damm

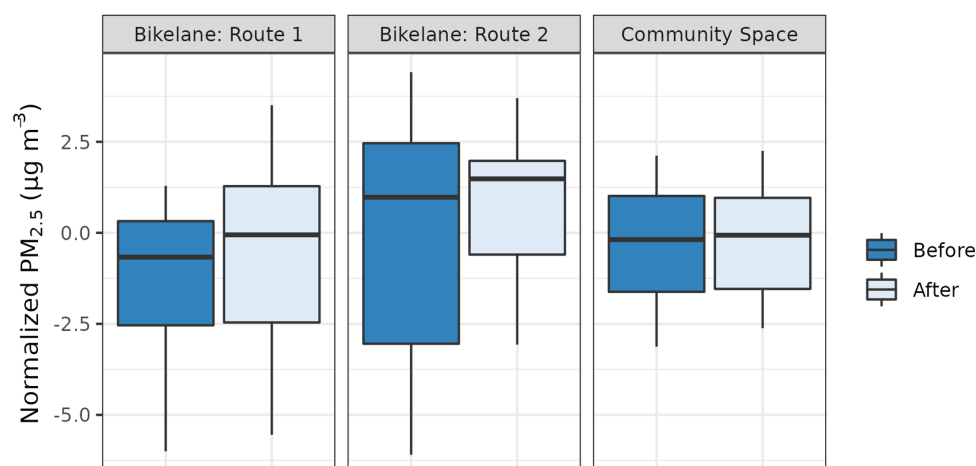
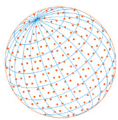
Only marginal differences in PM concentrations were measured on KD and on the Böckhstrasse following the implementation of the traffic policies (Fig. 5 and Table 3). An increase in PM concentrations was observed along the KD route after the implementation of the measures. Differences in median concentrations were seen on the primary mobile measurements route along KD of  $-0.61 \pm 1.76 \mu\text{g m}^{-3}$  for  $PM_{2.5}$ . A similar increase of PM concentrations was observed at the secondary mobile route ( $-0.51 \pm 1.75 \mu\text{g m}^{-3}$  for  $PM_{2.5}$ ). On the side street, the difference in median concentrations between days with and without the community space was  $-0.12 \pm 2.18 \mu\text{g m}^{-3}$  for  $PM_{2.5}$ . In no case did these differences exceed the propagated uncertainty associated with the measurements, though almost all were statistically significant.

The measured extreme concentrations produced differences along the primary route of mobile measurements on KD of  $2.14 \pm 2.61 \mu\text{g m}^{-3}$  in median. On side-streets, along the secondary route, the median difference in extreme concentrations was  $9.95 \pm 2.78 \mu\text{g m}^{-3}$ . On the community space, a median difference of  $-0.52 \pm 2.56 \mu\text{g m}^{-3}$  in extreme concentrations was observed. On the secondary mobile route differences between extreme concentrations were greater than the range of uncertainty. All differences were statistically significant under a WMW U-test at  $p < 0.005$ , except for the Böckhstrasse.



**Fig. 4.** Hourly plots for weekdays (left) and weekends (right) for  $PM_{2.5}$  concentrations from stationary Zephyrs on KD (top panel) and FR (bottom panel).





**Fig. 5.** Boxplots of normalized PM<sub>2.5</sub> concentrations from the mobile measurements and the community space measurements on KD.

**Table 3.** Differences in median concentrations, calculated by subtracting the median after from the median before the policy implementation on KD for PM<sub>2.5</sub> with propagated error. These were also calculated at the 95<sup>th</sup> percentile to assess changes in extreme concentrations ( $p < 0.005 = ***$ ,  $p < 0.05 = **$ ,  $p < 0.01 = *$ ).

PM <sub>2.5</sub>	Median Before	Median after	Median Difference	± error	Median Before (95 <sup>th</sup> Percentile)	Median after (95 <sup>th</sup> Percentile)	Median Difference (95 <sup>th</sup> Percentile)	± error
Route #1	-0.67	-0.06	-0.61***	1.76	6.7	4.55	2.14***	2.61
Route #2	0.98	1.48	-0.51***	1.75	15.29	5.33	9.95***	2.78
Community Space	-0.19	-0.07	-0.12	2.18	4.07	4.59	-0.52	2.56

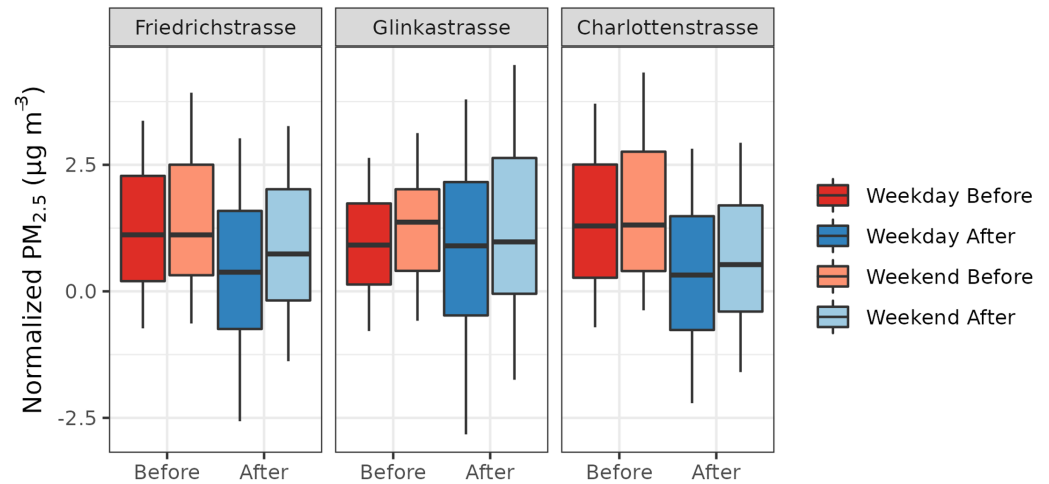
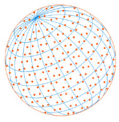
### 3.4 Impact of Traffic Policies: Friedrichstrasse

In Fig. 6 and Table 4 differences in PM concentrations before and after the implementation of the street closure are presented. At FR a difference of  $0.64 \pm 2.61 \mu\text{g m}^{-3}$  was measured in median. At Glinkastrasse and Charlottenstrasse, changes of a similar magnitude and direction were measured, indicating the changes were not localized to FR. None of the differences exceeded the range of uncertainty calculated for these sensors, despite all being statistically significant at  $p < 0.005$  under a WMW U-test. For the extreme concentrations, there are some statistically significant differences for PM<sub>2.5</sub>, though these are very small and not beyond the range of uncertainty. The minor decrease in PM<sub>2.5</sub> concentrations before and after the implementation of the policy are consistent on weekdays and weekends.

As can be seen in the density plots in Fig. 7, any changes before and after the implementation of the measure in local concentrations at the FR measurement site mirror changes in the urban background. While there are slight differences in the shape of the density curves, the changes in magnitude and direction of PM concentrations agree between FR and the urban background. In addition, the density curve is almost identical at all three FR locations, further indicating the relatively limited contribution of the local traffic at FR to the total PM load.

## 4 DISCUSSION

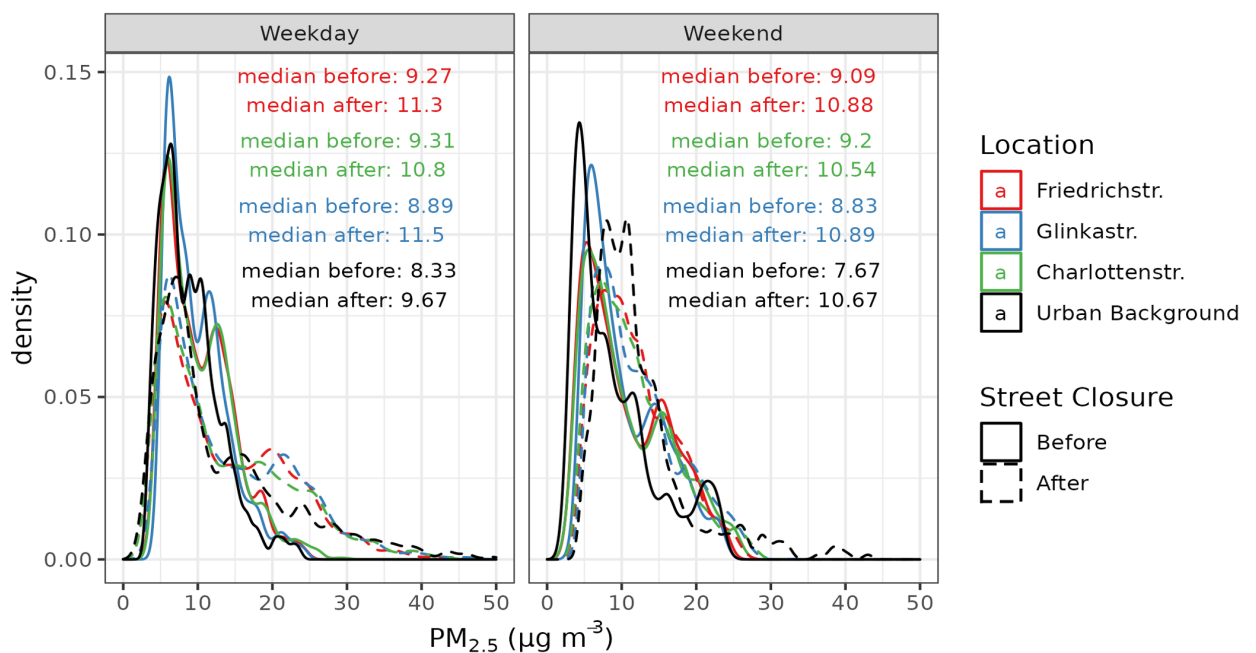
In this study we measured changes in PM<sub>2.5</sub> concentrations alongside three different local traffic policies in Berlin. Results show that highly localized policies, such as the closure of FR to through traffic and the establishment of a community space and a new bike-lane on KD, do not have an impact on local PM<sub>2.5</sub> concentrations. We have shown that though there are statistically significant differences in concentrations before and after the implementation of these measures, the magnitude is too small and not beyond the range of uncertainty of the sensors to be able to conclude that these measures have affected local patterns of PM<sub>2.5</sub> pollution.



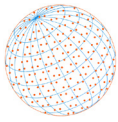
**Fig. 6.** Boxplots of  $PM_{2.5}$  concentrations from the stationary measurements on FR normalized to the urban background.

**Table 4.** Differences in median concentrations, after the policy implementation on FR with propagated error. These were also calculated at the 95<sup>th</sup> percentile to assess changes in extreme concentrations. Statistically significant differences in distributions via the WMW U-test are designated with asterisks ( $p < 0.005 = ***$ ,  $p < 0.05 = **$ ,  $p < 0.01 = *$ ).

$PM_{2.5}$	Median Difference	$\pm$ error	Median Difference (95 <sup>th</sup> Percentile)	$\pm$ error (95 <sup>th</sup> Percentile)
Friedrichstrasse	0.64***	2.61	-0.06*	3.05
Glinkastrasse	0.14***	2.84	-0.23**	3.36
Charlottenstrasse	0.91***	2.75	0.14**	3.23



**Fig. 7.** Density plots of all  $PM_{2.5}$  concentrations measured before and after the implementation of the street closure on FR.



On KD, small differences in PM<sub>2.5</sub> concentrations were measured on both along the street as well as on the side streets, indicating that the bike-lane and associated changes in traffic were not the driver of change. Similarly, minor differences in concentrations were measured on FR following the closure of the street to traffic, which were also measured on parallel side streets and mirrored changes in the urban background. This is an indication that while these policies do have an impact on local NO<sub>2</sub> concentrations (Caseiro *et al.*, 2024; Schmitz *et al.*, 2021a), the same cannot be said for PM<sub>2.5</sub>. Instead, changes in regional and urban emissions and meteorology are likely the cause of the small differences measured in this study. Localized traffic policies will be insufficient in reducing PM<sub>2.5</sub> concentrations in Berlin to meet WHO guidelines. These will need to occur at a wider scale, so that, from a greater number of sectors, including household combustion and urban traffic, as we know these are the largest contributors to PM concentrations in Berlin (Pültz *et al.*, 2023).

#### 4.1 Limitations

There are some key limitations to this study. During 2020 and 2021, the onset of the COVID-19 pandemic led to a series of lockdowns that overlapped with the timeframe of these measurement campaigns. While normalizing local results to urban and local background concentrations partially accounts for any changes in pollution attributable to impacts of COVID-19 lockdowns, it does not do so completely and should therefore be considered a limitation of this study. In addition, due to the rapid implementation of the bike-lane on KD in pop-up form as a response to COVID-19, only two months of “before” data could be measured there, one of which was during a lockdown. More data are needed to definitively conclude that policies such as the removal of a motor vehicle traffic lane and addition of a bike-lane do not impact local patterns of PM pollution. Another limitation is that high temporal resolution traffic data were not available for this study and as such the impacts on local pollution that might have been attributed to changes in traffic behavior could not be quantified. Future studies should seek to include this data in their analysis.

## 5 CONCLUSIONS

We have shown that these measures did not have a significant impact on local concentrations of PM<sub>2.5</sub>. Any changes measured at each site were measured across the entire study area and matched patterns of changes to PM concentrations in the urban background. In addition, this study found further evidence that Plantower PMS5003 sensors are appropriate for the measurement of PM<sub>2.5</sub>.

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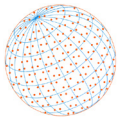
## ADDITIONAL INFORMATION

### Data Availability Statement

The data that support the findings of this study are available upon reasonable request from the authors.

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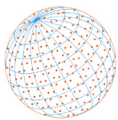
by the Federal Ministry of Education and Research of Germany (BMBF) and the Ministry for Science, Research and Culture of the State of Brandenburg (MWFK).

### Supplementary Material

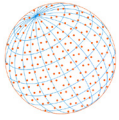
Supplementary material for this article can be found in the online version at <https://doi.org/10.4209/aaqr.240050>

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