Performance evaluation of six low-cost particulate matter sensors in the field

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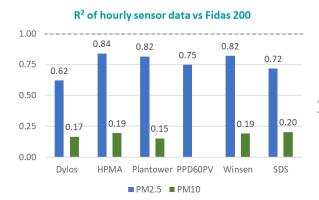


Summary

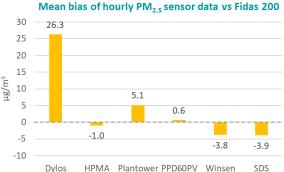
- Six different sensor types were compared to one automated reference (Palas Fidas 200) and one EU gravimetric sampler (Derenda PNS T-DM) at the VMM urban monitoring site in Borgerhout in Antwerp (Belgium) over the course of **401 days**. For each sensor type 5 units were co-located.
- Given the typical non-regulatory uses of low-cost sensors (e.g. hotspot detection, awareness raising,...) the main focus was on the **hourly averages**. Comparison with the EU gravimetric reference sampler was carried out at the daily level.
- **Basic validation was required** for several sensor types and data availability varied considerably between units. Typical issues were spikes in data signals, periods of elevated measurements compared to other units, dust piling up inside certain sensor units, electronic issues, interference by light or heat and loss of signal. Since local power issues and data communication problems also occurred it is difficult to quantify how much of data loss could be attributed to the sensor units themselves.
- Given the above, a practical **recommendation** could be to co-locate more than one unit of the same type to be able to identify aberrant behaviour and to increase data availability and data quality.
- In general sensors showed acceptable to good correlation for PM_{2.5} (R² between 0.62 and 0.84). Due to the high proportion of PM_{2.5} in PM₁₀ some sensors did show some correlation for PM₁₀, but this can be considered artificial since there was poor to non-existing correlation for the coarse PM fraction (=PM₁₀ PM_{2.5}). At least for the tested configurations none of the sensors could therefore be described as a true PM₁₀ sensor. The Dylos and the SDS (the two units with the biggest fan) were the only types that appeared to sometimes pick up certain particles larger than 2.5 μm.
- Plotting the correlation graph of the coarse PM fraction (= PM₁₀ PM_{2.5}) of sensor vs. reference is recommended. In addition, plotting the correlation graph of the coarse PM fraction vs. the PM_{2.5} fraction for the sensors gives insight in the sensor algorithm and appears to show some sort of sensor 'fingerprint'.
- Between-sensor uncertainty, a measure for the comparability between different units of the same sensor type varied between 14% and 27% or between 1.5 and 7.2 μg/m³ for PM_{2.5}. This should be taken into account when considering applications. For example, picking up small differences in PM concentrations might be difficult or would require co-location and/or calibration of sensors.
- Some types showed little bias out of the box while **others required additional calibration** to significantly lower bias and uncertainty at the limit value.



- As expected, all sensor unit showed a **dependency on relative humidity** and temperature. The increase in sensor/reference ratio from 50% RH to above 90% RH varied between a factor of 1.4 and 2.4.
- After applying a linear calibration to all valid 24h PM_{2.5} averages, 5 out of 6 sensor types had an expanded uncertainty below 25% vs. the reference (at 30 μg/m³ and for the full dataset).
- Analysis of SDS011 sensors co-located with Fidas Palas 200 at 8 different monitoring sites showed that other locations can give less favourable results than the VAQUUMS test site in Borgerhout. These results could be linked to more frequent episodes of high relative humidity at other locations. The presence of vegetation close to the monitoring sites appears to play an important role.



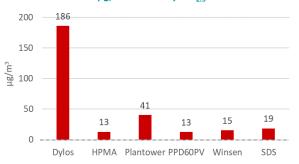
Summary plots



Between-sensor uncertainty for hourly PM_{2.5} data (u_{bs})



95% CI around 30 μ g/m³ for hourly PM_{2.5} data vs Fidas 200

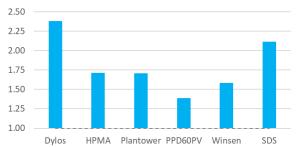




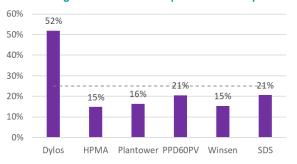


Expanded uncertainty of <u>24h</u> PM_{2.5} sensor data vs gravimetric reference (no calibration) 873%

Increase in PM_{2.5} sensor/Fidas ratio from 50% to +90% relative humidity



Expanded uncertainty of <u>24h</u> PM_{2.5} sensor data vs gravimetric reference (after calibration)





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Introduction

This report describes the field comparison of 6 types of low-cost PM sensors. Full details of the testing are provided in the test protocol^a.

The PM sensors were compared to two 'reference' systems:

1. an 'equivalent' automatic **optical PM monitor** (Palas Fidas 200) measuring at a high time resolution (5-min averages) and operating according to EN16450;

2. an official European **gravimetric reference sampler** (Derenda PNS T-DM with Pall Tissuquartz QAT-UP filters) operating according to EN12341 and providing 24-h average data.

For each sensor type we discuss the following points:

a. Validation and data coverage: specific issues with the validation are mentioned here, in addition the number of available and not available hourly data per validation code (0: valid, -1: suspicious, -2: invalid) are shown. Although the campaign lasted 401 full days, no sensors were able to attain 100% coverage, partially due to power failures at the monitoring site. The highest observed data coverage was 379 days or 95%.

b. **Comparison of PM_{2.5} sensor data with the Palas Fidas 200 monitor**: presented as timeplots and scatterplot with the main focus on the hourly averages. The 95% confidence interval for values around $30 \ \mu g/m^3$ is also reported. In addition, the ratio sensor/Fidas is plotted in function of time, temperature and relative humidity. To quantify the humidity effect the median hourly sensor/Fidas ratio between 45% and 55% RH is compared to the median hourly sensor/Fidas ratio above 90% RH.

c. **Comparison of 24-h average PM_{2.5} sensor data with Fidas and gravimetric reference:** A timeplot and scatterplot are shown for the comparison with the Fidas. For the comparison with the gravimetric reference method we use the daily average of all valid sensors (so basically simulating a multi-sensor setup) and show the results of the official EU-spreadsheet for demonstration of equivalence which includes slope and intercept of a linear regression, R², bias at the limit (pseudo) limit value of $30 \,\mu\text{g/m}^3$ and expanded uncertainty expressed at that (pseudo) limit value. Since EN16450 allows the user to apply a correction equation based on the comparison, we also check how applying the slope and intercept influences the different benchmarks. One important remark is that the relation between sensor and reference will most likely change in time and space, so applying the locally found slope and intercept correction should be seen as a 'best case scenario'.

d. Between-sensor uncertainty: this is given for the hourly level in absolute and relative terms.

e. Comparison of PM₁₀ and PM_{coarse} sensor data with the Palas Fidas 200 monitor: Scatterplots and timeplots are used to indicate whether the sensors actually pick up any of the coarser PM (defined as PM_{10} minus $PM_{2.5}$). A final scatterplot shows the correlation between the sensor $PM_{2.5}$ and PM_{coarse} data, sometimes revealing specific algorithms to 'estimate' PM_{10} .

^a <u>https://vaquums.eu/sensor-db/tests/protocols/life-vaquums_testprotocol_final.pdf</u>



Note: Since we found a very low correlation between the sensors and the automatic reference for PM_{coarse} it is clear that the sensors here cannot be considered true PM_{10} sensors. Therefore the focus in this report is on $PM_{2.5}$. Although the PM_{10} scatterplots show a certain degree of correlation, this appears to be almost completely due to the usually high fraction of $PM_{2.5}$ in PM_{10} .

8 Types of sensors started the test (see Table 1), but the Shinyei PPD42NS and the Alphasense OPC-N2 were excluded from this report due to substantial technical problems.

Honeywell HPMA 115S0	Dylos DC1700	Nova Fitness SDS 011
Plantower PMS7003	Winsen ZH03B	Shinyei PPD 60PV
(Shinyei PPD42NS)	(Alphasense OPC-N2)	

Table 1:PM-sensors that started the Vaquums field campaign.



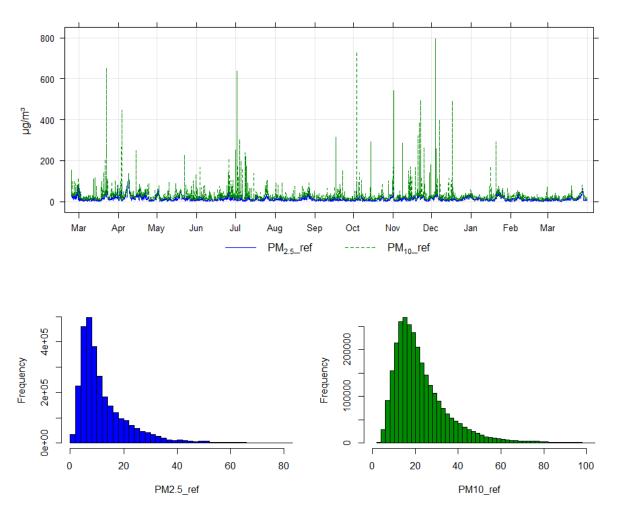
PM-concentrations and atmospheric conditions during the campaign

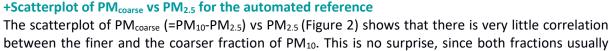
Sensor units were co-located at the R801 urban background measurement site of VMM in Borgerhout, Antwerp (Belgium) for about 400 days (from February 23, 2019 until March 31, 2020). Sensor data were given 3 validation codes: valid (0), suspicious(-1) and invalid (-2). Only valid data were used in the current report. Sensors usually reported data per second but these were aggregated as 5-minute, hourly and daily averages. The hourly level was chosen as the main aggregation level for most analyses. Daily averages were used for comparison with the gravimetric reference method for about 10 months (from June 21, 2019 to March 31, 2020).

+ Hourly PM values of the automated reference (Palas Fidas 200)

Conditions during the campaign were considered typical for the urban background site in Borgerhout. The mean $PM_{2.5}$ concentration was 13 µg/m³ and the mean PM_{10} concentration was 23 µg/m³. As can be seen in Figure 1 some events with high hourly PM_{10} values occurred during the campaign. The origin of these peaks varies but in most cases they could be assigned to resuspension events or building works nearby.

Figure 1: Timeplot and histograms of hourly averages for $PM_{2.5}$ and PM_{10} as measured by the Palas Fidas 200 monitor







have different origins. In $PM_{2.5}$, secondary aerosols are often the dominant fraction, while for PM_{coarse} this is almost always primary aerosol due to some sort of mechanical process (e.g. resuspension, sea spray, building activities).

Creating a similar plot for the low-cost sensors will give an indication of how good (or bad) sensors are at detecting the coarse particles and/or whether certain algorithms are used to estimate PM_{10} from $PM_{2.5}$. (see Annex 2 for a graphic summary)

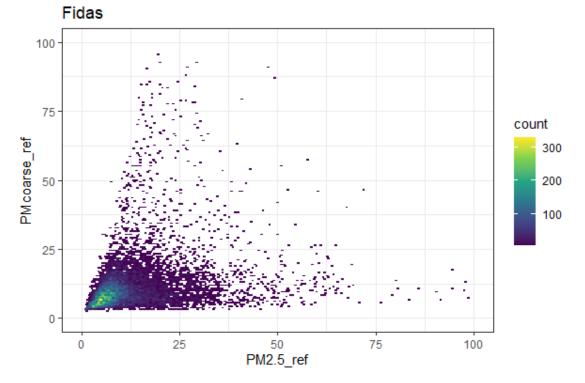
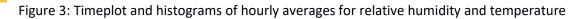


Figure 2: Scatterplot of PM_{coarse} vs $PM_{2.5}$ for the Palas Fidas 200 reference monitor (in $\mu g/m^3$)

+ Temperature and relative humidity values

Figure 3 shows the variation in daily averages of temperature and relative humidity during the campaign. The average temperature and relative humidity in Borgerhout were 12.4°C and 74%, respectively.





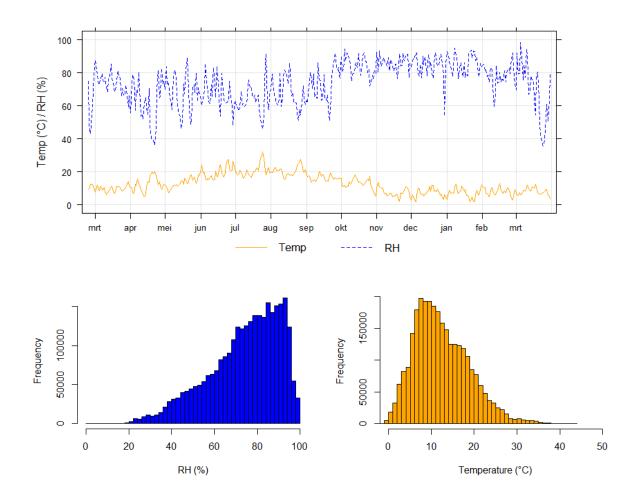


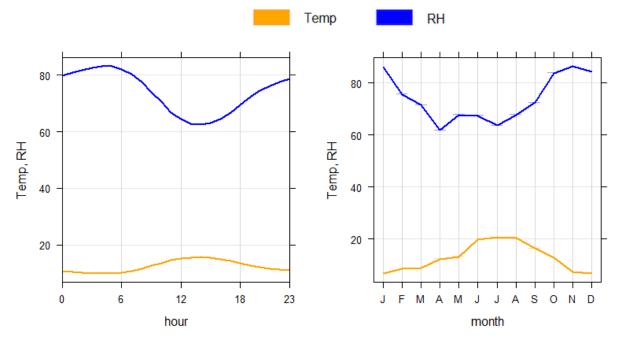
Figure 4 shows the variation of temperature and relative humidity within an average day. It's interesting to note the day vs. night pattern for both parameters and the inverse relation between both parameters.

It is well known that most particles grow due to absorption of water at higher relative humidity (RH). In particular when RH gets over 80-85% this effect becomes significant and it is therefore that highend PM monitors perform some sort of drying process. The drying process should also be specific enough not to evaporate semi-volatile particles. Since the amount of water absorption depends on the nature of the particles (which is usually unknown) it is not easy to correct for this effect without physically drying the air.

In general low-cost sensors do not have any specific heating/drying parts, although certain sensors (e.g. Shinyei PPD60pv) do use a thermal resistance to heat the air and draw it into the optical chamber.



Figure 4: Average timevariation per hour and per month for temperature and relative humidity





SENSOR RESULTS





Honeywell HPMA 115S0







Honeywell HPMA 115S0

+Validation and data coverage

Of the 5 units that were tested only sensors 2 and 4 showed a good overall data recovery of around 360 days with data (= 90%). Units 1 and 5 only had about 110 valid days (27%) and unit 3 had none (0%). All units were troubled by spikes in their signal (which were validated as 'suspicious'), but the amount of spikes varied considerably between the units. For unit 3 this problem occurred most frequently and all data up to August were given a 'suspicious' status (see Figure 5). That unit also started reporting erroneous data from the end of August and was decommissioned mid-October. Unit 1 did not report data between April and September 2019 (reason unknown), while unit 5 started showing erroneous data from August 2019 and was eventually also decommissioned at the end of November.

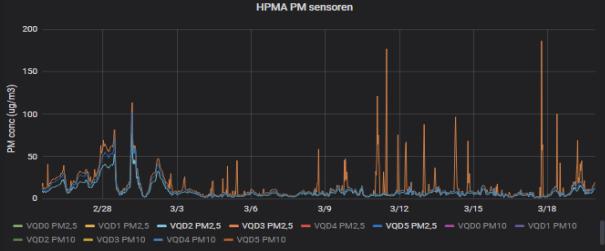
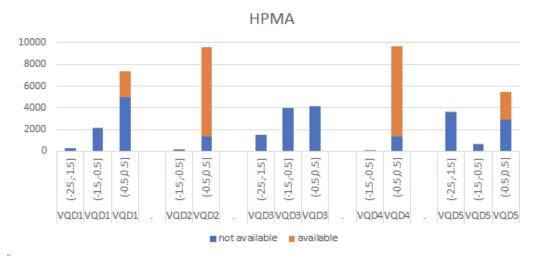


Figure 5: Example of typical 'spikes' observed for HPMA sensor unit 3

Figure 6: Overview of available hourly data per validation code (-2: invalid / -1: suspicious / 0: valid) for the different units





+PM_{2.5} comparison with Fidas monitor

The average hourly signal of all valid HPMA data appears to match the Fidas $PM_{2.5}$ quite well. When looking at the individual units we notice small differences. Units 4 and 5 appear to match the Fidas reference the best while unit 1 slightly overestimates and unit 2 slightly underestimates. The value of R^2 for all valid hourly data vs Fidas $PM_{2.5}$ was 0.84 (which was the highest of all tested sensor types).

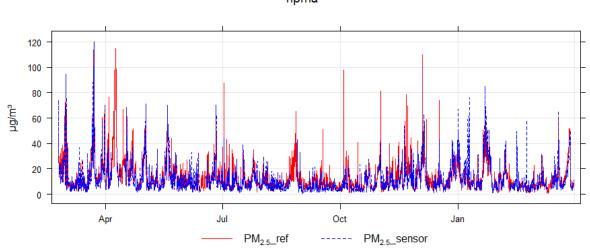


Figure 7: Hourly average of all valid HPMA PM_{2.5} sensor data vs Fidas reference hpma

Figure 8: Hourly average of individual HPMA PM_{2.5} sensor data vs Fidas reference

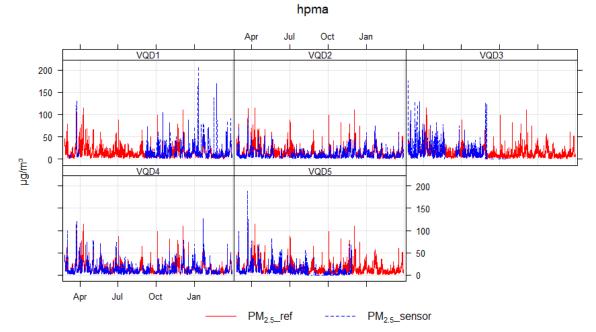




Figure 9: Density plot of all hourly $PM_{2.5}$ HPMA sensor data vs $PM_{2.5}$ Fidas (in $\mu g/m^3$)

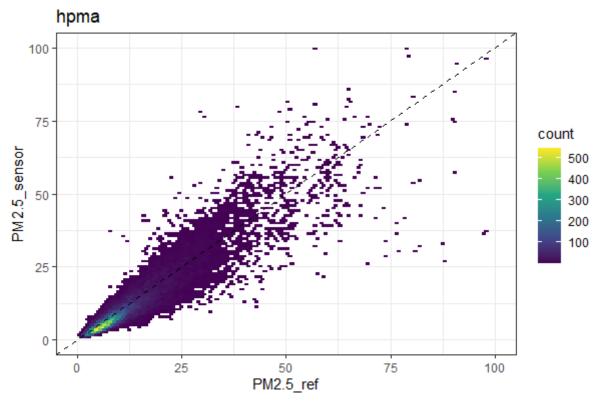
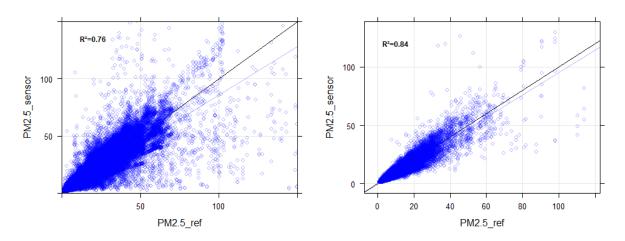


Figure 10: $PM_{2.5}$ scatterplot for all HPMA sensor 5-min averages (left) and all hourly averages (right) in $\mu g/m^3$





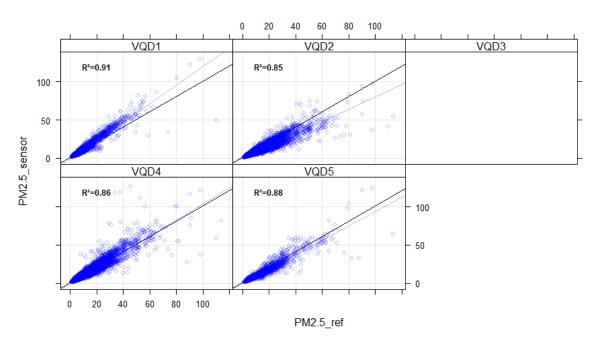
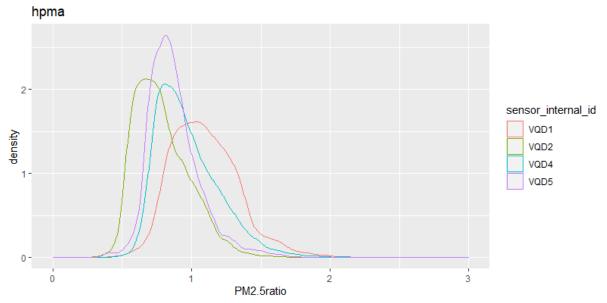


Figure 11: $PM_{2.5}$ scatterplots for hourly HPMA averages per sensor in $\mu g/m^3$

The sensor/Fidas ratios also show that sensor 2 gives a lower signal than the others. Sensor 1 appears higher than the others, but this might be due to the fact that sensor 1 has most of its valid data at the end of the campaign.

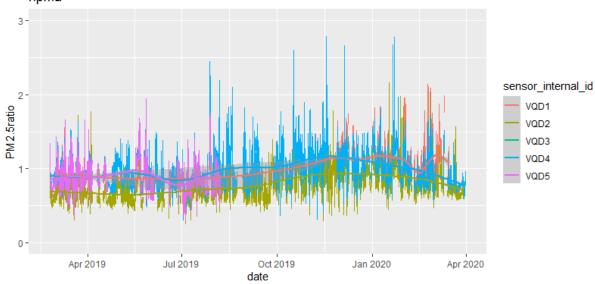
Figure 12: Distribution of hourly PM_{2.5} ratio (HPMA sensor/Fidas)



The drift plot does not show significant changes, the ratios appear to increase a bit during the winter months.

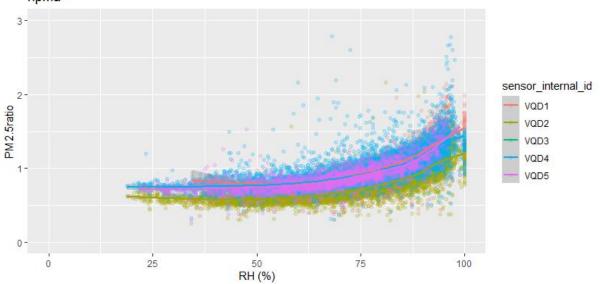


Figure 13: Hourly PM_{2.5} ratio (HPMA sensor/Fidas) in function of time hpma



The effect of RH and T appears to be relatively small compared to other sensor types. As expected, ratios go up at higher RH and at lower T. Above 90% RH the sensor/Fidas ratio is 1.7 times higher than between 45% and 55% RH.

Figure 14: Hourly PM_{2.5} ratio (HPMA sensor/Fidas) in function of relative humidity hpma





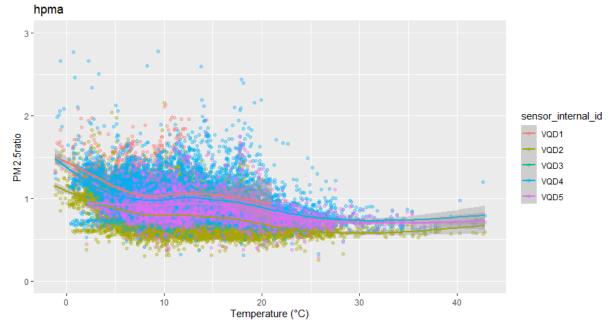
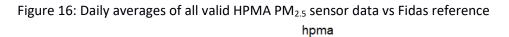
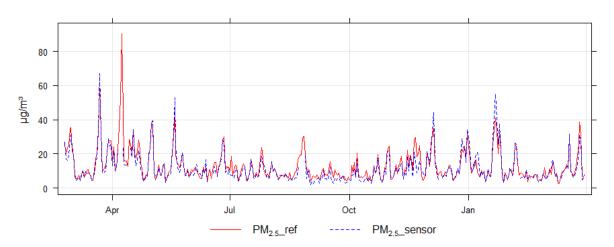


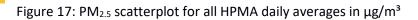
Figure 15: Hourly $PM_{2.5}$ ratio (HPMA sensor/Fidas) in function of temperature

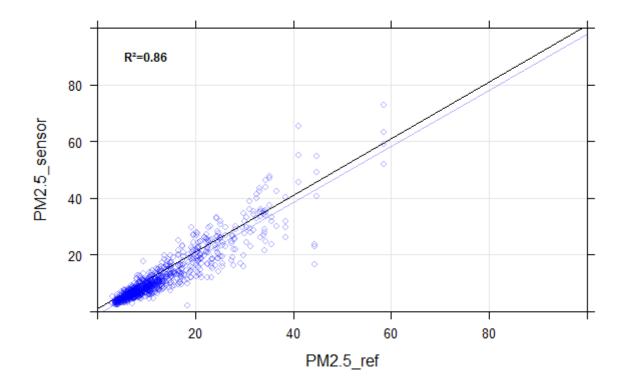
The timeplot and scatterplot of all daily values show good correlation and little systematic bias compared to the Fidas reference.











+PM_{2.5} 95% confidence interval around 30 μ g/m³

The overall 95 percentile of absolute deviations for hourly values between 25 and 35 μ g/m³ was 13 μ g/m³ (and ranged between 12 and 14 μ g/m³ for individual units).

+PM_{2.5} comparison with gravimetric reference

When comparing the daily overall sensor average with the $PM_{2.5}$ gravimetric data using the official European equivalence spreadsheet to compare a reference method (RM) with a candidate method (CM) we find an <u>R² of 0.89</u> and an expanded uncertainty of <u>38%</u>. The bias at the limit value was about <u>5 µg/m³</u>.



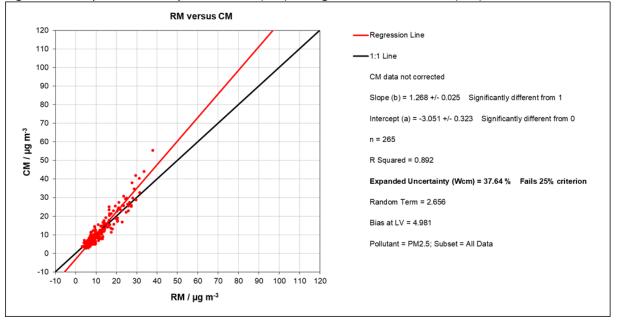


Figure 18:Comparison of daily sensor data (CM) with gravimetric reference (RM)

After applying slope and intercept correction for the full Borgerhout dataset we find an expanded uncertainty of 15%. The local correction consisted of first adding $3.1 \,\mu\text{g/m}^3$ (i.e. correcting the offset) and then dividing by 1.27 (i.e. correcting the slope).

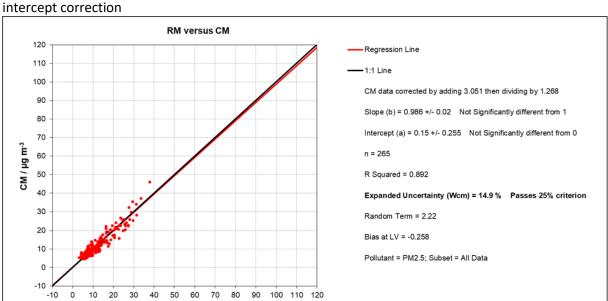


Figure 19: Comparison of daily sensor data (CM) with gravimetric reference (RM) after slope and intercept correction

+Variation between sensors

The between-sensor uncertainty of available hourly $PM_{2.5}$ data was 2.59 $\mu g/m^3$ or 21.8%.

+PM₁₀ and PM_{coarse} vs Fidas monitor

RM / µg m-3

The PM_{10} sensor signal showed some correlation with the Fidas but the sensor clearly underestimates the Fidas. As with almost all sensors in our test the observed correlation was merely due to the fact



that most of the time PM_{10} is made up for the most part of $PM_{2.5}$. See next section for the correlation of the coarse fraction alone.

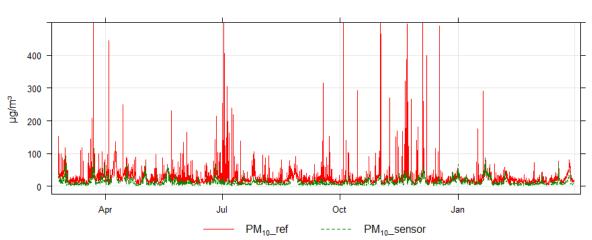
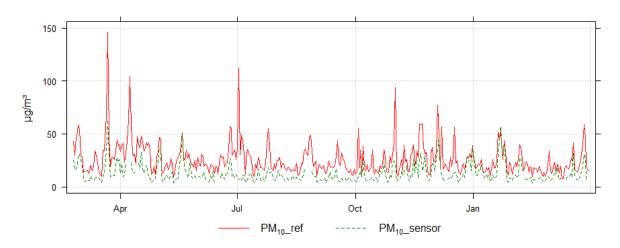


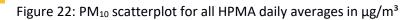
Figure 20: Hourly averages of HPMA PM_{10} sensor data vs Fidas reference in $\mu g/m^3$

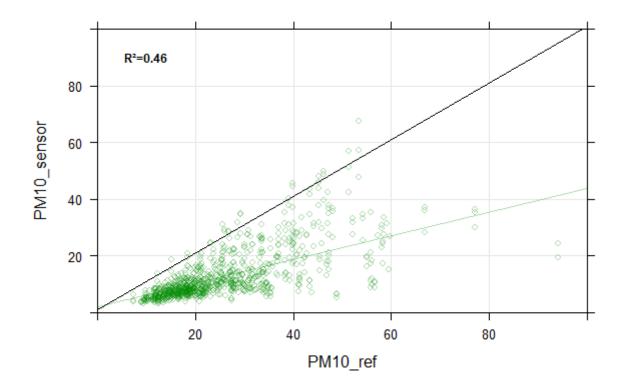
hpma

Figure 21: Daily averages of HPMA PM_{10} sensor data vs Fidas reference in $\mu g/m^3$ hpma



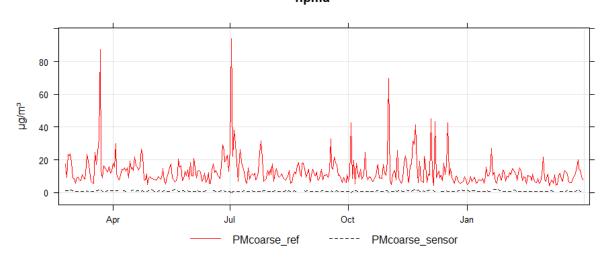




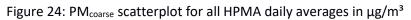


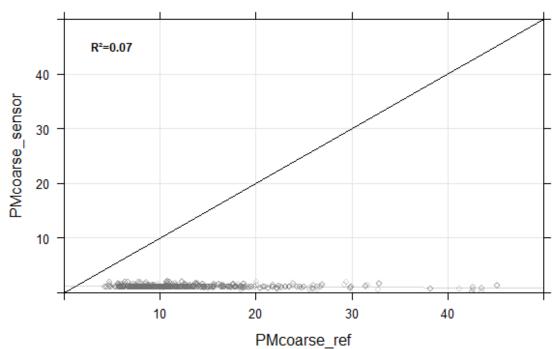
When we only look at the PM_{coarse} signal of the sensor we find no correlation at all and it is clear that the sensor did not pick up the coarse fraction of PM_{10} .

Figure 23: Daily averages of HPMA PM_{coarse} sensor data vs Fidas reference in $\mu g/m^3$ hpma



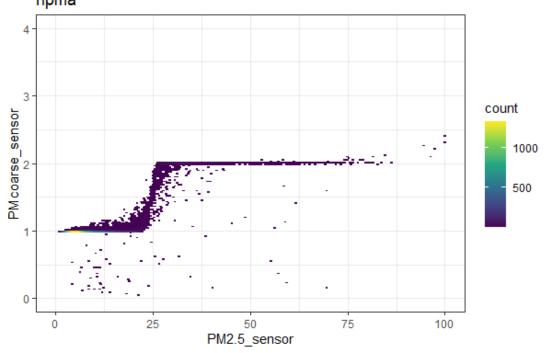






The PM_{coarse} vs PM_{2.5} plot (Figure 25) clearly shows that the sensor applies a very simple algorithm to estimate PM₁₀. For PM_{2.5} concentrations up to 25 μ g/m³ 1 μ g/m³ is added and for higher concentrations 2 μ g/m³ is added (the observed deviation from this fixed pattern can be attributed to the hourly averaging).

Figure 25: Density plot for PM_{coarse} vs $PM_{2.5}$ for hourly HPMA sensor data in $\mu g/m^3$ hpma







Dylos DC1700





Dylos DC1700

+Validation and data coverage

Most Dylos units showed a rather good overall valid data recovery. However, except for unit 5 all units had frequent problems with erroneous data between April and June/July (see Figure 26) which turned out to be caused by dust and fluff in the optical chamber (see Figure 27). Those data were classified as invalid. After cleaning the units performed normal again. The amount of valid days varied between 251 (63%) for unit 1 to 351 (88%) for unit 5.



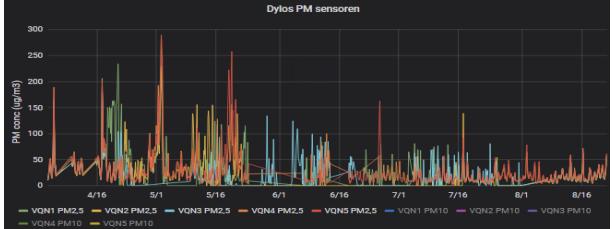


Figure 27: Dust and fluff inside the Dylos





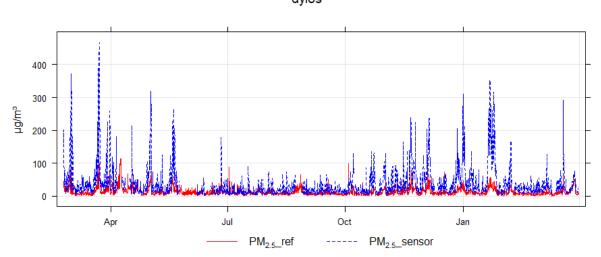
Figure 28: Overview of available hourly data per validation code (-2: invalid / -1: suspicious / 0: valid) for the different units



+PM_{2.5} comparison with Fidas monitor

The timeplots and scatterplots clearly show that the Dylos significantly overestimates the $PM_{2.5}$ signal vs the Fidas; on average the Dylos reports values 3 times higher than the Fidas. The value of R^2 for all valid hourly data vs Fidas $PM_{2.5}$ was 0.62 (which was the lowest of all tested sensor types).

Figure 29: Hourly average of all valid Dylos PM_{2.5} sensor data vs Fidas reference



dylos



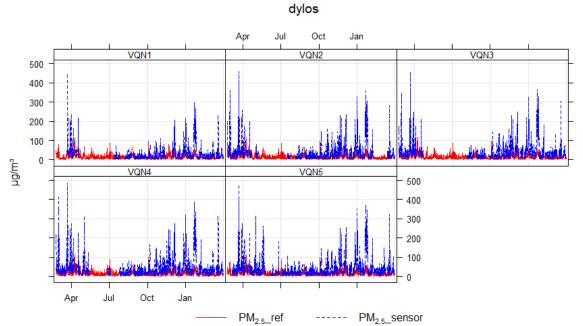


Figure 30: Hourly average of all individual Dylos $\mathsf{PM}_{2.5}$ sensor data vs Fidas reference



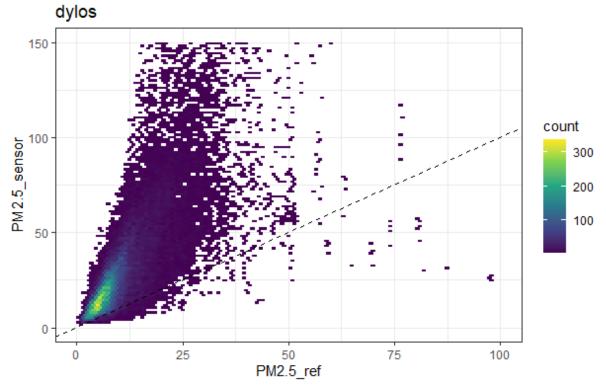




Figure 32: $PM_{2.5}$ scatterplot for all Dylos sensor 5min averages (left) and all hourly averages (right) in $\mu g/m^3$

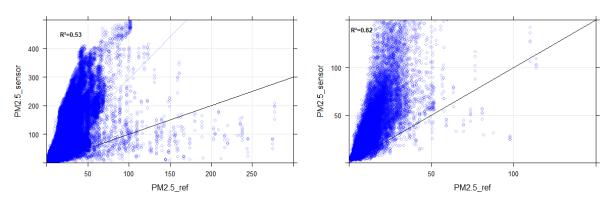
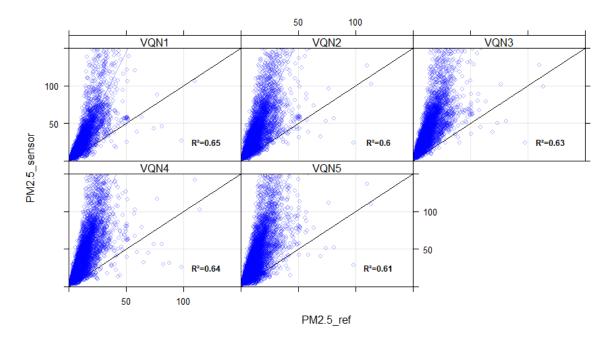


Figure 33: PM_{2.5} scatterplots for hourly Dylos averages per sensor in $\mu g/m^3$



The different units agree quite well, except for unit 1 which appears to give lower values than the others in the second part of the campaign. There appears to be quite some seasonal drift in the sensor/Fidas ratio with higher overestimation in winter than in summer.



Figure 34: Distribution of hourly PM_{2.5} ratio (Dylos sensor/Fidas)

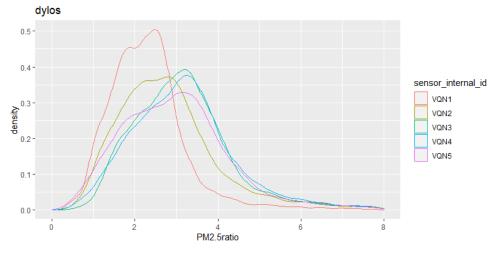
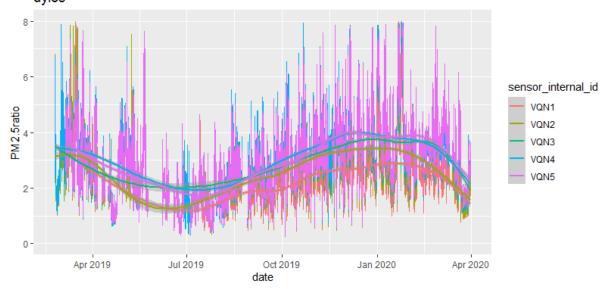


Figure 35: Hourly PM_{2.5} ratio (Dylos sensor/Fidas) in function of time dylos



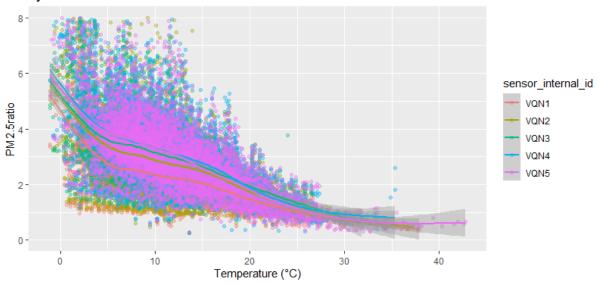
The effect of RH and T is large compared to other sensor types. As expected, ratios go up at higher RH and at lower T. Above 90% RH the sensor/Fidas ratio is 2.4 times higher than between 45% and 55% RH.



8 -6 sensor_internal_id PM2.5ratio VQN1 VQN2 VQN3 VQN4 VQN5 2-0 -25 75 100 0 50 RH (%)

Figure 36: Hourly PM_{2.5} ratio (Dylos sensor/Fidas) in function of relative humidity dylos

Figure 37: Hourly PM_{2.5} ratio (Dylos sensor/Fidas) in function of temperature dylos





The timeplot and scatterplot of the daily values show the same overestimation and spread as the hourly values.

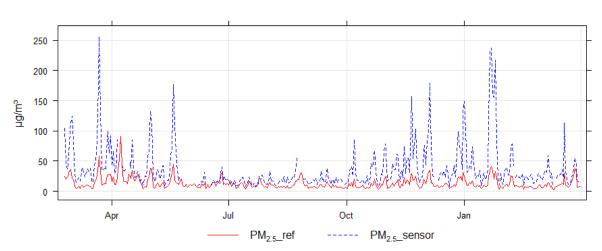
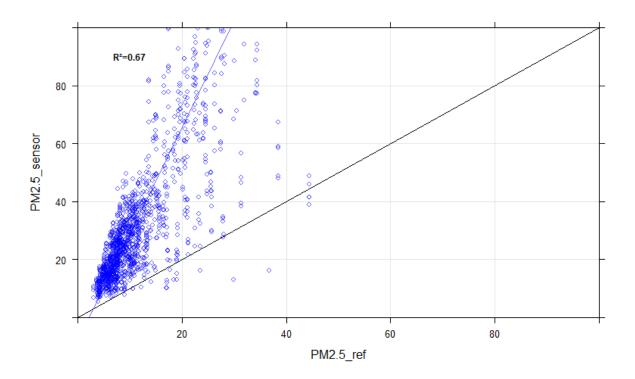


Figure 38: Daily average of all valid Dylos PM_{2.5} sensor data vs Fidas reference

dylos

Figure 39: $PM_{2.5}$ scatterplot for all Dylos daily averages in $\mu g/m^3$



+PM_{2.5} 95% confidence interval around 30 μ g/m³

The overall 95 percentile of absolute deviations for hourly values between 25 and 35 μ g/m³ was 186 μ g/m³ (and ranged between 149 and 203 μ g/m³ for individual units).



+ PM_{2.5} comparison with gravimetric reference

When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an $\underline{R^2 \text{ of } 0.69}$ and an expanded uncertainty of <u>873%</u>. The bias at the limit value was about <u>129 µg/m³</u>. This was the worst performance of all tested sensors.

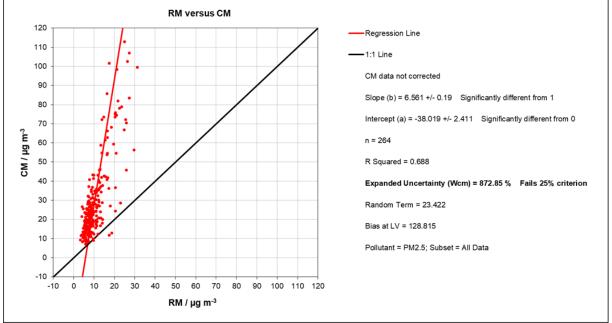


Figure 40: Comparison of daily sensor data (CM) with gravimetric reference (RM)

After applying slope and intercept for the full Borgerhout dataset we find an expanded uncertainty of 52%. The local correction consisted of first adding 38 μ g/m³ and then dividing by 6.56.

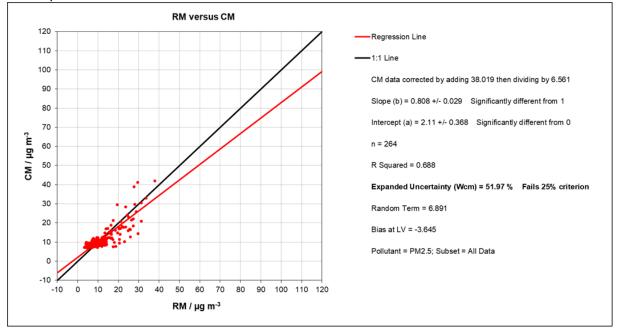


Figure 41: Comparison of daily sensor data (CM) with gravimetric reference (RM) after slope and intercept correction

+Variation between sensors



The between sensor uncertainty of available hourly $PM_{2.5}$ data was 7.2 $\mu g/m^3$ or 18.5%.

+PM₁₀ and PM_{coarse} vs Fidas monitor

The PM_{10} sensor signal showed some correlation but clearly also overestimates compared to the FIDAS. As with almost all sensors in our test the observed correlation was mostly due to the fact that most of the time PM_{10} is made up for the most part of $PM_{2.5}$. See next section for the correlation of the coarse fraction alone.

Figure 42: Hourly average of all valid Dylos PM₁₀ sensor data vs Fidas reference

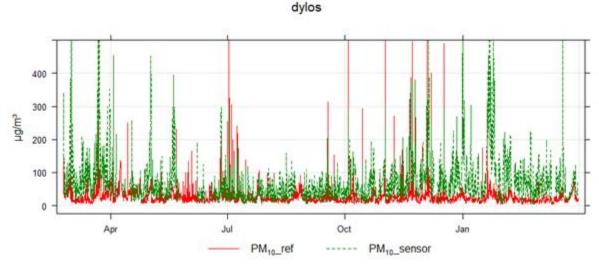


Figure 43: Daily average of all valid Dylos PM_{2.5} sensor data vs Fidas reference dylos

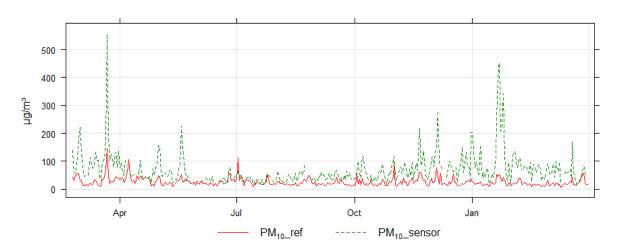
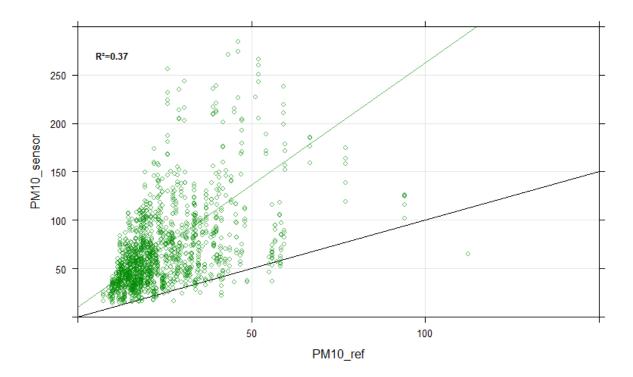


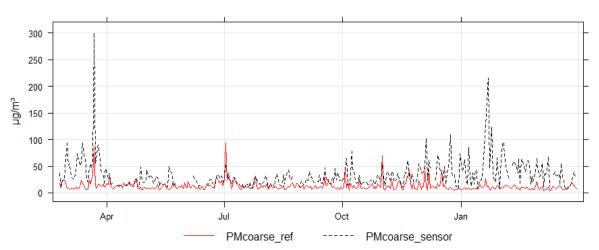


Figure 44: PM_{10} scatterplot for all Dylos daily averages in $\mu g/m^3$



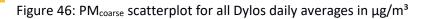
The Dylos was the only sensor that appeared to pick up some of the PM_{coarse} signal. However, the correlation with the Fidas was still poor.

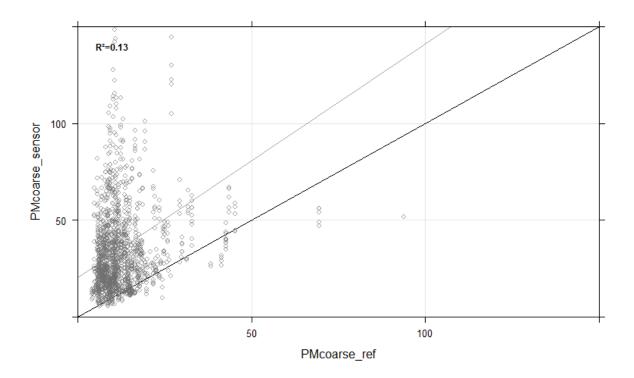
Figure 45: Daily average of all valid Dylos $\mathsf{PM}_{\mathsf{coarse}}$ sensor data vs Fidas reference



dylos

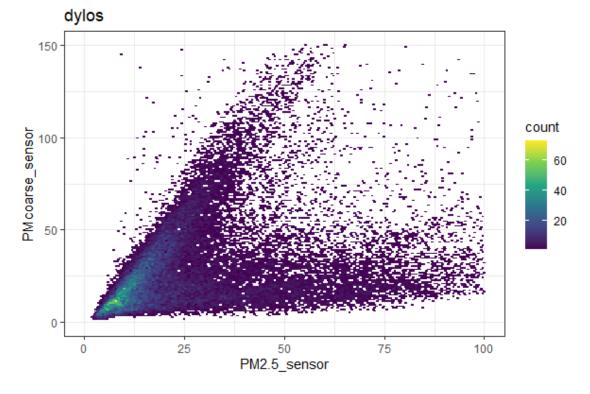






The PM_{coarse} vs $PM_{2.5}$ plot clearly shows that the PM_{coarse} is generally capped at 2.5 times the $PM_{2.5}$ concentration of the sensor.

Figure 47: Density plot for PM_{coarse} vs $PM_{2.5}$ for hourly Dylos sensor data in $\mu g/m^3$





Nova Fitness SDS011



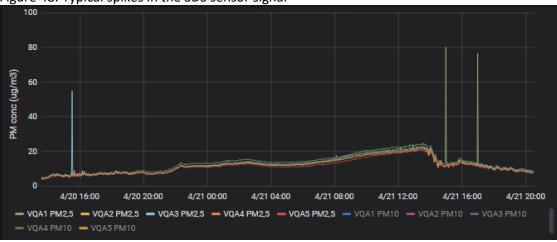


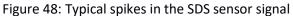


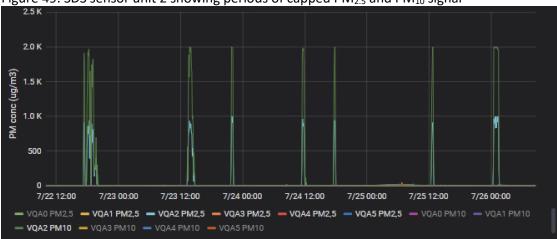
Nova Fitness SDS011

+Validation and data coverage

All SDS units had problems with spikes from time to time (see Figure 48), which were classified as suspicious. Unit 1 had a period of missing or flat (i.e. sensor reported same value continuously) data between the end of May and beginning of September. Unit 2 had an extended period, between June and August, with frequent reporting of capped of (maximum) values for both PM_{2.5} and PM_{2.5} (see Figure 49). Unit 4 had most spikes and had several periods with flat data in the last 3 months of the campaign. The number of valid days ranged from 283 (71%) for unit 1 to 367 (92%) for unit 3.







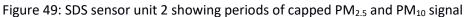
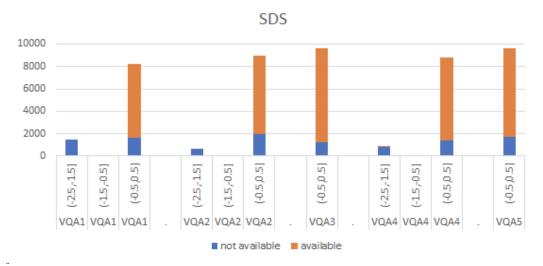




Figure 50: Overview of available hourly data per validation code (-2 :invalid / -1: suspicious /0: valid) for the different units



+PM_{2.5} comparison with Fidas monitor

In general all SDS units somewhat underestimate $PM_{2.5}$ compared to the Fidas monitor. The SDS sensors generally did not correlate as well as most of the others in the test (apart from the Dylos). The R^2 values for all valid hourly data compared to the Fidas $PM_{2.5}$ was 0.72 (which was the second lowest of all tested sensor types).

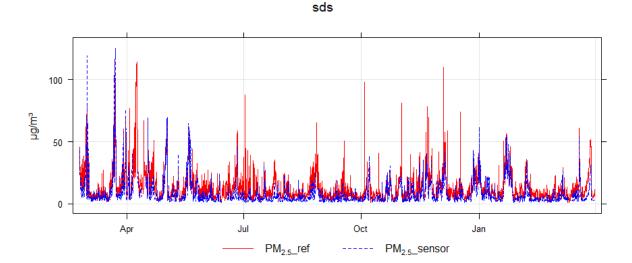


Figure 51: Hourly average of all valid SDS PM_{2.5} sensor data vs Fidas reference



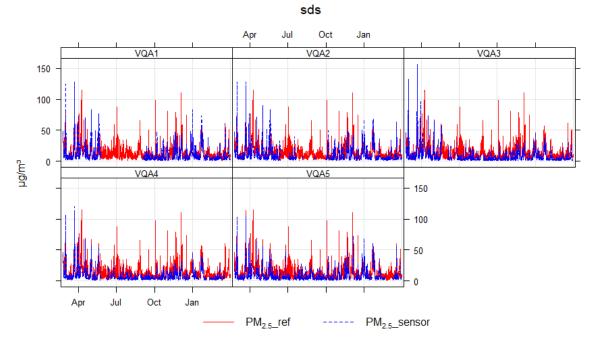


Figure 52: Hourly average of all individual SDS $\mathsf{PM}_{2.5}$ sensor data vs Fidas reference



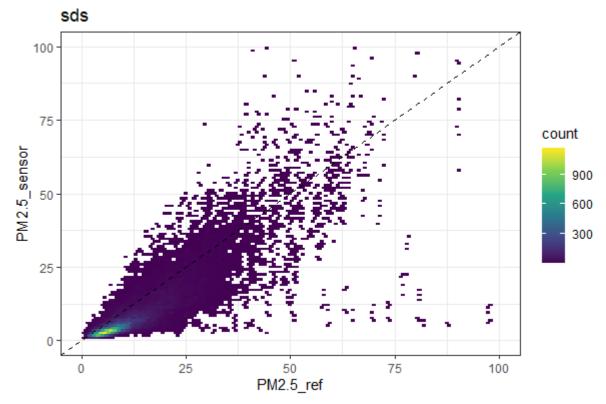




Figure 54: $PM_{2.5}$ scatterplot for all SDS sensor 5min averages (left) and all hourly averages (right) in $\mu g/m^3$

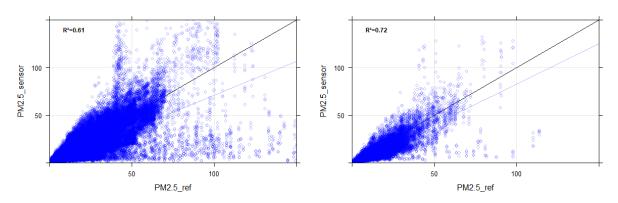
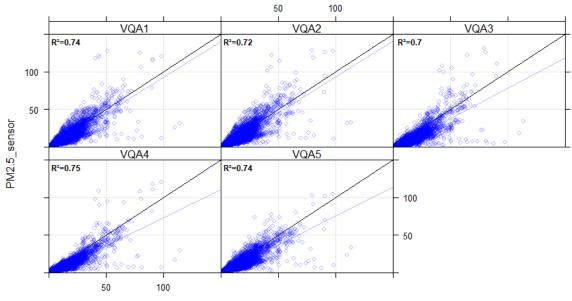


Figure 55: $PM_{2.5}$ scatterplots for hourly SDS averages per sensor in $\mu g/m^3$

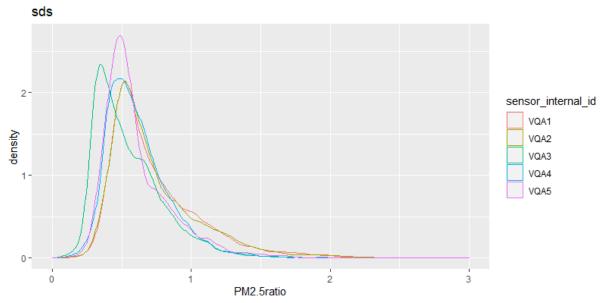




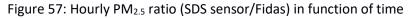


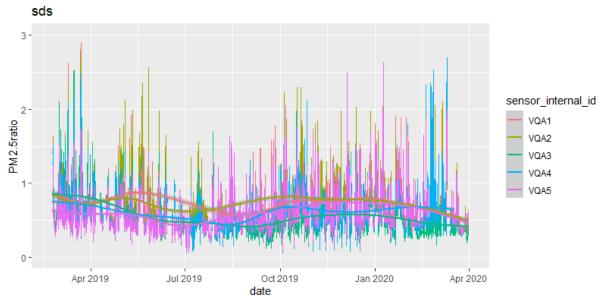
The sensor/Fidas ratios show that sensor 3 gives a lower signal than the others. This is most likely linked to the lower ratio in the second half of the campaign.

Figure 56: Distribution of hourly PM_{2.5} ratio (SDS sensor/Fidas)



The drift plot does not show much seasonal variation and changes vary from unit to unit. Sensor 3 appears to lose some sensitivity in the second part of the test.







The effect of RH and T is as expected, ratios go up at higher RH and at lower T. At lower RH and high T the sensors all report the lowest ratios compared to the Fidas. Above 90% RH the sensor/Fidas ratio is 2.1 times higher than between 45% and 55% RH.

Figure 58: Hourly $PM_{2.5}$ ratio (SDS sensor/Fidas) in function of relative humidity

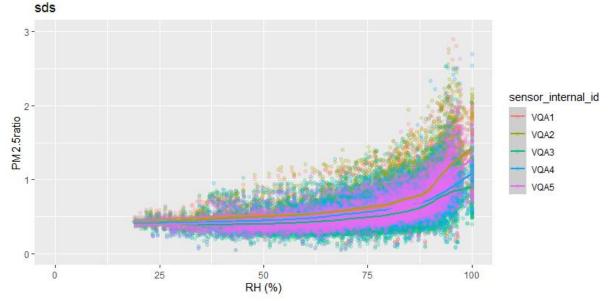
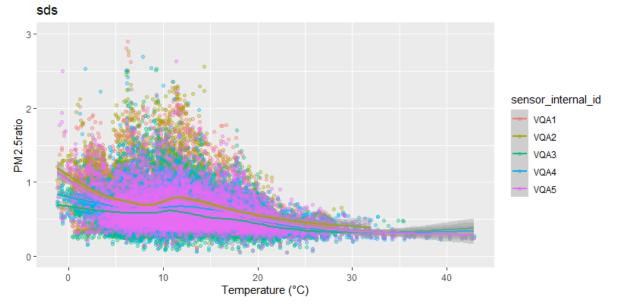


Figure 59: Hourly $PM_{2.5}$ ratio (SDS sensor/Fidas) in function of temperature



The timeplot and scatterplot of all daily values show a reasonable correlation with the Fidas. However, underestimation is clearly visible during the summer months.



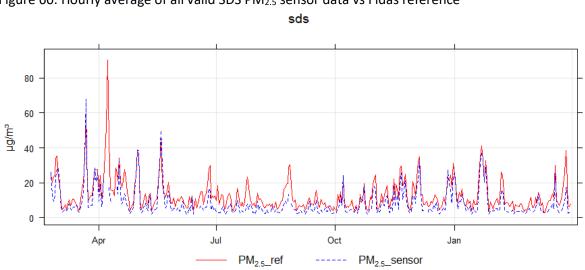
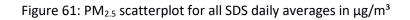
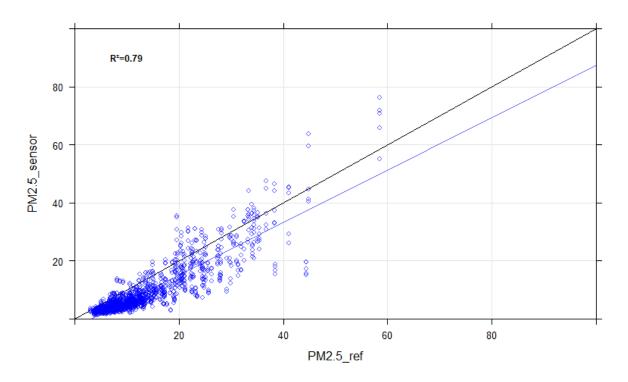


Figure 60: Hourly average of all valid SDS $\mathsf{PM}_{2.5}$ sensor data vs Fidas reference





+PM_{2.5} 95% confidence interval around 30 μ g/m³

The overall 95 percentile of absolute deviations for hourly values between 25 and 35 μ g/m³ was 19 μ g/m³ (and ranged between 18 and 19 μ g/m³ for individual units).

+PM_{2.5} comparison with gravimetric reference

When comparing the daily overall average with the PM_{2.5} gravimetric data we find an $\underline{R^2}$ of 0.80 and an expanded uncertainty of <u>35%</u>. The bias at the limit value was about -<u>4 µg/m³</u>.



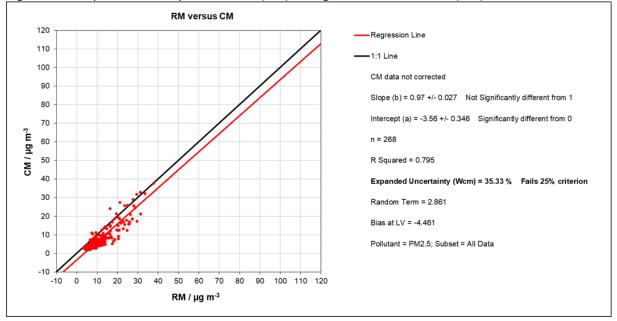


Figure 62:Comparison of daily sensor data (CM) with gravimetric reference (RM)

After applying slope and intercept for the full Borgerhout dataset we find an expanded uncertainty of 21%. The local correction consisted of first adding 3.6 μ g/m³ and then dividing by 0.97.

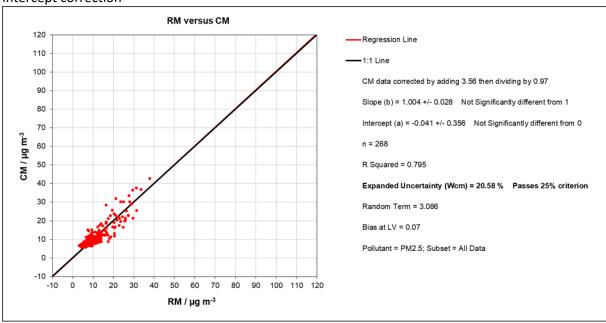


Figure 63: Comparison of daily sensor data (CM) with gravimetric reference (RM) after slope and intercept correction

+Variation between sensors

The between-sampler uncertainty of available hourly $PM_{2.5}$ data was 2.36 μ g/m³ or 26.6%.



+PM $_{10}$ and PM $_{coarse}$ vs Fidas monitor

The PM_{10} sensor signal showed some correlation but clearly underestimates compared to the Fidas. As with almost all sensors, in our test the observed correlation was mostly due to the fact that most of the time PM_{10} is made up for the most part of $PM_{2.5}$. See next section for the correlation of the coarse fraction alone.

Figure 64: Hourly average of all valid SDS PM_{10} sensor data vs Fidas reference

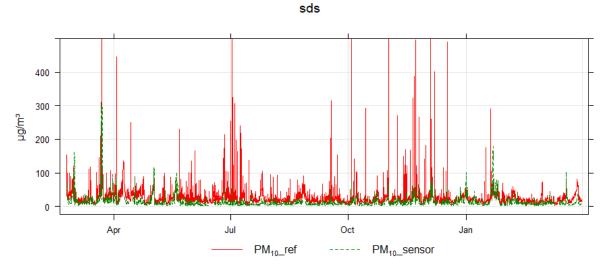


Figure 65: Daily average of all valid Dylos PM_{10} sensor data vs Fidas reference

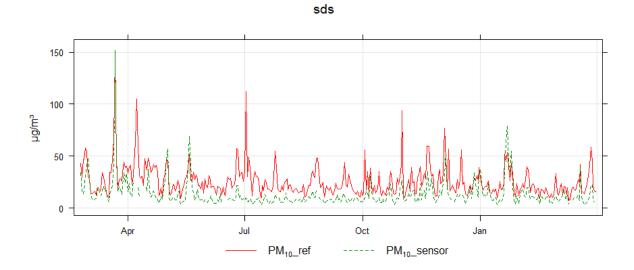
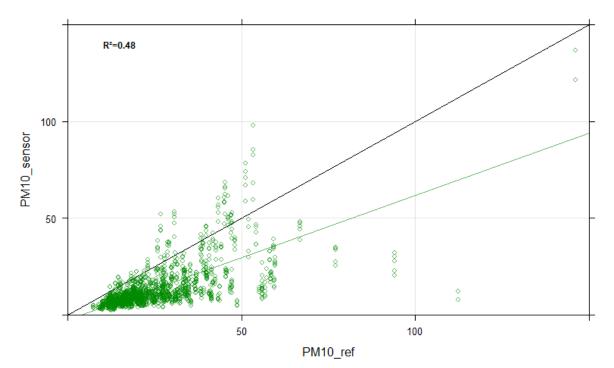


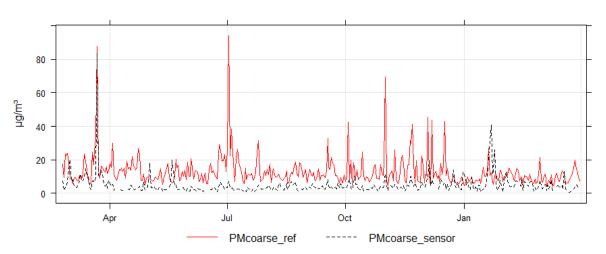


Figure 66: PM_{10} scatterplot for all SDS daily averages in $\mu g/m^3$



When we only look at the PM_{coarse} signal of the sensor we find little correlation, except for the peak in March 2019 which the SDS appeared to pick up quite well. This could indicate that the sensor is able to pick up certain smaller particles in the range of 2.5 to 10 μ m, but not all.

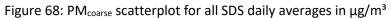
Figure 67: Hourly average of all valid SDS PM_{coarse} sensor data vs Fidas reference

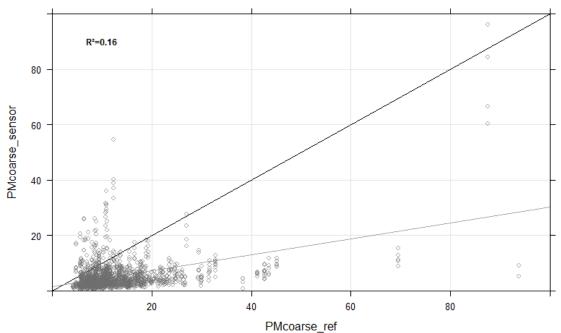


sds



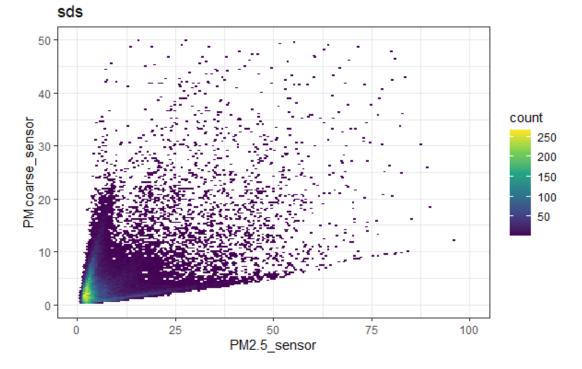






The PM_{coarse} vs $PM_{2.5}$ plot does not indicate any obvious link between $PM_{2.5}$ and PM_{coarse} . At lower concentrations there appears to be a relatively higher number of data close to the PM_{coarse} = 4 $PM_{2.5}$ ratio. The plot also shows that the ratio between the two fractions is more or less capped between 0.125 and 4.

Figure 69: Density plot for $PM_{coarse}\,vs\,PM_{2.5}$ for hourly SDS sensor data in $\mu g/m^3$







Plantower PMS7003



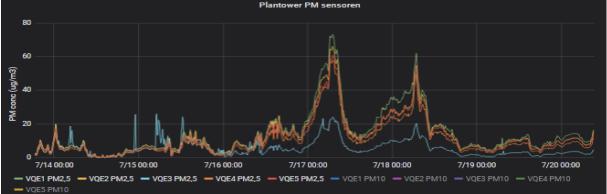


Plantower PMS7003

+Validation and data coverage

Of the 5 units that were tested 3 units did not show any significant problems. Unit 3 had frequent problems with 'ghost' peaks and appeared to drop to half sensitivity from mid-July onward (see Figure 70), so these data were validated as suspicious. Unit 1 frequently had periods with strange elevated signals compared to the other units (see Figure 71), and these episodes were also marked as suspicious. The number of valid days varied between 352 (88%) and 372 (93%), except for unit 3 which had only 258 valid days (64%).





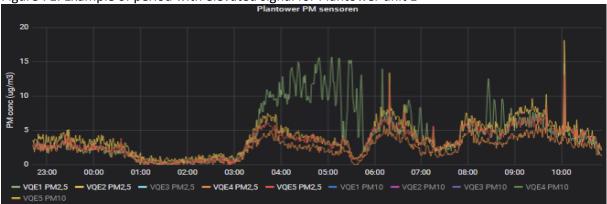
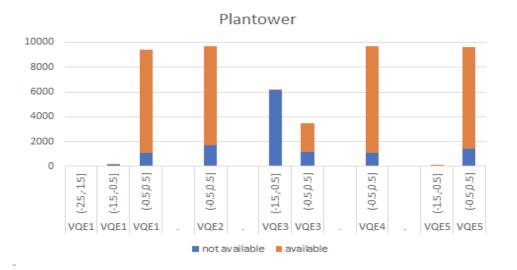


Figure 71: Example of period with elevated signal for Plantower unit 1



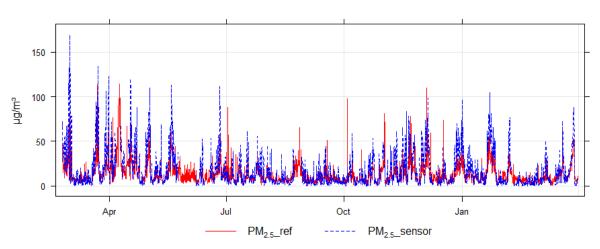
Figure 72: Overview of available hourly data per validation code (-2 :invalid / -1: suspicious /0: valid) for the different units



+PM_{2.5} comparison with Fidas monitor

The average hourly signal of all valid data shows that the Plantower correlates quite well but does overestimate compared to the Fidas. The R^2 value for all valid hourly data compared to the Fidas $PM_{2.5}$ was 0.82, which is only slightly less than the best scoring sensor in the test. The scatterplots also appear to indicate a somewhat non-linear correlation with a slightly lower slope at higher concentrations.

Figure 73: Hourly average of all valid Plantower $\mathsf{PM}_{2.5}$ sensor data vs Fidas reference



plantower





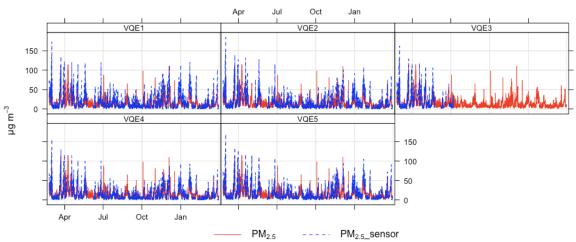


Figure 75: Density plot of all hourly $PM_{2.5}$ Plantower sensor data vs $PM_{2.5}$ Fidas (in $\mu g/m^3$)

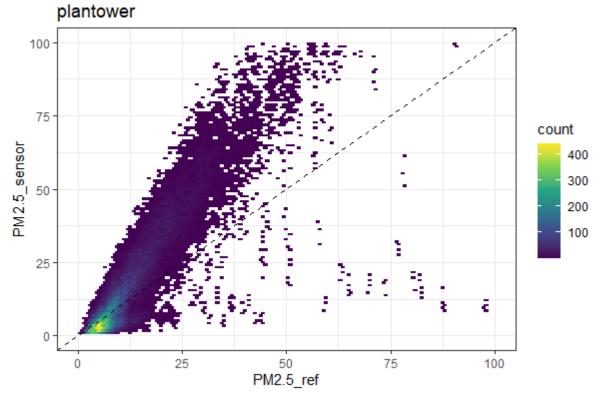




Figure 76: $PM_{2.5}$ scatterplot for all Plantower sensor 5-min averages (left) and all hourly averages (right) in $\mu g/m^3$

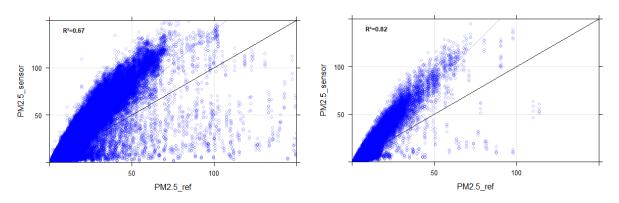
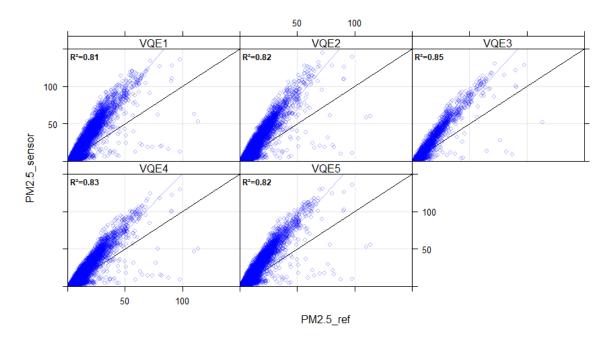


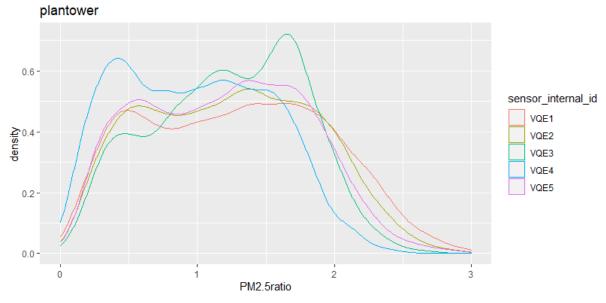
Figure 77: PM_{2.5} scatterplots for hourly Plantower averages per sensor in µg/m³



The sensor/Fidas ratios appear to show some sort of bi-modal pattern. This could just be translation of the relation between the Plantower and the Fidas where the Plantower does underestimate the lower concentrations but overestimates the higher concentrations. Unit 4 appears to give a somewhat lower signal than the others. This effect also explains the relatively large spread in the other plots that show the sensor/Fidas ratio.



Figure 78: Distribution of hourly PM_{2.5} ratio (Plantower sensor/Fidas)



The drift plot (Figure 79) does show some seasonality that is similar for most sensors (the deviating behaviour of the trendline for unit 3 is an artefact of the shorter dataset).

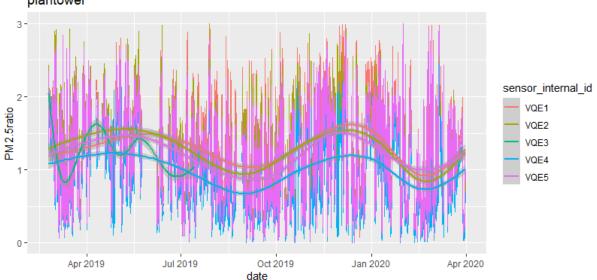


Figure 79: Hourly PM_{2.5} ratio (Plantower sensor/Fidas) in function of time plantower

The effect of RH and T is along the same lines as with the other sensors. Above 90% RH the sensor/Fidas ratio is 1.7 times higher than between 45% and 55% RH.



Figure 80: Hourly PM_{2.5} ratio (Plantower sensor/Fidas) in function of relative humidity plantower

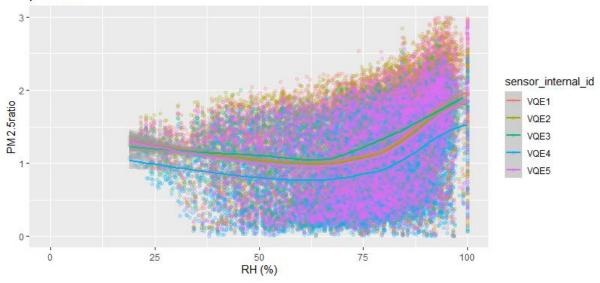
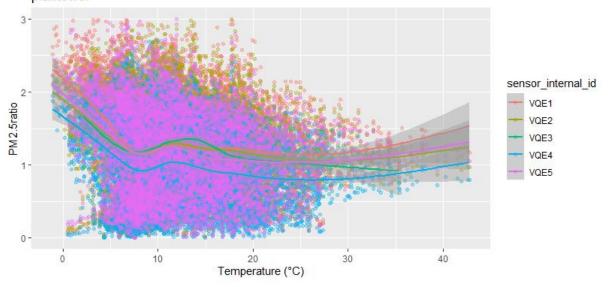
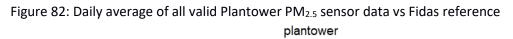


Figure 81: Hourly PM_{2.5} ratio (Plantower sensor/Fidas) in function of temperature plantower



The timeplot and scatterplot of all daily values show good correlation with the Fidas. However, systematic differences with the Fidas do occur.





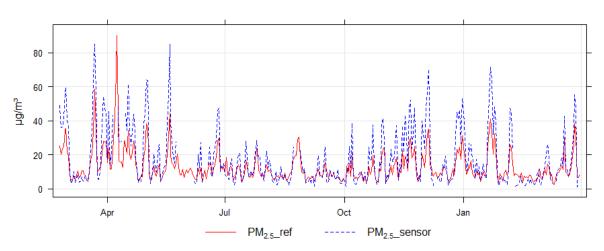
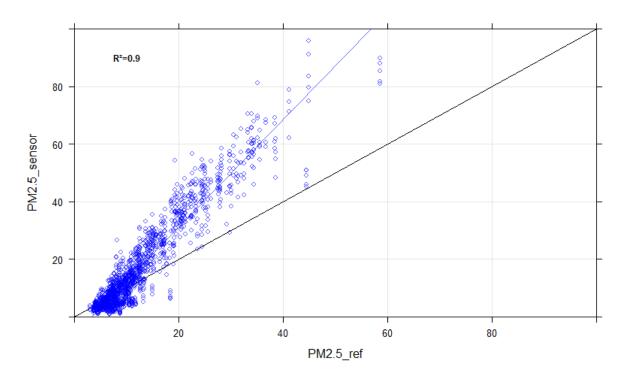


Figure 83: $PM_{2.5}$ scatterplot for all Plantower daily averages in $\mu g/m^3$



+PM_{2.5} 95% confidence interval around 30 μ g/m³

The overall 95 percentile of absolute deviations for hourly values between 25 and 35 μ g/m³ was 41 μ g/m³ (and ranged between 32 and 46 μ g/m³ for individual units).

+PM_{2.5} comparison with gravimetric reference

When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an $\underline{R^2 \text{ of } 0.90}$ and an expanded uncertainty of <u>197%</u>. The bias at the limit value was about <u>29 µg/m³</u>.



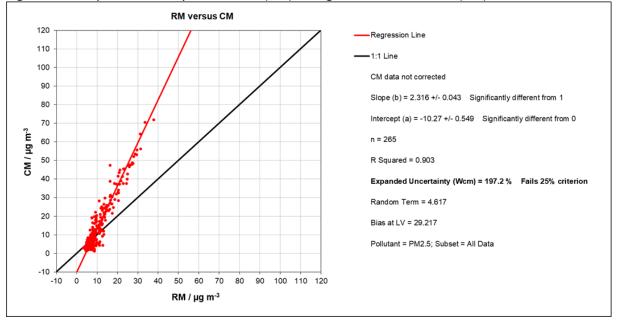


Figure 84: Comparison of daily sensor data (CM) with gravimetric reference (RM)

After applying slope and intercept for the full Borgerhout dataset we find an expanded uncertainty of 16%. The local correction consisted of first adding 10.3 μ g/m³ and then dividing by 2.32.

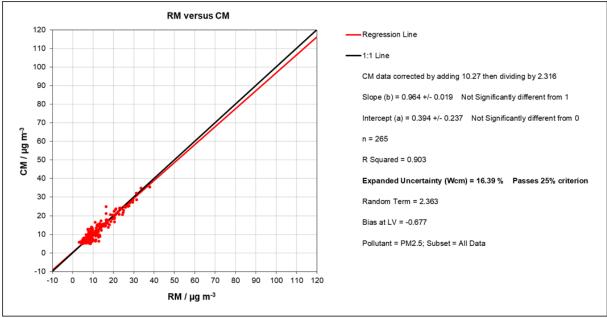


Figure 85: Comparison of daily sensor data (CM) with gravimetric reference (RM) after slope and intercept correction

+Variation between sensors

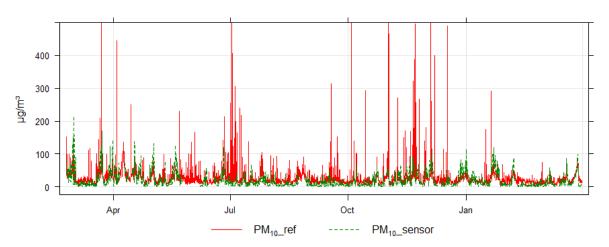
The between-sampler uncertainty of available hourly $PM_{2.5}$ data was 2.62 μ g/m³ or 14.5%.

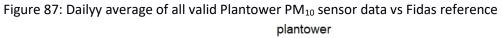


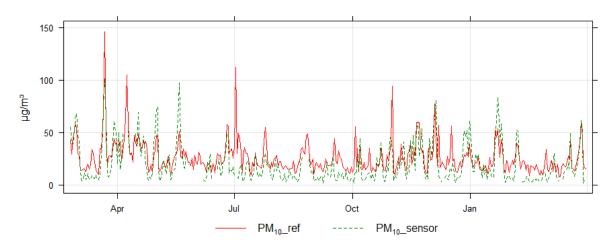
+PM $_{10}$ and PM $_{coarse}$ vs Fidas monitor

The PM_{10} sensor signal showed some correlation with the Fidas, but as with the other sensors this could be attributed to the contribution of $PM_{2.5}$.

Figure 86: Hourly average of all valid Plantower PM₁₀ sensor data vs Fidas reference plantower

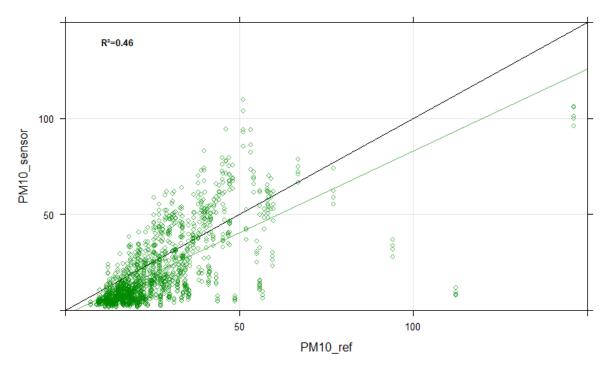






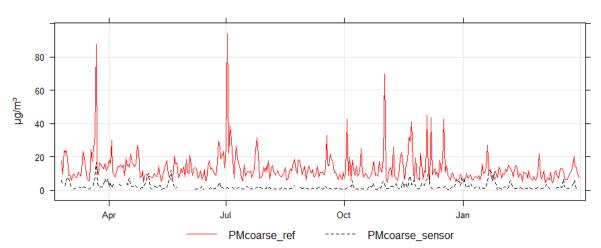






When we only look at the PM_{coarse} signal of the sensor we find no correlation at all and it is clear that the sensor did not pick up the coarse fraction of PM_{10} .

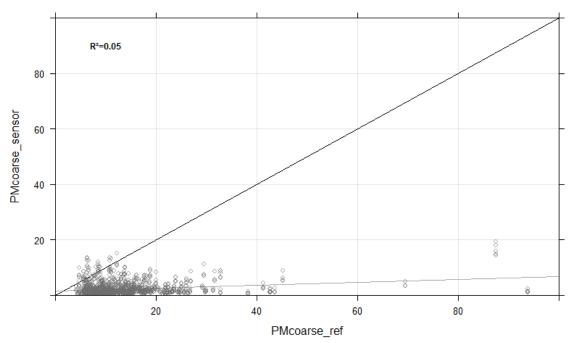
Figure 89: Daily average of all valid Plantower PM_{coarse} sensor data vs Fidas reference



plantower

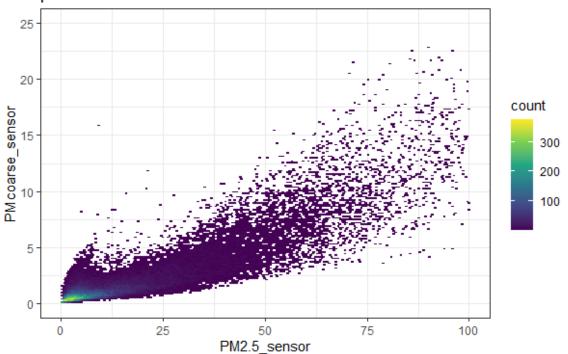






The PM_{coarse} vs PM_{2.5} plot shows a rather high correlation between PM_{2.5} and PM_{coarse}, which suggests some sort of simple internal calculation along the lines of PM_{coarse} = $0.1 \times PM_{2.5}$. However at lower PM_{2.5} concentrations (below 10 µg/m³) this does not always appear to apply.

Figure 91: Density plot for PM_{coarse} vs $PM_{2.5}$ for hourly Plantower sensor data in $\mu g/m^3$









Winsen ZH03B







Winsen ZH03B

+Validation and data coverage

In general, units 3 and 4 performed very well. Unit 1, 2 and 5 all had issues at varying times and in varying degrees. Unit 1 had several periods with spikes that occurred exactly at the hour or half hour which suggests some electronic interference (see Figure 92). Unit 2 had a similar issue, but to a much smaller extent. This unit also had some unstable periods during the test and 2 periods in summer with elevated concentrations that always appeared to start around 12:00 UTC (see Figure 93). We suspect this might have been linked to a disturbance caused by light (or heat?). Unit 5 was fine until early February 2020, when the signal became elevated and unstable. The number of valid days varied between 244 days (61%) for unit 1 and 368 days (92%) for unit 4.

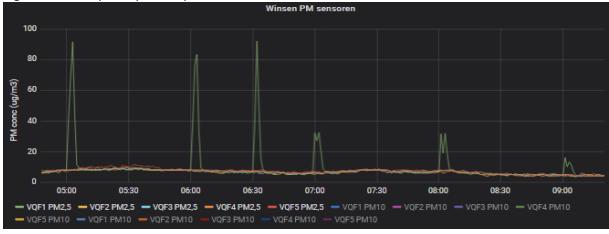


Figure 92: Example of period spikes for Winsen unit 1



Figure 93: Periods of elevated signal starting around noon for Winsen unit 2



Figure 94: Overview of available hourly data per validation code (-2 :invalid / -1: suspicious /0: valid) for the different units



+PM_{2.5} comparison with Fidas monitor

The average hourly signal of all valid data showed a good correlation and only a slight underestimation compared to the Fidas. The R^2 value for all hourly $PM_{2.5}$ data vs Fidas was 0.82 (same as Plantower and only just lower than HPMA).

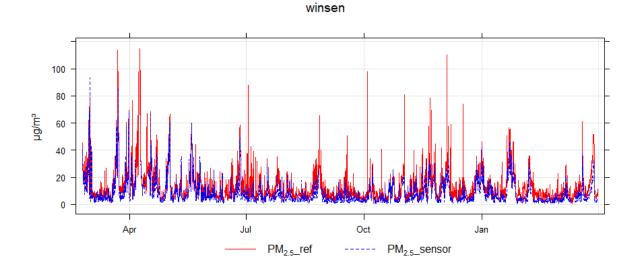


Figure 95: Hourly average of all valid Winsen PM_{2.5} sensor data vs Fidas reference



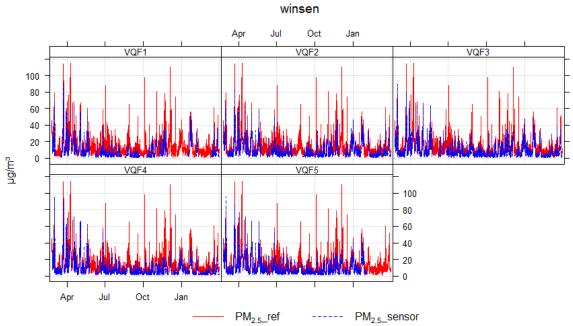
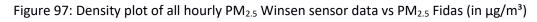


Figure 96: Hourly average of all individual Winsen PM_{2.5} sensor data vs Fidas reference



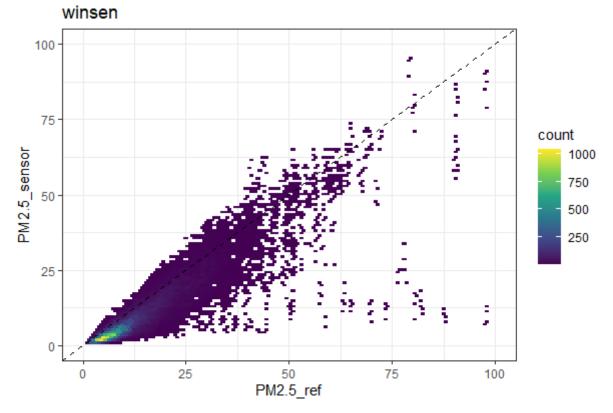




Figure 98: $PM_{2.5}$ scatterplot for all Winsen sensor 5-min averages (left) and all hourly averages (right) in $\mu g/m^3$

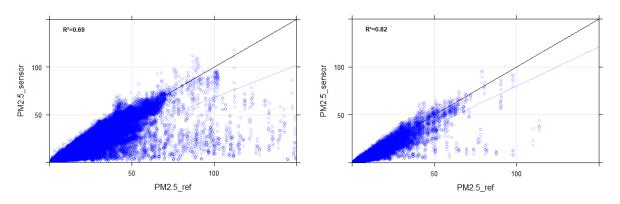
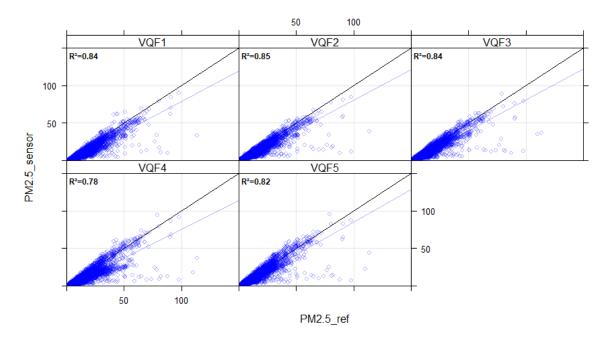


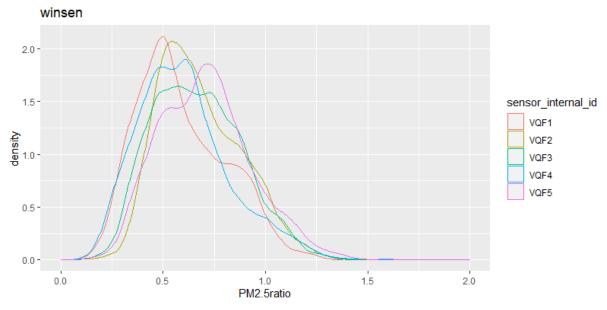
Figure 99: $PM_{2.5}$ scatterplots for hourly Winsen averages per sensor in $\mu g/m^3$



The sensor/Fidas ratios also show the general underestimation and relatively good comparability between the different units.



Figure 100: Distribution of hourly PM_{2.5} ratio (Winsen sensor/Fidas)



The drift plot shows a rather good agreement between the different units but does indicate some level of deviation for unit 1 in the first part of the test and for unit 4 at the end of the test.

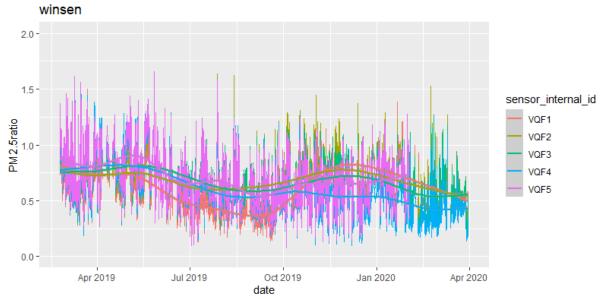


Figure 101: Hourly $\mathsf{PM}_{2.5}$ ratio (Winsen sensor/Fidas) in function of time

The effect of RH and T appears to be somewhat smaller than for the other sensors. Unit 4 appears to behave somewhat different at lower temperatures, but this might be related to the drift at the end of the test (in the first winter months of 2020). Above 90% RH the sensor/Fidas ratio is 1.6 times higher than between 45% and 55% RH.



Figure 102: Hourly PM_{2.5} ratio (Winsen sensor/Fidas) in function of relative humidity winsen

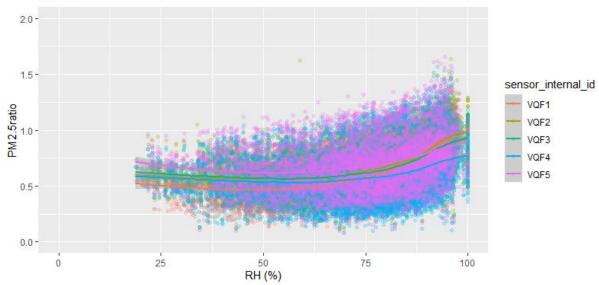
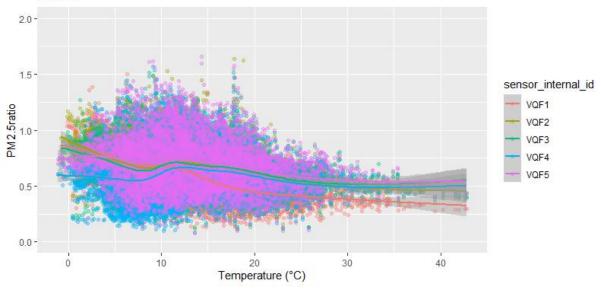


Figure 103: Hourly PM_{2.5} ratio (Winsen sensor/Fidas) in function of temperature winsen



The timeplot and scatterplot of all daily values show a good correlation with the Fidas, with a slight underestimation of $PM_{2.5}$.



Figure 104: Daily average of all valid Winsen PM_{2.5} sensor data vs Fidas reference winsen

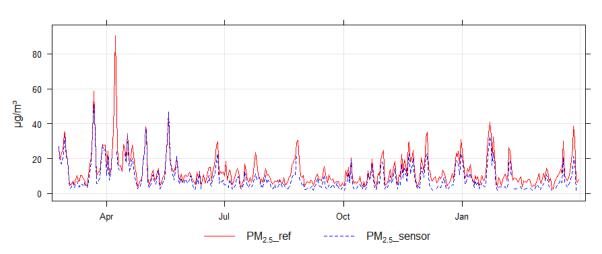
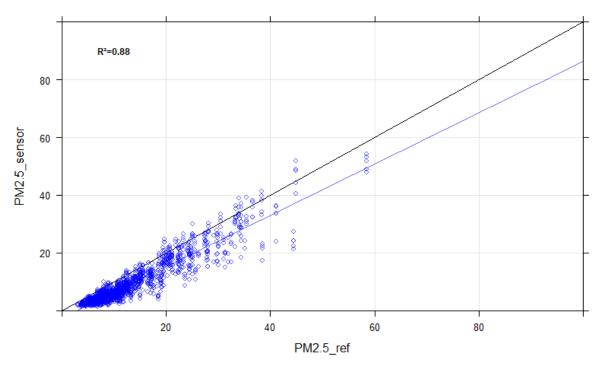


Figure 105: $PM_{2.5}$ scatterplot for all Winsen daily averages in $\mu g/m^3$



+PM_{2.5} 95% confidence interval around 30 $\mu g/m^3$

The overall 95 percentile of absolute deviations for hourly values between 25 and 35 μ g/m³ was 15 μ g/m³ (and ranged between 13 and 18 μ g/m³ for individual units).

+PM_{2.5} comparison with gravimetric reference

When comparing the daily overall average with the PM_{2.5} gravimetric data we find an $\frac{R^2 \text{ of } 0.88}{42\%}$ and an expanded uncertainty of $\frac{42\%}{1000}$. The bias at the limit value was about $\frac{-6 \ \mu g/m^3}{10000}$.



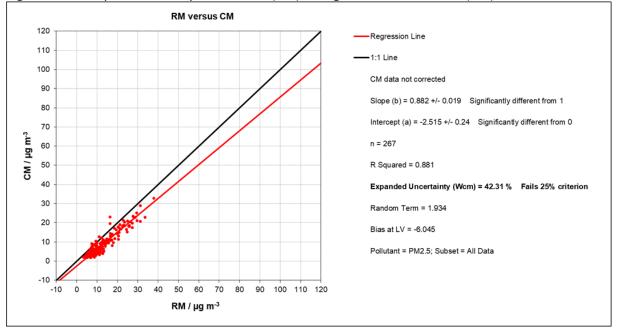


Figure 106: Comparison of daily sensor data (CM) with gravimetric reference (RM)

After applying slope and intercept for the full Borgerhout dataset we find an expanded uncertainty of 15%. The local correction consisted of first adding 2.5 μ g/m³ and then dividing by 0.88.

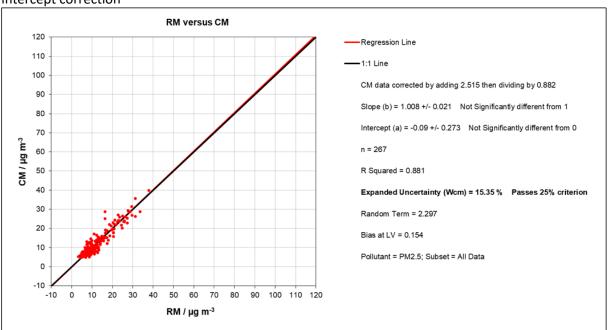


Figure 107: Comparison of daily sensor data (CM) with gravimetric reference (RM) after slope and intercept correction

+Variation between sensors

The between sampler uncertainty of available hourly $PM_{2.5}$ data was 1.44 μ g/m³ or 15.7%.

+PM₁₀ and PM_{coarse} vs Fidas monitor

As with most of the other sensors the PM_{10} signal does show some correlation, but this effect is merely due to the usually high fraction of $PM_{2.5}$ in PM_{10} .



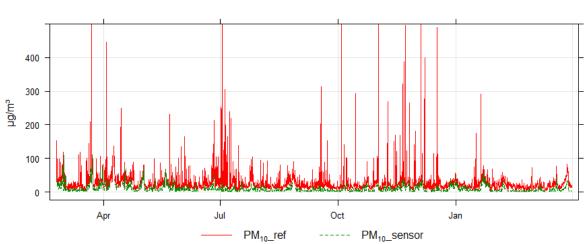
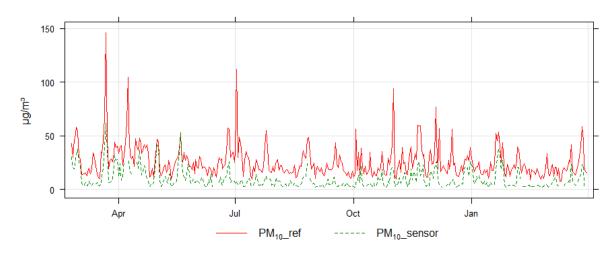
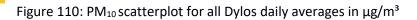


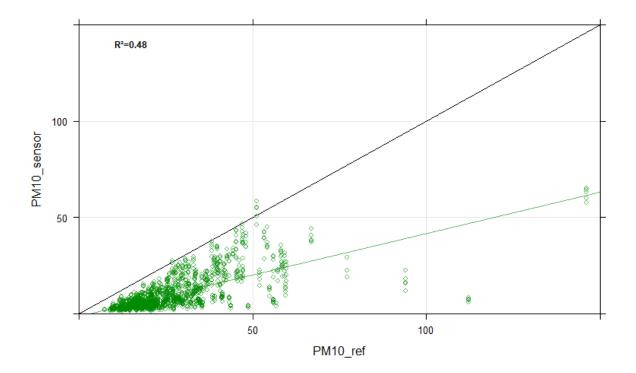
Figure 108: Hourly average of all valid Winsen PM₁₀ sensor data vs Fidas reference winsen

Figure 109: Daily average of all valid Winsen PM₁₀ sensor data vs Fidas reference winsen



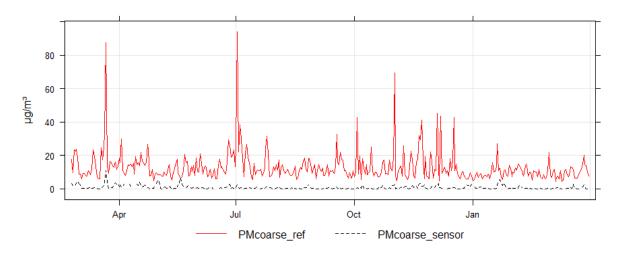




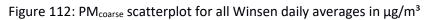


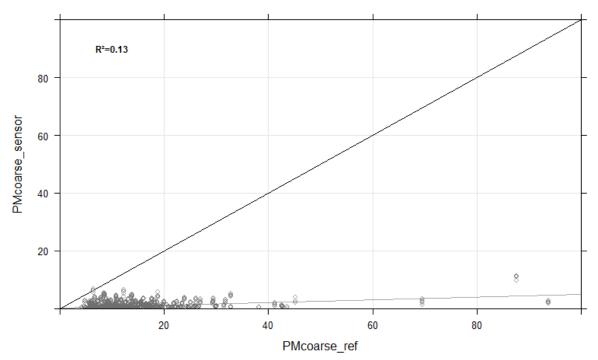
When we only look at the PM_{coarse} signal of the sensor we find no correlation at all and it is clear that the sensor did not pick up the coarse fraction of $PM_{2.5}$.

Figure 111: Daily average of all valid Winsen PM_{coarse} sensor data vs Fidas reference winsen



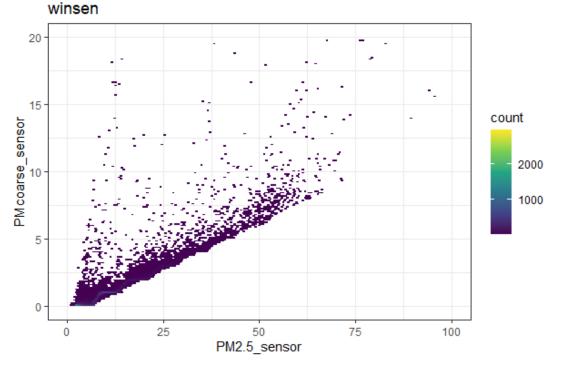






The PM_{coarse} vs $PM_{2.5}$ plot clearly shows that the sensor applies a very simple algorithm to estimate $PM_{2.5}$. In almost all cases a relation of $PM_{coarse} = 0.15 PM_{2.5}$ is found. Only in a very small number of cases there appears to be a deviation from this relation.

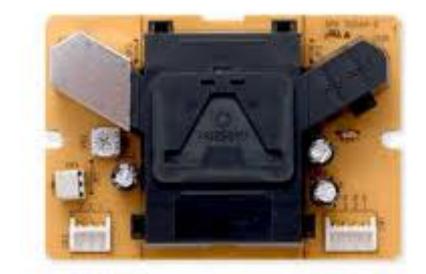
Figure 113: Density plot for $PM_{coarse}\,vs\,PM_{2.5}$ for hourly Winsen sensor data in $\mu g/m^3$







Shinyei **PPD**60PV





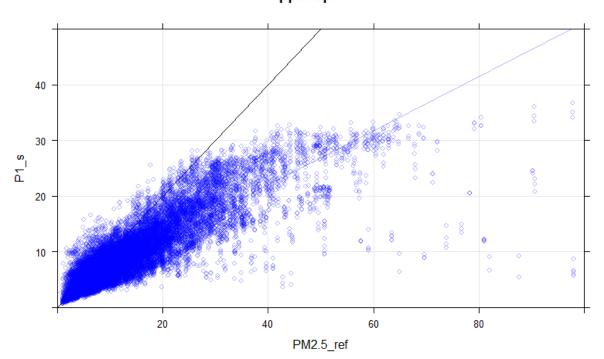


Shinyei PPD60PV

+Required calibration

According to the spec sheet the PPD60PV requires a <u>non-linear calibration</u> of the output signal (P1). This is indeed observed in the scatterplot of the P1 hourly signal vs Fidas PM_{2.5}.

Figure 114: Scatterplot of raw hourly average PPD sensor output vs Fidas PM_{2.5} reference in µg/m³ ppd60pv



After testing some different options in a trial and error type of way, and taking into account the full dataset, we choose the following 'dual linear' calibration which was applied at the shortest aggregated time resolution (5-min averages).

P1<26.8: PM_{2.5} = P1_s/0.67 P1>=26.8: PM_{2.5} = 40+(P1_s-26.8)/0.17

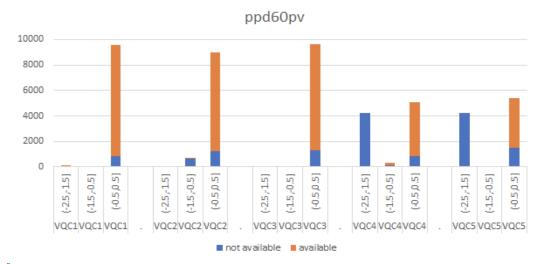
This solution was the best compromise between good results at the 5-min level, ease of use and realistic applicability at higher concentrations. Since variation between units was quite low we applied an overall calibration instead of a unit-specific function.

+Validation and data coverage

Unit 1 to 3 showed very little problems. Unit 4 and 5 did not report data in the first months of the test. Unit 5 was repaired, but for unit 4 this was not possible and it had to be replaced by a different unit. Therefore the number of valid days varied between 379 (95%) for unit 1, highest of all sensors in the test, and 174 (43%) for unit 5.



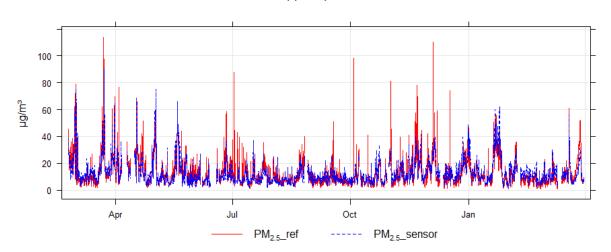
Figure 115: Overview of amount of available hourly data per validation code (-2: invalid / -1: suspicious / 0: valid) for the different units



+PM_{2.5} comparison with Fidas monitor

The average hourly signal shows a good correlation and little systematic bias (as expected due to the calibration). The R^2 value for the comparison between the calibrated sensor signal and the Fidas $PM_{2.5}$ was 0.75.

Figure 116: Hourly average of all valid PPD PM_{2.5} sensor data vs Fidas reference ppd60pv





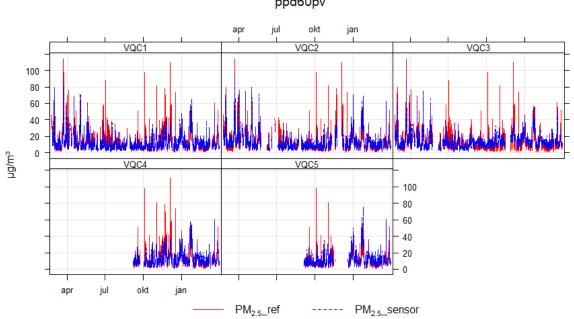


Figure 117: Hourly average of all individual PPD PM_{2.5} sensor data vs Fidas reference ppd60pv



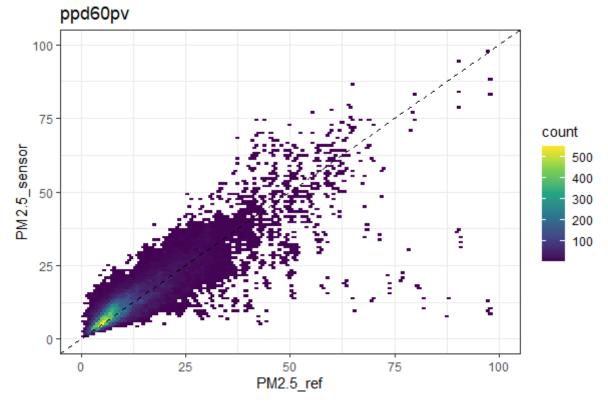




Figure 119: $PM_{2.5}$ scatterplot for all PPD sensor 5-min averages (left) and all hourly averages (right) in $\mu g/m^3$

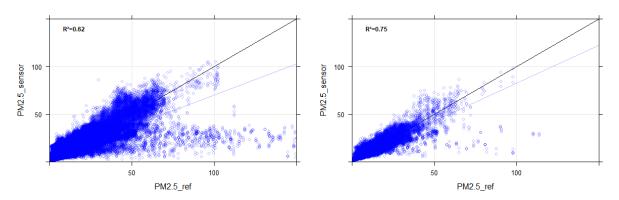
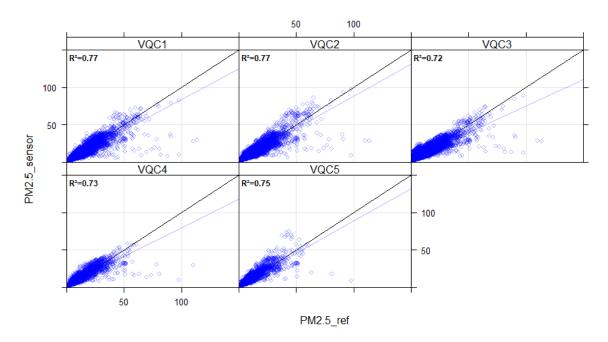
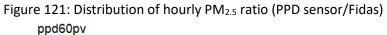


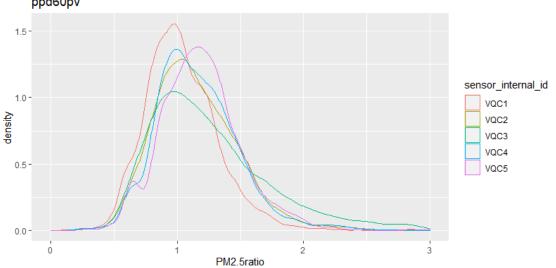
Figure 120: $PM_{2.5}$ scatterplots for hourly PPD averages per sensor in $\mu g/m^3$



The sensor/Fidas ratios show a good comparability between units and a distribution around 1.

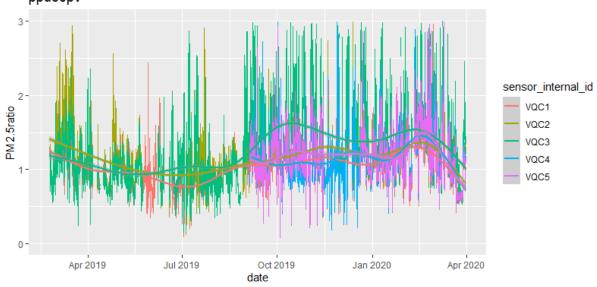






The drift plot shows very little seasonal variation except for a drop in the last month of the project. Unit 3 does appear to show a higher ratio in the second part of the test.

Figure 122: Hourly PM_{2.5} ratio (PPD sensor/Fidas) in function of time ppd60pv



The effect of RH and T is along the lines of the other sensors but is generally smaller. The sensor tends to show a more linear behaviour to RH than the other sensors. This could be (partially) due to the non-linear calibration, since a lot of the higher concentrations occur at high relative humidity. Another possible explanation could be the use of the thermal resistance (instead of a fan) that heats the air to passively draw it into the detection chamber. Above 90% RH the sensor/Fidas ratio is 1.4 times higher than between 45% and 55% RH.



Figure 123: Hourly PM_{2.5} ratio (PPD sensor/Fidas) in function of relative humidity ppd60pv

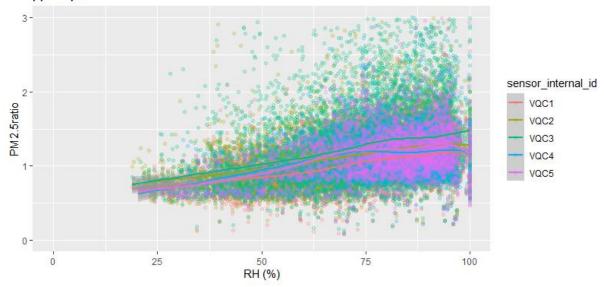
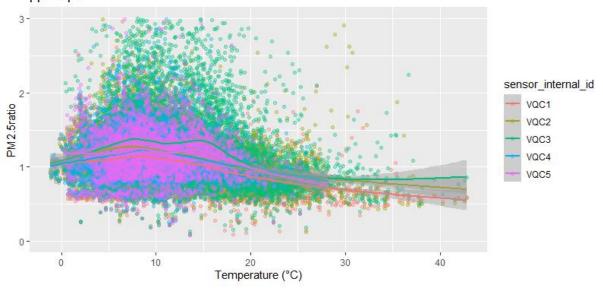
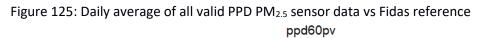


Figure 124: Hourly PM_{2.5} ratio (PPD sensor/Fidas) in function of temperature ppd60pv



The timeplot and scatterplot of all daily values show good correlation with the Fidas and little systematic bias with the Fidas reference. This was to be expected, since the calibration was determined over this dataset.





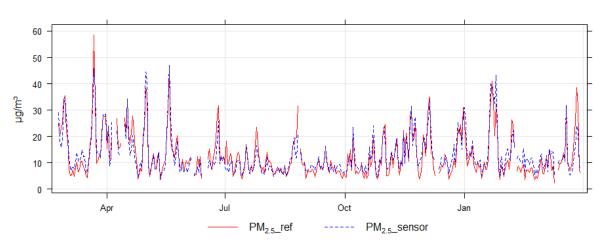
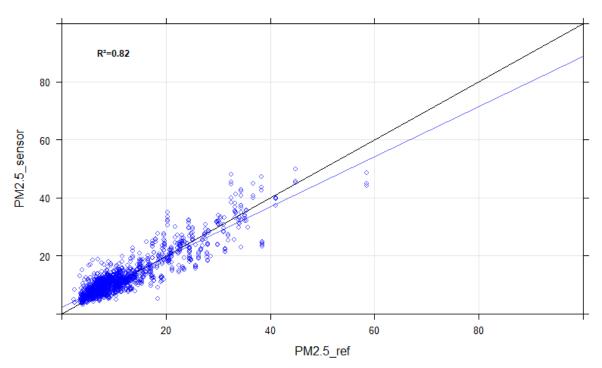


Figure 126: $PM_{2.5}$ scatterplot for all PPD daily averages in $\mu g/m^3$



+PM_{2.5} 95% confidence interval around 30 $\mu g/m^3$

The overall 95 percentile of absolute deviations for hourly values between 25 and 35 μ g/m³ was 13 μ g/m³ (and ranged between 11 and 16 μ g/m³ for individual units).

+PM_{2.5} comparison with gravimetric reference

When comparing the daily overall average with the PM_{2.5} gravimetric data we find an <u>R² of 0.80</u> and an expanded uncertainty of <u>24.6%</u>. The bias at the limit value was about <u>2 μ g/m³</u>.



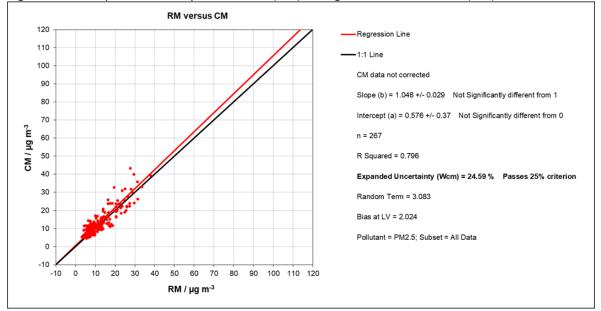


Figure 127: Comparison of daily sensor data (CM) with gravimetric reference (RM)

After applying slope and intercept for the full Borgerhout dataset we find an expanded uncertainty of 21%. The local correction consisted of first subtracting 0.6 μ g/m³ and then dividing by 1.05.

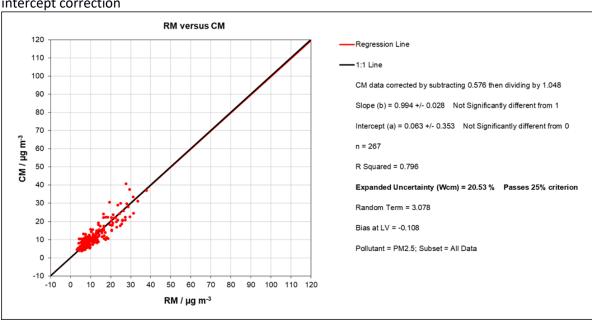


Figure 128: Comparison of daily sensor data (CM) with gravimetric reference (RM) after slope and intercept correction

+Variation between sensors

The between-sampler uncertainty of available hourly $PM_{2.5}$ data was 1.84 μ g/m³ or 14.2%.

+PM₁₀ and PM_{coarse} vs Fidas

This sensor only reports $PM_{2.5}$, so no analysis can be done on PM_{10} data.





Comparison of SDS011 with Palas Fidas 200 at 8 different monitoring sites





+Setup and locations

Since February 2019 VMM has co-located SDS011 sensors at 8 of its monitoring sites in Flanders. These sensors are built and operated as part of the 'Sensor.Community' citizen science project (https://sensor.community/en/ formerly known as 'Luftdaten'). This section describes the data until December 1 2020, a total of 21 months of comparisons. Sensor data were extracted from the Sensor.Community archives (https://archive.sensor.community/). Unless stated otherwise, the calculations are based on hourly PM_{2.5} averages. We should also mention that the measurement protocol is slightly different than in the actual Vaquums project since the Sensor.Community software switches the sensor on and off (to extend the sensor lifetime) in a cycle of 145 seconds.

The 8 locations vary in type:

- **R701**: urban background station in the city of Ghent (sensor ID= 22589)
- R702: traffic station in the city of Ghent (sensor ID= 22591)
- **R750**: industrial/urban/traffic station in Zelzate (sensor ID= 22593)
- **R801**: urban background station in the city of Antwerp (sensor ID=21695)
- R802: traffic station in the city of Antwerp (sensor ID=21466)
- R805: traffic station in street canyon in the city of Antwerp (sensor ID=22585)
- R817: suburban station in the district Wilrijk, Antwerp (sensor ID=22587)
- **R834**: rural station in Boom (sensor ID=22595)

In addition to the type of location, the local meteorological conditions also vary. Especially the relative humidity (as measured by the Palas Fidas 200) appears to show site-specific behaviour (see Figure 129). This is probably due to the presence of vegetation close to certain monitoring sites such as R750 (Figure 130), R817 (Figure 131) and R834 (Figure 132). One site (R805, Figure 133), an urban street canyon, has a RH curve shifted towards lower RH values. This is most likely a small measurement artefact.

Figure 129: Density plots of hourly relative humidity, full range (left) and high range only (right)

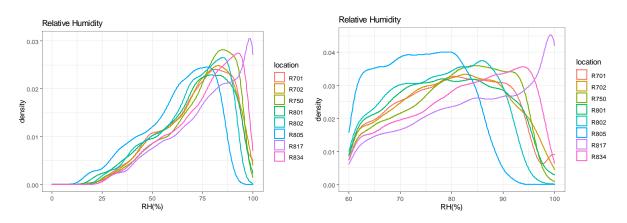




Figure 130: Monitoring site R750 (Zelzate)

Figure 131: Monitoring site R817 (Wilrijk)





Figure 132: Monitoring site R834 (Boom)

Figure 133: Monitoring site R805 (Antwerp)



+Timeplot and correlation

Figure 134 and Figure 135 show the timeplot and the correlation plot for the full comparison period. The figures and Table 2 show that the relation between the SDS011 and the Palas Fidas 200 varies between the locations. At site R701 there appears to be a shift in sensitivity from July 2020 on which negatively impacts the correlation. The three other sites with a considerably lower correlation than the Vaquums site (R801) are the three 'green' sites with higher relative humidity (R750, R817 and R834).

Table 2: Coefficients of determination (R^2) between sensor and Fidas Palas $PM_{2.5}$ at the 8 different locations

	R ² (hour)	R² (day)
R701	0.42	0.47
R834	0.57	0.76
R817	0.58	0.75
R750	0.59	0.76
<u>R801</u>	0.68	0.80
R702	0.73	0.84
R802	0.73	0.80
R805	0.82	0.83



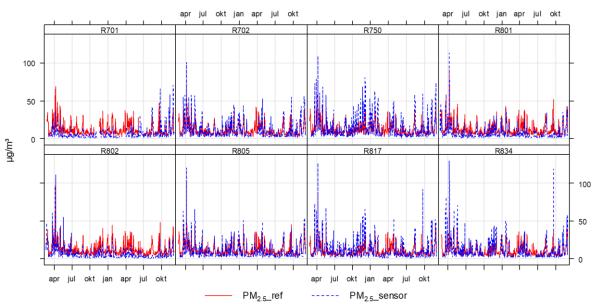
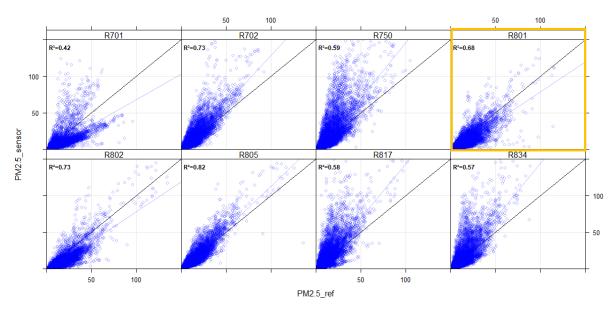


Figure 134: Timeplot of sensor and reference PM_{2.5} signal for the full period SDS011 vs Fidas Palas 200

Figure 135: Scatterplot of the SDS011 sensors vs Fidas reference at the 8 locations (R801=Vaquums field test site)



+Sensor/reference ratio, linear regression and expanded uncertainty around 30 μ g/m³ The difference between the sites is also clearly visible in the density plot of the sensor/reference ratio (Figure 136) and in the plot showing the linear regressions (Figure 137). The ratio plot does indicate that most of the time the SDS011 underestimates (sensor/reference < 1) but since values at higher concentrations have a larger impact on the slope of the linear regression some sites do have linear regressions with slopes > 1. This is probably due to a combination of individual sensor sensitivity and local increases in relative humidity.



Figure 136: Density plot of sensor/reference ratio for the 8 different sites SDS011

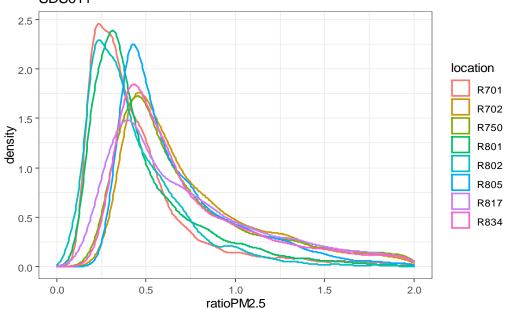
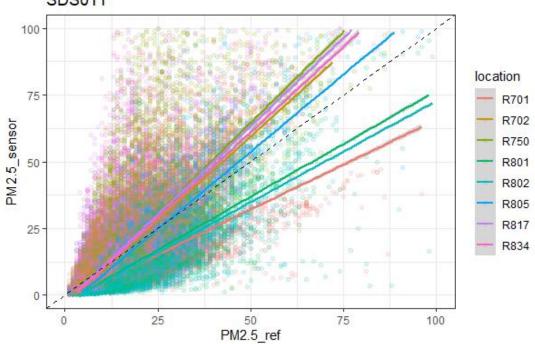


Figure 137: Linear regressions for the 8 different sites SDS011



Just like in the sensor section we can estimate the expanded uncertainty around the $PM_{2.5}$ 'daily pseudo limit value' of 30 µg/m³. We do this by calculating the 95% percentile of the absolute difference between sensor and reference data for the part of the dataset with reference values between 25 and 35 µg/m³ (see Figure 138). These numbers also show that other locations besides R801 are more challenging for the SDS011 sensors, and that the expanded uncertainty at the hourly level can be up to 3 times higher.



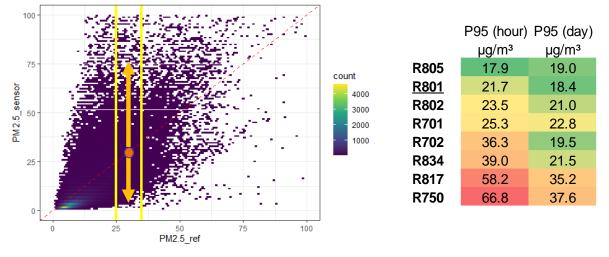


Figure 138: Estimate of the expanded uncertainty around 30 μ g/m³

When we plot the sensor/reference ratio vs the relative humidity (Figure 139) it is clear that the sensor/reference ratio rapidly goes up when relative humidity passes 80%. This zone around 80% RH appears to be some sort of 'tipping point' in the graph which can also be linked to particle growth in literature^b. The curves do appear to vary somewhat between locations. Whether this difference in behaviour is due to the different amounts of measurements at high humidity, small differences in local PM composition, small shifts in the RH measurements themselves and/or other factors is less clear.

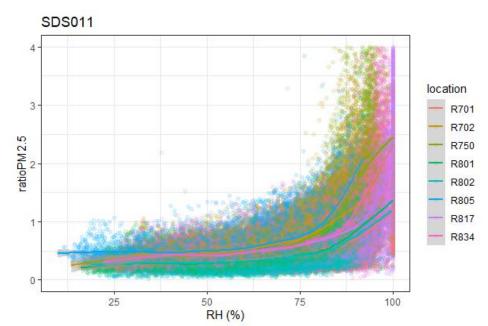


Figure 139: Sensor/reference ratio vs relative humidity at the 8 locations

+Hourly variation of relative humidity and sensor/reference ratio

Figure 140 and Figure 141 show the average variation within a day for the relative humidity and the sensor/reference ratio (expressed in UT). It is very clear that the diurnal pattern is similar for these 2 parameters, with higher values at night and morning and lower values during the day. Since these



^b https://amt.copernicus.org/articles/10/1269/2017/

relative humidity cycles are close to the 'tipping point' around 80% RH this could explain why daily averages show better performance (R^2 and P95) than hourly values. In other words, on average the underestimation during daytime will be (partially) compensated by the overestimation at night and morning.

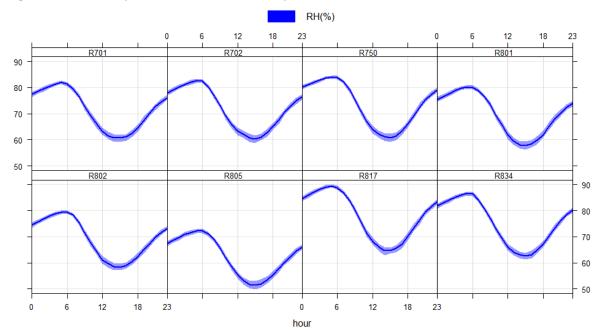
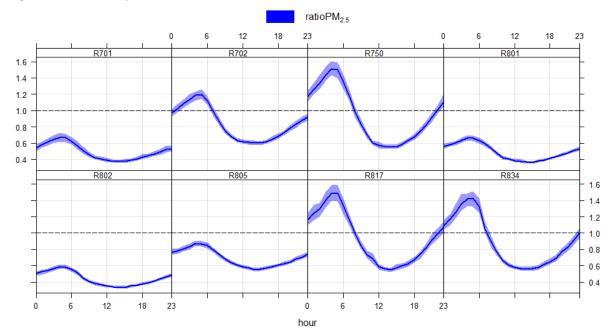


Figure 140: Diurnal pattern of relative humidity for the 8 different sites

Figure 141: Diurnal pattern of the sensor/reference ratio for the 8 different sites



Since the average sensor/reference ratio varies between sites, we also calculated the normalised pattern (Figure 142) thereby eliminating the difference in sensitivity between sensors. This graph clearly shows that the 'green' sites with vegetation nearby also have a larger diurnal variation in sensor/reference ratio.



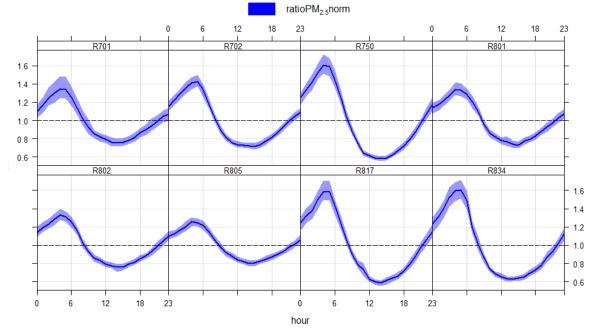
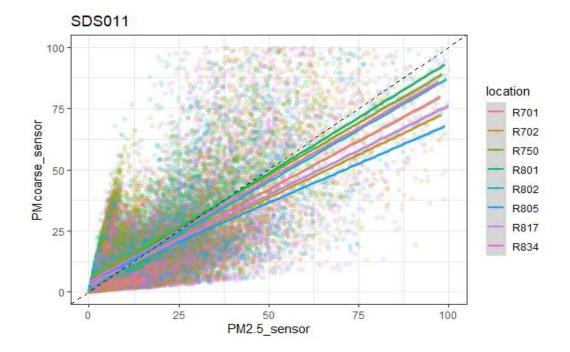


Figure 142: Diurnal pattern of the normalized sensor/reference ratio for the 8 different sites

+PM_{coarse} vs PM_{2.5} scatterplot

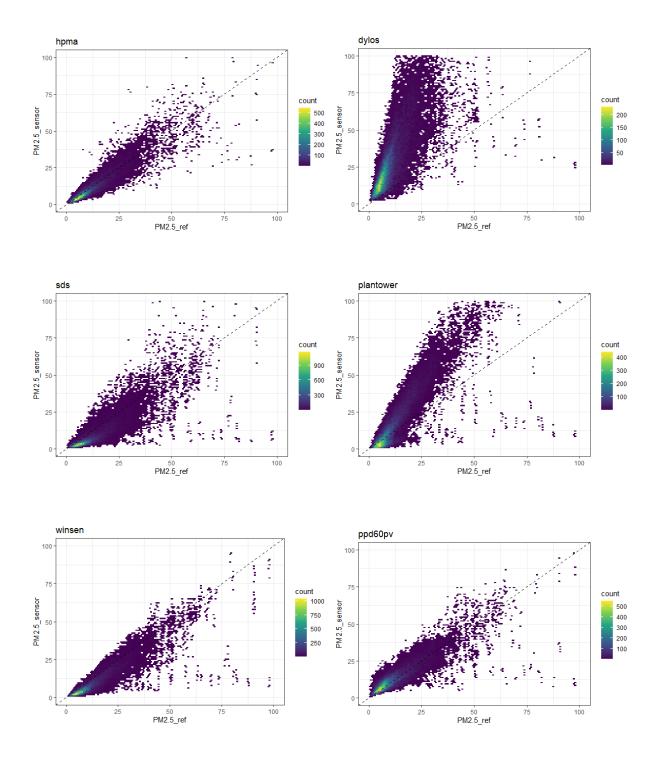
Just like in the different sensor sections we also plotted the PM_{coarse} vs the PM_{2.5} signal of the sensor (Figure *143*). Although the linear relation between sites (or sensors) appears to vary a bit, it is obvious that all share the same upper and lower limit. This could imply that plotting PM_{coarse} vs PM_{2.5} could be used as a sensor type 'fingerprint', since the plot shape appears to depend on the sensor type or firmware (see also Annex 2).

Figure 143: Scatterplot of PM_{coarse} vs $PM_{2.5}$ for all 8 sites



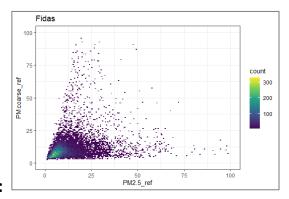


Annex 1: PM_{2.5_sensor} vs PM_{2.5_ref} scatterplots

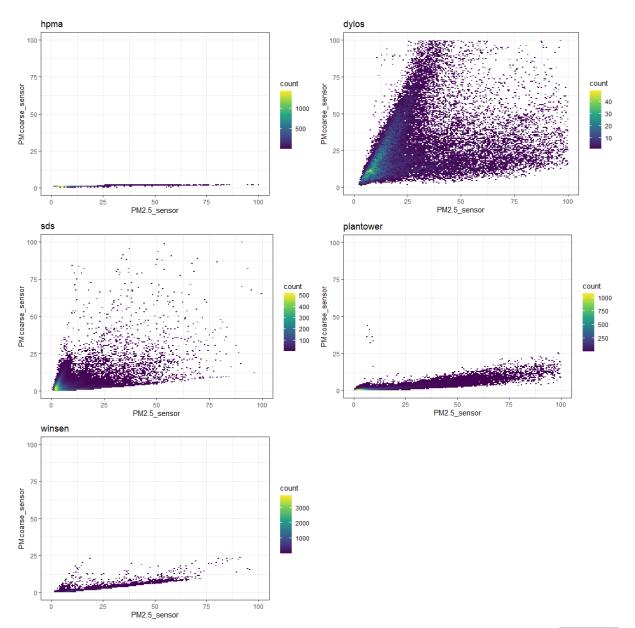




Annex 2: PM_{coarse} vs PM_{2.5} scatterplots



Reference:





Annex 3: modstats^c vs Palas Fidas 200

+**n**: the number of complete data pairs.

+**FAC**2: fraction of predictions within a factor of two.

+**MB**: the mean bias.

+MGE: the mean gross error.

+NMB: the normalised mean bias.

+NMGE: the normalised mean gross error.

+RMSE: the root mean squared error.

+**r**: the Pearson correlation coefficient.

+**COE**: the Coefficient of Efficiency based on Legates and McCabe (1999, 2012). There have been many suggestions for measuring model performance over the years, but the COE is a simple formulation which is easy to interpret.

A perfect model has a COE = 1. As noted by Legates and McCabe although the COE has no lower bound, a value of COE = 0.0 has a fundamental meaning. It implies that the model is no more able to predict the observed values than does the observed mean. Therefore, since the model can explain no more of the variation in the observed values than can the observed mean, such a model can have no predictive advantage.

For negative values of COE, the model is less effective than the observed mean in predicting the variation in the observations.

+**IOA**: the Index of Agreement based on Willmott et al. (2011), which spans between -1 and +1 with values approaching +1 representing better model performance.

An IOA of 0.5, for example, indicates that the sum of the error-magnitudes is one half of the sum of the observed-deviation magnitudes. When IOA = 0.0, it signifies that the sum of the magnitudes of the errors and the sum of the observed-deviation magnitudes are equivalent. When IOA = -0.5, it indicates that the sum of the error-magnitudes is twice the sum of the perfect model-deviation and observed-deviation magnitudes. Values of IOA near -1.0 can mean that the model-estimated deviations about 0 are poor estimates of the observed deviations; but, they also can mean that there simply is little observed variability - so some caution is needed when the IOA approaches -1.

^c <u>https://www.rdocumentation.org/packages/openair/versions/0.4-17/topics/modStats</u>



Honeywell HPMA 115S0

HOUL	eyweii	HPIVIA 115	30									
5min	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	27795	0.99	1.68	2.82	0.13	0.22	5.49	0.92	0.62	0.81
		VQD2	97773	0.97	-2.52	3.12	-0.20	0.25	5.93	0.88	0.58	0.79
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD3 VQD4										
			98765	0.99	0.00	2.52	0.00	0.20	5.75	0.88	0.66	0.83
		VQD5	30155	0.99	-1.48	2.79	-0.10	0.19	6.47	0.88	0.67	0.83
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	254488	0.98	-0.96	2.82	-0.07	0.22	5.88	0.87	0.62	0.81
hour	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	2339	1.00	1.66	2.74	0.13	0.22	4.71	0.96	0.63	0.81
		VQD2	8195	0.98	-2.52	3.07	-0.20	0.24	4.71	0.92	0.58	0.79
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	8276	1.00	0.00	2.38	0.00	0.19	4.31	0.93	0.67	0.83
		VQD5	2528	0.99	-1.48	2.66	-0.10	0.18	4.29	0.94	0.67	0.84
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	21338	0.99	-0.96	2.72	-0.08	0.21	4.51	0.92	0.63	0.82
day	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
uay	1 102.5	VQD1	110	1.00	1.65	2.41	0.13	0.19	3.76	0.99	0.62	0.81
		VQD2	362	0.98	-2.71	2.95	-0.21	0.23	4.15	0.93	0.53	0.77
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	361	1.00	-0.10	2.01	-0.01	0.16	3.19	0.94	0.67	0.84
		VQD5	115	1.00	-1.72	2.28	-0.11	0.15	3.39	0.95	0.68	0.84
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	948	0.99	-1.09	2.45	-0.08	0.19	3.67	0.93	0.62	0.81
5min	PM10	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
JIIIII	FINITU											
		VQD1	27795	0.67	-8.50	10.03	-0.35	0.42	39.28	0.35	0.14	0.57
		VQD2	97773	0.37	-14.14	14.29	-0.56	0.57	44.57	0.36	-0.09	0.45
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	98765	0.54	-11.84	12.58	-0.46	0.49	45.72	0.34	0.05	0.53
		VQD5	30155	0.47	-16.29	16.68	-0.54	0.55	55.93	0.32	0.02	0.51
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	254488	0.48	-12.89	13.44	-0.50	0.52	45.97	0.34	0.01	0.50
	DMAG											
nour	PM10	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	2339	0.67	-8.63	10.08	-0.36	0.42	24.65	0.45	0.13	0.56
		VQD2	8195	0.36	-14.17	14.28	-0.56	0.56	28.53	0.46	-0.13	0.44
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	8276	0.52	-11.87	12.56	-0.47	0.49	28.11	0.45	0.02	0.51
		VQD5	2528	0.45	-16.29	16.64	-0.54	0.55	35.22	0.42	-0.04	0.48
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	21338	0.46	-12.92	13.43	-0.50	0.52	28.86	0.44	-0.03	0.49
4	DMAG											
day	PM10	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	110	0.60	-9.23	9.80	-0.37	0.40	13.59	0.80	0.02	0.51
		VQD2	362	0.30	-14.69	14.69	-0.57	0.57	18.43	0.67	-0.42	0.29
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	361	0.44	-11.95	12.24	-0.47	0.48	15.88	0.69	-0.23	0.38
		VQD5	115	0.37	-16.61	16.64	-0.54	0.54	21.28	0.68	-0.48	0.26
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	948	0.40	-13.24	13.43	-0.51	0.51	17.38	0.68	-0.29	0.36
5min	Pmcoar	se sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	27795	0.02	-10.18	10.18	-0.90	0.90	36.36	-0.56	-0.56	0.22
		VQD2	97773	0.01	-11.62	11.62	-0.92	0.92	39.72	-0.52	-0.51	0.24
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	98765	0.01	-11.84	11.84	-0.92	0.92	42.08	-0.56	-0.51	0.25
		VQD5	30155	0.00	-14.81	14.81	-0.93	0.93	50.65	-0.54	-0.37	0.32
		default										
			n	FAC2	MB	MGE	NMB	NMGE	RMSE	1	COE	IOA
	_	all	254488	0.01	-11.93	11.93	-0.92	0.92	41.74	-0.53	-0.49	0.25
hour	Pmcoar	se sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	2339	0.02	-10.29	10.29	-0.90	0.90	23.00	-0.44	-0.62	0.19
		VQD2	8195	0.00	-11.64	11.64	-0.92	0.92	24.89	-0.48	-0.59	0.21
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	8276	0.01	-11.86	11.86	-0.92	0.92	26.06	-0.66	-0.59	0.21
		VQD5	2528									
				0.00	-14.81	14.81	-0.93	0.93	31.93	-0.67	-0.46	0.27
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	21338	0.01	-11.96	11.96	-0.92	0.92	26.08	-0.58	-0.57	0.22
day	Pmcoar	se sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQD1	110	0.00	-10.88	10.88	-0.91	0.91	14.72	0.14	-1.12	-0.05
		VQD2	362	0.00	-11.98	11.98	-0.92	0.92	15.20	-0.06	-1.17	-0.08
		VQD3	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
		VQD4	361	0.00	-11.85	11.85	-0.92	0.92	15.03	-0.43	-1.25	-0.11
		VQD5	115	0.00	-14.89	14.89	-0.93	0.93	19.16	-0.47	-1.20	-0.09
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	948	0.00	-12.15	12.15	-0.92	0.92	15.62	-0.26	-1.16	-0.08



Dula	- DC1700											
	s DC1700		-	FACO	MD	MCE		MAGE	DMCE	_	COL	104
Smin	PM2.5	sensor_id	n 07400	FAC2	MB	MGE	NMB	NMGE	RMSE	Г 0.75	COE	AOI
		VQN1 VQN2	67429 72748	0.39 0.26	17.63 26.50	18.00 26.81	1.50 2.03	1.53 2.05	33.84 47.53	0.75 0.71	-1.68 -2.48	-0.25 -0.42
		VQN2 VQN3	74802	0.26	28.81	28.99	2.03	2.05	47.89	0.73	-2.40	-0.42
		VQN4	86799	0.10	30.05	30.35	2.40	2.20	51.06	0.73	-2.04	-0.40
		VQN5	96244	0.23	27.06	27.49	2.20	2.24	48.17	0.72	-2.86	-0.48
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	398022	0.24	26.34	26.66	2.11	2.14	46.56	0.73	-2.65	-0.45
hour	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQN1	5675	0.39	17.60	17.87	1.50	1.52	33.50	0.81	-1.70	-0.26
		VQN2	6103	0.27	26.43	26.63	2.03	2.04	47.11	0.77	-2.51	-0.43
		VQN3	6266	0.16	28.75	28.84	2.26	2.27	47.48	0.79	-2.87	-0.48
		VQN4	7379	0.17	30.04	30.25	2.40	2.42	50.81	0.80	-3.18	-0.52
		VQN5	8059	0.23	27.03	27.34	2.20	2.22	47.79	0.78	-2.91	-0.49
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	33482	0.24	26.31	26.53	2.11	2.13	46.21	0.79	-2.69	-0.46
day	PM2.5	sensor_id	n 054	FAC2	MB	MGE	NMB	NMGE	RMSE	r 0.05	COE	IOA 0.22
		VQN1	251	0.33	17.96	18.10	1.50	1.51	31.07	0.85	-2.00	-0.33
		VQN2 VQN3	268 275	0.20 0.12	25.89 28.30	26.15 28.32	1.95 2.21	1.97 2.21	41.13 41.93	0.80 0.82	-2.83 -3.26	-0.48 -0.53
		VQN4	323	0.12	29.53	29.73	2.21	2.21	41.55	0.83	-3.63	-0.53
		VQN5	352	0.21	26.74	26.83	2.16	2.16	42.57	0.82	-3.43	-0.55
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1469	0.19	25.99	26.13	2.06	2.07	41.02	0.82	-3.08	-0.51
5min	PM10	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	г	COE	IOA
		VQN1	67429	0.39	36.10	38.52	1.54	1.64	75.95	0.39	-2.40	-0.41
		VQN2	72748	0.33	49.15	52.10	1.89	2.00	100.22	0.35	-2.83	-0.48
		VQN3	74802	0.25	54.27	56.37	2.14	2.22	95.74	0.40	-3.24	-0.53
		VQN4	86799	0.24	53.87	56.50	2.12	2.23	93.92	0.41	-3.22	-0.53
		VQN5	96244	0.28	52.29	54.98	2.09	2.20	94.50	0.40	-3.29	-0.53
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
	-	all	398022	0.29	49.69	52.26	1.98	2.08	92.84	0.39	-3.04	-0.51
hour	PM10	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r 0.40	COE	IOA 0.40
		VQN1 VQN2	5675	0.40	36.00	37.80	1.53	1.61	69.91	0.40 0.37	-2.43 -2.88	-0.42
		VQN2 VQN3	6103 6266	0.34 0.26	48.99 54.12	51.10 55.43	1.89 2.13	1.97 2.18	94.14 88.83	0.37	-2.00	-0.48 -0.53
		VQN4	7379	0.25	53.81	55.64	2.13	2.10	88.75	0.42	-3.28	-0.53
		VQN5	8059	0.30	52.17	53.80	2.09	2.15	88.93	0.42	-3.34	-0.54
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	33482	0.31	49.58	51.31	1.98	2.05	86.95	0.41	-3.09	-0.51
day	PM10	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQN1	251	0.34	36.27	36.63	1.50	1.52	59.16	0.67	-2.87	-0.48
		VQN2	268	0.29	47.89	48.32	1.83	1.84	75.51	0.61	-3.56	-0.56
		VQN3	275	0.22	53.22	53.24	2.09	2.09	73.82	0.62	-4.06	-0.60
		VQN4	323	0.22	52.85	53.39	2.06	2.08	74.69	0.57	-4.05	-0.60
		VQN5 default	352	0.27 FAC2	51.58 MB	51.83 MGE	2.05 NMB	2.06 NMGE	75.80 RMSE	0.58	-4.29 COE	-0.62 IOA
		all	n 1469	0.27	48.88	49.20	1.93	1.94	72.54	r 0.61	-3.82	-0.58
5min	Pmcoarse	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	0.01 r	COE	IOA
		VQN1	67429	0.42	18.47	20.98	1.57	1.79	49.93	0.36	-2.30	-0.39
		VQN2	72748	0.38	22.65	26.09	1.75	2.02	62.38	0.32	-2.28	-0.39
		VQN3	74802	0.33	25.46	28.05	2.01	2.22	58.31	0.38	-2.62	-0.45
		VQN4	86799	0.33	23.82	26.82	1.85	2.09	53.00	0.45	-2.36	-0.40
		VQN5	96244	0.34	25.22	28.00	1.99	2.21	55.80	0.40	-2.68	-0.46
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
	-	all	398022	0.36	23.35	26.21	1.85	2.08	56.02	0.38	-2.46	-0.42
hour	Pmcoarse	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	г 0.07	COE	IOA
		VQN1	5675	0.44	18.40 22.56	20.39 25.32	1.56	1.73	42.24	0.27	-2.37	-0.41
		VQN2 VQN3	6103 6266	0.40 0.34	22.56	25.32	1.74 2.00	1.95 2.15	54.37 48.65	0.23 0.31	-2.34 -2.67	-0.40 -0.46
		VQN4	7379	0.34	23.77	26.07	1.84	2.15	45.51	0.33	-2.40	-0.40
		VQN5	8059	0.36	25.14	26.97	1.98	2.02	48.13	0.32	-2.71	-0.41
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	0.32 F	COE	IOA
		all	33482	0.38	23.27	25.40	1.84	2.01	47.94	0.29	-2.51	-0.43
day	Pmcoarse	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQN1	251	0.40	18.31	19.08	1.51	1.57	31.15	0.45	-3.10	-0.51
		VQN2	268	0.40	22.00	22.87	1.70	1.76	37.98	0.38	-3.33	-0.54
		VQN3	275	0.33	24.92	25.37	1.97	2.00	36.22	0.40	-3.88	-0.59
		VQN4	323	0.35	23.32	24.11	1.80	1.86	34.36	0.32	-3.32	-0.54
		VQN5	352	0.34	24.84	25.34	1.95	1.99	37.73	0.33	-3.93	-0.59
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	1	COE	IOA
		all	1469	0.36	22.89	23.56	1.80	1.85	35.71	0.37	-3.53	-0.56



Nove	Eitness S	DC011										
	Fitness S PM2.5			FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
JIIII	PIVIZ.J	sensor_id VQA1	n 78112	0.76	-2.66	4.58	-0.20	0.35	8.03	0.81	0.43	0.71
		VQA2	83177	0.76	-2.74	4.78	-0.20	0.36	8.23	0.79	0.45	0.69
		VQA3	100681	0.48	-4.81	5.41	-0.39	0.43	8.94	0.76	0.26	0.63
		VQA4	88860	0.65	-4.57	4.92	-0.37	0.40	8.31	0.79	0.33	0.66
		VQA5	93514	0.60	-4.47	5.09	-0.35	0.40	8.40	0.79	0.32	0.66
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r a Ta	COE	IOA
	D11 0 5	all	444344	0.64	-3.92	4.98	-0.31	0.39	8.42	0.78	0.34	0.67
hour	PM2.5	sensor_id VQA1	n 6537	FAC2 0.76	MB -2.67	MGE 4.52	NMB -0.20	NMGE 0.34	RMSE 6.76	r 0.86	COE 0.43	IOA 0.71
		VQA1 VQA2	6969	0.76	-2.07	4.52	-0.20	0.34	6.96	0.85	0.43	0.69
		VQA3	8427	0.48	-4.81	5.39	-0.39	0.43	7.47	0.84	0.25	0.62
		VQA4	7462	0.64	-4.57	4.89	-0.37	0.40	6.88	0.87	0.32	0.66
		VQA5	7899	0.60	-4.48	5.08	-0.35	0.40	7.00	0.86	0.31	0.65
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	37294	0.64	-3.93	4.95	-0.31	0.39	7.03	0.85	0.33	0.67
day	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	1	COE	IOA
		VQA1 VQA2	283 305	0.85 0.83	-2.77 -2.83	3.89 4.07	-0.21 -0.21	0.29 0.31	5.00 5.25	0.91 0.90	0.44 0.39	0.72
		VQA2 VQA3	305	0.85	-2.03	5.29	-0.21	0.31	6.37	0.90	0.39	0.69
		VQA4	339	0.65	-4.77	4.90	-0.38	0.39	5.99	0.90	0.21	0.61
		VQA5	351	0.64	-4.59	4.85	-0.35	0.37	5.92	0.90	0.24	0.62
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1645	0.68	-4.05	4.65	-0.31	0.36	5.77	0.89	0.28	0.64
5min	PM10	sensor_id	n 70110	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQA1 VQA2	78112 83177	0.51 0.47	-10.28 -10.99	13.65 13.98	-0.40 -0.42	0.53 0.54	42.56 42.23	0.45 0.48	0.00 -0.02	0.50 0.49
		VQA2 VQA3	100681	0.47	-10.99	14.40	-0.42	0.54	42.23	0.46	-0.02	0.49
		VQA4	88860	0.52	-11.14	13.35	-0.44	0.53	44.55	0.38	0.00	0.50
		VQA5	93514	0.49	-12.01	13.85	-0.47	0.54	44.38	0.47	-0.04	0.48
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	444344	0.48	-11.51	13.86	-0.45	0.54	44.45	0.42	-0.03	0.49
hour	PM10	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r A 10	COE	AOI
		VQA1 VQA2	6537 6969	0.49 0.46	-10.31 -11.03	13.55 13.90	-0.40 -0.43	0.52 0.54	28.77 28.17	0.46 0.48	-0.02 -0.05	0.49 0.47
		VQA2 VQA3	8427	0.38	-12.76	14.36	-0.40	0.54	29.83	0.40	-0.05	0.47
		VQA4	7462	0.51	-11.19	13.30	-0.44	0.53	28.43	0.45	-0.02	0.49
		VQA5	7899	0.48	-12.10	13.86	-0.47	0.54	28.67	0.47	-0.07	0.47
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	37294	0.46	-11.55	13.81	-0.45	0.54	28.81	0.45	-0.06	0.47
day	PM10	sensor_id	n 2022	FAC2	MB	MGE	NMB	NMGE	RMSE	r 0.75	COE	AOI
		VQA1 VQA2	283 305	0.51 0.47	-10.46 -11.22	11.96 12.48	-0.40 -0.43	0.46 0.48	14.92 15.43	0.75 0.73	-0.12 -0.21	0.44 0.39
		VQA3	367	0.37	-12.95	13.75	-0.50	0.54	17.25	0.66	-0.34	0.33
		VQA4	339	0.47	-11.46	12.62	-0.45	0.49	15.67	0.71	-0.23	0.38
		VQA5	351	0.48	-12.35	13.20	-0.47	0.50	16.77	0.66	-0.29	0.36
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
F .		all	1645	0.46	-11.77	12.86	-0.45	0.50	16.11	0.70	-0.24	0.38
5min	Pmcoarse	sensor_id VQA1	n 70110	FAC2	MB	MGE	NMB	NMGE	RMSE	r 0.42	COE	IOA 0.27
		VQA1 VQA2	78112 83177	0.25 0.23	-7.62 -8.25	9.83 10.01	-0.60 -0.65	0.78 0.79	35.88 35.51	0.43 0.50	-0.26 -0.26	0.37 0.37
		VQA3	100681	0.28	-7.92	9.86	-0.61	0.76	40.37	0.31	-0.23	0.38
		VQA4	88860	0.37	-6.57	9.36	-0.51	0.72	37.71	0.31	-0.16	0.42
		VQA5	93514	0.31	-7.55	9.30	-0.58	0.71	37.37	0.48	-0.18	0.41
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
	D	all	444344	0.29	-7.58	9.67	-0.59	0.75	37.55	0.40	-0.22	0.39
nour	Pmcoarse	sensor_id VQA1	n 6537	FAC2 0.24	MB -7.65	MGE 9.77	NMB -0.60	NMGE 0.77	23.50	r 0.32	COE -0.31	IOA 0.35
		VQA1 VQA2	6969	0.24	-7.65	9.77	-0.60	0.77	23.50	0.32	-0.31	0.35 0.34
		VQA3	8427	0.27	-7.95	9.80	-0.61	0.75	24.36	0.24	-0.28	0.34
		VQA4	7462	0.36	-6.62	9.26	-0.51	0.71	23.24	0.28	-0.20	0.40
		VQA5	7899	0.30	-7.62	9.29	-0.58	0.71	23.19	0.36	-0.23	0.39
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	37294	0.28	-7.62	9.61	-0.59	0.74	23.47	0.31	-0.26	0.37
day	Pmcoarse	_	n	FAC2	MB	MGE	NMB	NMGE	RMSE	1	COE	IOA
		VQA1	283	0.23 0.23	-7.69	8.58 8.99	-0.61	0.68	11.07	0.51	-0.62	0.19
		VQA2 VQA3	305 367	0.23	-8.39 -8.05	8.99 9.25	-0.66 -0.62	0.70 0.71	11.44 12.38	0.49 0.27	-0.68 -0.67	0.16 0.16
		VQA3 VQA4	339	0.23	-6.70	9.25 8.34	-0.62	0.64	12.30	0.27	-0.67	0.18
		VQA5	351	0.30	-7.76	8.67	-0.59	0.66	11.83	0.37	-0.61	0.20
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1645	0.26	-7.71	8.77	-0.60	0.68	11.58	0.41	-0.62	0.19



Plan	tower	PMS7003										
5min	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQE1	99496	0.68	6.61	9.23	0.52	0.73	15.09	0.82	-0.24	0.38
		VQE2	94711	0.72	5.85	8.42	0.46	0.67	14.04	0.82	-0.15	0.43
		VQE3	28241	0.80	6.92	9.48	0.44	0.60	15.38	0.85	0.02	0.51
		VQE4 VQE5	102473 96989	0.73 0.75	2.60 5.20	6.33 7.95	0.21 0.41	0.50 0.62	10.86 13.29	0.82 0.82	0.14 -0.06	0.57 0.47
		default	50505 n	FAC2	MB	MGE	NMB	NMGE	RMSE	0.02 r	COE	IOA
		all	421910	0.73	5.16	8.06	0.40	0.63	13.53	0.82	-0.06	0.47
hour	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQE1	8348	0.69	6.58	9.05	0.52	0.71	14.20	0.90	-0.24	0.38
		VQE2	7950	0.73	5.84	8.24	0.46	0.66	13.13	0.90	-0.14	0.43
		VQE3	2369	0.82	6.89	9.27	0.43	0.59	14.26	0.92	0.02	0.51
		VQE4	8573	0.73	2.59	6.18	0.21	0.49	9.64	0.91	0.14	0.57
		VQE5	8127	0.76 FAC2	5.19	7.77 MGE	0.41 NMB	0.61	12.26 RMSE	0.91	-0.06	0.47 IOA
		default all	n 35367	0.73	MB 5.15	7.89	0.40	NMGE 0.61	12.53	r 0.90	COE -0.06	0.47
day	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
,		VQE1	367	0.81	6.53	8.16	0.51	0.64	12.11	0.95	-0.29	0.35
		VQE2	352	0.85	5.90	7.45	0.47	0.59	11.27	0.95	-0.20	0.40
		VQE3	108	0.95	6.63	8.23	0.42	0.52	11.55	0.95	-0.03	0.49
		VQE4	372	0.84	2.56	5.23	0.20	0.41	7.70	0.96	0.17	0.58
		VQE5	359	0.90	5.15	6.90	0.40	0.54	10.27	0.96	-0.09	0.45
		default all	n 1558	FAC2 0.86	MB 5.13	MGE 7.01	NMB 0.40	NMGE 0.54	RMSE 10.53	r 0.95	COE -0.09	IOA 0.46
5min	PM10	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	0.35 r	COE	IOA
511111		VQE1	99496	0.57	-3.48	15.04	-0.14	0.58	49.13	0.26	-0.11	0.44
		VQE2	94711	0.56	-5.48	14.49	-0.21	0.56	48.76	0.26	-0.08	0.46
		VQE3	28241	0.64	-5.11	16.57	-0.16	0.53	55.86	0.28	0.05	0.53
		VQE4	102473	0.50	-8.55	14.21	-0.33	0.55	48.71	0.26	-0.05	0.47
		VQE5	96989	0.57	-6.21	14.40	-0.24	0.55	49.78	0.25	-0.05	0.48
		default	n 421010	FAC2 0.55	MB	MGE	NMB	NMGE	RMSE	1 0.00	COE	IOA
hour	PM10	all sensor id	421910 n	FAC2	-5.90 MB	14.67 MGE	-0.23 NMB	0.56 NMGE	49.57 RMSE	0.26 r	-0.06 COE	0.47 IOA
noui		VQE1	8348	0.56	-3.53	14.61	-0.14	0.57	30.15	0.39	-0.12	0.44
		VQE2	7950	0.55	-5.50	14.12	-0.21	0.55	30.09	0.39	-0.08	0.46
		VQE3	2369	0.63	-5.16	16.11	-0.16	0.52	35.48	0.41	0.04	0.52
		VQE4	8573	0.49	-8.58	13.97	-0.33	0.54	29.74	0.39	-0.07	0.46
		VQE5	8127	0.56	-6.24	14.06	-0.24	0.54	30.37	0.38	-0.06	0.47
		default all	n 35367	FAC2 0.55	MB -5.93	MGE 14.32	NMB -0.23	NMGE	RMSE 30.48	r 0.39	COE -0.07	IOA
day	PM10	sensor id	35367 N	FAC2	-5.93 MB	MGE	NMB	0.55 NMGE	RMSE	0.39 F	COE	0.47 IOA
uuy		VQE1	367	0.65	-3.60	11.35	-0.14	0.44	15.30	0.68	-0.10	0.45
		VQE2	352	0.61	-5.42	11.32	-0.21	0.44	15.02	0.68	-0.11	0.45
		VQE3	108	0.69	-5.44	12.57	-0.17	0.40	17.78	0.65	-0.04	0.48
		VQE4	372	0.49	-8.64	11.84	-0.33	0.46	15.27	0.69	-0.15	0.42
		VQE5	359	0.60	-6.22	11.36	-0.24	0.44	15.02	0.68	-0.10	0.45
		default all	n 1558	FAC2 0.59	MB -5.94	MGE 11.54	NMB -0.23	NMGE 0.44	RMSE 15.35	r 0.68	COE -0.10	IOA 0.45
5min	Pmcoar	se sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQE1	99496	0.16	-10.09	10.78	-0.77	0.82	42.54	0.14	-0.33	0.34
		VQE2	94711	0.09	-11.33	11.68	-0.86	0.89	42.75	0.08	-0.43	0.28
		VQE3	28241	0.15	-12.03	12.90	-0.78	0.84	48.74	0.12	-0.24	0.38
		VQE4	102473	0.10	-11.15	11.45	-0.85	0.88	42.63	0.15	-0.41	0.29
		VQE5 default	96989	0.09 FAC2	-11.41 MB	11.73 MGE	-0.86 NMB	0.88 NMGE	43.64 RMSE	0.11 r	-0.41 COE	0.29 IOA
		all	n 421910	0.12	-11.06	11.50	-0.83	0.86	43.30	0.12	-0.38	0.31
hour	Pmcoar	se sensor id	-121010 N	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQE1	8348	0.15	-10.11	10.74	-0.77	0.82	25.53	0.13	-0.39	0.31
		VQE2	7950	0.09	-11.34	11.66	-0.86	0.88	26.34	0.11	-0.50	0.25
		VQE3	2369	0.15	-12.04	12.85	-0.78	0.83	30.90	0.14	-0.30	0.35
		VQE4	8573	0.10	-11.17	11.45	-0.85	0.87	26.04	0.13	-0.48	0.26
		VQE5	8127	0.09	-11.43	11.72 MCE	-0.86	0.88	26.65 DMSE	0.12	-0.48	0.26
		default all	n 35367	FAC2 0.11	MB -11.08	MGE 11.48	NMB -0.83	NMGE 0.86	RMSE 26.48	r 0.12	COE -0.45	IOA 0.28
day	Pmcoar	sesensorid	35367 N	FAC2	-11.08 MB	MGE	NMB	NMGE	RMSE	0.12 r	COE	IOA
,		VQE1	367	0.12	-10.13	10.37	-0.77	0.79	13.63	0.21	-0.88	0.06
		VQE2	352	0.07	-11.32	11.40	-0.86	0.87	14.52	0.23	-1.07	-0.03
		VQE3	108	0.11	-12.07	12.29	-0.78	0.80	16.94	0.25	-0.78	0.11
		VQE4	372	0.08	-11.20	11.26	-0.85	0.86	14.42	0.21	-1.03	-0.02
		VQE5	359	0.06	-11.36	11.42 MCE	-0.86	0.86	14.62	0.21	-1.05	-0.02
		default all	n 1558	FAC2 0.08	MB -11.07	MGE 11.19	NMB -0.83	NMGE 0.84	RMSE 14.50	r 0.22	COE -0.98	IOA 0.01
		CIII	1000	0.00	-11.07	11.15	-0.05	0.04	14.00	V.22	-0.50	0.01



Winsen ZH03B

Smin PMZ5 eeresc., id VQF1 n FAC2 MB MGE NMGE RMMSE r COB ODA VQF2 0.61 3.56 3.91 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.24 0.02 0.22 0.22 0.22 0.22 0.22 0.76 0.04 0.03 0.44 0.03 0.42 0.32 0.50 0.76 0.03 0.46 0.73 0.03 0.44 0.73 0.30 4.46 0.73 0.23 0.46 0.74 0.22 0.22 0.43 0.75 0.75 0.63 0.43 0.23 0.23 0.50 0.92 0.43 0.75 0.76 0.64 0.73 0.40 0.41 0.23 0.33 0.45 0.45 0.41 0.41 0.41 0.41 0.41 0.41 0.41		sen zhu											
VGF2 84398 0.80 -3.45 3.81 -0.27 0.29 7.20 0.85 0.49 0.75 VGF3 100226 0.64 4.38 4.71 0.35 0.38 8.16 0.81 0.82 0.52 0.75 other other 4.0076 F.72 3.80 M45 0.03 0.87 0.82 0.52 0.75 0.33 0.87 0.82 0.83 0.82 0.82 0.82 0.82 0.93 0.75 0.83 0.83 0.83 0.83 0.82 0.82 0.83 <	5min	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
VGF2 84398 0.80 -3.45 3.81 -0.27 0.29 7.20 0.85 0.49 0.75 VGF3 100226 0.64 4.38 4.71 0.35 0.38 8.16 0.81 0.82 0.52 0.75 other other 4.0076 F.72 3.80 M45 0.03 0.87 0.82 0.52 0.75 0.33 0.87 0.82 0.83 0.82 0.82 0.82 0.82 0.93 0.75 0.83 0.83 0.83 0.83 0.82 0.82 0.83 <			VQF1	63276	0.61	-4.89	5.09	-0.34	0.35	8.32	0.85	0.40	0.70
VGF3 100211 0.75 -3.46 3.71 -0.28 0.30 6.89 0.85 0.81 0.36 6.68 VGF4 100212 0.64 -3.30 3.65 0.24 0.28 7.40 0.82 0.76 0.82 0.76 nour PM2.5 off-1 0.73 -3.80 4.13 4.07 0.32 0.32 7.59 0.83 0.84 0.75 v0F1 0.72 2.30 4.13 4.05 MM2 MM2 MM2 MM2 MM2 MM2 0.22 0.32 0.44 0.75			VQF2	84398	0 80	-3.55	3 81	-0.27	0.29		0.85	0.50	0.75
VDF4 101226 0.64 4.38 4.71 -0.35 0.38 0.81 0.91 0.92 0.93 0.44 0.73 hour PM2.5 sensor_1d n FAC2 MB MGE NMB NMGE RMSE r COE IOA VDF4 4979 0.63 3.45 3.66 0.23 0.30 5.53 0.92 0.30 5.53 0.91 0.66 0.51 0.76 0.86 0.91 0.64 0.71 0.80 0.80 0.81 0.32 5.56 0.91 0.76 0.80 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 0.81 <th></th>													
VOF5 99965 0.81 -3.02 3.59 -0.24 0.28 7.40 0.82 0.75 IOA hour PM2.5 ensor_id n FAC2 MB MGE RMGE RMGE r COE IOA hour PM2.5 ensor_id n FAC2 MB MGE RMGE RMSE r COE IOA VC171 5310 0.60 4.88 5.06 0.33 0.33 6.72 0.92 0.56 0.03 0.75 0.05 0.07 0.05 0.07 0.05 0.07 0.05 0.07 0.05 0.07 0.06 0.07 0.07 0.01 0.05 0.01 0.05 0.01 0.05 0.01 0.05 0.01 0.04 0.07 0.01 0.01 0.04 0.02 0.03 0.05 0.04 0.03 0.04 0.07 0.04 0.03 0.04 0.07 0.04 0.03 0.04 0.05 0.04													
edmlut nn FAC2 MB MAGE FMME runce runce FMME runce runce FAC2 MB MAGE RMME RMSE runce FAC3 FAC3 hour PM2.5 sensor_id n FAC2 MB MGE RMME NGE RMSE runce 0.92 0.93 0.70 VCP3 8884 0.73 3.48 3.66 0.22 0.33 0.63 0.71 0.655 0.88 0.71 0.72 0.92 0.48 0.74 0.74 0.77 0.92 0.83 0.91 0.75 0.84 0.74 0.77 0.92 0.83 0.71 0.75 0.84 0.74 0.77 0.92 0.83 0.77 0.94 0.72 0.83 0.77 0.94 0.72 0.83 0.94 0.72 0.75 0.94 0.72 0.73 0.73 0.73 0.73 0.73 0.73 0.73 0.73 0.73 0.73 0.7													
all 440076 0.73 -3.80 4.13 -0.29 0.32 7.59 0.83 0.46 0.71 Nour PML2.5 Sensor, id 0.60 4.88 5.06 0.34 0.35 6.72 0.29 0.50 0.75 VGP3 8384 0.75 3.44 3.64 0.85 0.37 0.30 6.31 0.37 0.50 0.80 0.35 0.80 0.81 0.35 0.80 0.81 0.85 0.81 0.81 0.85 0.81 0.85 0.81 0.85 0.81													
hour PMD2.5 sensor, id VGF1 n FAC2 MMB NMGE NMME RNMSE r COE IOA VGF2 7065 0.80 -3.54 3.76 0.27 0.29 5.42 0.92 0.63 0.71 VGF3 88/4 0.75 -3.46 3.66 0.28 0.33 0.51 0.22 0.68 0.75 0.72 0.93 6.53 0.92 0.46 0.74 0.75 0.75 0.75 0.56 0.83 0.93 6.53 0.92 0.46 0.74 0.76 <t< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>													
VGF1 5310 0.60 4.88 5.06 -0.34 0.35 6.72 0.22 0.54 0.75 VGF3 8384 0.75 -3.46 3.69 -0.28 5.30 0.92 0.64 0.75 VGF4 8384 0.75 -3.46 3.69 -0.28 5.33 0.91 0.51 0.65 0.88 0.35 0.66 0.88 0.35 0.66 0.88 0.35 0.66 0.88 0.35 0.66 0.88 0.35 0.68 0.91 0.45 0.66 0.28 0.32 5.86 0.91 0.45 0.75 0.44 0.34 0.34 5.75 0.84 0.36 0.40 0.71 0.36 0.36 0.36 0.73 0.36			all	440076	0.73	-3.80	4.13	-0.29	0.32	7.59	0.83	0.46	0.73
VGF2 7065 0.80 0.344 3.76 0.27 0.29 6.42 0.92 0.48 0.74 VGF3 884 0.75 3.46 3.66 0.28 0.30 5.30 9.92 0.48 0.74 VGF5 7519 0.81 3.02 3.03 0.73 6.56 0.88 0.95 0.66 default n FAC2 MB MGE NME NMEE RMSE r COE IOA day Sensor_id n FAC2 MB MGE NME NME RMSE r COE IOA VGF3 353 0.82 5.86 0.91 0.28 6.31 0.33 5.57 0.94 0.36 0.73 VGF3 353 0.82 1.86 NGGE NME NMGE RMSE r COE IOA IMA	hour	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
VGF2 7065 0.80 0.344 3.76 0.27 0.29 6.42 0.92 0.48 0.74 VGF3 884 0.75 3.46 3.66 0.28 0.30 5.30 9.92 0.48 0.74 VGF5 7519 0.81 3.02 3.03 0.73 6.56 0.88 0.95 0.66 default n FAC2 MB MGE NME NMEE RMSE r COE IOA day Sensor_id n FAC2 MB MGE NME NME RMSE r COE IOA VGF3 353 0.82 5.86 0.91 0.28 6.31 0.33 5.57 0.94 0.36 0.73 VGF3 353 0.82 1.86 NGGE NME NMGE RMSE r COE IOA IMA			VQF1	5310	0.60	-4.88	5.06	-0.34	0.35	6.72	0.92	0.39	0.70
VQF3 8384 0.75 3.46 3.69 0.28 0.30 5.30 0.52 0.66 0.68 0.55 0.66 VQF5 7619 0.81 3.30 2.35 0.24 0.28 5.33 0.91 0.51 0.76 all 36877 0.72 3.80 4.10 0.29 0.32 5.86 0.91 0.45 0.75 day PM2.5 sensor, id n FAC2 MB MGE NMGE RMSE r CCC IOA VQF1 244 0.66 4.91 4.92 0.31 0.34 8.75 0.84 0.30 0.66 VQF2 3.36 0.22 3.86 0.27 3.41 0.95 0.45 0.73 default n FAC2 MB MGE NMME RMSE r CCDE IOA default n FAC2 MB MGE NME RMSE C CCDE IOA			VOF2									0.50	
VQF5 F0F9 0.63 4.38 4.69 -0.35 0.37 6.66 0.88 0.35 0.68 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA day Sensor id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 244 0.66 4.91 9.92 0.32 6.36 0.91 0.36 0.30 0.65 VQF2 315 0.86 -3.15 3.61 0.27 0.28 4.37 0.95 0.44 0.72 VQF3 338 0.86 -3.11 3.42 0.28 0.35 5.60 0.62 0.28 4.37 0.95 0.44 0.72 VQF4 388 0.86 -3.11 3.42 0.028 0.27 0.42 0.27 0.28 0.37 6.63 0.61 0.62 4.73 0.83 0.31 0.61													
vQF5 7619 0.61 -3.02 3.56 -0.24 0.28 5.33 0.91 0.61 0.76 day PM2.5 sensor id n FAC2 MB MMGE NMSE r CCCE IOA VQF1 224 0.66 -4.191 4.92 -0.34 0.33 5.75 0.95 0.44 0.76 VQF2 333 0.82 -3.52 3.61 -0.27 0.28 4.31 0.95 0.44 0.76 VQF5 328 0.86 -3.11 3.42 -0.24 0.27 4.14 0.76 0.38 0.30 5.60 0.91 0.32 6.60 0.91 0.32 6.60 0.41 0.77 0.72 0.77 0.72 0.73 0.71 0.76 0.78 0.78 0.78 0.78 0.73 0.76 0.72 0.73 0.71 0.38 0.75 0.72 0.73 0.71 0.76 0.73 0.76 0.74 0.76													
default n FAC2 MB MGE NMB NMGE RMSE r COE IOA day PM2.5 sensor id n FAC2 -3.80 MGE NMB IMGE RMSE r COE IOA VQF1 244 0.66 -1.91 4.92 0.32 5.60 0.91 0.45 0.00 0.65 VQF2 3163 0.66 -1.91 3.60 0.28 0.28 4.31 0.95 0.44 0.72 VQF3 0.33 6.60 0.44 4.60 0.35 0.35 5.60 0.91 0.26 0.63 0.61 vQF4 366 0.66 4.44 4.60 0.31 4.65 0.44 0.72 0.38 0.61 0.72 0.73 0.83 0.61 0.72 0.73 0.73 4.65 0.61 0.51 0.73 0.35 0.18 0.41 vQF1 0.277 1.550 1.61 1.61 1.6													
day PM2.5 sensor id vQF1 24.0 0.66 4.10 -0.29 0.32 5.86 0.91 0.45 0.73 VQF1 24.4 0.66 -1.51 3.61 0.27 0.22 0.84 5.75 0.95 0.44 0.73 VQF2 315 0.86 -3.55 3.61 022 0.28 4.31 0.95 0.44 0.71 VQF4 3368 0.66 4.44 0.66 -0.28 0.28 4.31 0.55 0.41 0.73 0.66 0.71 VQF5 328 0.88 -3.11 3.42 0.28 0.33 4.85 0.45 0.33 0.45 <													
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VOF1 244 0.66 4.91 4.92 -0.34 0.34 5.75 0.94 0.03 0.65 VOF2 315 0.66 -3.55 360 -0.28 4.31 0.95 0.44 0.72 VOF4 388 0.66 4.44 4.60 -0.28 0.28 4.31 0.95 0.44 0.78 0.66 VOF5 328 0.88 -3.11 3.42 -0.24 0.27 4.14 0.95 0.45 0.78 outpet entrain 11618 0.78 3.86 3.99 -0.30 0.31 4.85 or COE 0.04 outpet entrain 11618 0.78 3.86 3.99 -0.30 0.31 4.85 or COE 0.04 0.35 -0.18 0.41 VOF2 44398 0.21 1.56 15.66 0.61 0.61 63 0.35 0.13 0.41 0.41 0.42 0.43 0.46 0.41 <th></th> <th></th> <th>all</th> <th>36877</th> <th>0.72</th> <th>-3.80</th> <th>4.10</th> <th>-0.29</th> <th>0.32</th> <th>5.86</th> <th>0.91</th> <th>0.45</th> <th>0.73</th>			all	36877	0.72	-3.80	4.10	-0.29	0.32	5.86	0.91	0.45	0.73
VOF2 315 0.86 -3.55 361 -0.27 0.28 0.28 4.31 0.95 0.44 0.71 VOF4 368 0.66 -4.44 4.60 -0.35 0.36 560 0.91 0.26 0.63 odefault n FAC2 MB MGE NMB ENME F.14 0.95 0.43 0.63 0.63 0.91 0.26 0.63 5min PM10 sensor.jd n FAC2 MB MGE NMB ENME FMM2E FM 0.64 64 52.34 0.35 -0.22 0.38 VOF2 8338 0.28 -16.1 16.11 -0.64 0.64 52.34 0.35 -0.22 0.38 VOF2 8338 0.28 -115.70 16.87 -0.65 0.66 48.80 0.32 -0.62 0.43 VOF3 50965 0.27 16.52 -0.62 0.63 50.15 0.34 -0.16 0.44 </th <th>day</th> <th>PM2.5</th> <th>sensor id</th> <th>n</th> <th>FAC2</th> <th>MB</th> <th>MGE</th> <th>NMB</th> <th>NMGE</th> <th>RMSE</th> <th>r</th> <th>COE</th> <th>IOA</th>	day	PM2.5	sensor id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
VOF2 315 0.86 -3.55 361 -0.27 0.28 0.28 4.31 0.95 0.44 0.71 VOF4 368 0.66 -4.44 4.60 -0.35 0.36 560 0.91 0.26 0.63 odefault n FAC2 MB MGE NMB ENME F.14 0.95 0.43 0.63 0.63 0.91 0.26 0.63 5min PM10 sensor.jd n FAC2 MB MGE NMB ENME FMM2E FM 0.64 64 52.34 0.35 -0.22 0.38 VOF2 8338 0.28 -16.1 16.11 -0.64 0.64 52.34 0.35 -0.22 0.38 VOF2 8338 0.28 -115.70 16.87 -0.65 0.66 48.80 0.32 -0.62 0.43 VOF3 50965 0.27 16.52 -0.62 0.63 50.15 0.34 -0.16 0.44 </th <th></th> <th></th> <th>VQF1</th> <th>244</th> <th>0.66</th> <th>-4.91</th> <th>4.92</th> <th>-0.34</th> <th>0.34</th> <th>5.75</th> <th>0.94</th> <th>0.30</th> <th>0.65</th>			VQF1	244	0.66	-4.91	4.92	-0.34	0.34	5.75	0.94	0.30	0.65
VQF3 363 0.82 3.52 360 -0.28 0.28 0.31 0.75 0.26 0.63 VQF4 368 0.66 4.44 4.60 -0.35 0.35 560 0.91 0.26 0.63 overside outsail 1618 0.78 -3.86 3.99 -0.30 0.31 4.86 0.94 0.38 0.69 Simin PM10 sensor_id n FAC2 MB MGE NMB NMGE RMS 0.31 4.86 0.94 0.38 0.69 Simin PM10 sensor_id n FAC2 MB MGE NMB NMGE RMS 0.35 -0.45 0.42 0.35 -0.45 0.42 0.32 -0.16 0.42 0.35 0.44 0.43 0.41 VQF1 6339 0.26 0.15 1.63 0.64 0.64 4.40 0.41 0.41 hour PM10 sensor_id n FAC2			VOF2	315		-3.55		-0.27			0.95	0 44	
VOF4 368 0.66 4.44 4.60 -0.35 0.36 5.60 0.91 0.26 0.63 odefault n FAC2 MB MGE NMB ENMSE r CCE IOA smin PM10 sensorid n FAC2 MB MGE NMB ENMSE r CCE IOA VOF1 63276 0.24 166 1880 -0.64 0.64 452.34 0.35 -0.22 0.39 VOF2 84398 0.28 -161 1611 -0.61 0.62 4753 0.35 -0.22 0.38 VOF2 84398 0.28 -161 1617 -0.65 0.60 52.19 0.32 -0.12 0.44 VOF3 90965 0.21 1.67 1.68 -0.62 0.63 50.16 0.34 -0.18 0.41 VOF4 10205 90965 0.27 16.00 16.08 -0.61 0.62 3.63													
VQF5 328 0.88 -3.11 3.42 -0.24 0.27 4.14 0.95 0.45 0.77 all 1618 0.78 3.86 3.99 -0.30 0.31 4.85 0.94 0.38 0.69 Semsor_1d n FAC2 MB MGE NMB NMCE RMSE r COE IOA VQF1 63276 0.24 -18.65 18.80 -0.64 0.64 49.97 0.35 -0.22 0.39 VQF2 102211 0.27 -15.66 16.65 -0.65 0.66 49.80 0.32 -0.12 0.44 VQF3 10225 0.21 -16.67 16.52 0.62 40.61 0.82 47.53 0.35 -0.12 0.44 dataut n FAC2 MB MGE NMB NMCE RMSE r COE 10.43 hour PM10 sensor_1d n FAC2 MB MGE NMB													
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ath 1618 0.78 -3.86 3.99 -0.30 0.31 4.48 0.94 0.38 0.65 Smin PM10 sensor_id n FAC2 MB MGE RMSE r COE FOA VOF2 84398 0.24 -16.65 18.80 -0.64 0.64 0.64 9.71 0.35 -0.12 0.42 VOF3 100211 0.27 -15.56 15.65 -0.61 0.62 47.93 0.32 -0.22 0.38 VOF4 101226 0.21 -16.70 16.65 -0.61 0.66 49.80 0.32 -0.15 0.41 dafaut n FAC2 MB MGE NM6E RMSE r COE 10.04 volF1 5310 0.22 -16.03 18.76 0.64 0.64 34.07 0.45 -0.27 0.37 volF2 7056 0.27 -16.03 16.87 -0.65 0.66 31.74 <t< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>													
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VQF2 84398 0.04 -12.46 12.52 -0.93 0.93 43.12 0.53 -0.48 0.26 VQF3 100211 0.04 -12.10 12.14 -0.94 0.94 41.12 0.47 -0.54 0.23 VQF4 101226 0.03 -12.33 12.36 -0.94 0.95 42.73 0.41 -0.52 0.24 VQF5 90965 0.04 -12.60 12.65 -0.93 0.93 45.34 0.43 -0.42 0.29 default n FAC2 MB MGE NMB< NMGE RMSE r COE IOA all 440076 0.04 -12.56 12.61 -0.93 0.94 43.34 0.45 -0.49 0.26 hour Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 5310 0.04 -12.45 12.60 -0.93 0.93 <th>Smin</th> <th>Pmcoars</th> <th>_</th> <th></th>	Smin	Pmcoars	_										
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VQF4 101226 0.03 -12.33 12.36 -0.94 0.95 42.73 0.41 -0.52 0.24 VQF5 90965 0.04 -12.60 12.65 -0.93 0.93 45.34 0.43 -0.42 0.29 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 440076 0.04 -12.56 12.61 -0.93 0.94 43.34 0.45 -0.49 0.26 hour Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 5310 0.04 -13.75 13.82 -0.93 0.93 26.72 0.43 -0.56 0.22 VQF2 7085 0.04 -12.45 12.50 -0.93 0.94 26.42 0.33 -0.59 0.20 VQF4 8479 0.03 -12.62 12.66 -0.93 0.94			VQF2	84398	0.04	-12.46	12.52	-0.93	0.93	43.12	0.53	-0.48	0.26
VQF5 90965 0.04 -12.60 12.65 -0.93 0.93 45.34 0.43 -0.42 0.29 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 440076 0.04 -12.56 12.61 -0.93 0.94 43.34 0.45 -0.49 0.26 hour Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 5310 0.04 -13.75 13.82 -0.93 0.94 28.45 0.34 -0.56 0.22 VQF2 7085 0.04 -12.45 12.50 -0.93 0.93 26.72 0.43 -0.56 0.22 VQF3 8384 0.03 -12.45 12.38 -0.94 0.94 26.42 0.33 -0.59 0.20 VQF5 7619 0.04 -12.62 12.66 -0.93 0.93			VQF3	100211	0.04	-12.10	12.14	-0.94	0.94	41.12	0.47	-0.54	0.23
default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 440076 0.04 -12.56 12.61 -0.93 0.94 43.34 0.45 -0.49 0.26 hour Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 5310 0.04 -13.75 13.82 -0.93 0.94 28.45 0.34 -0.56 0.22 VQF2 7085 0.04 -12.45 12.50 -0.93 0.94 28.45 0.34 -0.56 0.22 VQF3 8384 0.03 -12.45 12.50 -0.93 0.93 26.72 0.33 -0.59 0.20 VQF4 8479 0.03 -12.62 12.66 -0.93 0.93 27.74 0.34 -0.50 0.22 default n FAC2 MB MGE NMB NMGE			VQF4	101226	0.03	-12.33	12.36	-0.94	0.95	42.73	0.41	-0.52	0.24
default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 440076 0.04 -12.56 12.61 -0.93 0.94 43.34 0.45 -0.49 0.26 hour Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 5310 0.04 -13.75 13.82 -0.93 0.94 28.45 0.34 -0.56 0.22 VQF2 7085 0.04 -12.45 12.50 -0.93 0.94 28.45 0.34 -0.56 0.22 VQF3 8384 0.03 -12.45 12.50 -0.93 0.93 26.72 0.33 -0.59 0.20 VQF4 8479 0.03 -12.62 12.66 -0.93 0.93 27.74 0.34 -0.50 0.22 default n FAC2 MB MGE NMB NMGE													
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VQF1 5310 0.04 -13.75 13.82 -0.93 0.94 28.45 0.34 -0.56 0.22 VQF2 7085 0.04 -12.45 12.50 -0.93 0.93 26.72 0.43 -0.56 0.22 VQF3 8384 0.03 -12.14 12.17 -0.94 0.94 25.89 0.36 -0.61 0.19 VQF4 8479 0.03 -12.35 12.38 -0.94 0.94 26.42 0.33 -0.59 0.20 VQF5 7619 0.04 -12.62 12.66 -0.93 0.93 27.74 0.34 -0.50 0.25 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 36877 0.03 -12.37 12.36 -0.93 0.94 26.94 0.36 -0.56 0.22 day Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE	have	Dunces											
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VQF4 8479 0.03 -12.35 12.38 -0.94 0.94 26.42 0.33 -0.59 0.20 VQF5 7619 0.04 -12.62 12.66 -0.93 0.93 27.74 0.34 -0.50 0.25 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 36877 0.03 -12.58 12.62 -0.93 0.94 26.94 0.36 -0.56 0.22 day Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 244 0.02 -13.50 13.50 -0.93 0.93 16.58 0.39 -1.17 -0.08 VQF2 315 0.02 -12.37 12.37 -0.93 0.93 15.09 0.40 -1.17 -0.88 VQF3 363 0.01 -12.19 12.35 -0.93 0.93													
VQF5 7619 0.04 -12.62 12.66 -0.93 0.93 27.74 0.34 -0.50 0.25 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 36877 0.03 -12.58 12.62 -0.93 0.94 26.94 0.36 -0.56 0.22 day Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 244 0.02 -13.50 13.50 -0.93 0.93 16.58 0.39 -1.31 -0.13 VQF2 315 0.02 -12.37 12.37 -0.93 0.93 15.59 0.40 -1.17 -0.08 VQF3 363 0.01 -12.35 12.35 -0.93 0.93 15.07 0.36 -1.23 -0.10 VQF4 368 0.01 -12.35 12.35 -0.94 0.94			VQF3	8384	0.03	-12.14	12.17	-0.94	0.94	25.89	0.36	-0.61	0.19
default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 36877 0.03 -12.58 12.62 -0.93 0.94 26.94 0.36 -0.56 0.22 day Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 244 0.02 -13.50 13.50 -0.93 0.93 16.58 0.39 -1.31 -0.13 VQF2 315 0.02 -12.37 12.37 -0.93 0.93 15.59 0.40 -1.17 -0.08 VQF3 363 0.01 -12.35 12.35 -0.94 0.93 15.07 0.36 -1.24 -0.10 VQF4 368 0.01 -12.35 12.35 -0.94 0.94 15.27 0.36 -1.24 -0.10 VQF5 328 0.02 -12.60 12.61 -0.93 0.93			VQF4	8479	0.03	-12.35	12.38	-0.94	0.94	26.42	0.33	-0.59	0.20
default n FAC2 MB MGE NMB NMGE RMSE r COE IOA all 36877 0.03 -12.58 12.62 -0.93 0.94 26.94 0.36 -0.56 0.22 day Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 244 0.02 -13.50 13.50 -0.93 0.93 16.58 0.39 -1.31 -0.13 VQF2 315 0.02 -12.37 12.37 -0.93 0.93 15.59 0.40 -1.17 -0.08 VQF3 363 0.01 -12.35 12.35 -0.94 0.93 15.07 0.36 -1.24 -0.10 VQF4 368 0.01 -12.35 12.35 -0.94 0.94 15.27 0.36 -1.24 -0.10 VQF5 328 0.02 -12.60 12.61 -0.93 0.93			VQF5	7619	0.04	-12.62	12.66	-0.93	0.93			-0.50	
all 36877 0.03 -12.58 12.62 -0.93 0.94 26.94 0.36 -0.56 0.22 day Pmcoarse sensor_id n FAC2 MB MGE NMB NMGE RMSE r COE IOA VQF1 244 0.02 -13.50 13.50 -0.93 0.93 16.58 0.39 -1.31 -0.13 VQF2 315 0.02 -12.37 12.37 -0.93 0.93 16.58 0.39 -1.17 -0.08 VQF3 363 0.01 -12.37 12.37 -0.93 0.93 15.07 0.36 -1.24 -0.11 VQF4 368 0.01 -12.35 12.35 -0.94 0.94 15.27 0.36 -1.23 -0.10 VQF5 328 0.02 -12.60 12.61 -0.93 0.93 15.72 0.33 -1.15 -0.07 default n FAC2 MB MGE NMB NMGE													
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VQF2 315 0.02 -12.37 12.37 -0.93 0.93 15.39 0.40 -1.17 -0.08 VQF3 363 0.01 -12.19 12.19 -0.93 0.93 15.07 0.36 -1.24 -0.11 VQF4 368 0.01 -12.35 12.35 -0.94 0.94 15.27 0.36 -1.23 -0.10 VQF5 328 0.02 -12.60 12.61 -0.93 0.93 15.72 0.33 -1.15 -0.07 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA	uay	rincoars	_										
VQF3 363 0.01 -12.19 12.19 -0.93 0.93 15.07 0.36 -1.24 -0.11 VQF4 368 0.01 -12.35 12.35 -0.94 0.94 15.27 0.36 -1.23 -0.10 VQF5 328 0.02 -12.60 12.61 -0.93 0.93 15.72 0.33 -1.15 -0.07 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA													
VQF4 368 0.01 -12.35 12.35 -0.94 0.94 15.27 0.36 -1.23 -0.10 VQF5 328 0.02 -12.60 12.61 -0.93 0.93 15.72 0.33 -1.15 -0.07 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA													
VQF5 328 0.02 -12.60 12.61 -0.93 0.93 15.72 0.33 -1.15 -0.07 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA				363	0.01	-12.19		-0.93	0.93	15.07	0.36	-1.24	-0.11
VQF5 328 0.02 -12.60 12.61 -0.93 0.93 15.72 0.33 -1.15 -0.07 default n FAC2 MB MGE NMB NMGE RMSE r COE IOA			VQF4	368	0.01	-12.35	12.35	-0.94	0.94	15.27	0.36	-1.23	-0.10
default n FAC2 MB MGE NMB NMGE RMSE r COE IOA													
			CIII	1010	0.01	12.04	12.04	-0.33	0.00	13.33	0.51	1.41	0.00



Shinyei PPD60PV

5min	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQC1	104457	0.98	-0.27	2.86	-0.02	0.23	6.96	0.80	0.61	0.80
		VQC2	92834	0.97	0.68	3.19	0.05	0.26	6.75	0.81	0.57	0.78
		VQC3	99648	0.88	1.19	3.89	0.10	0.31	7.29	0.78	0.47	0.73
		VQC4	52609	0.97	0.74	3.03	0.06	0.25	7.25	0.75	0.56	0.78
		VQC5	46990	0.97	1.19	2.98	0.11	0.27	6.30	0.78	0.52	0.76
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		data	396538	0.95	0.63	3.23	0.05	0.26	6.96	0.79	0.55	0.77
hour	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQC1	8747	0.98	-0.27	2.73	-0.02	0.22	4.89	0.88	0.62	0.81
		VQC2	7776	0.97	0.68	3.05	0.05	0.25	5.07	0.88	0.58	0.79
		VQC3	8341	0.89	1.20	3.75	0.10	0.30	5.53	0.85	0.48	0.74
		VQC4	4413	0.97	0.74	2.89	0.06	0.24	4.92	0.86	0.58	0.79
		VQC5	3938	0.98	1.19	2.87	0.11	0.26	4.69	0.86	0.53	0.77
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		data	33215	0.95	0.63	3.10	0.05	0.25	5.08	0.87	0.56	0.78
day	PM2.5	-	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQC1	379	0.99	-0.25	2.19	-0.02	0.17	3.15	0.92	0.64	0.82
		VQC2	343	1.00	0.63	2.45	0.05	0.19	3.39	0.92	0.62	0.81
		VQC3	362	0.93	1.21	3.16	0.10	0.25	4.08	0.88	0.49	0.74
		VQC4	195	0.99	0.83	2.27	0.07	0.19	3.11	0.92	0.60	0.80
		VQC5	174	0.99	1.25	2.40	0.11	0.22	3.42	0.91	0.54	0.77
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		data	1453	0.98	0.65	2.53	0.05	0.21	3.48	0.91	0.58	0.79

