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 $PM_{2.5}$** (R^2 between 0.62 and 0.84). Due to the high proportion of $PM_{2.5}$ in PM_{10} some sensors did show some correlation for PM_{10}, but this can be considered artificial since there was **poor to non-existing correlation for the coarse PM fraction** (=PM_{10} - $PM_{2.5}$). At least for the tested configurations none of the sensors could therefore be described as a true PM_{10} 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** (= PM_{10} - $PM_{2.5}$) 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.

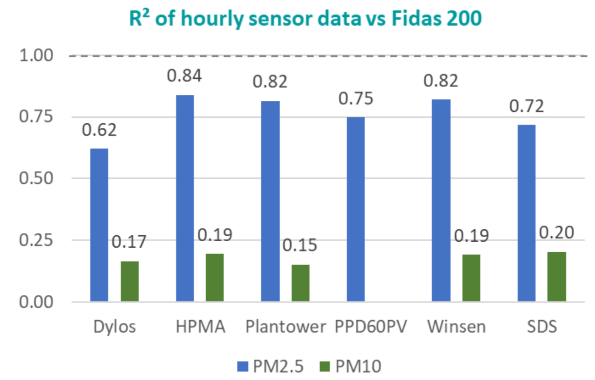
- Some types showed little bias out of the box while **others required additional calibration** to significantly lower bias and uncertainty at the limit value.

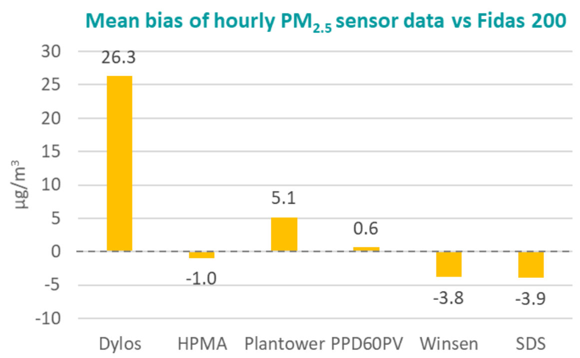
- As expected, all sensor unit showed a **dependency on relative humidity** and temperature. The increase in sensor/reference ratio from 50% RH to above 90% RH varied between a factor of 1.4 and 2.4.

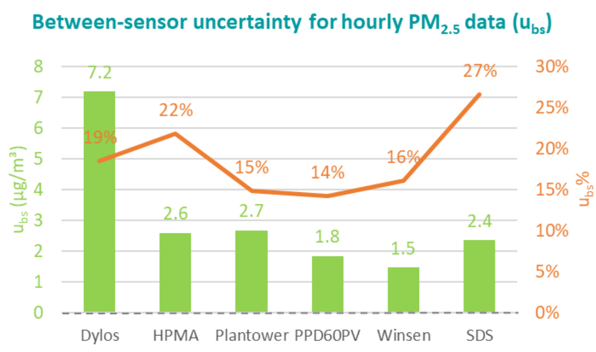
- After applying a linear calibration to all valid 24h $PM_{2.5}$ averages, 5 out of 6 sensor types had an **expanded uncertainty below 25%** vs. the reference (at 30 µg/m³ and for the full dataset).

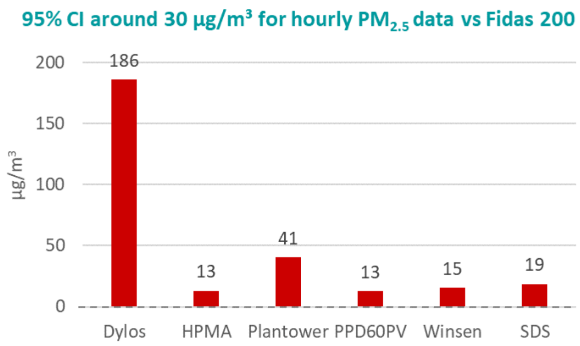
- Analysis of SDS011 sensors co-located with Fidas Palas 200 at 8 different monitoring sites showed that **other locations can give less favourable results** than the VAQUUMS test site in Borgerhout. These results could be linked to more frequent episodes of high relative humidity at other locations. The presence of vegetation close to the monitoring sites appears to play an important role.

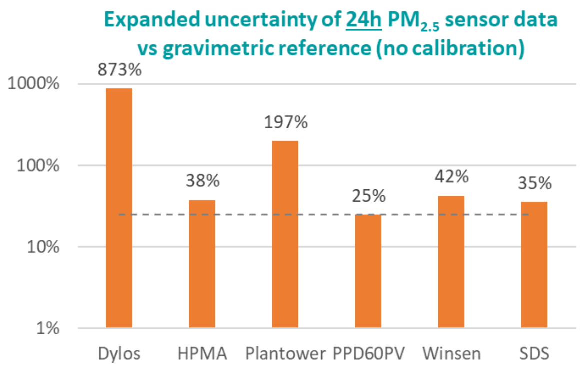
Summary plots

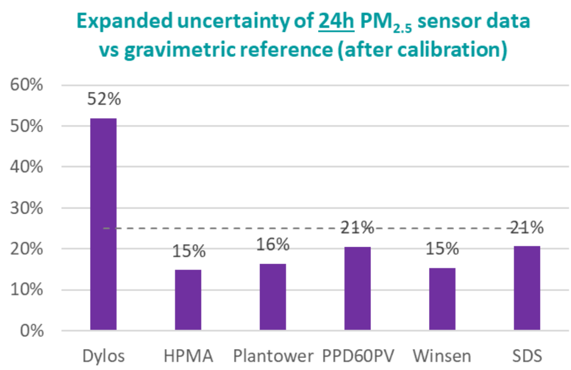


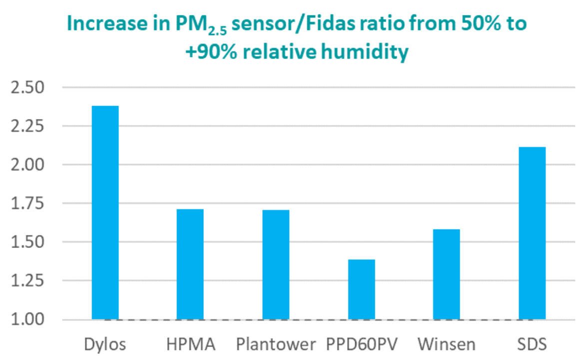







Expanded uncertainty of 24h PM2.5 sensor data vs gravimetric reference (no calibration)
873%
38%
197%
25%
42%
35%
1000%
100%
10%
1%
Dylos
HPMA
Plantower
PPD60PV
Winsen
SDS


Expanded uncertainty of 24h PM2.5 sensor data vs gravimetric reference (after calibration)
52%
15%
16%
21%
15%
21%
60%
50%
40%
30%
20%
10%
0%
Dylos
HPMA
Plantower
PPD60PV
Winsen
SDS


Increase in PM2.5 sensor/Fidas ratio from 50% to +90% relative humidity
2.50
2.25
2.00
1.75
1.50
1.25
1.00
Dylos
HPMA
Plantower
PPD60PV
Winsen
SDS

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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 µg/m³ 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, R^2, bias at the limit (pseudo) limit value of 30 µg/m³and 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.

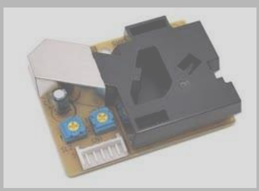
e. **Comparison of PM_{10} and PM_{coarse} sensor data with the Palas Fidas 200 monitor:** Scatterplots and timeplots are used to indicate whether the sensors actually pick up any of the coarser PM (defined as PM_{10} minus $PM_{2.5}$). A final scatterplot shows the correlation between the sensor $PM_{2.5}$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

[a] https://vaquums.eu/sensor-db/tests/protocols/life-vaquums_testprotocol_final.pdf

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.

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

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

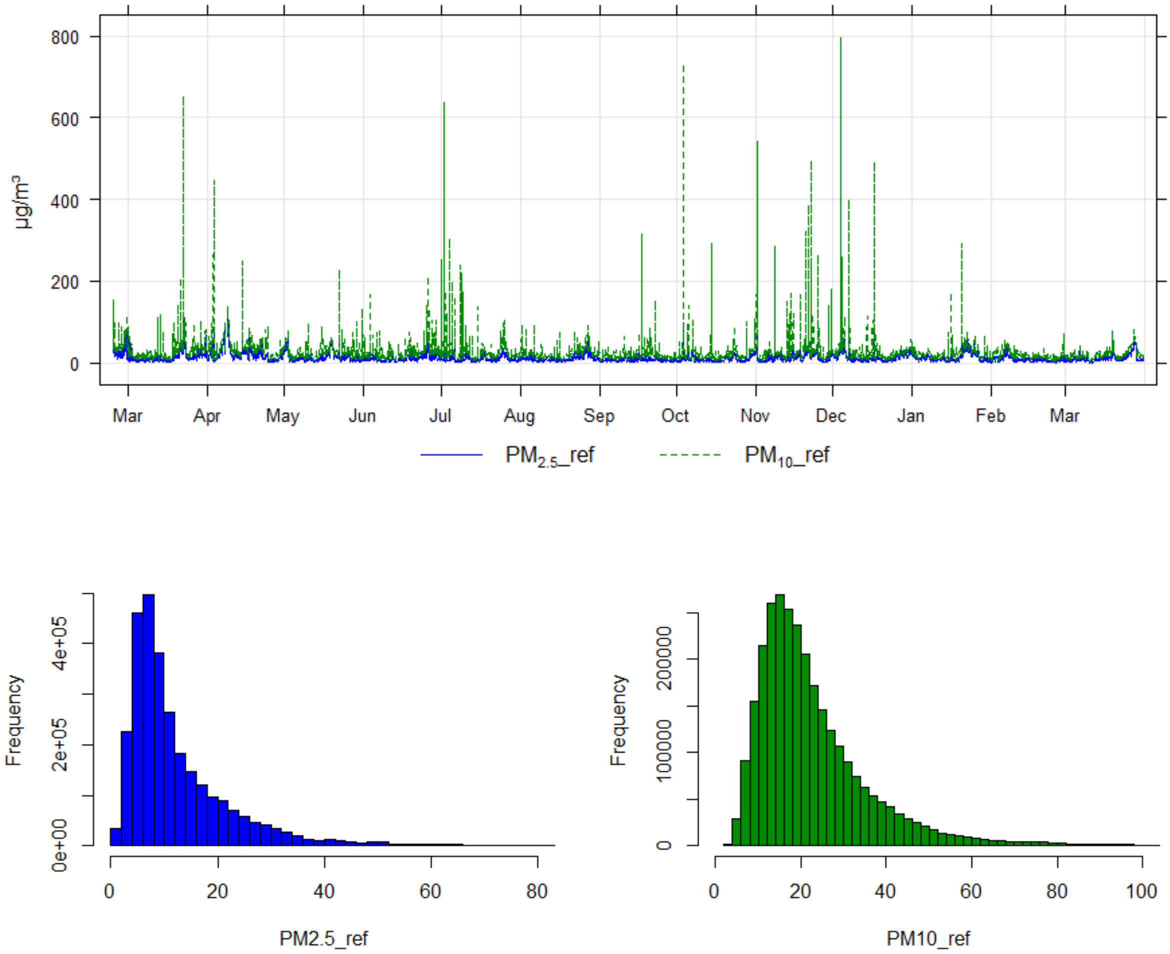
PM-concentrations and atmospheric conditions during the campaign

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/m^3 and the mean PM_{10} concentration was 23 µg/m^3. 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

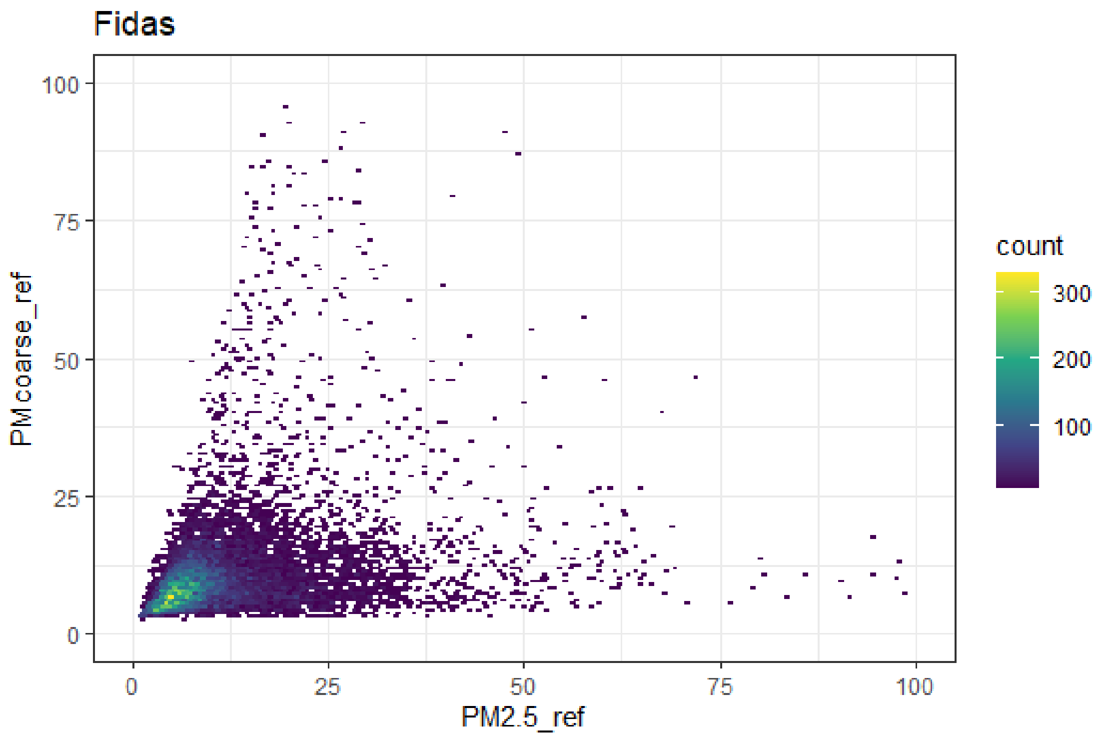


+Scatterplot of PM_{coarse} vs $PM_{2.5}$ for the automated reference

The scatterplot of PM_{coarse} (=PM_{10}-$PM_{2.5}$) vs $PM_{2.5}$ (Figure 2) shows that there is very little correlation between the finer and the coarser fraction of PM_{10}. This is no surprise, since both fractions usually 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 µg/m³)



+ 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 3: Timeplot and histograms of hourly averages for relative humidity and temperature

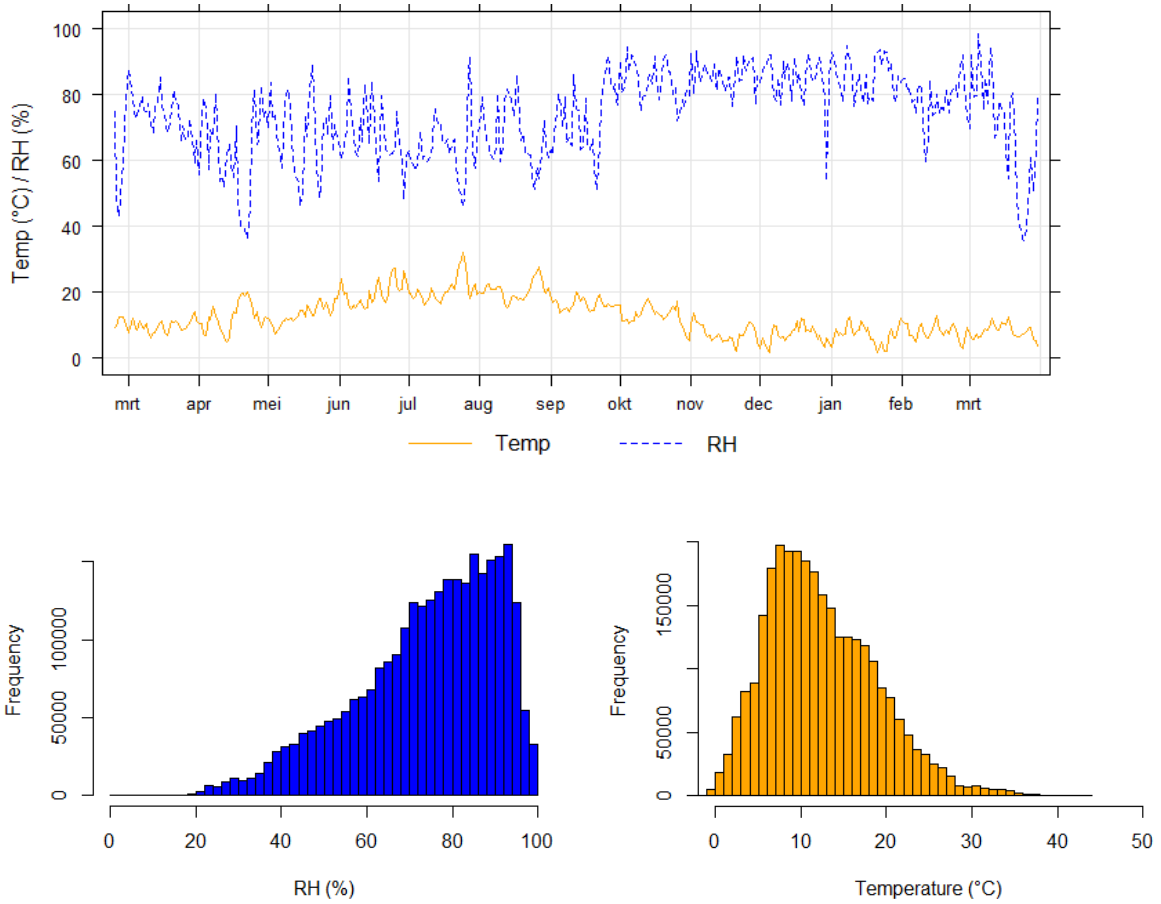
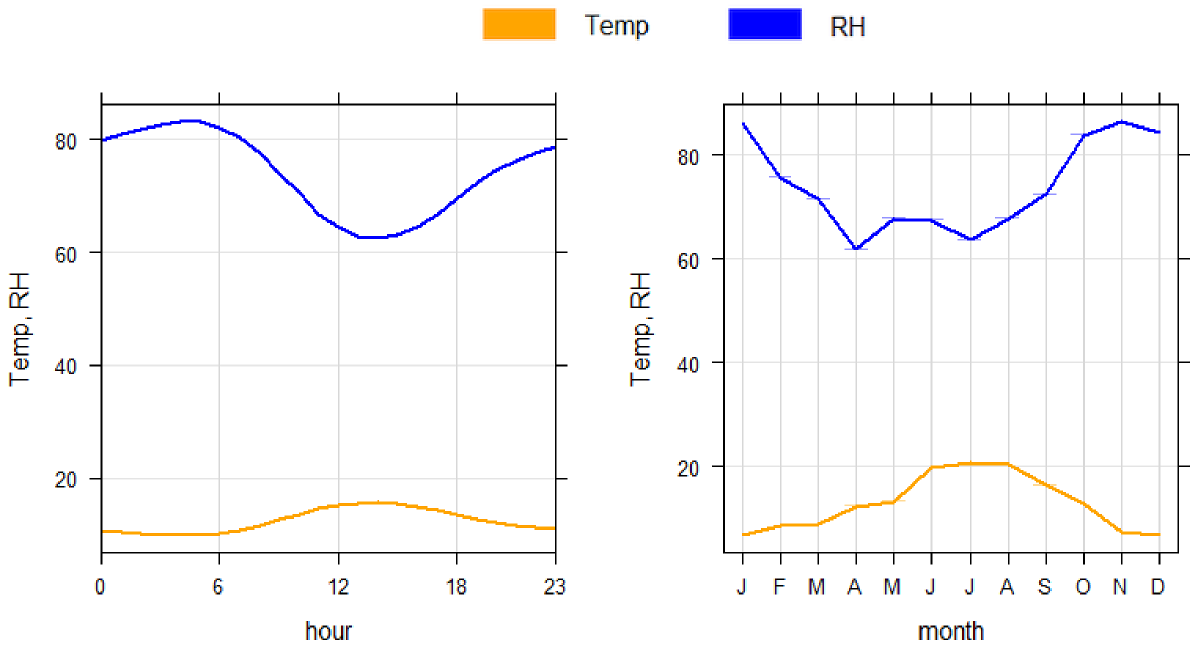


Figure 4 shows the variation of temperature and relative humidity within an average day. It's interesting to note the day vs. night pattern for both parameters and the inverse relation between both parameters.

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 high-end 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

+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

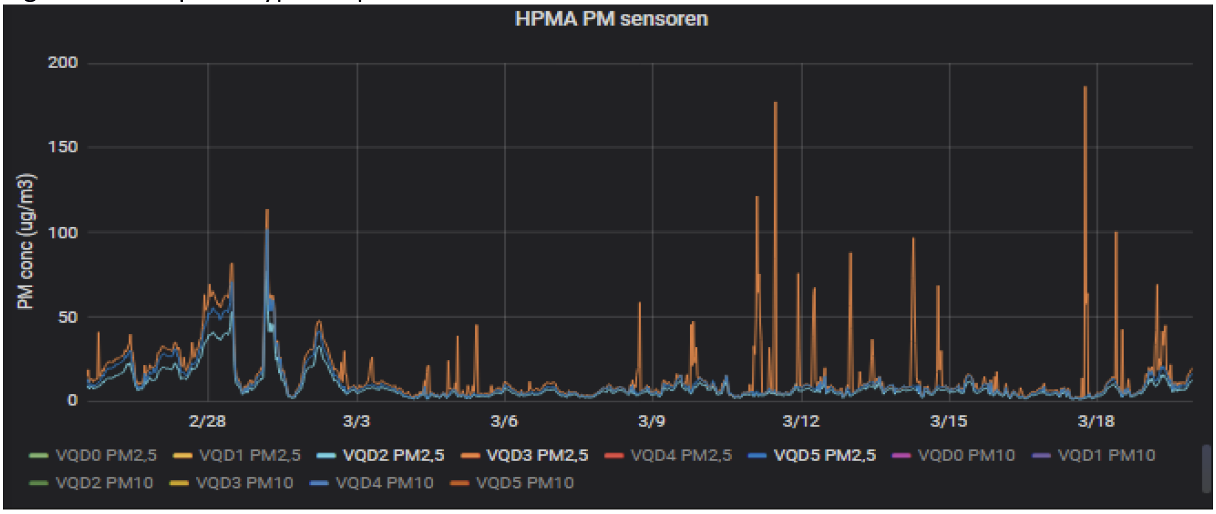
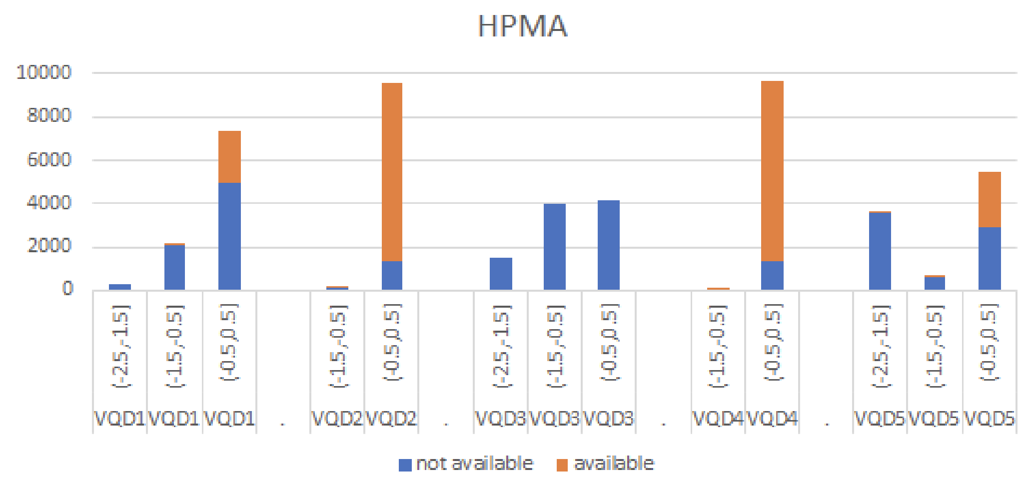


Figure 6: Overview of available hourly data per validation code (-2: invalid / -1: suspicious / 0: valid) for the different units



+$PM_{2.5}$ 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

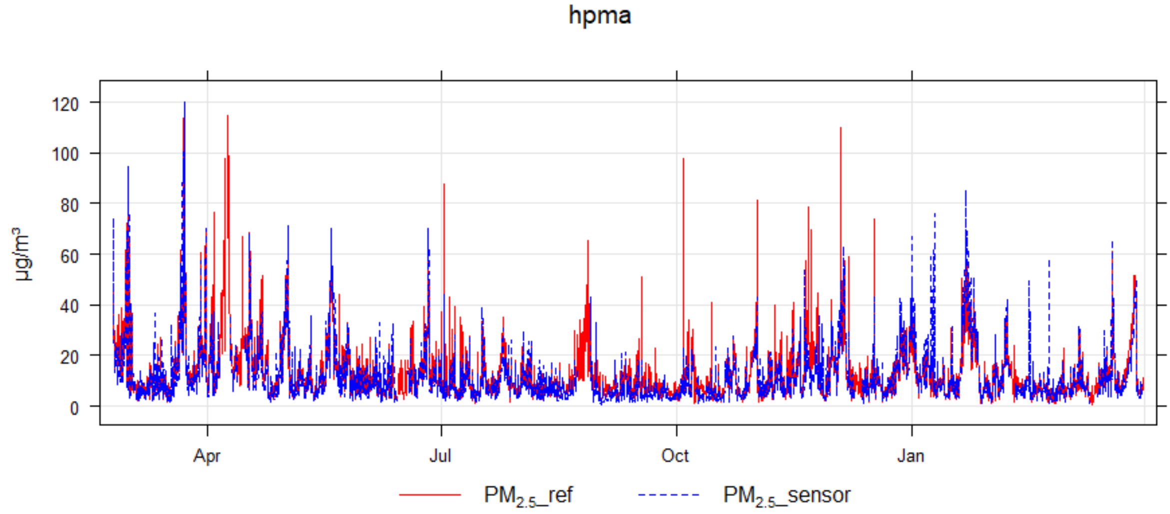


Figure 8: Hourly average of individual HPMA $PM_{2.5}$ sensor data vs Fidas reference

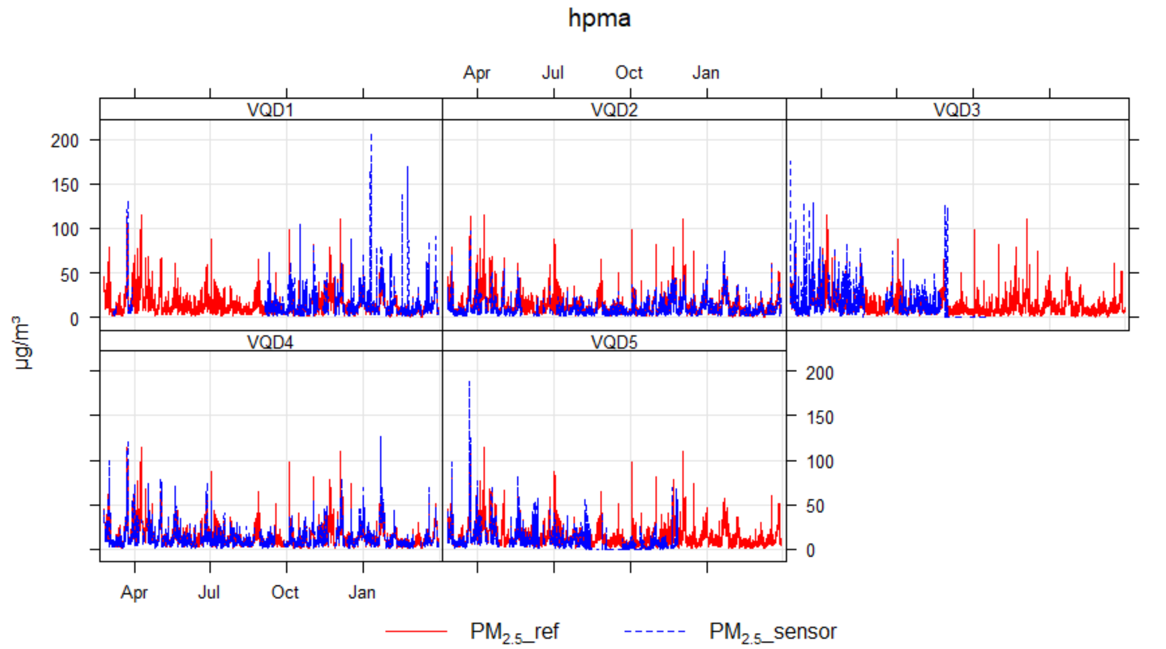


Figure 9: Density plot of all hourly $PM_{2.5}$ HPMA sensor data vs $PM_{2.5}$ Fidas (in µg/m³)

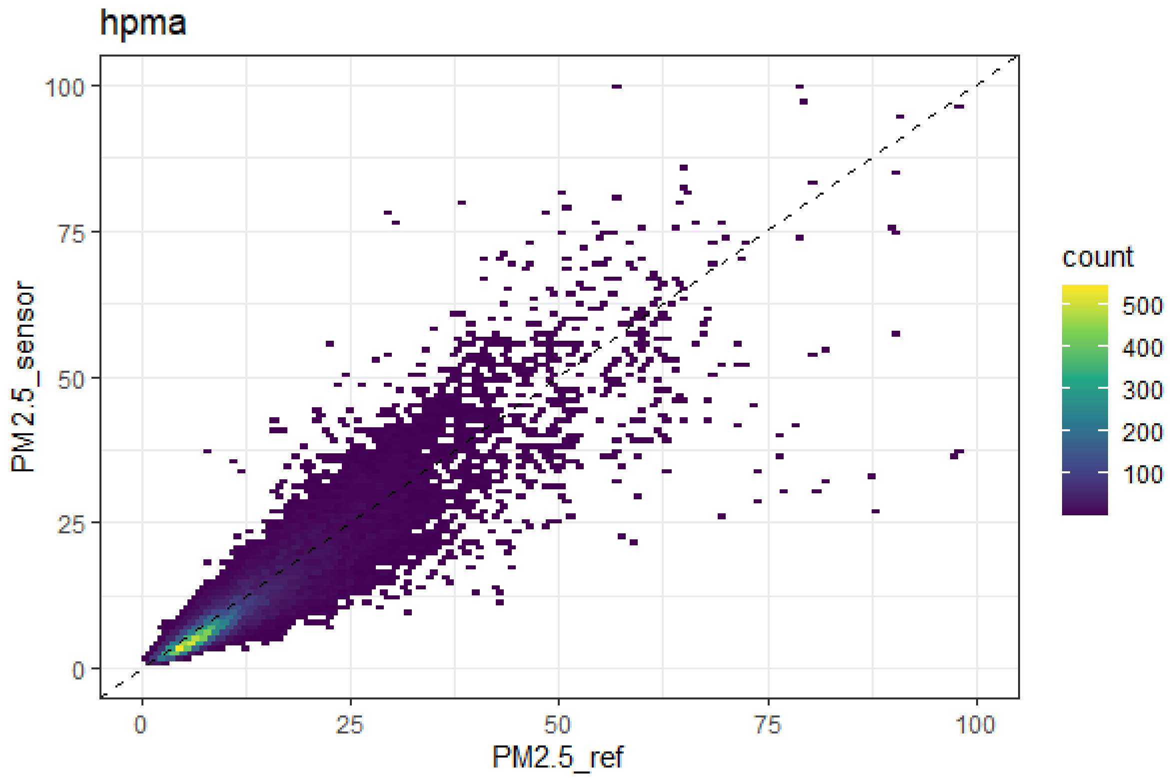


Figure 10: $PM_{2.5}$ scatterplot for all HPMA sensor 5-min averages (left) and all hourly averages (right) in µg/m³

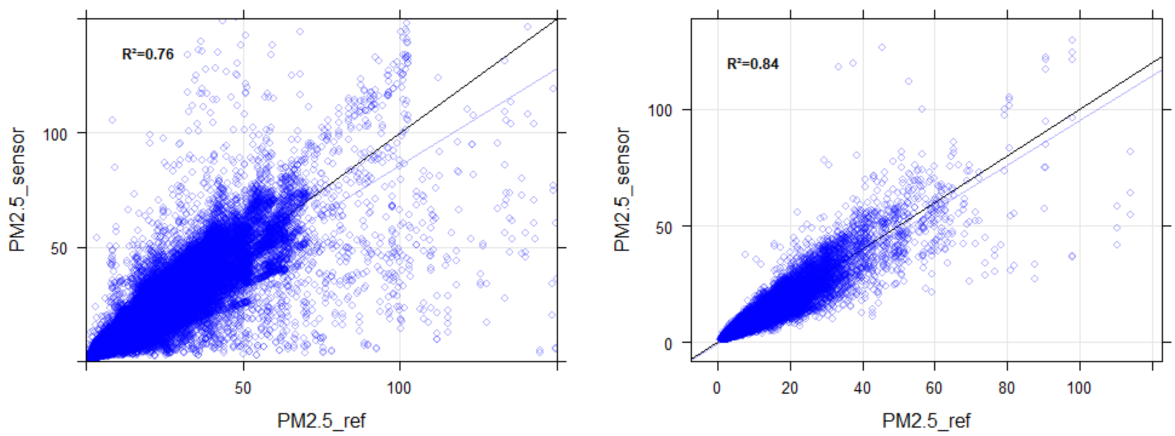
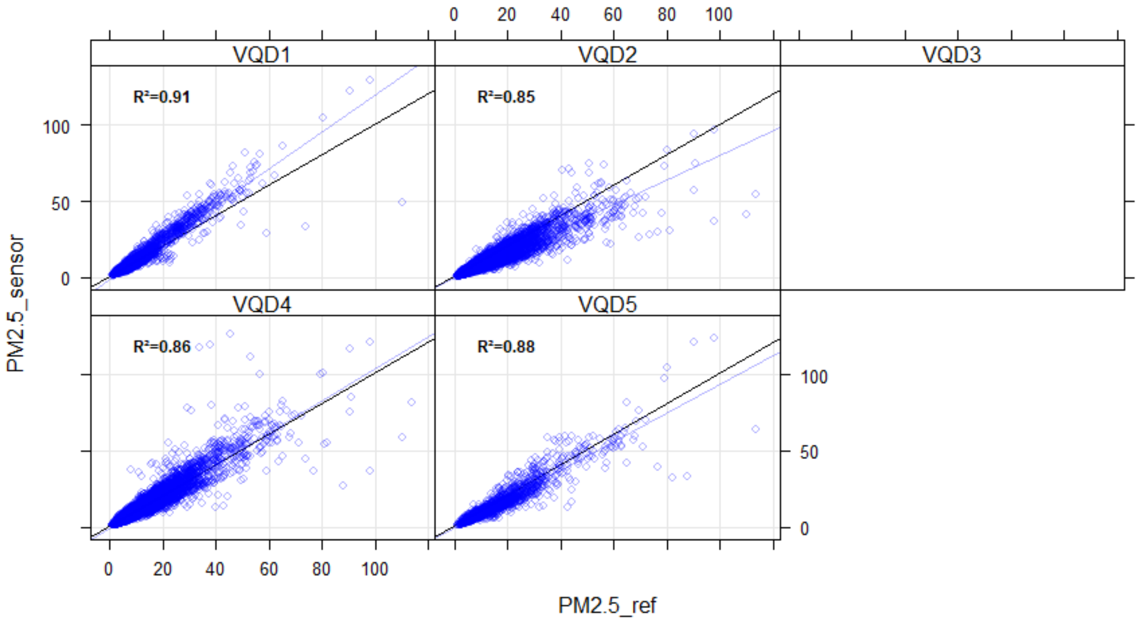
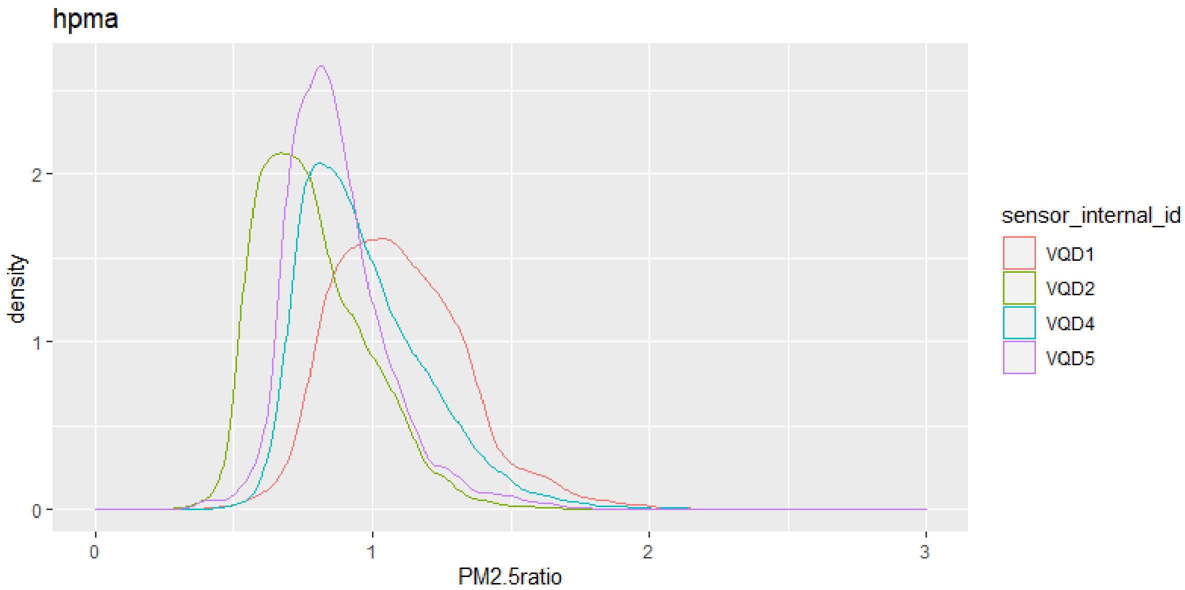


Figure 11: $PM_{2.5}$ scatterplots for hourly HPMA averages per sensor in µg/m³



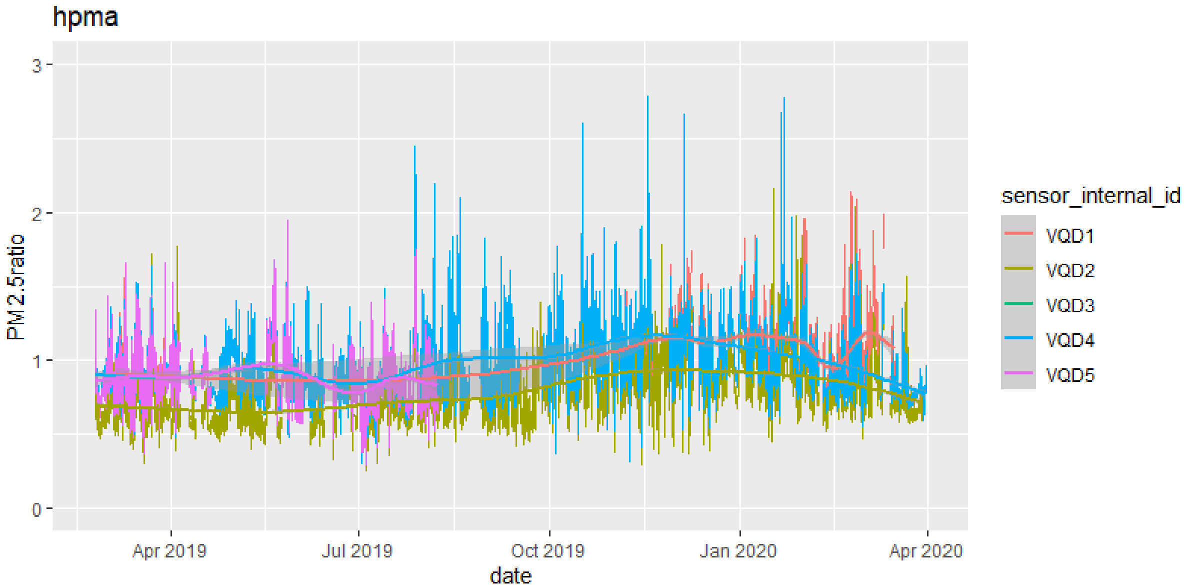
The sensor/Fidas ratios also show that sensor 2 gives a lower signal than the others. Sensor 1 appears higher than the others, but this might be due to the fact that sensor 1 has most of its valid data at the end of the campaign.

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



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

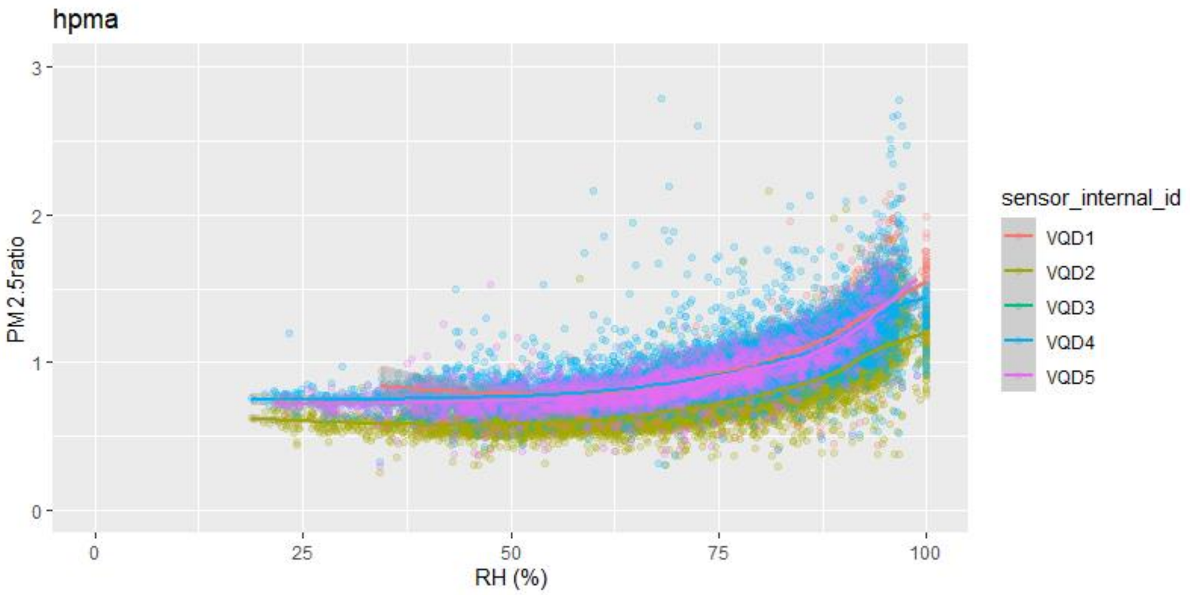
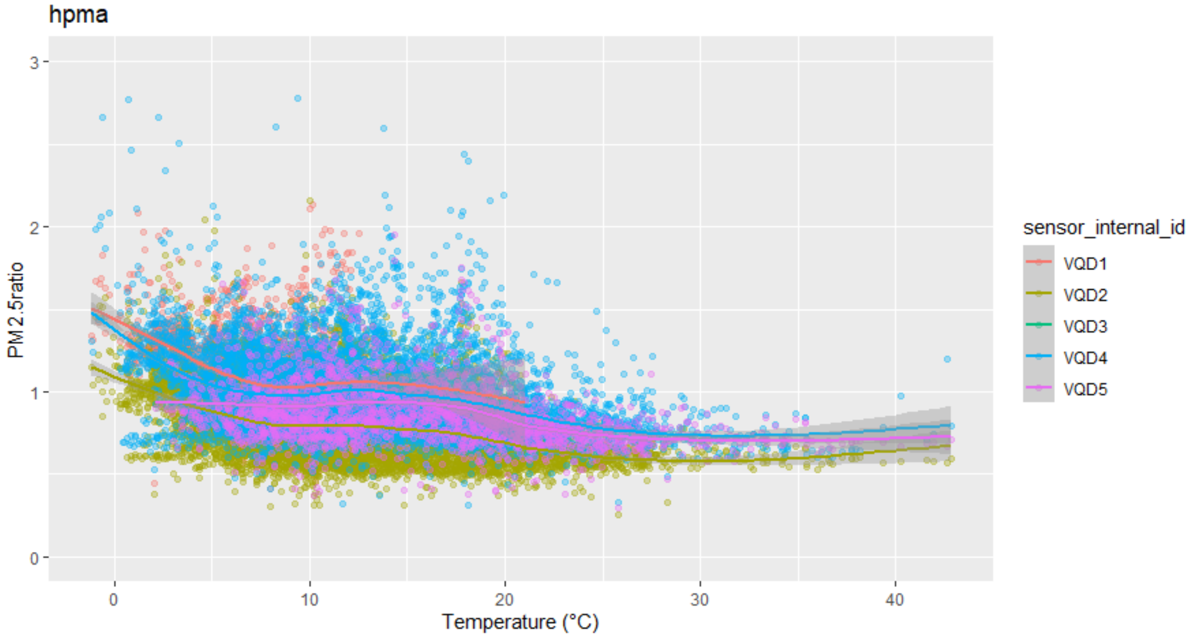


Figure 15: Hourly $PM_{2.5}$ ratio (HPMA sensor/Fidas) in function of temperature



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

Figure 16: Daily averages of all valid HPMA $PM_{2.5}$ sensor data vs Fidas reference

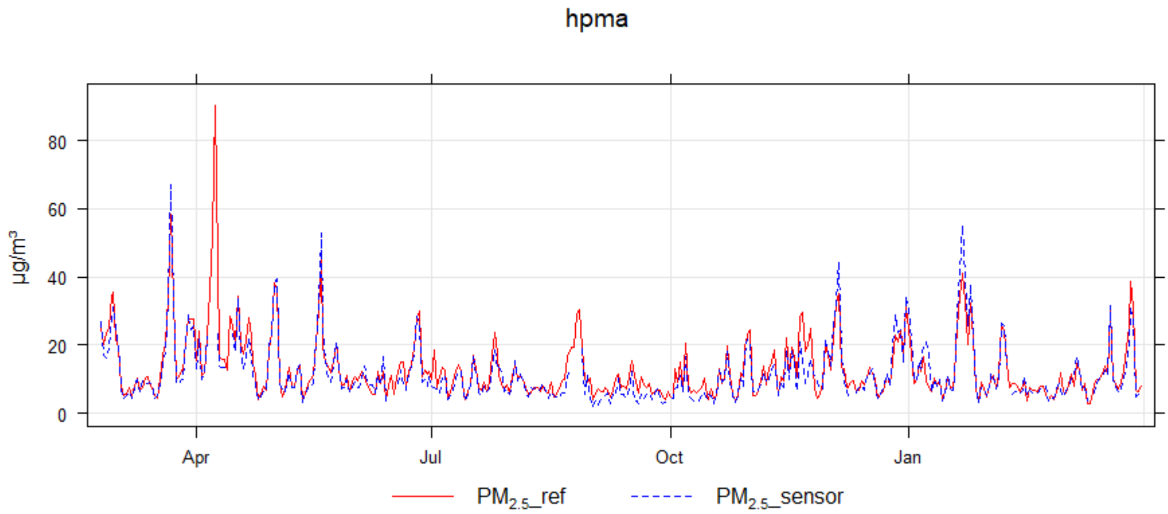
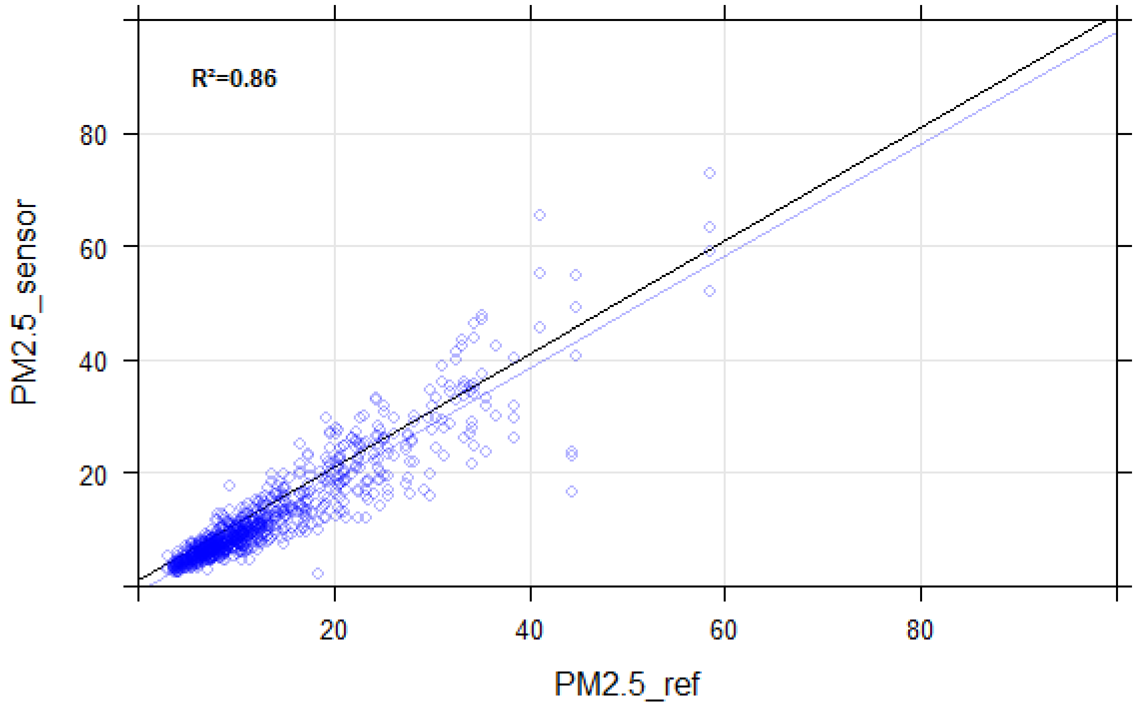


Figure 17: $PM_{2.5}$ scatterplot for all HPMA daily averages in µg/m³



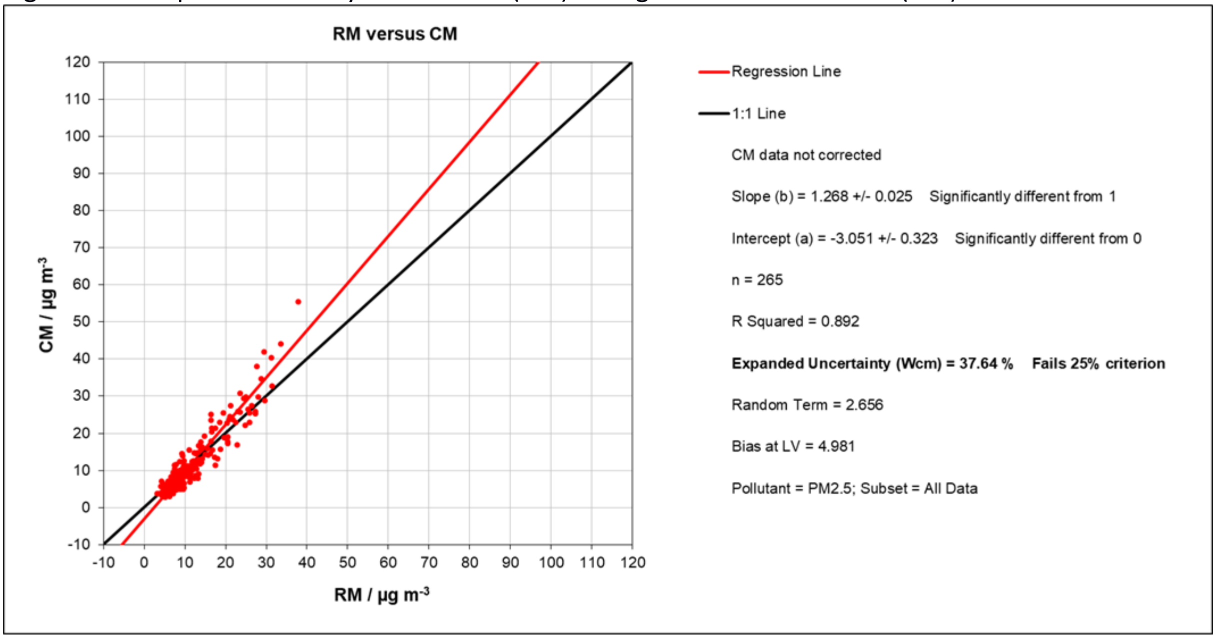
+$PM_{2.5}$ 95% confidence interval around 30 µg/m³

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

+$PM_{2.5}$ comparison with gravimetric reference

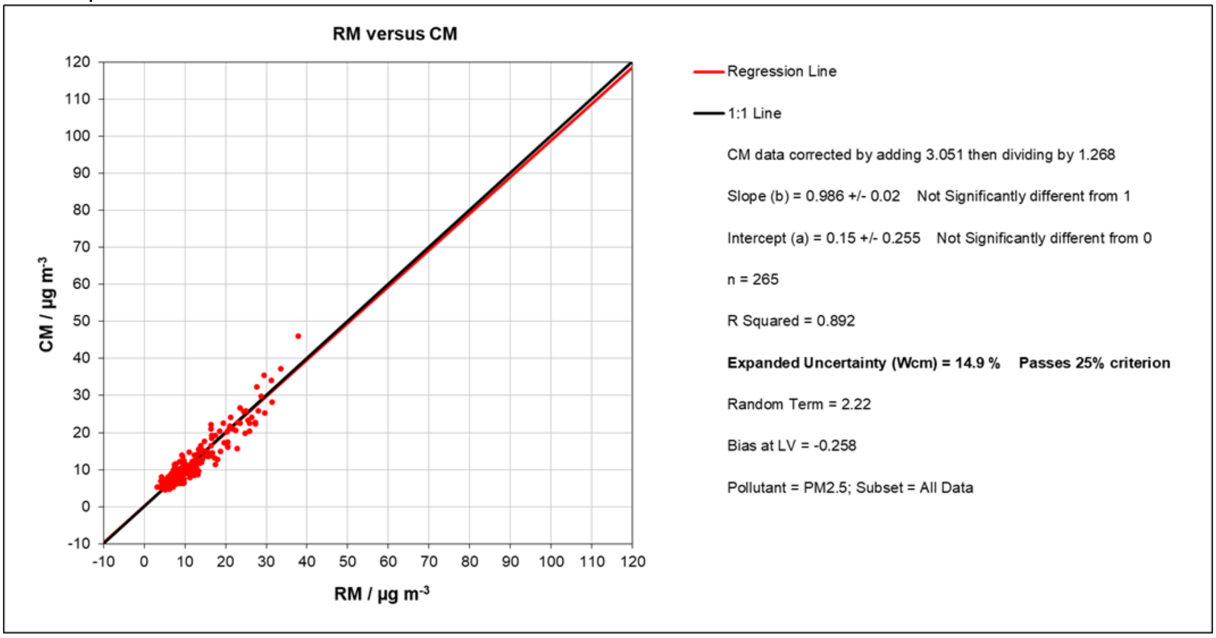
When comparing the daily overall sensor average with the $PM_{2.5}$ gravimetric data using the official European equivalence spreadsheet to compare a reference method (RM) with a candidate method (CM) we find an R^2 of 0.89 and an expanded uncertainty of 38%. The bias at the limit value was about 5 µg/m³.

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 µg/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 µg/m^3 or 21.8%.

+PM_{10} and PM_{coarse} vs Fidas monitor

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 µg/m³

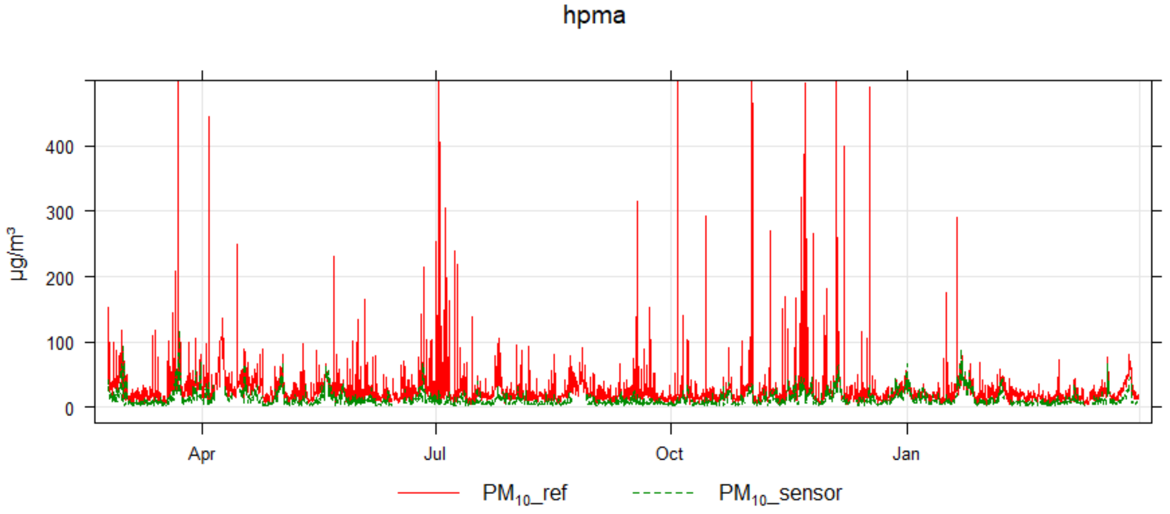


Figure 21: Daily averages of HPMA PM_{10} sensor data vs Fidas reference in µg/m³

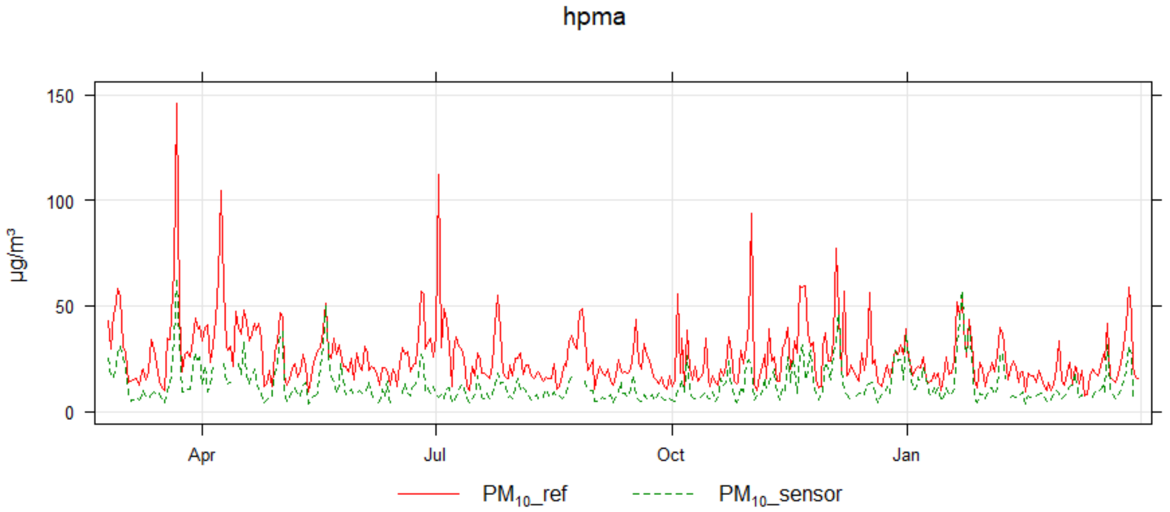
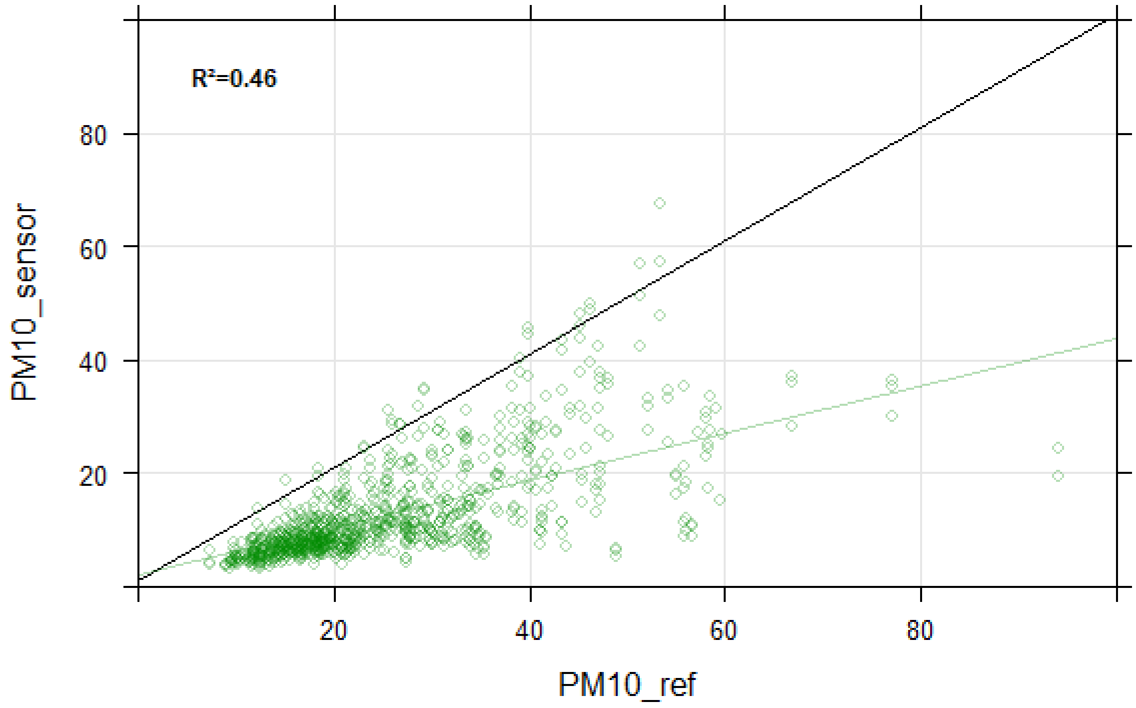


Figure 22: PM_{10} scatterplot for all HPMA daily averages in µg/m³



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 µg/m³

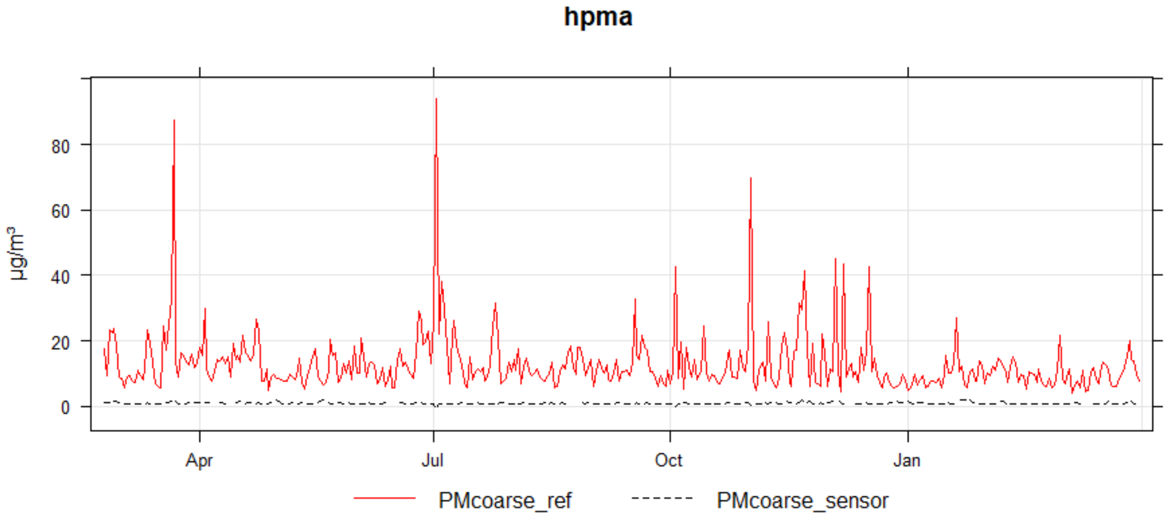
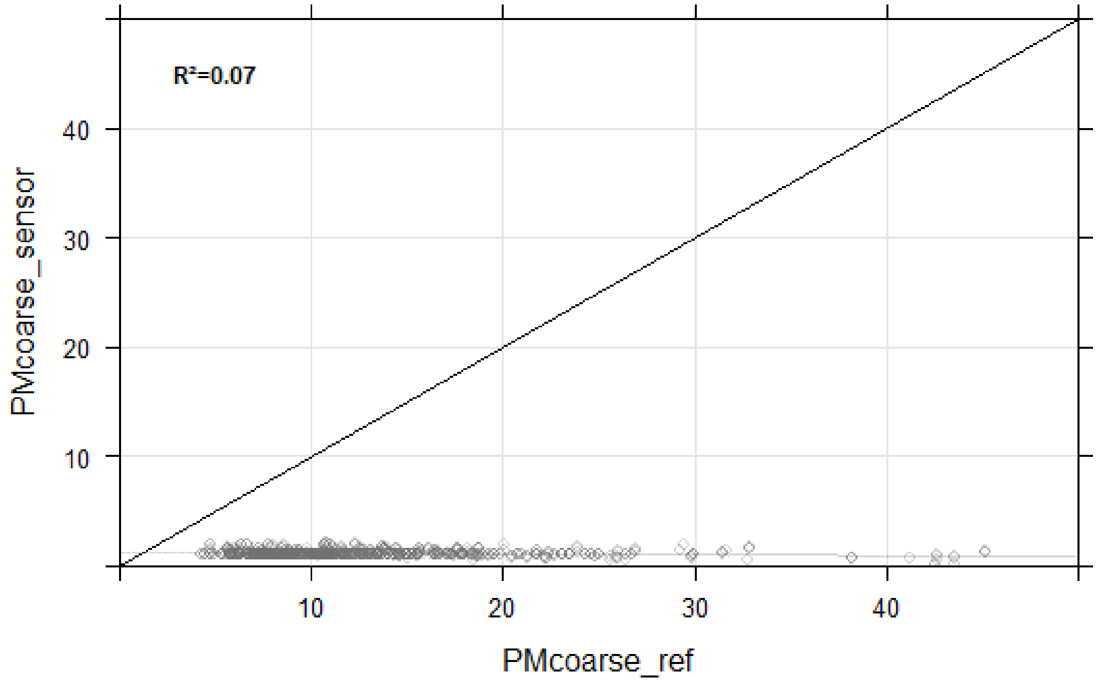
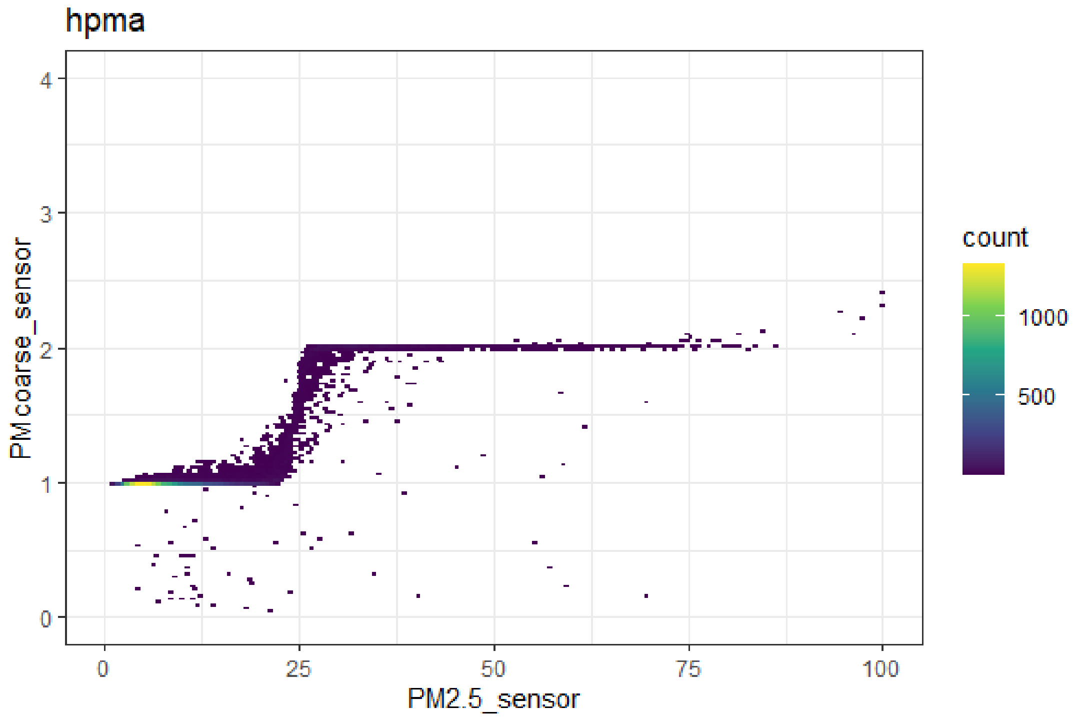


Figure 24: PM_{coarse} scatterplot for all HPMA daily averages in µg/m³



The PM_{coarse} vs $PM_{2.5}$ plot (Figure 25) clearly shows that the sensor applies a very simple algorithm to estimate PM_{10}. For $PM_{2.5}$ concentrations up to 25 µg/m³ 1 µg/m³ is added and for higher concentrations 2 µg/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 µg/m³



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 26: Example of multiple sensor problems between April and July 2019

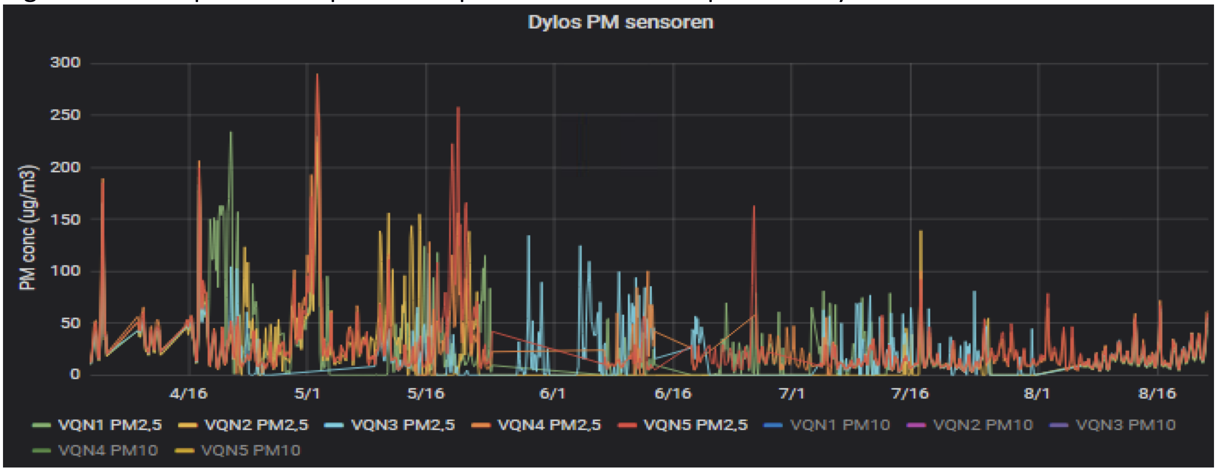


Figure 27: Dust and fluff inside the Dylos

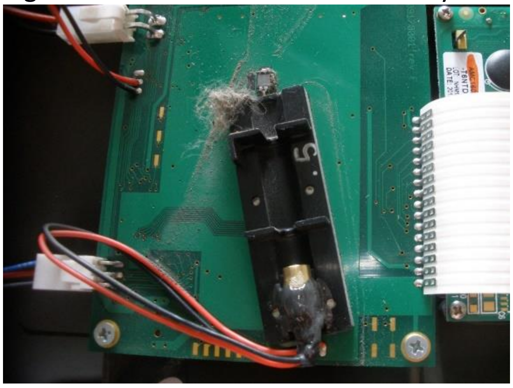
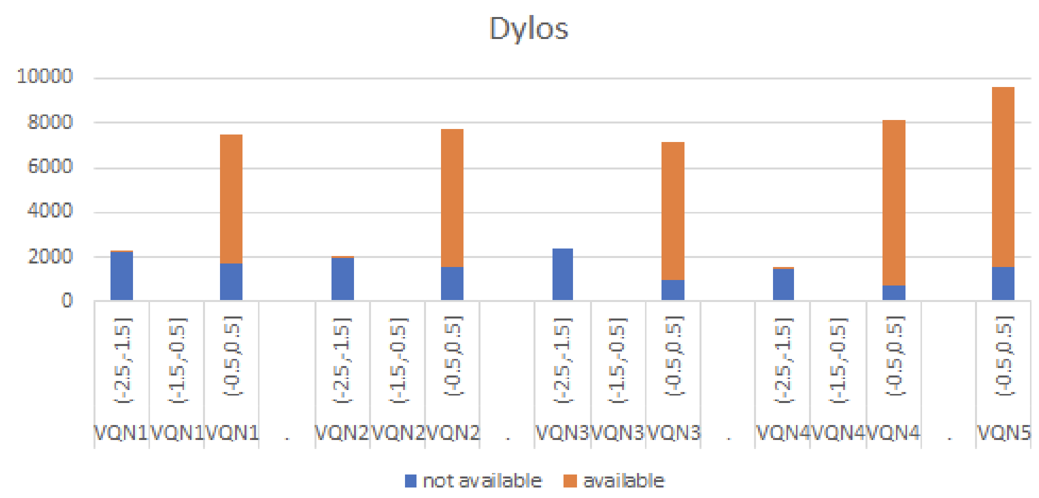


Figure 28: Overview of available hourly data per validation code (-2: invalid / -1: suspicious / 0: valid) for the different units



+$PM_{2.5}$ 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

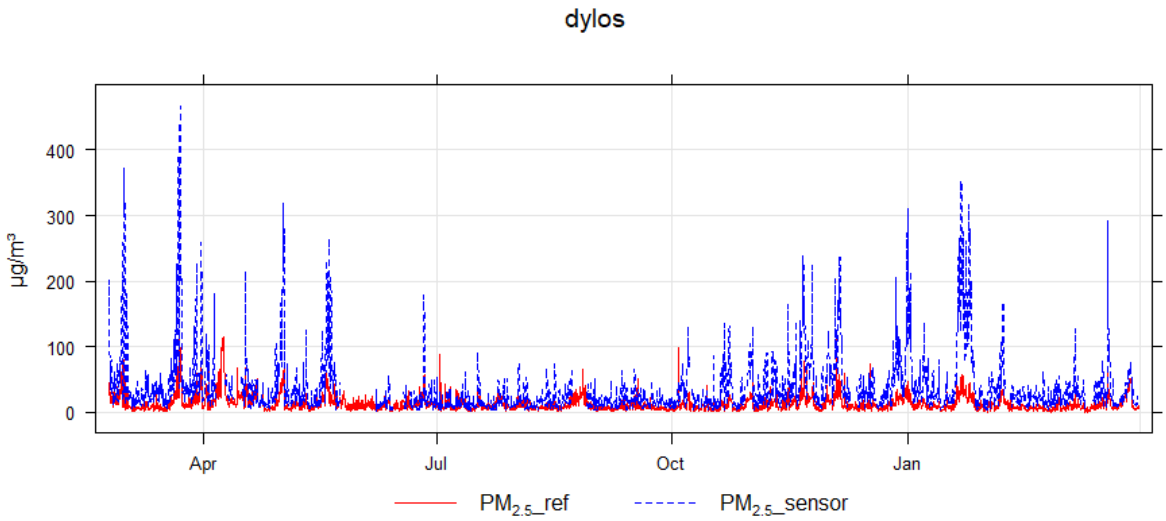


Figure 30: Hourly average of all individual Dylos $PM_{2.5}$ sensor data vs Fidas reference

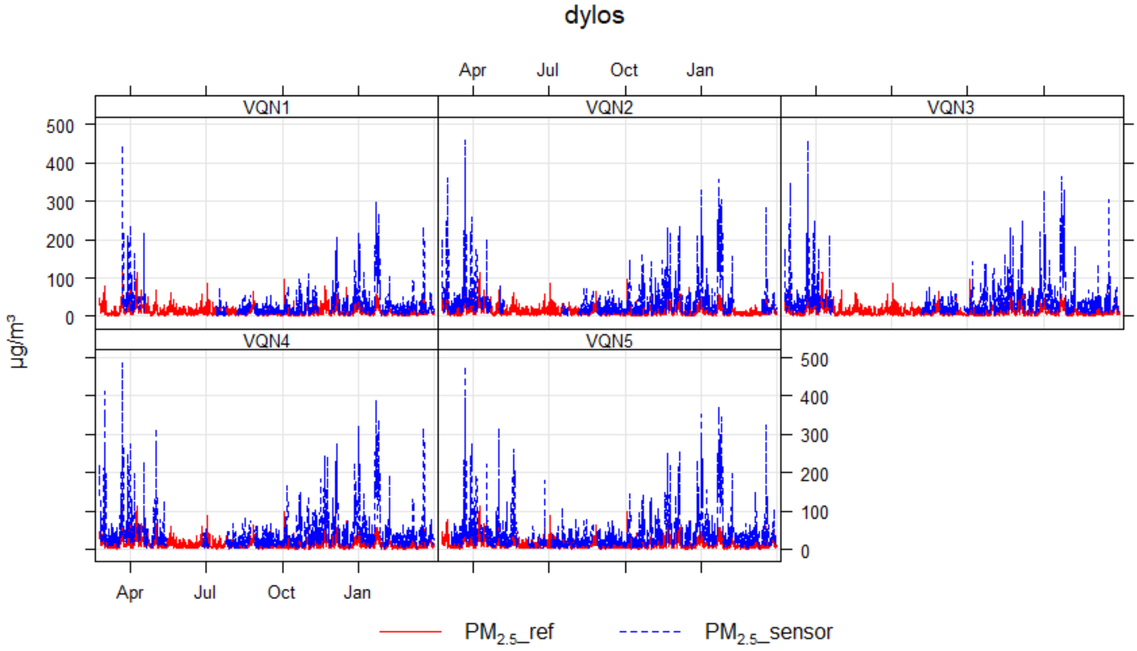


Figure 31: Density plot of all hourly $PM_{2.5}$ Dylos sensor data vs $PM_{2.5}$ Fidas (in µg/m³)

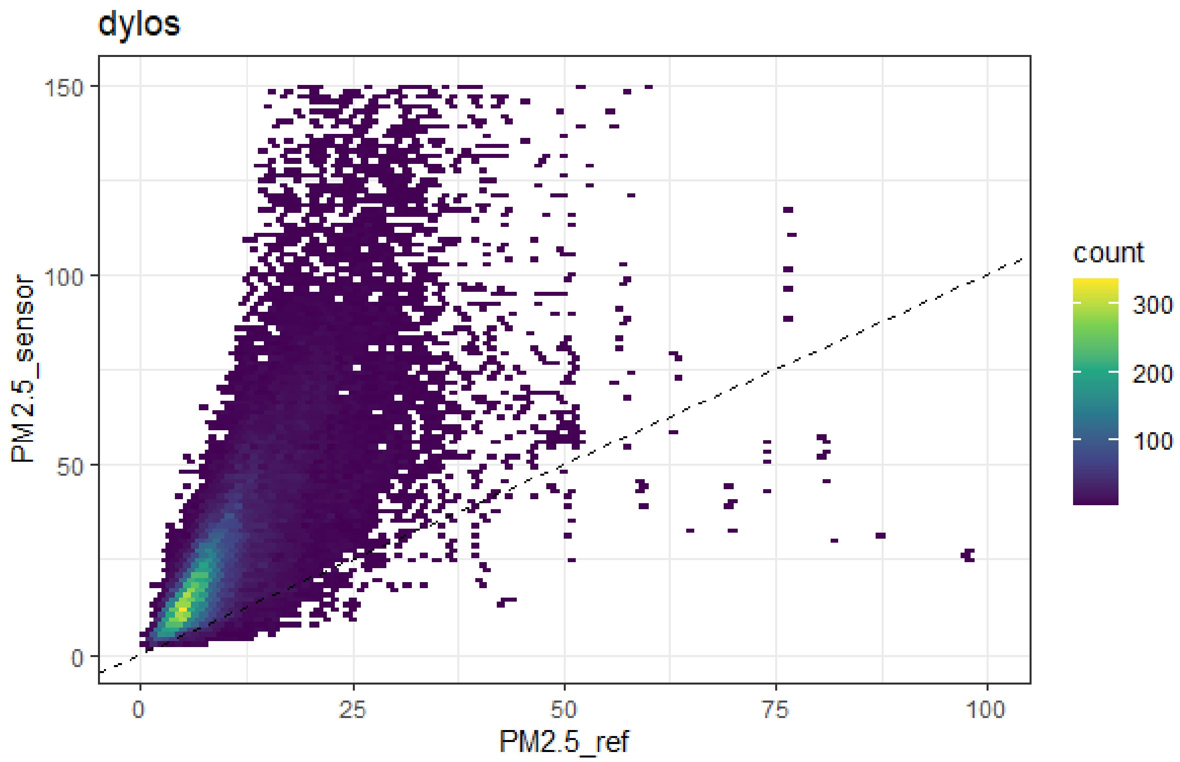


Figure 32: $PM_{2.5}$ scatterplot for all Dylos sensor 5min averages (left) and all hourly averages (right) in µg/m³

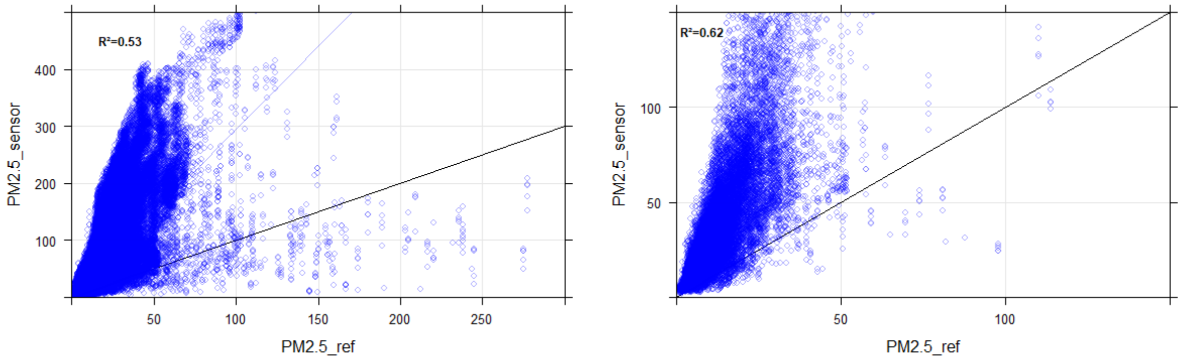
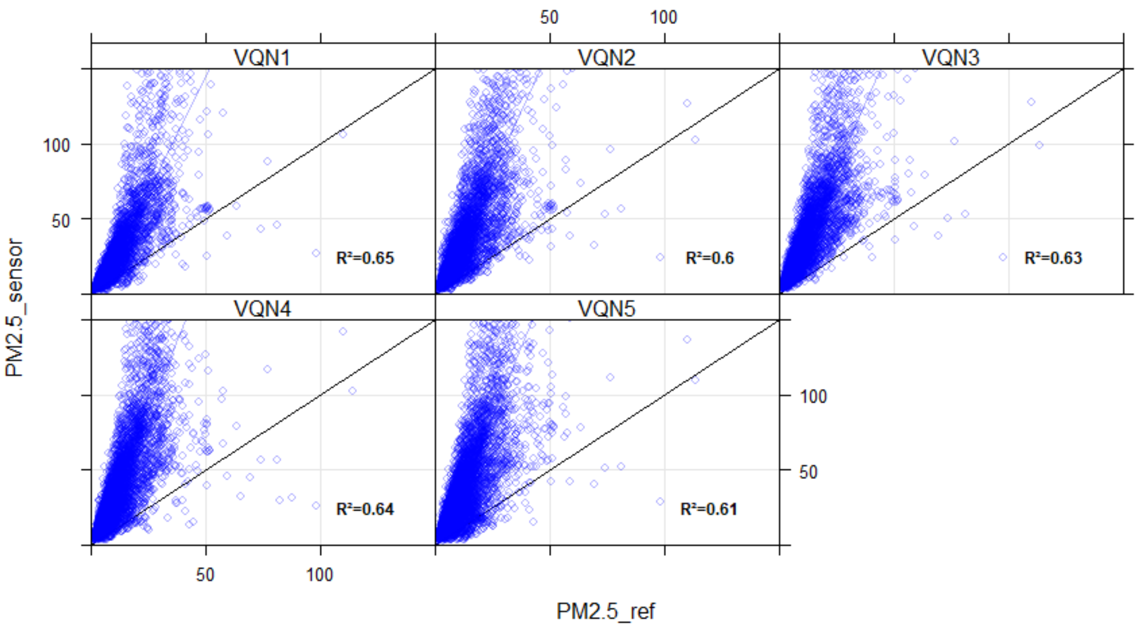


Figure 33: $PM_{2.5}$ scatterplots for hourly Dylos averages per sensor in µg/m³



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)

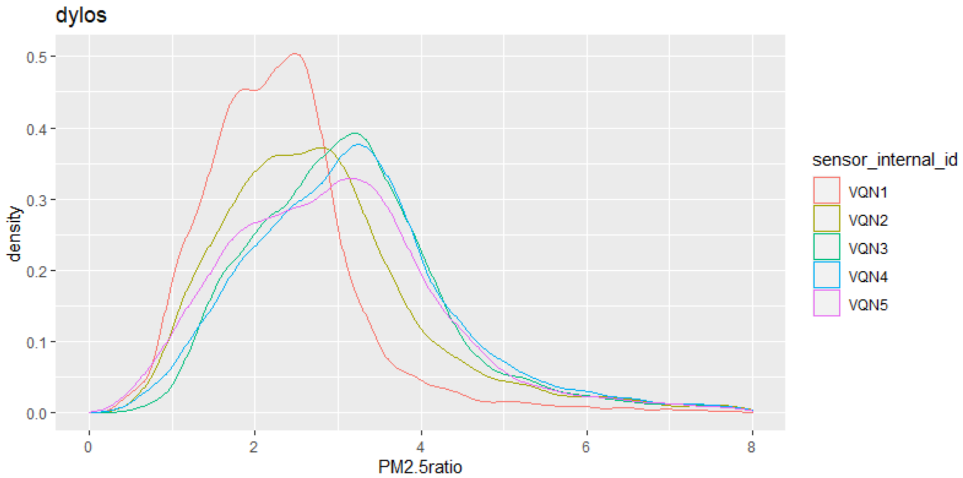
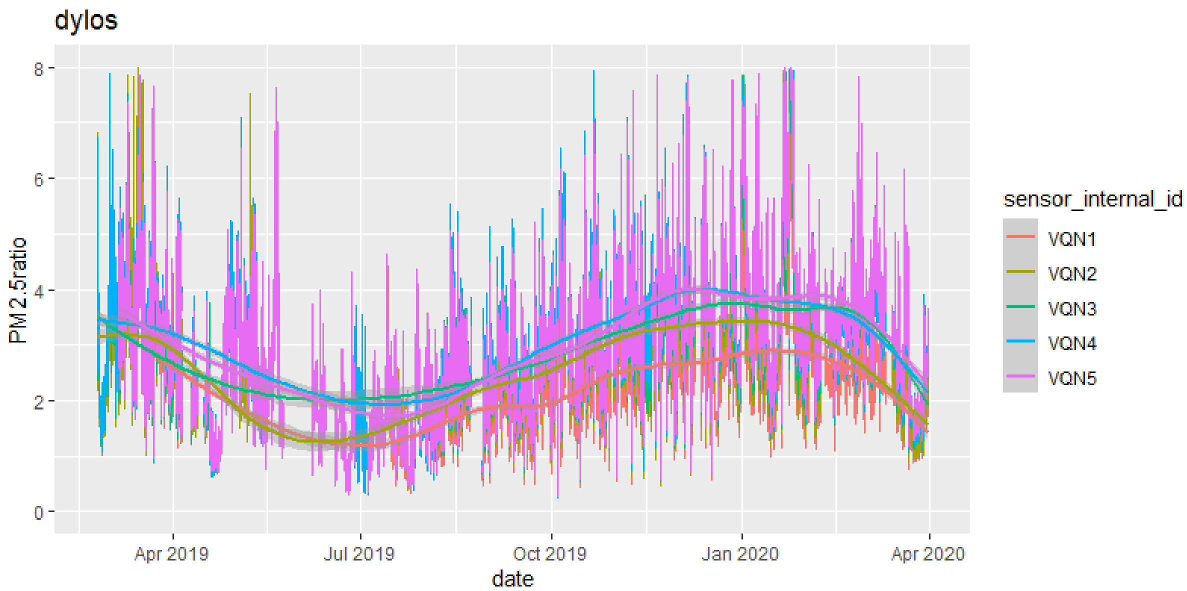


Figure 35: Hourly $PM_{2.5}$ ratio (Dylos sensor/Fidas) in function of time



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.

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

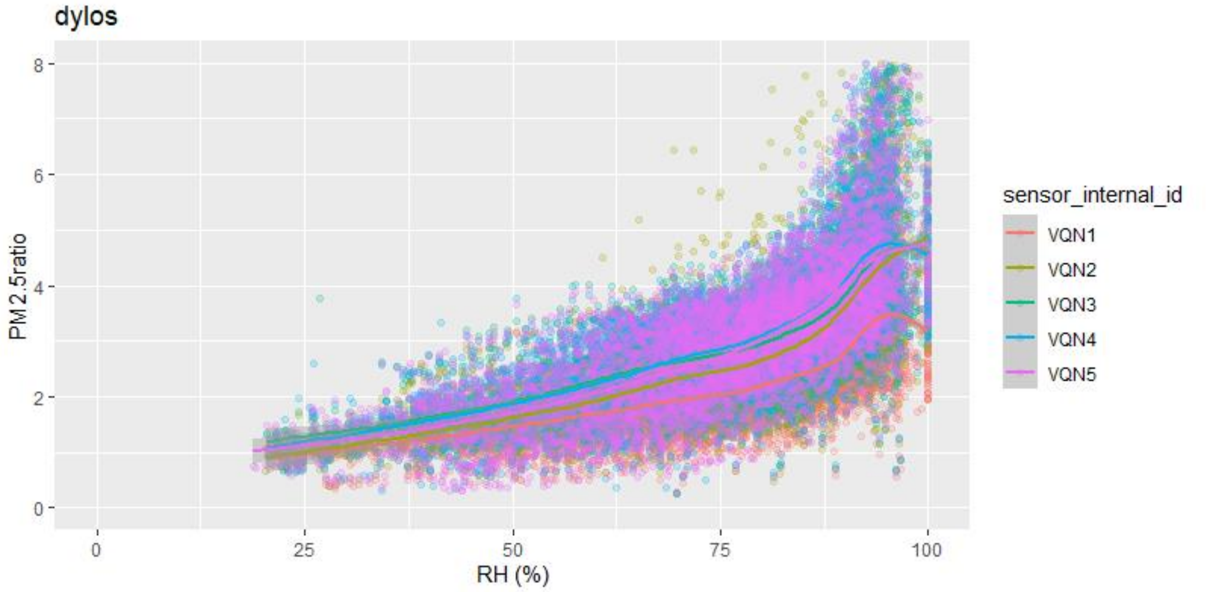
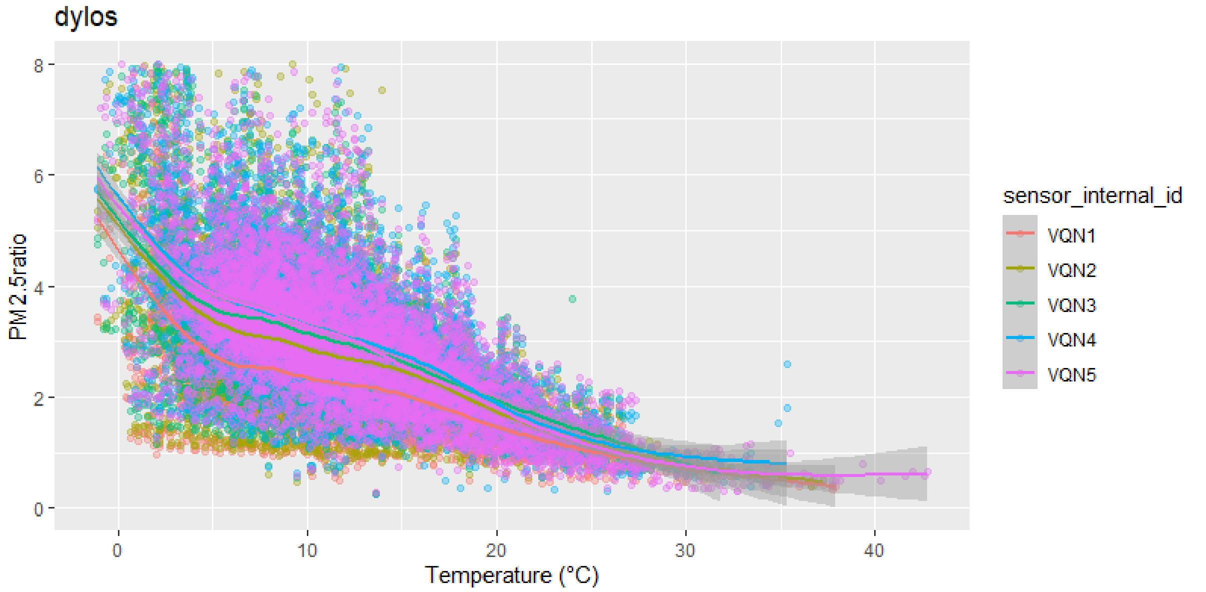


Figure 37: Hourly $PM_{2.5}$ ratio (Dylos sensor/Fidas) in function of temperature



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

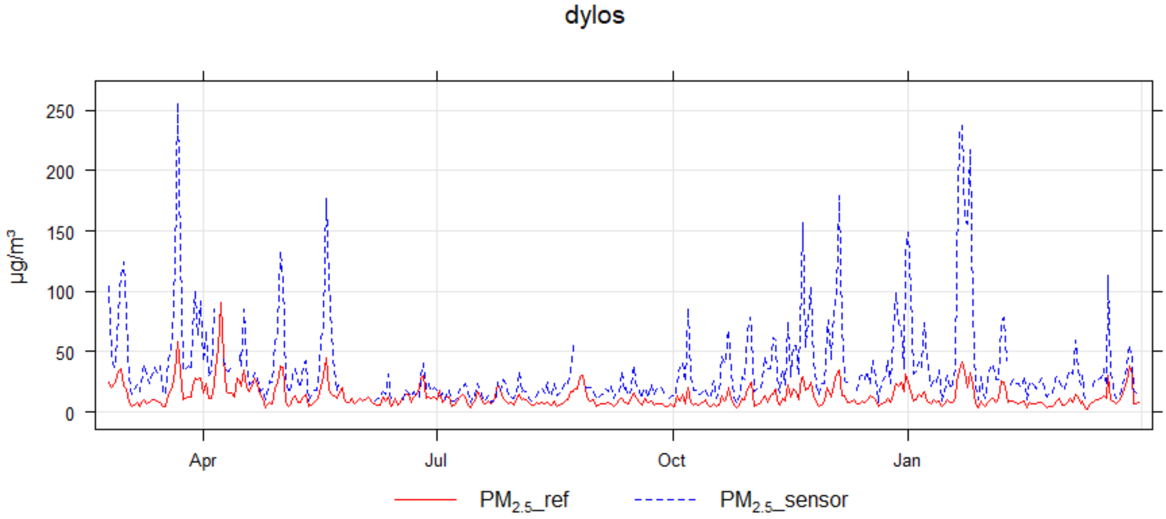
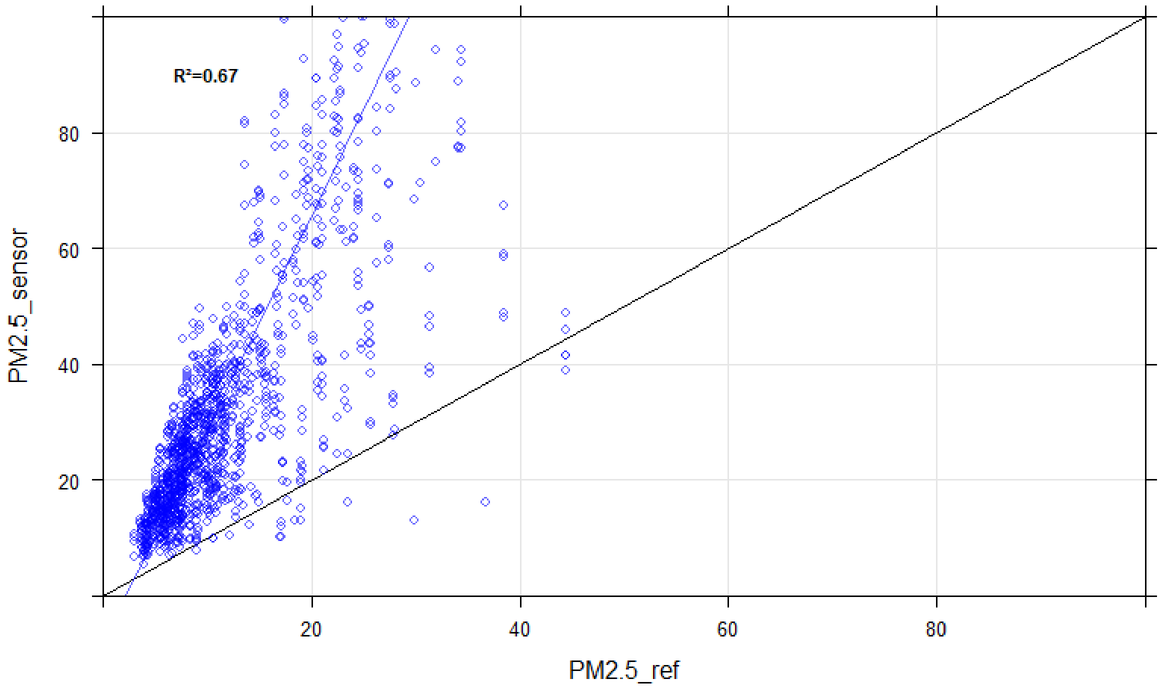


Figure 39: $PM_{2.5}$ scatterplot for all Dylos daily averages in µg/m³



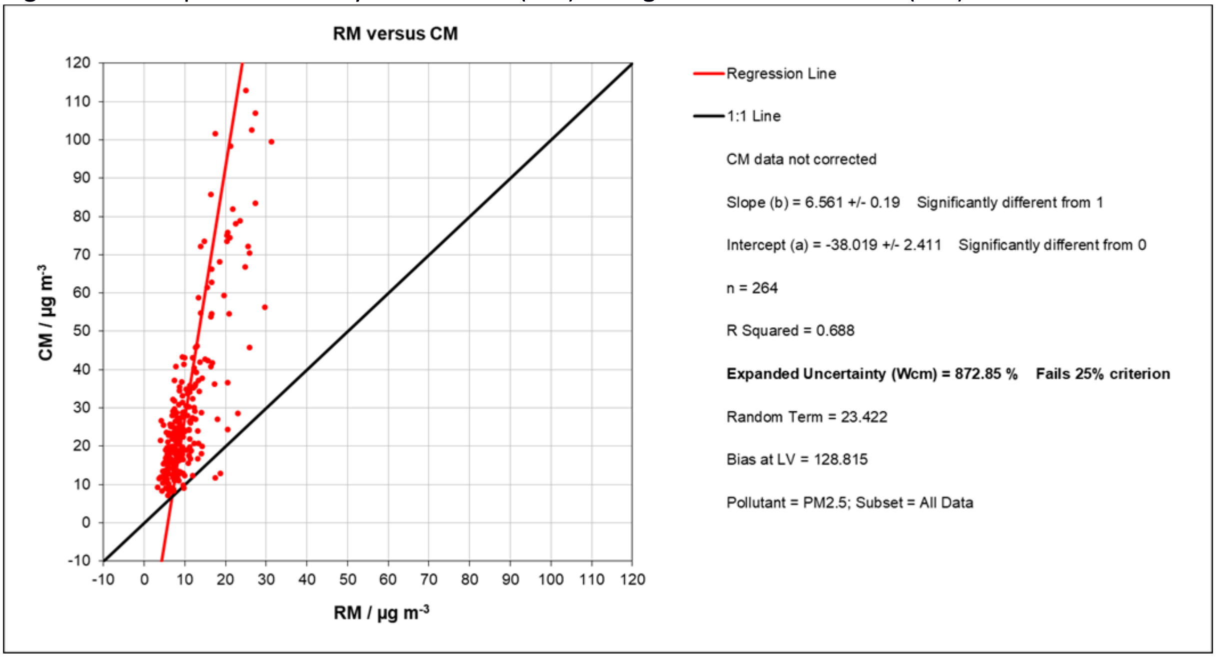
+$PM_{2.5}$ 95% confidence interval around 30 µg/m³

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

+ $PM_{2.5}$ comparison with gravimetric reference

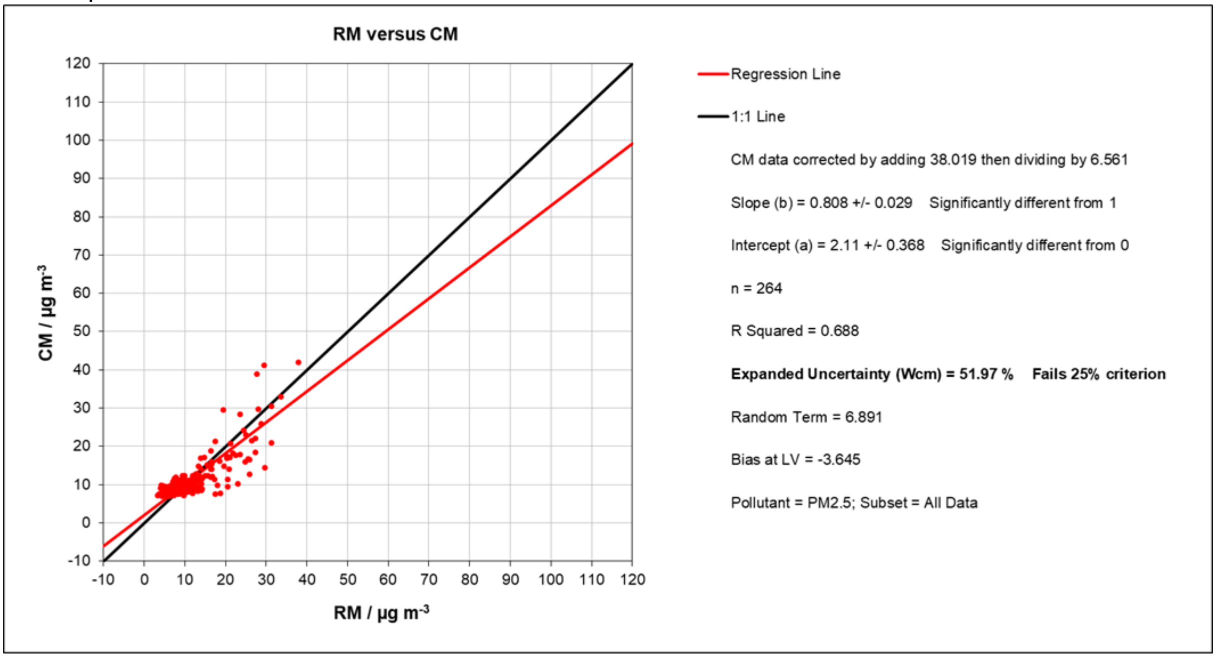
When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an R^2 of 0.69 and an expanded uncertainty of 873%. The bias at the limit value was about 129 µg/m³. This was the worst performance of all tested sensors.

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 µg/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 µg/m^3 or 18.5%.

+PM_{10} 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 PM_{10} sensor data vs Fidas reference

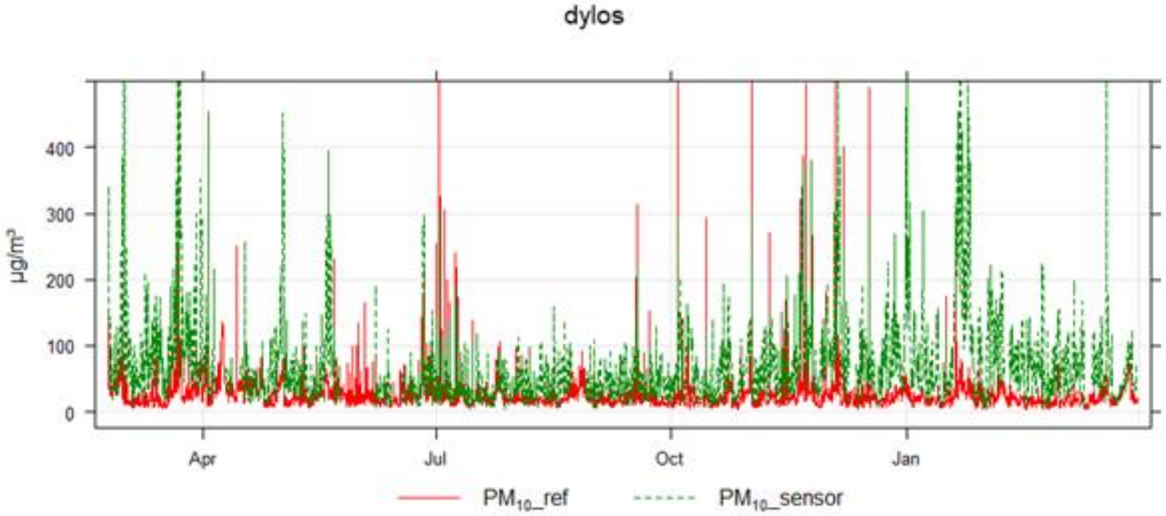


Figure 43: Daily average of all valid Dylos $PM_{2.5}$ sensor data vs Fidas reference

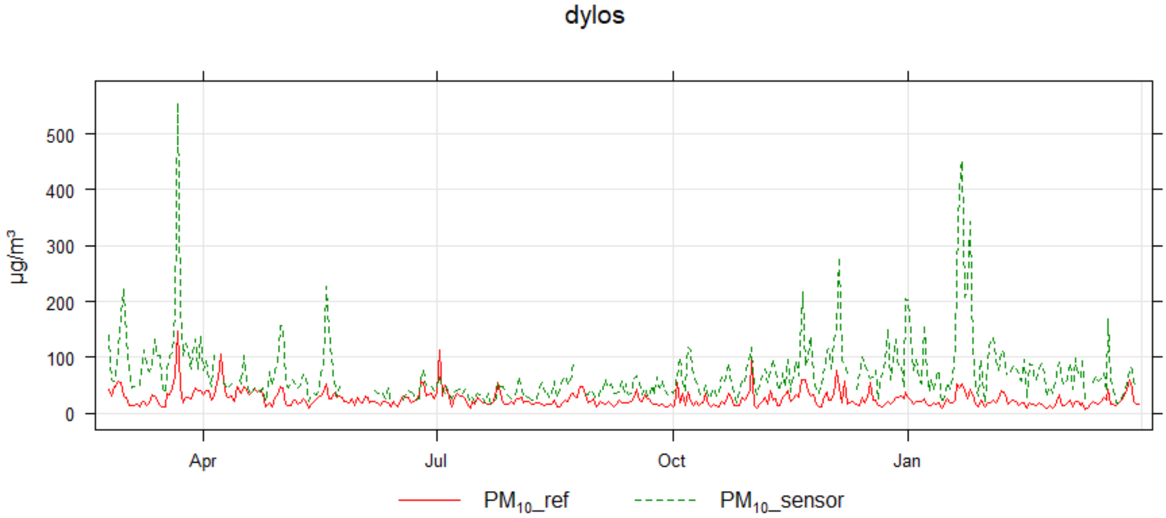
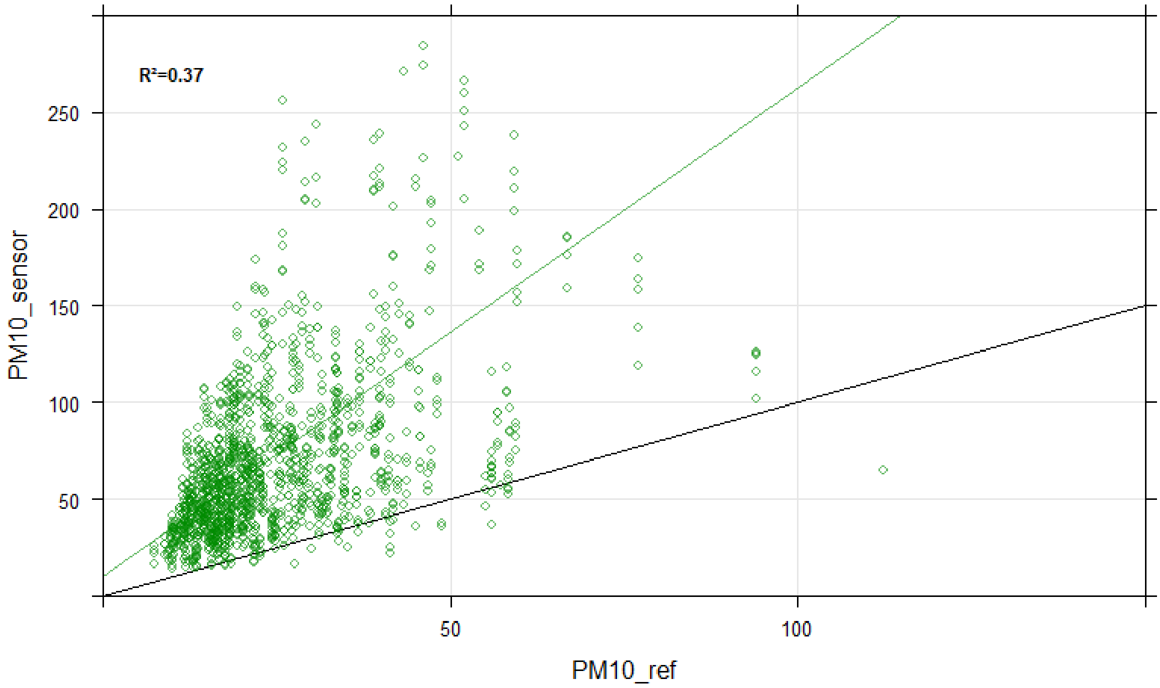


Figure 44: PM_{10} scatterplot for all Dylos daily averages in µg/m³



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 PM_{coarse} sensor data vs Fidas reference

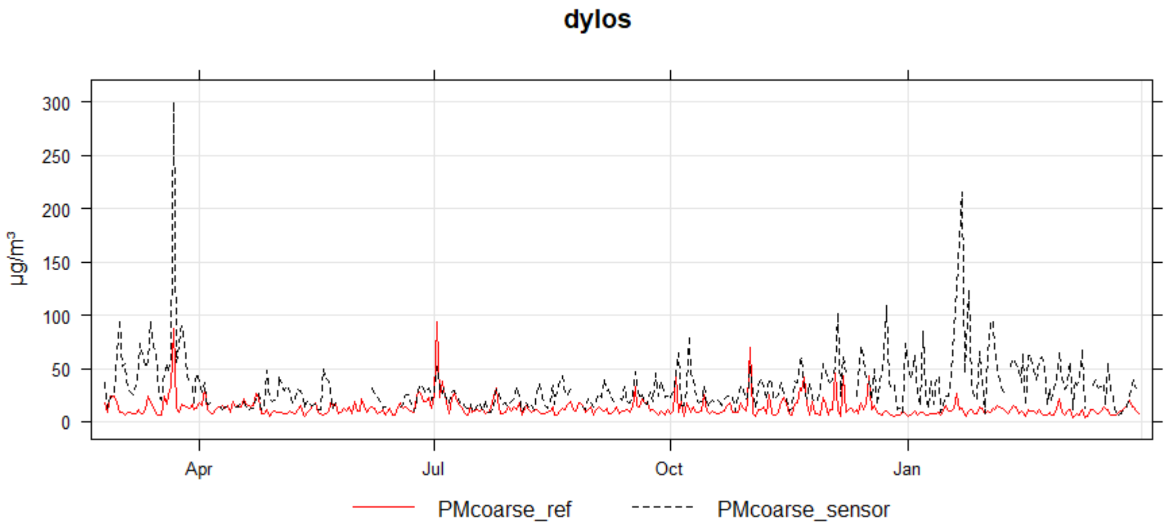
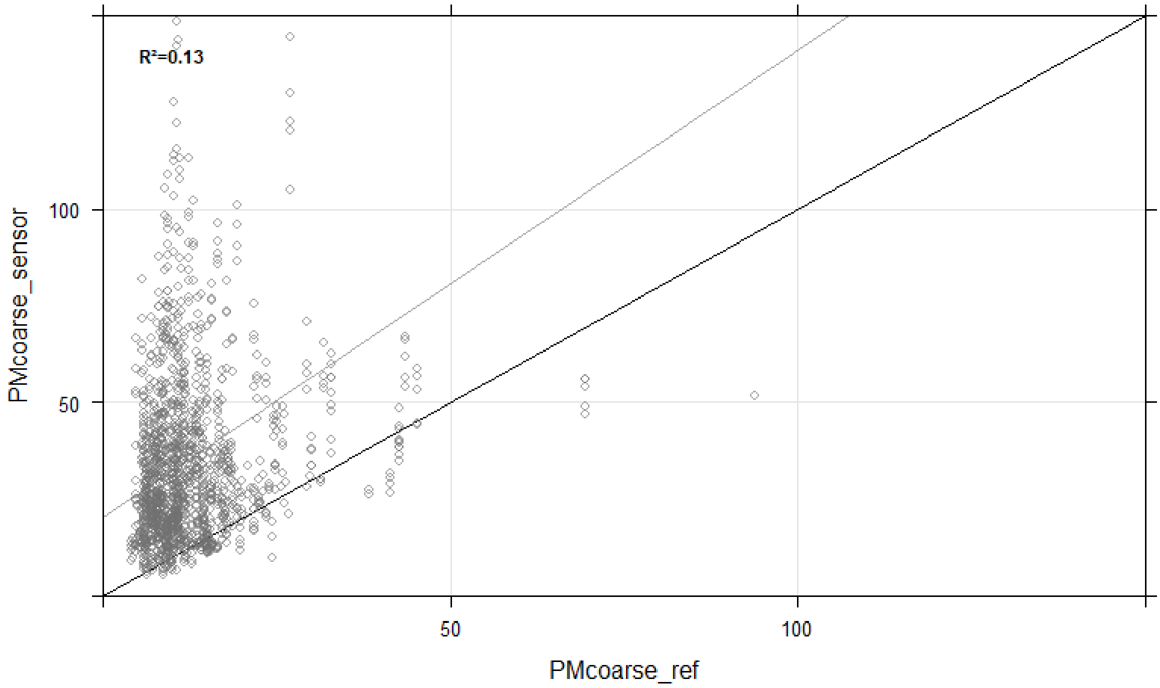
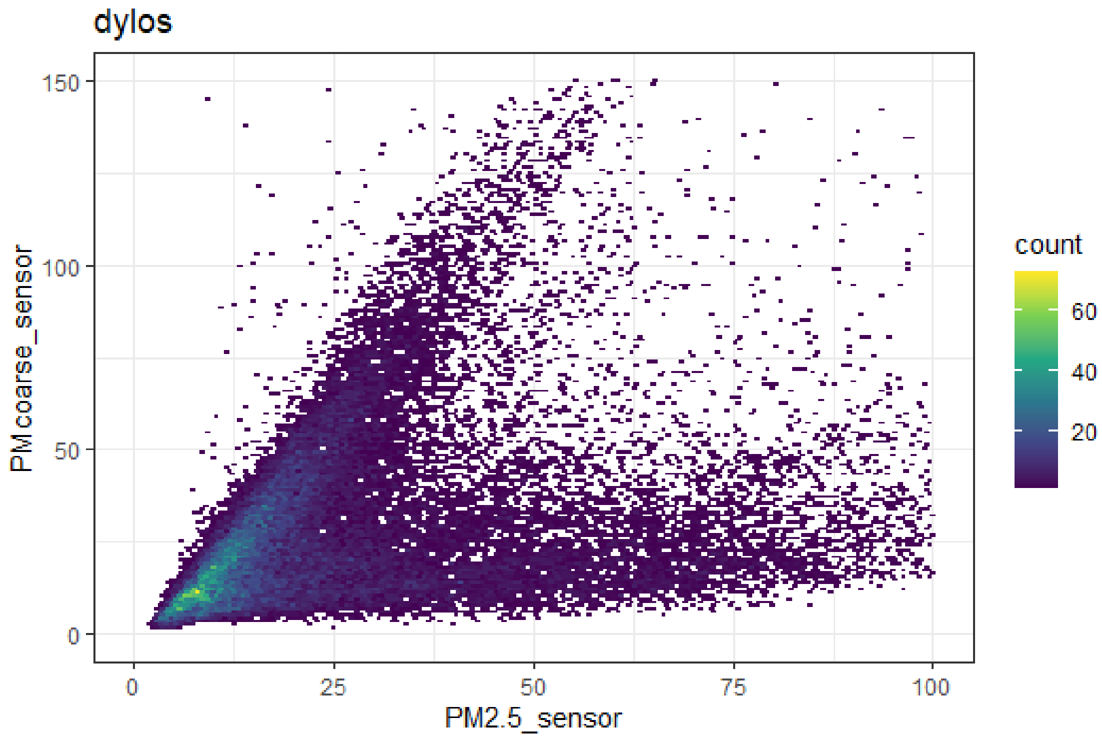


Figure 46: PM_{coarse} scatterplot for all Dylos daily averages in µg/m³



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 µg/m³



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 48: Typical spikes in the SDS sensor signal

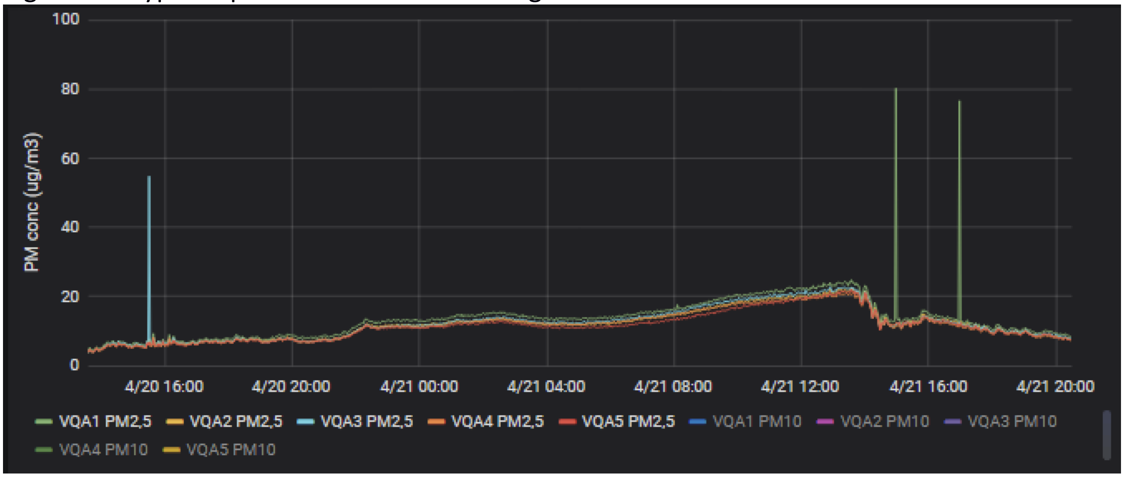


Figure 49: SDS sensor unit 2 showing periods of capped $PM_{2.5}$ and PM_{10} signal

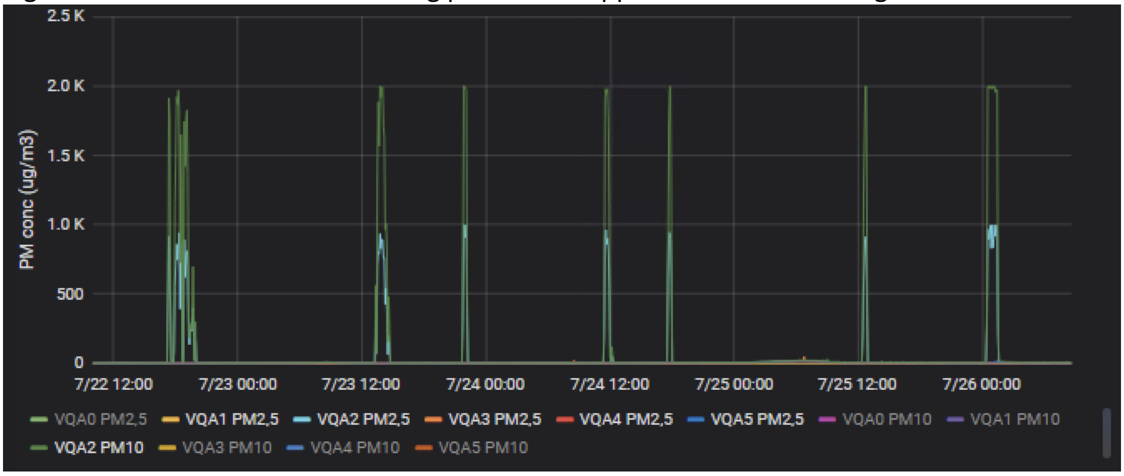
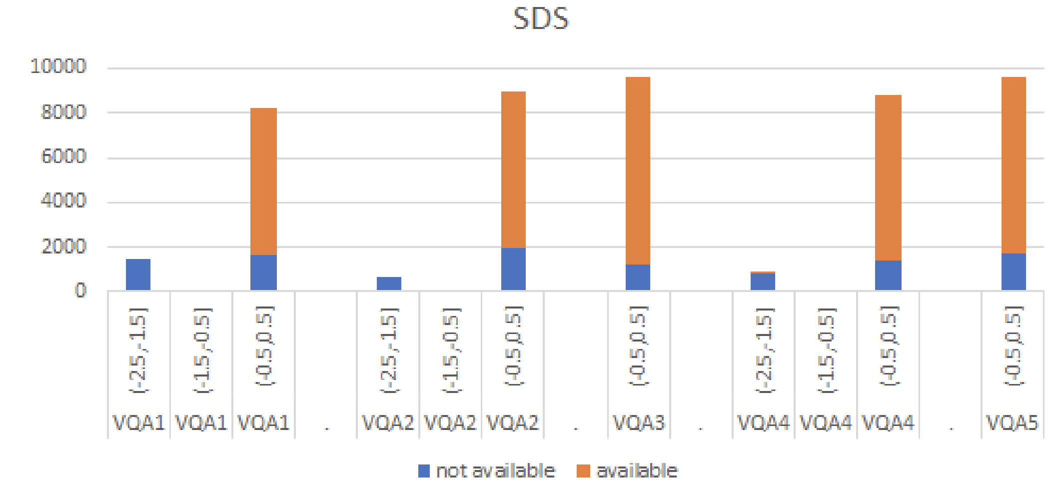


Figure 50: Overview of available hourly data per validation code (-2 :invalid / -1: suspicious /0: valid) for the different units



+$PM_{2.5}$ 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

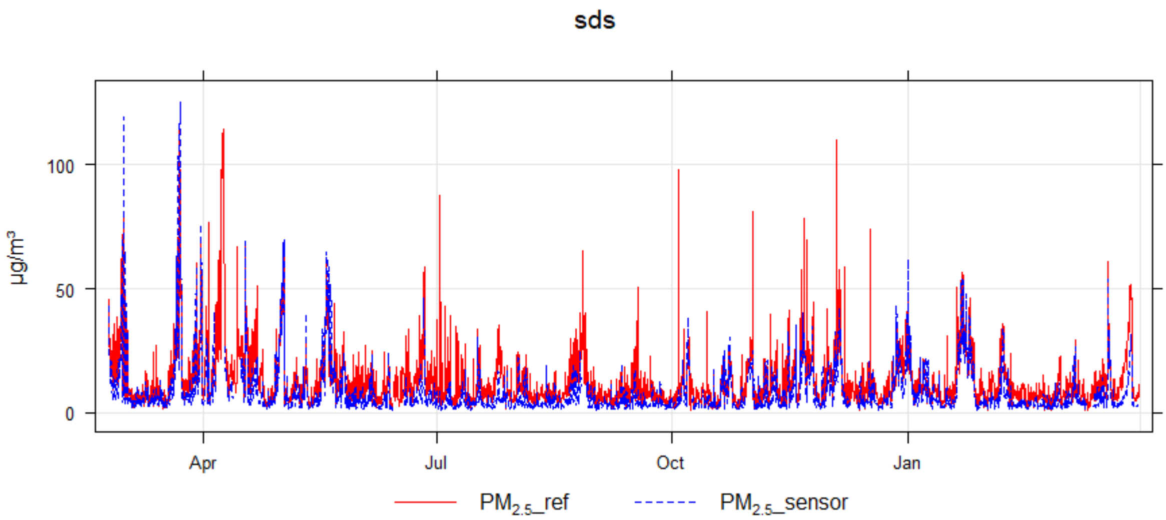


Figure 52: Hourly average of all individual SDS $PM_{2.5}$ sensor data vs Fidas reference

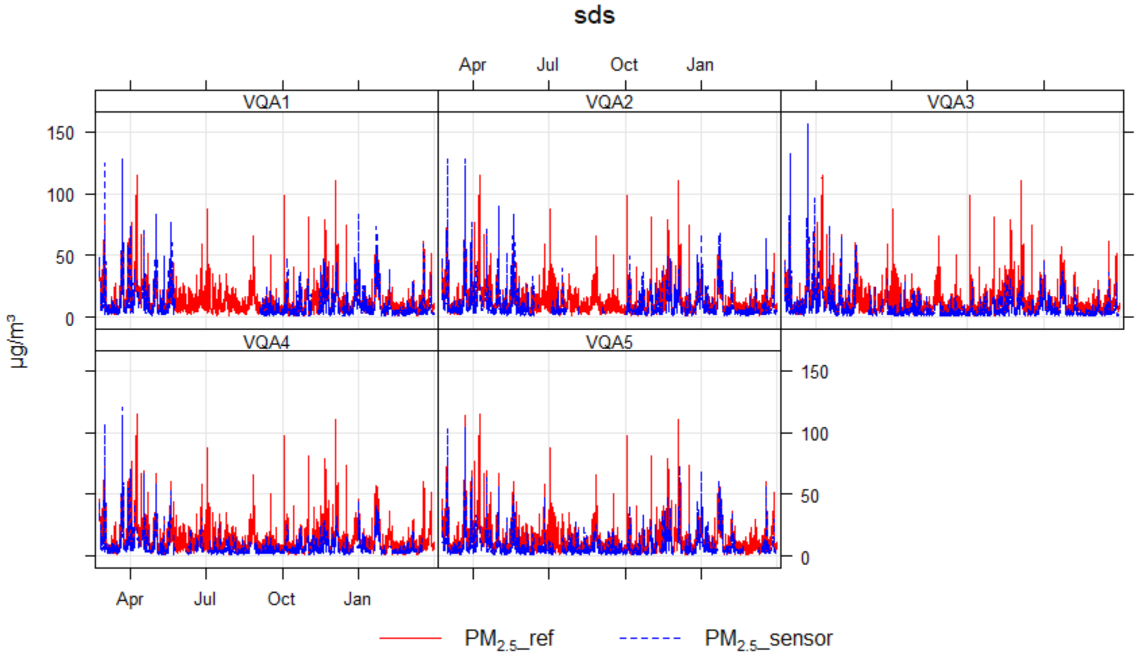


Figure 53: Density plot of all hourly $PM_{2.5}$ SDS sensor data vs $PM_{2.5}$ Fidas (in µg/m³)

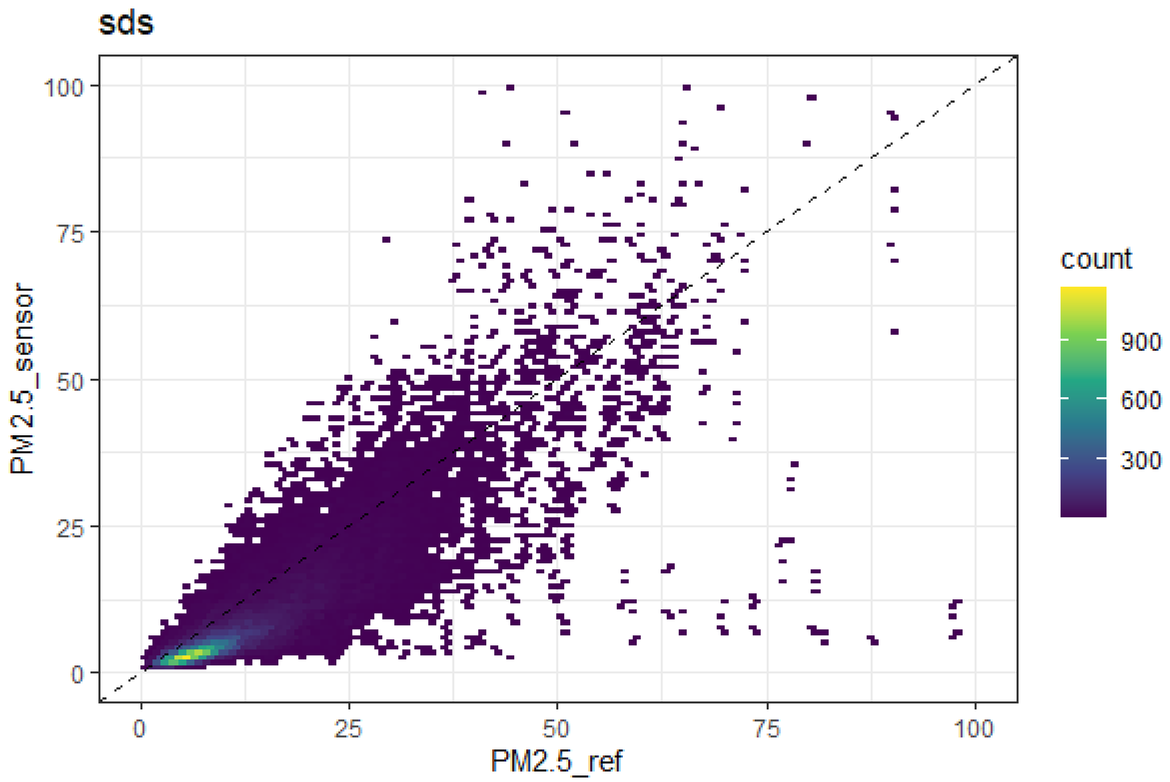


Figure 54: $PM_{2.5}$ scatterplot for all SDS sensor 5min averages (left) and all hourly averages (right) in µg/m³

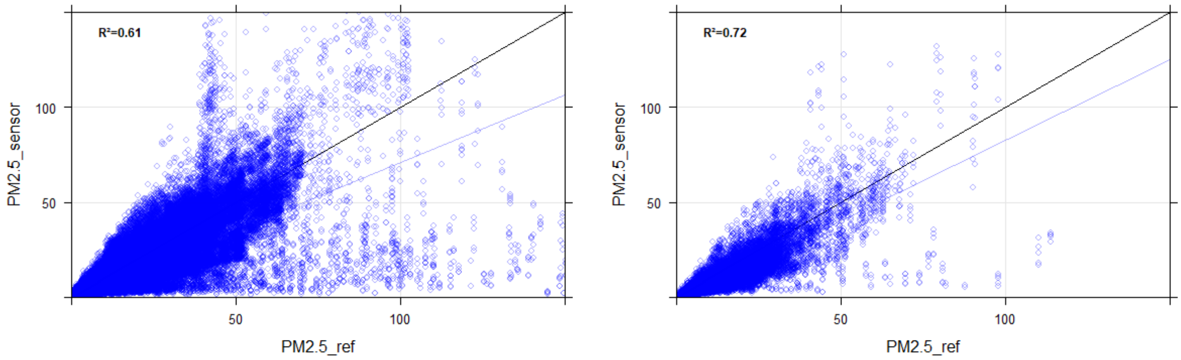
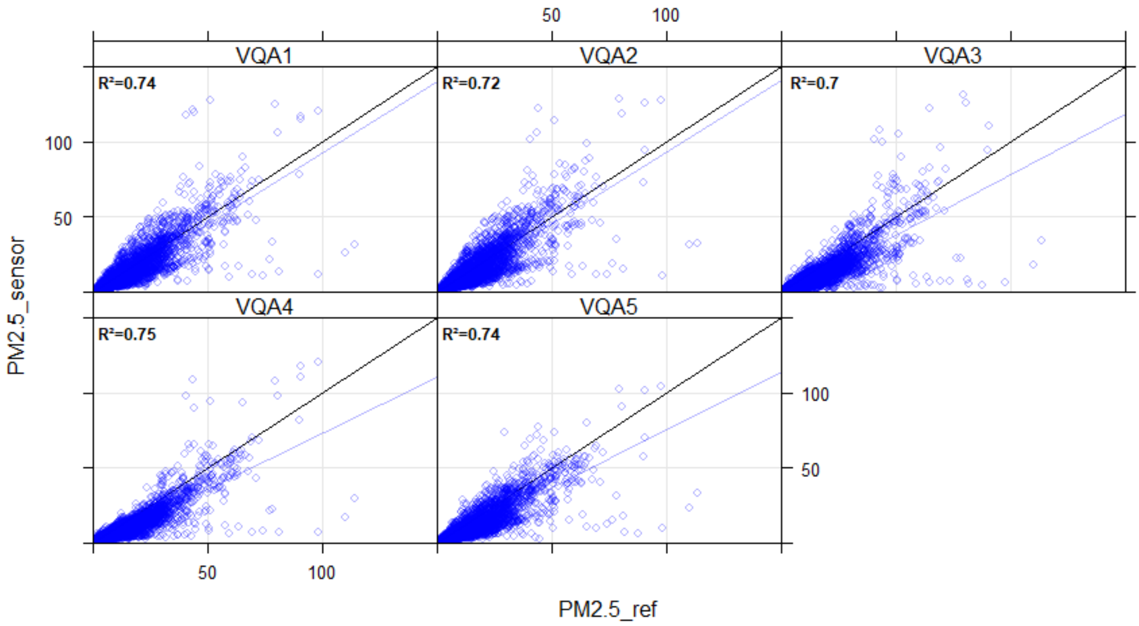
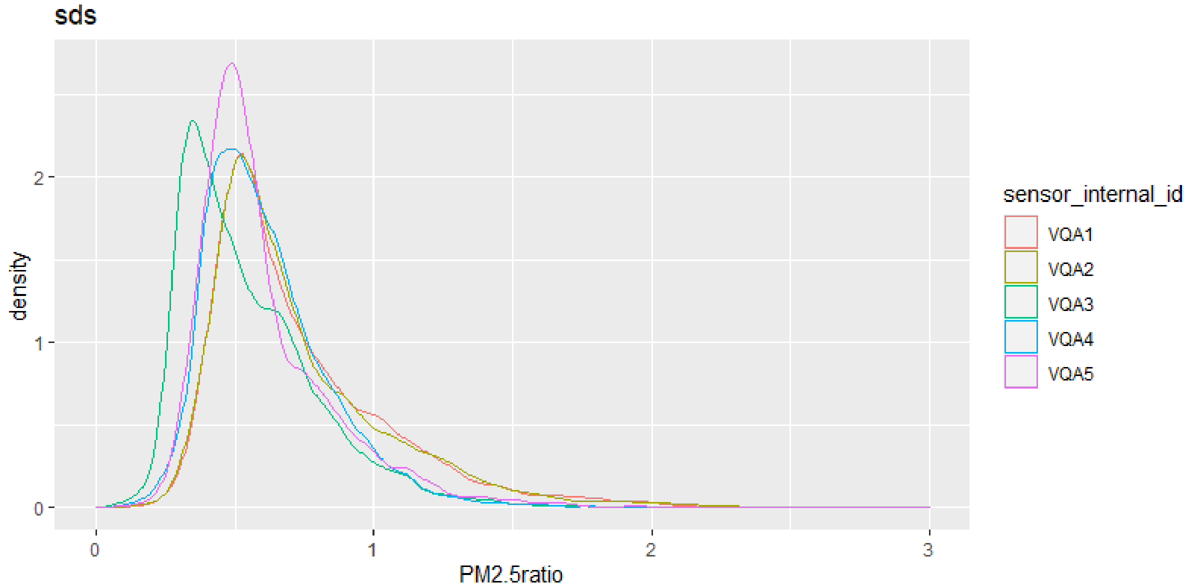


Figure 55: $PM_{2.5}$ scatterplots for hourly SDS averages per sensor in µg/m³



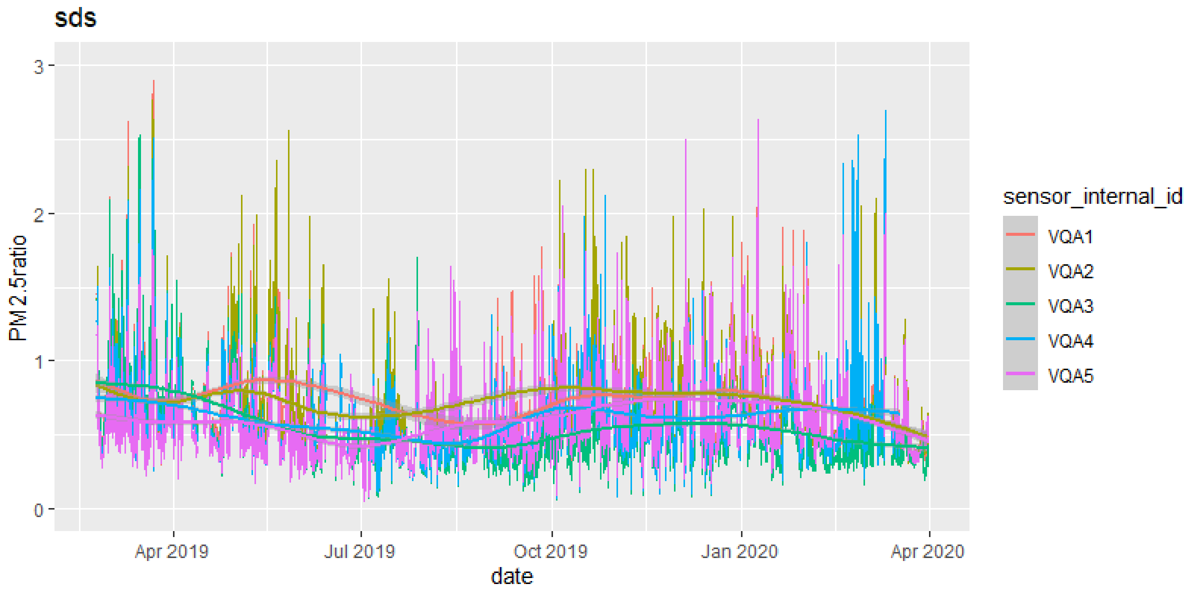
The sensor/Fidas ratios show that sensor 3 gives a lower signal than the others. This is most likely linked to the lower ratio in the second half of the campaign.

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.

Figure 57: Hourly $PM_{2.5}$ ratio (SDS sensor/Fidas) in function of time



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

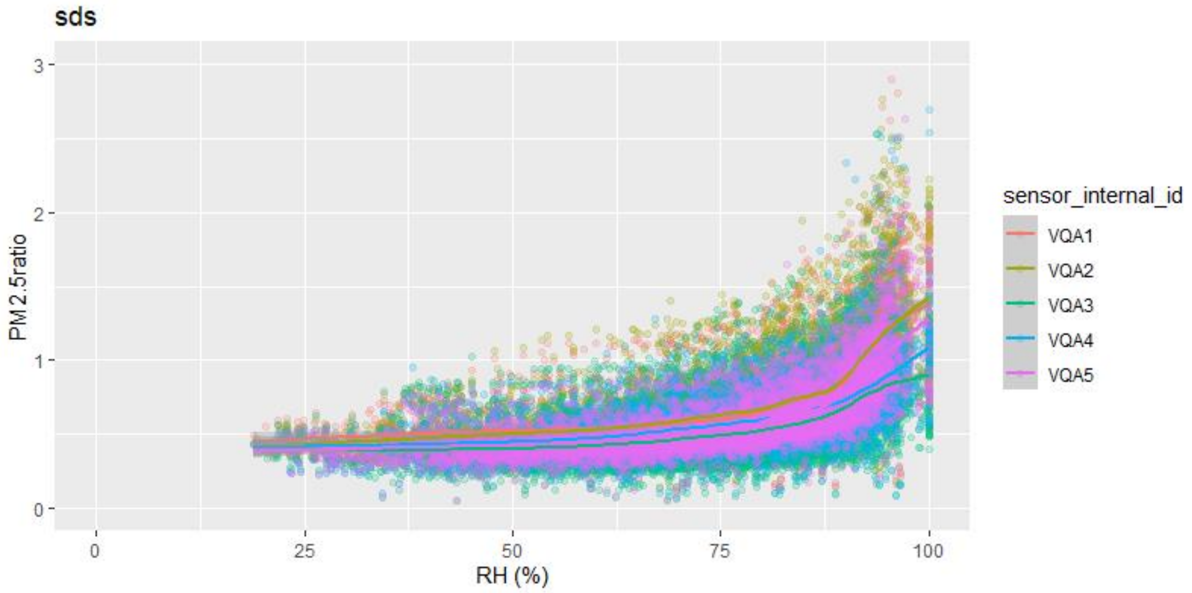
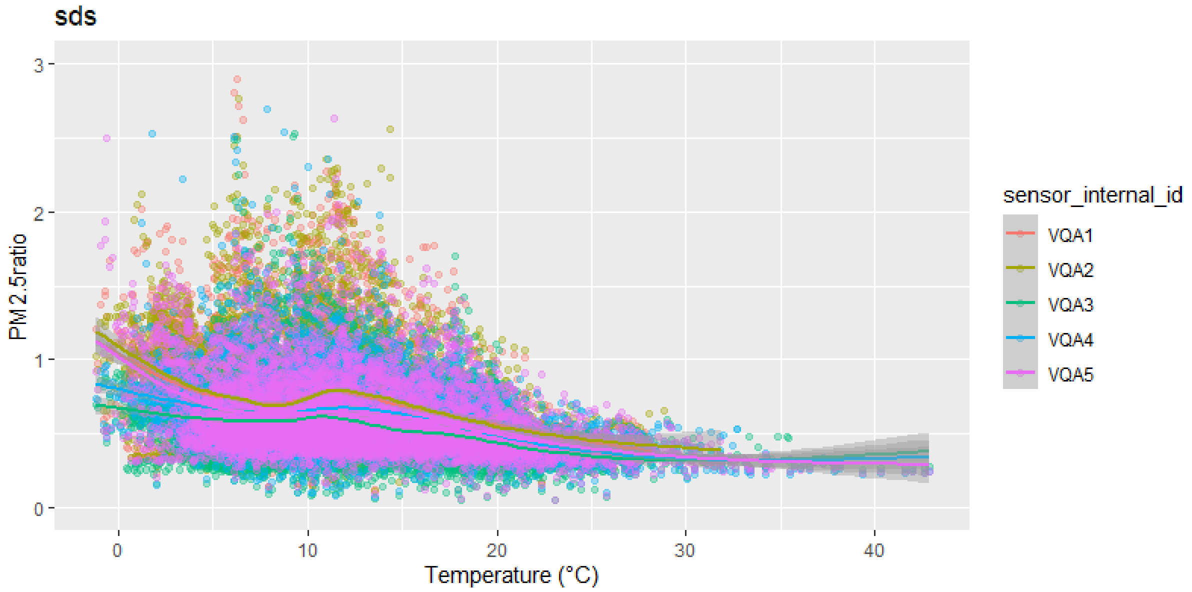


Figure 59: Hourly $PM_{2.5}$ ratio (SDS sensor/Fidas) in function of temperature



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 $PM_{2.5}$ sensor data vs Fidas reference

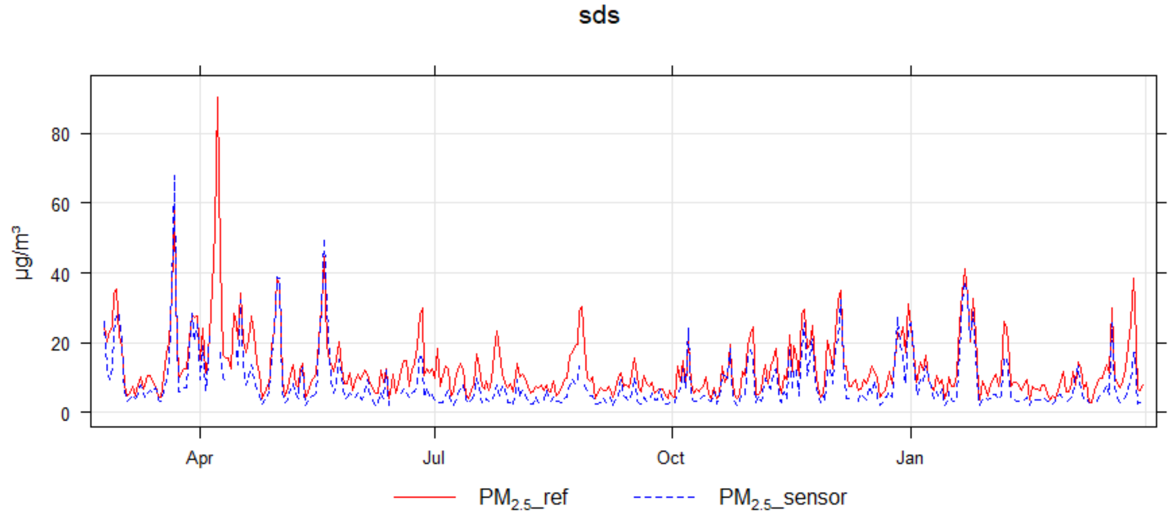
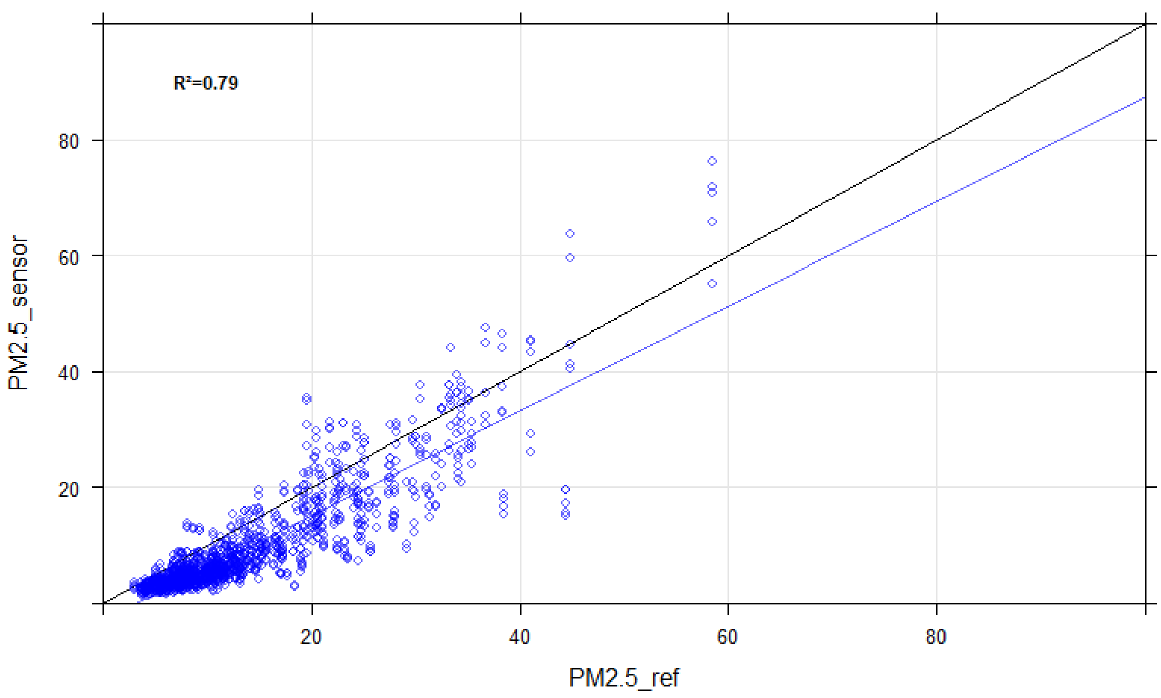


Figure 61: $PM_{2.5}$ scatterplot for all SDS daily averages in µg/m³



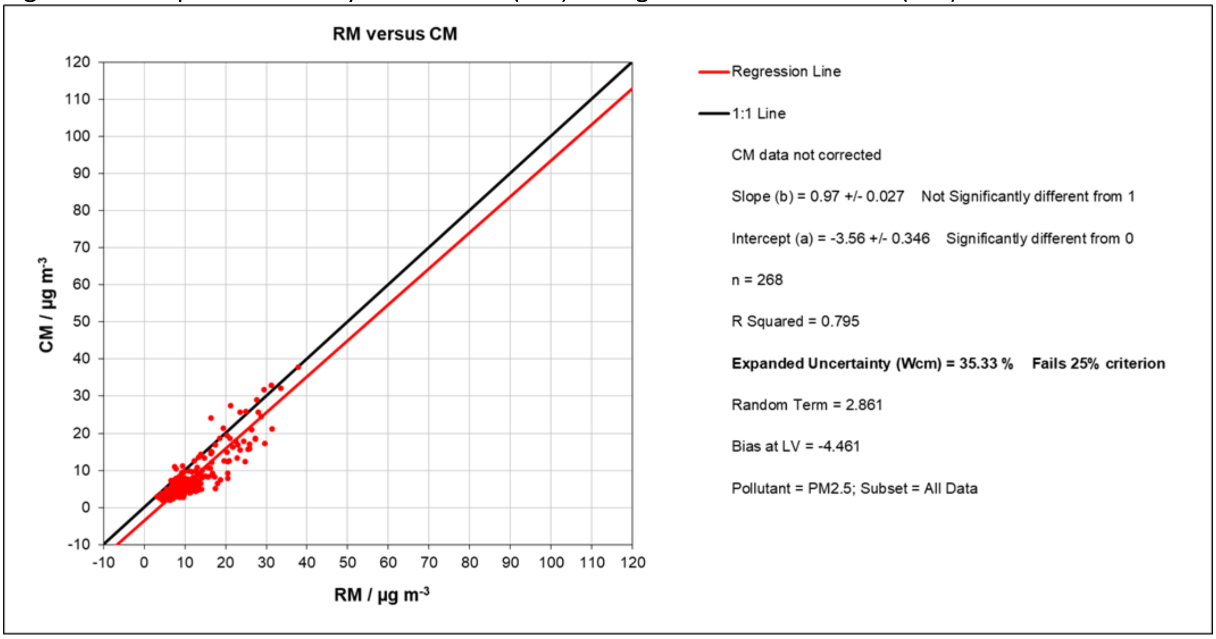
+$PM_{2.5}$ 95% confidence interval around 30 µg/m³

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

+$PM_{2.5}$ comparison with gravimetric reference

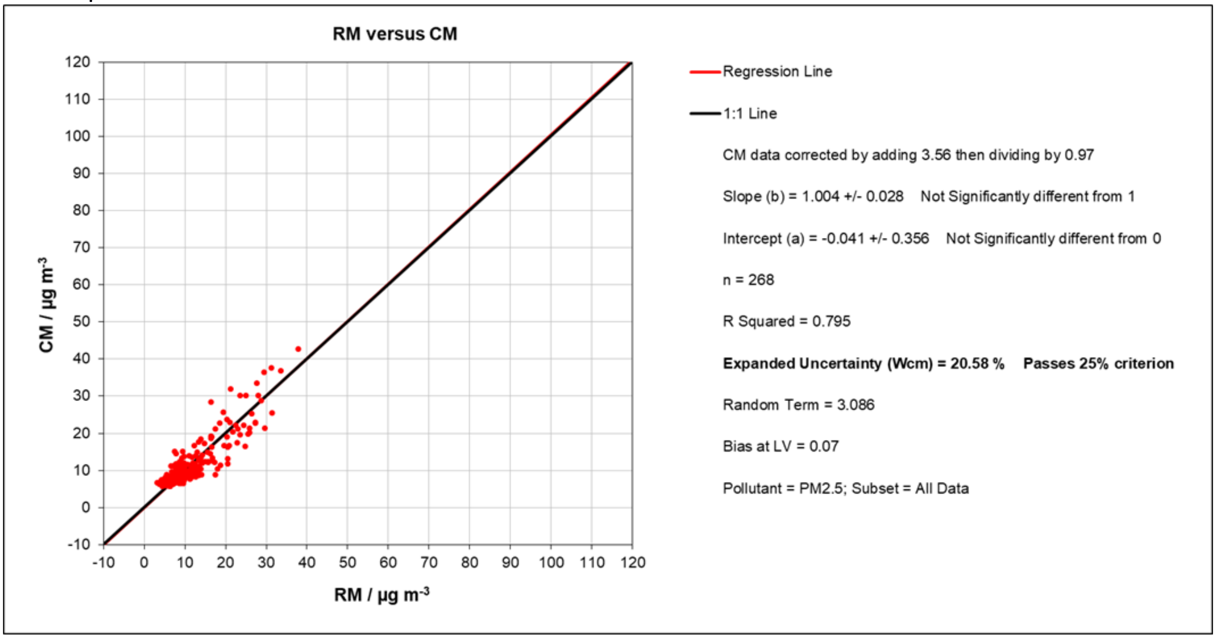
When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an R^2 of 0.80 and an expanded uncertainty of 35%. The bias at the limit value was about -4 µg/m³.

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 µg/m^3 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 µg/m^3 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

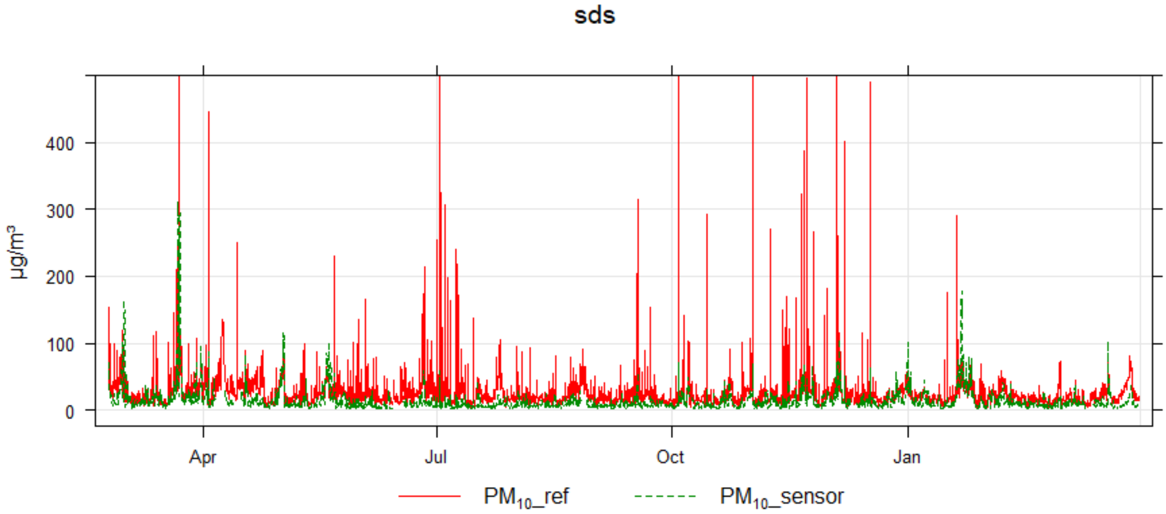


Figure 65: Daily average of all valid Dylos PM_{10} sensor data vs Fidas reference

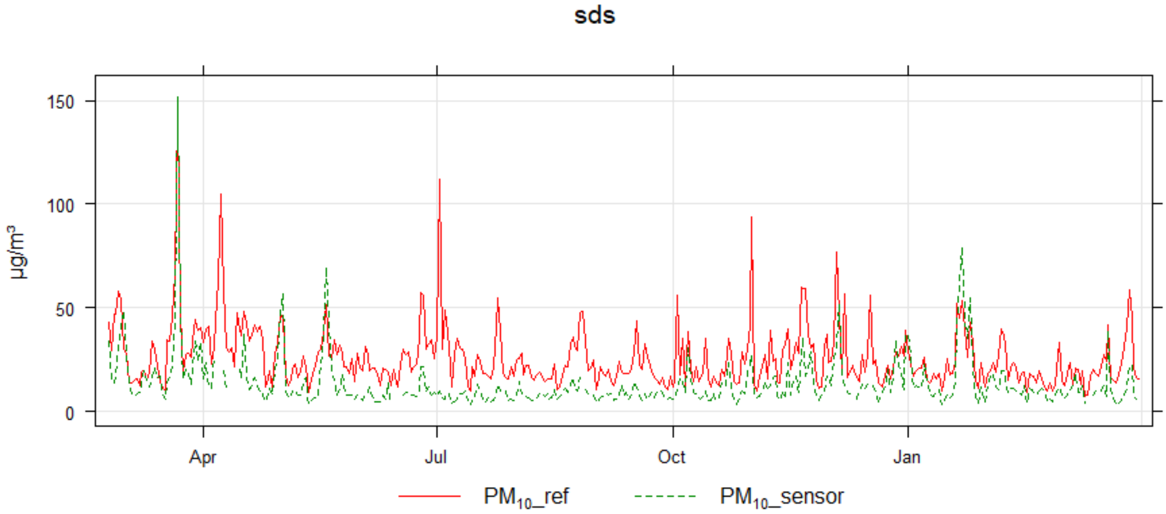
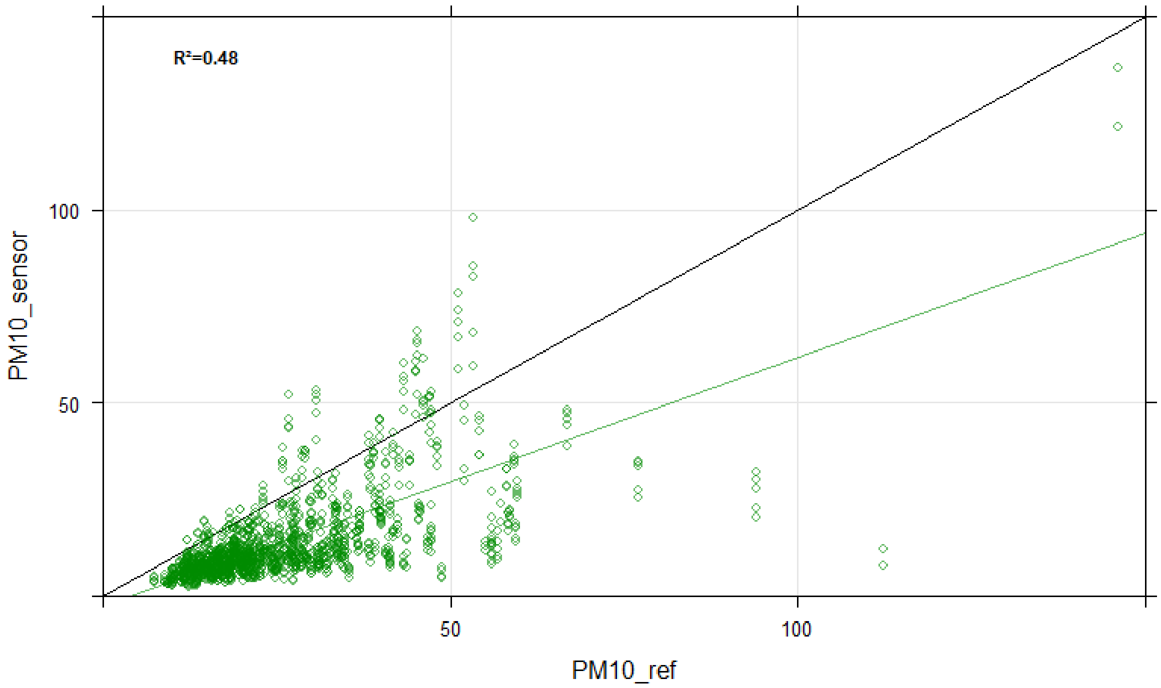


Figure 66: PM_{10} scatterplot for all SDS daily averages in µg/m³



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 µm, but not all.

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

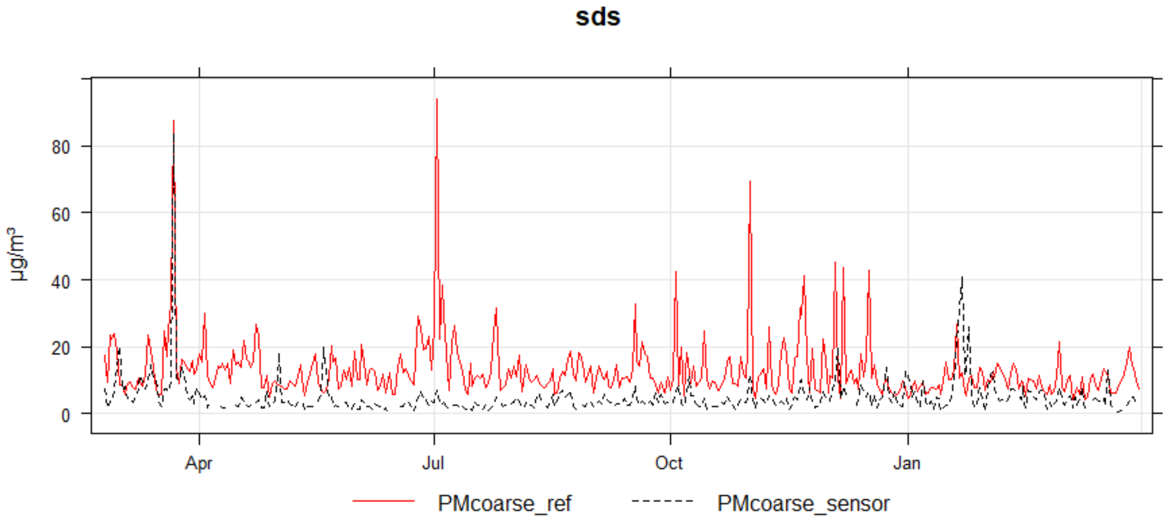
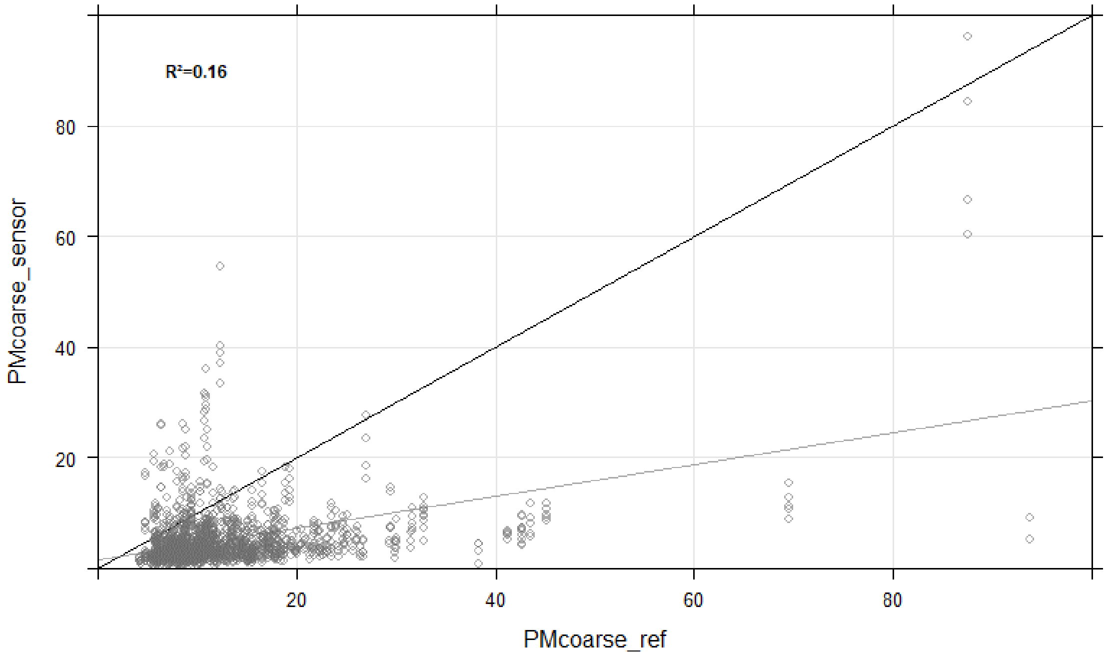
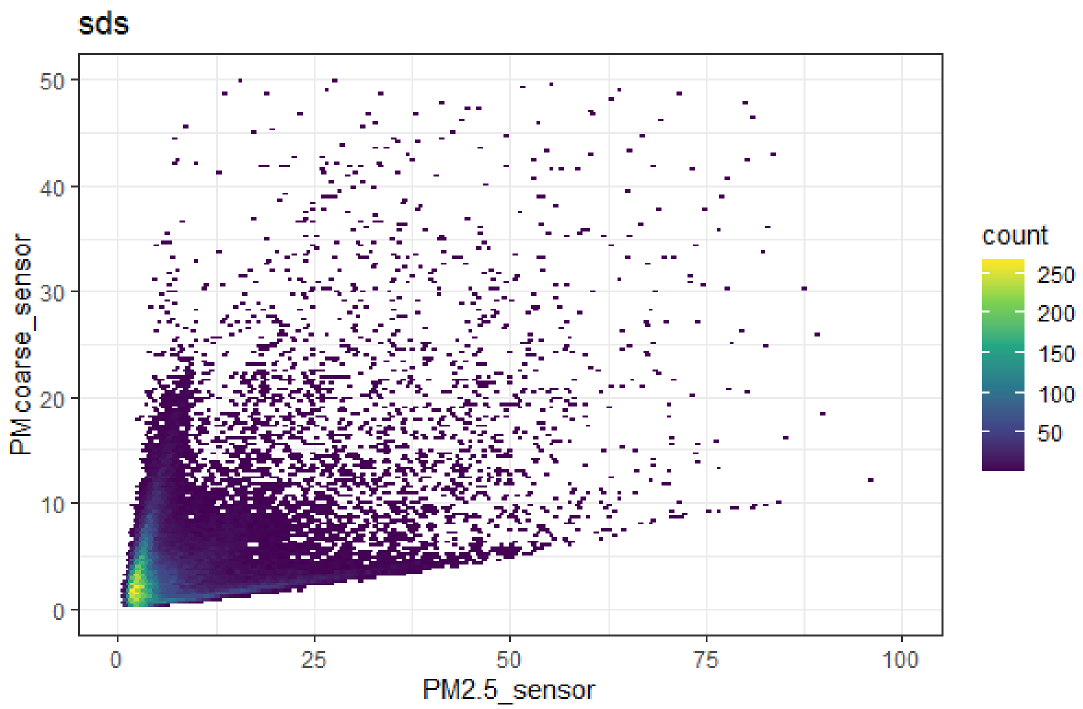


Figure 68: PM_{coarse} scatterplot for all SDS daily averages in µg/m³



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 µg/m³



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 70: Problems with Plantower unit 3 (blue line)

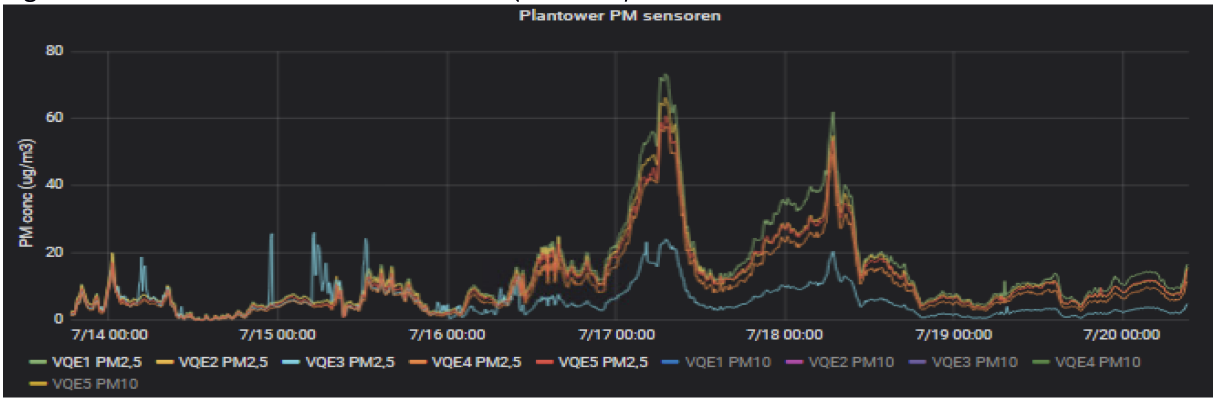


Figure 71: Example of period with elevated signal for Plantower unit 1

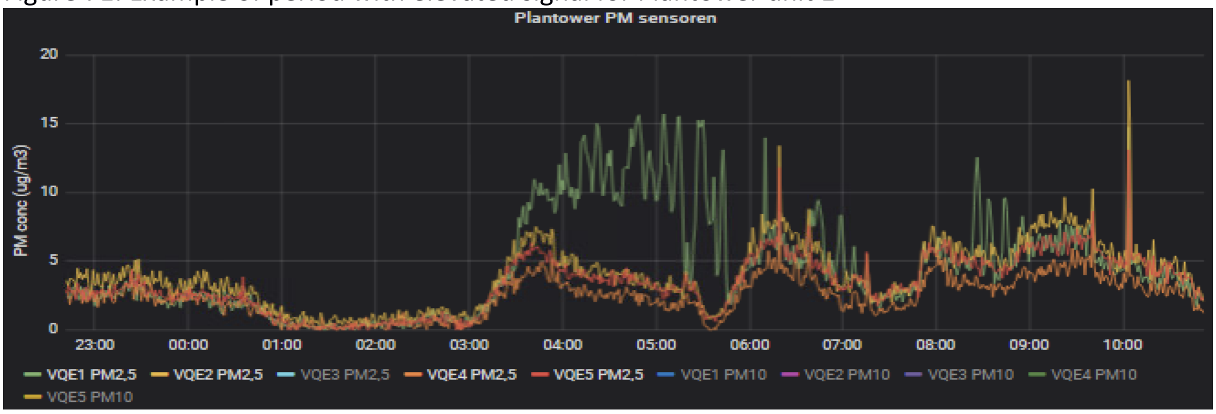
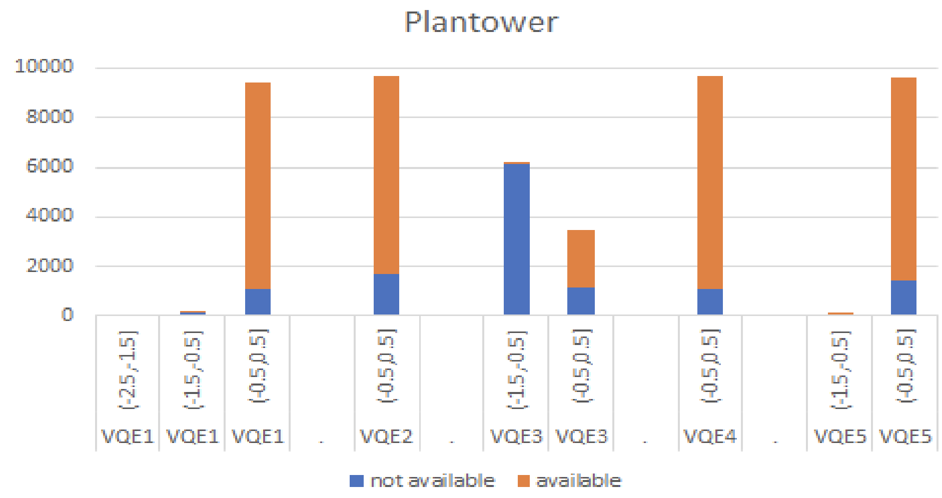


Figure 72: Overview of available hourly data per validation code (-2 :invalid / -1: suspicious /0: valid) for the different units



+$PM_{2.5}$ 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 $PM_{2.5}$ sensor data vs Fidas reference

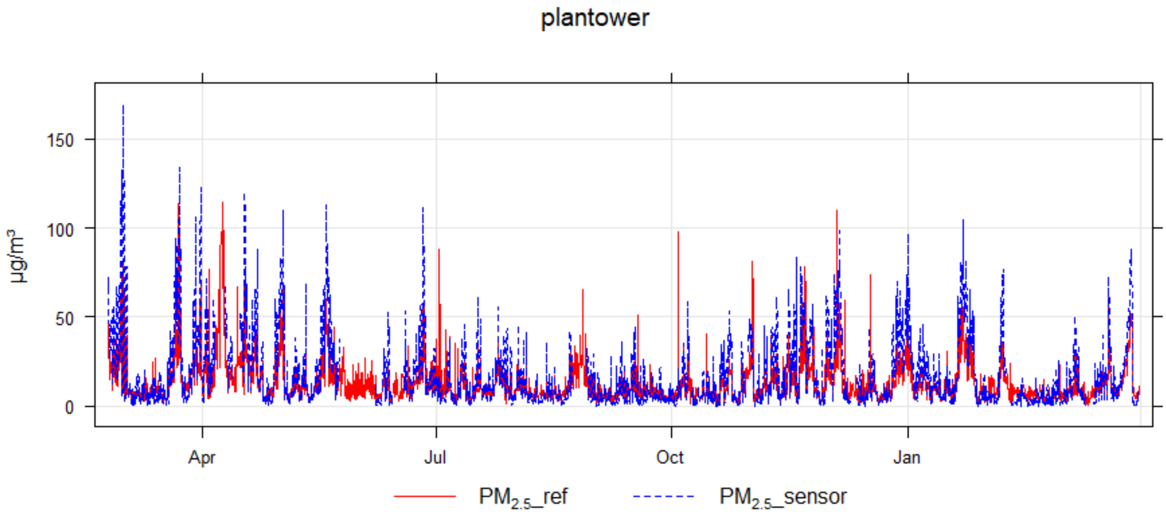


Figure 74: Hourly average of all individual Plantower $PM_{2.5}$ sensor data vs Fidas reference

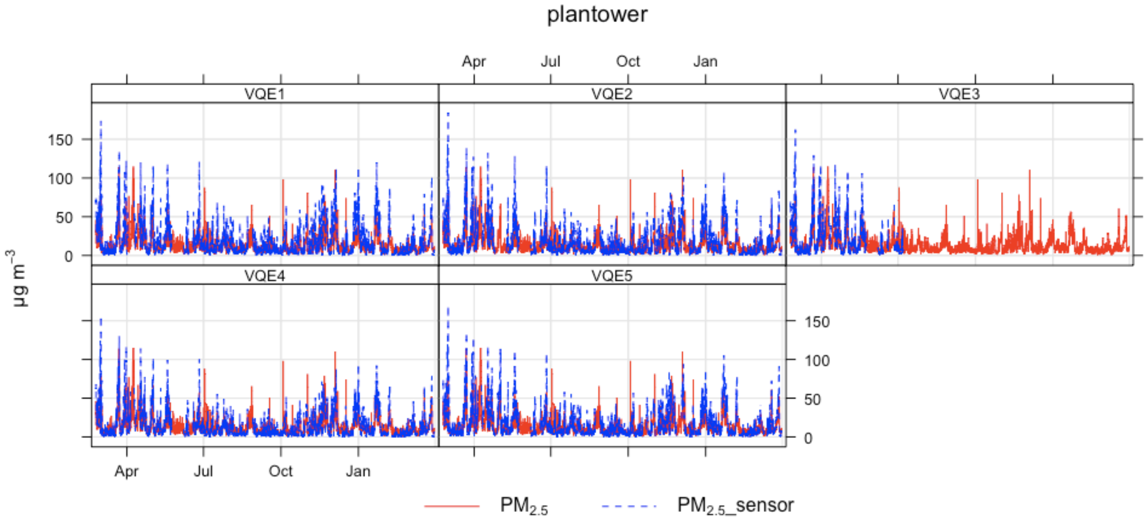


Figure 75: Density plot of all hourly $PM_{2.5}$ Plantower sensor data vs $PM_{2.5}$ Fidas (in µg/m³)

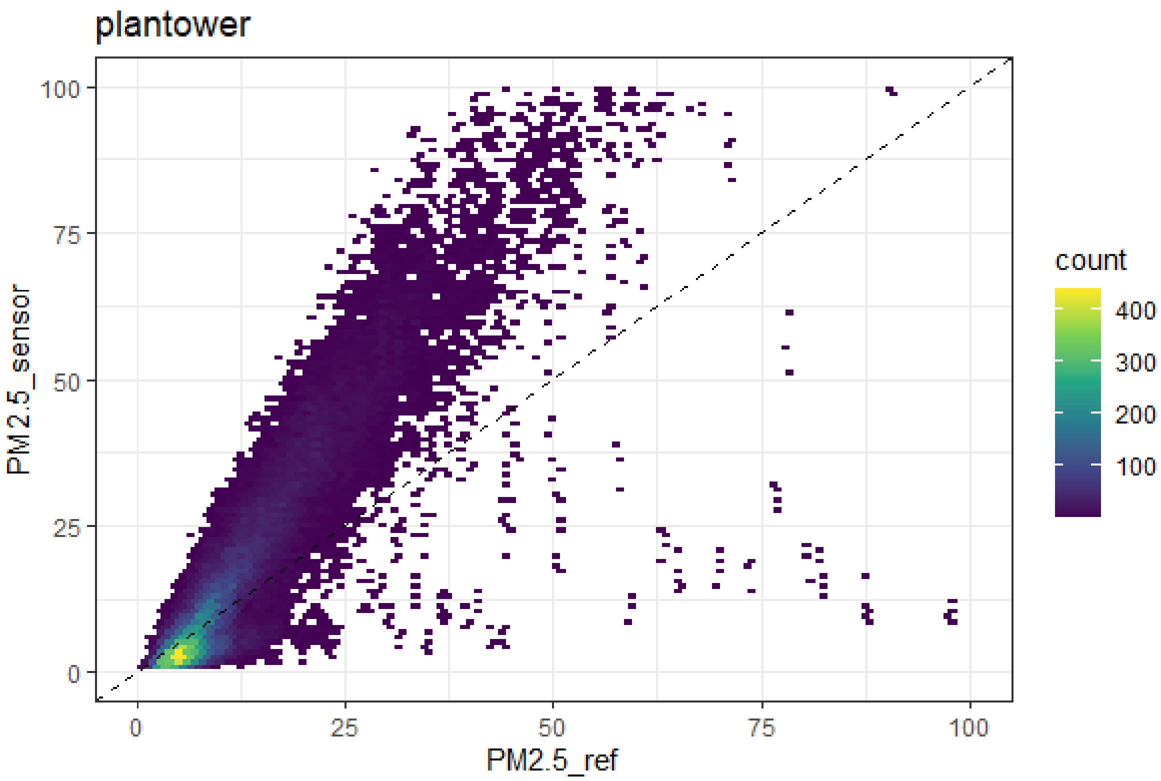


Figure 76: $PM_{2.5}$ scatterplot for all Plantower sensor 5-min averages (left) and all hourly averages (right) in µg/m³

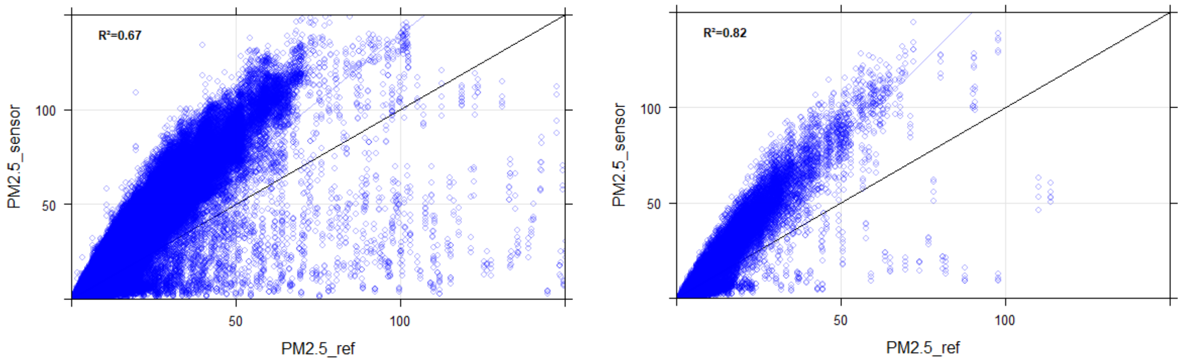
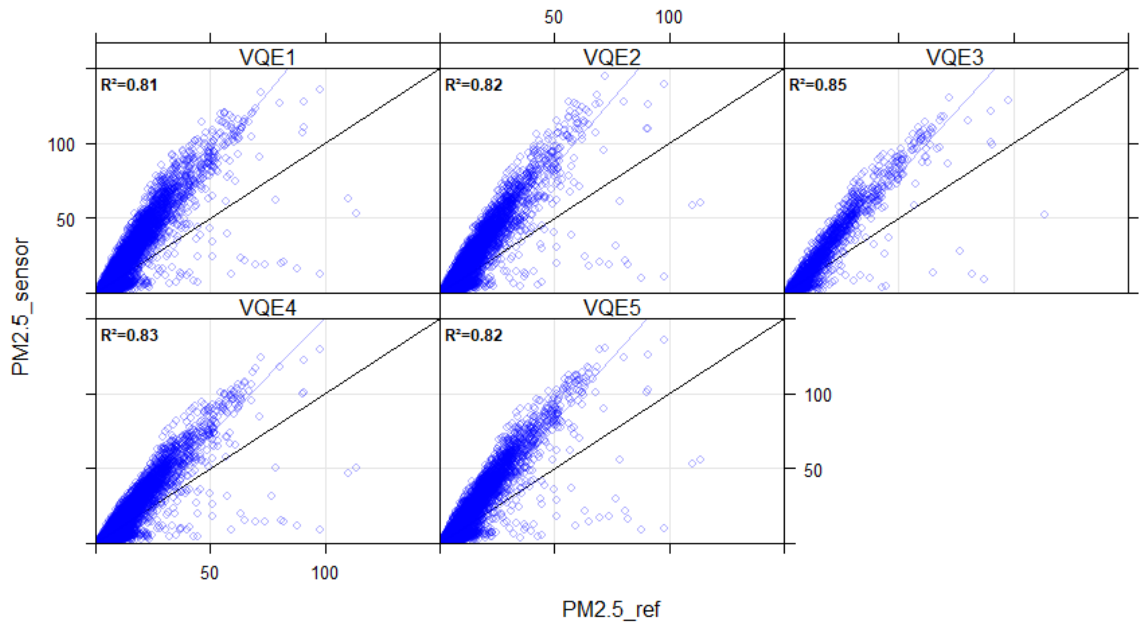
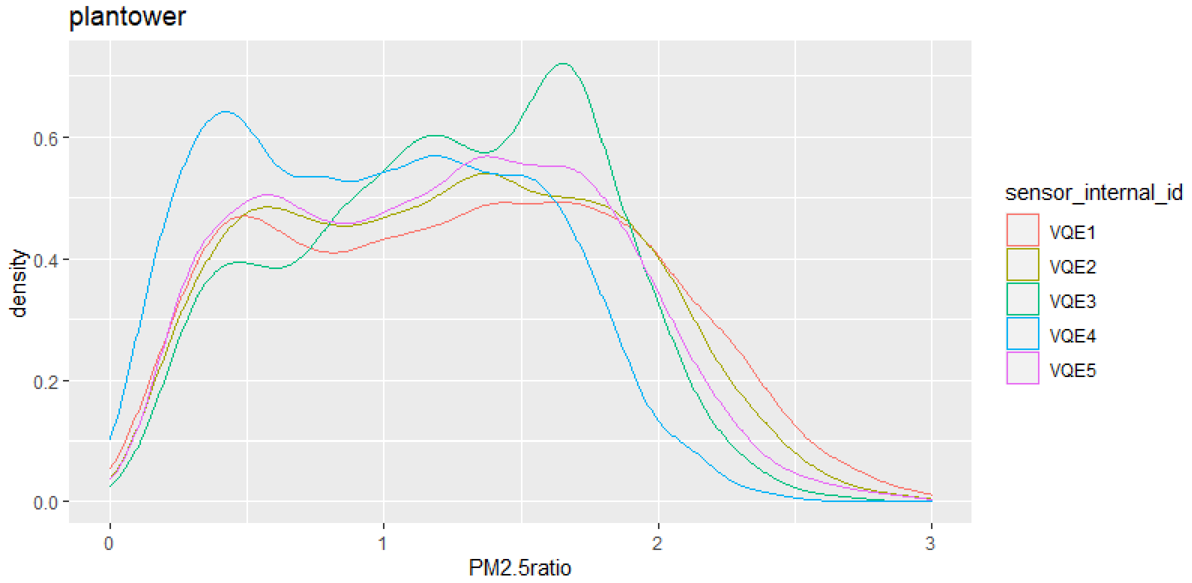


Figure 77: $PM_{2.5}$ scatterplots for hourly Plantower averages per sensor in µg/m³



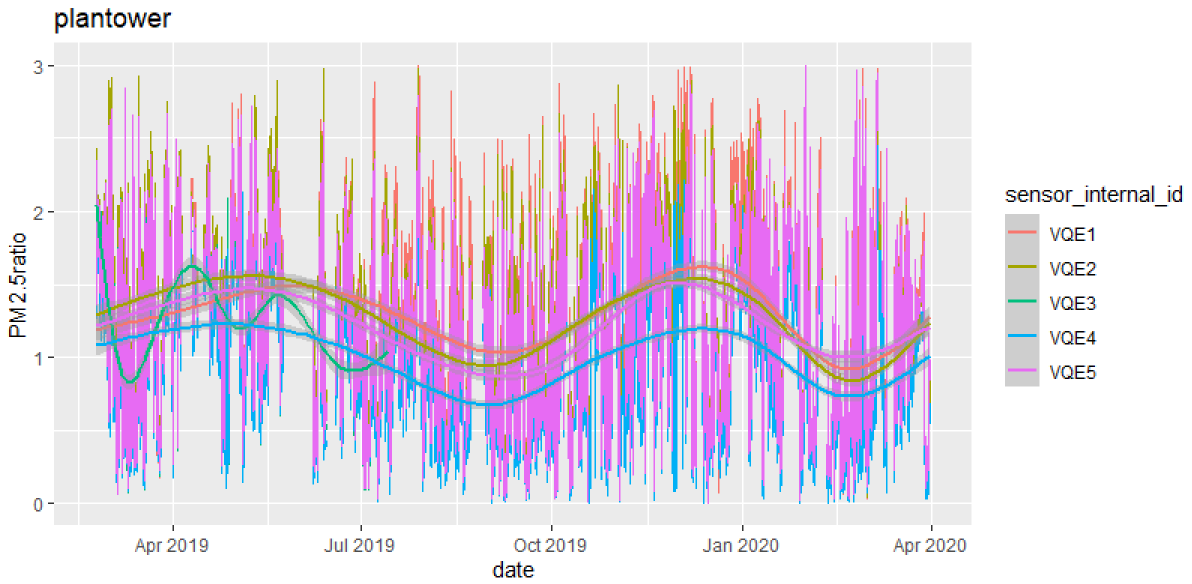
The sensor/Fidas ratios appear to show some sort of bi-modal pattern. This could just be translation of the relation between the Plantower and the Fidas where the Plantower does underestimate the lower concentrations but overestimates the higher concentrations. Unit 4 appears to give a somewhat lower 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



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

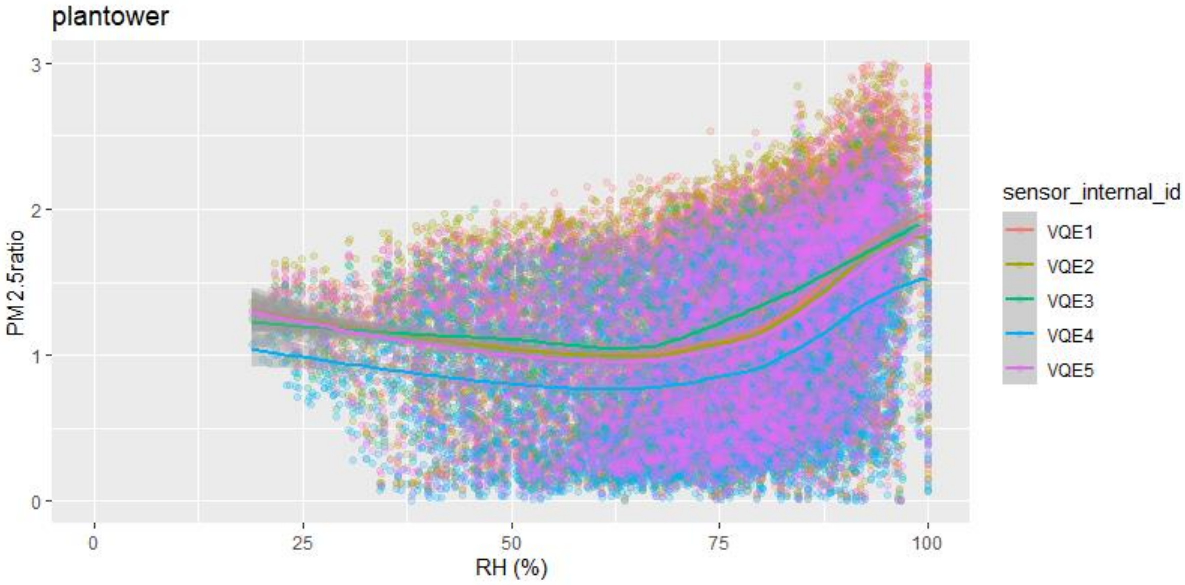
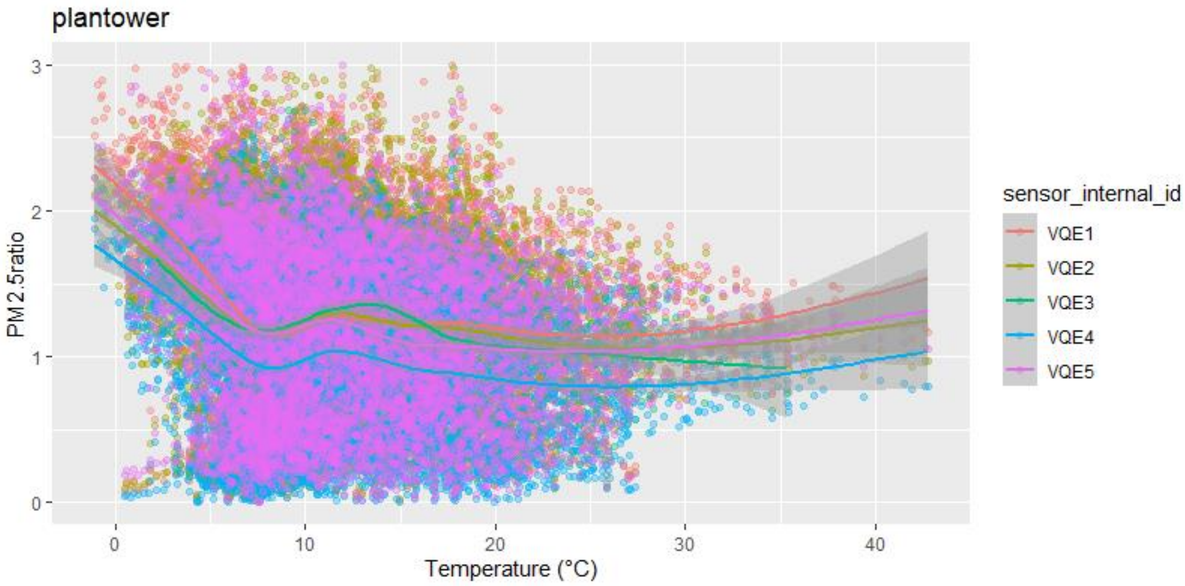


Figure 81: Hourly $PM_{2.5}$ ratio (Plantower sensor/Fidas) in function of temperature



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

Figure 82: Daily average of all valid Plantower $PM_{2.5}$ sensor data vs Fidas reference

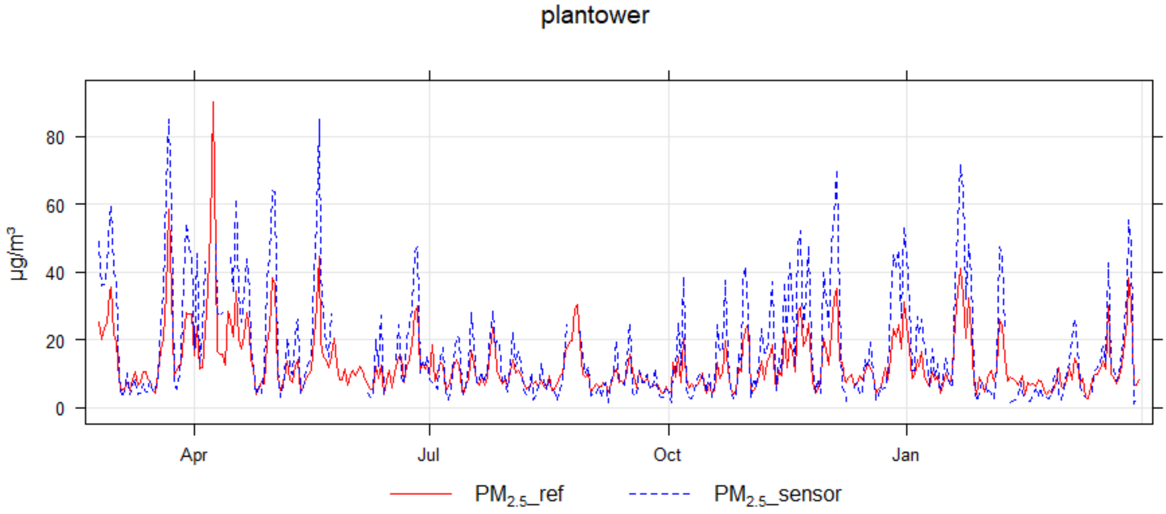
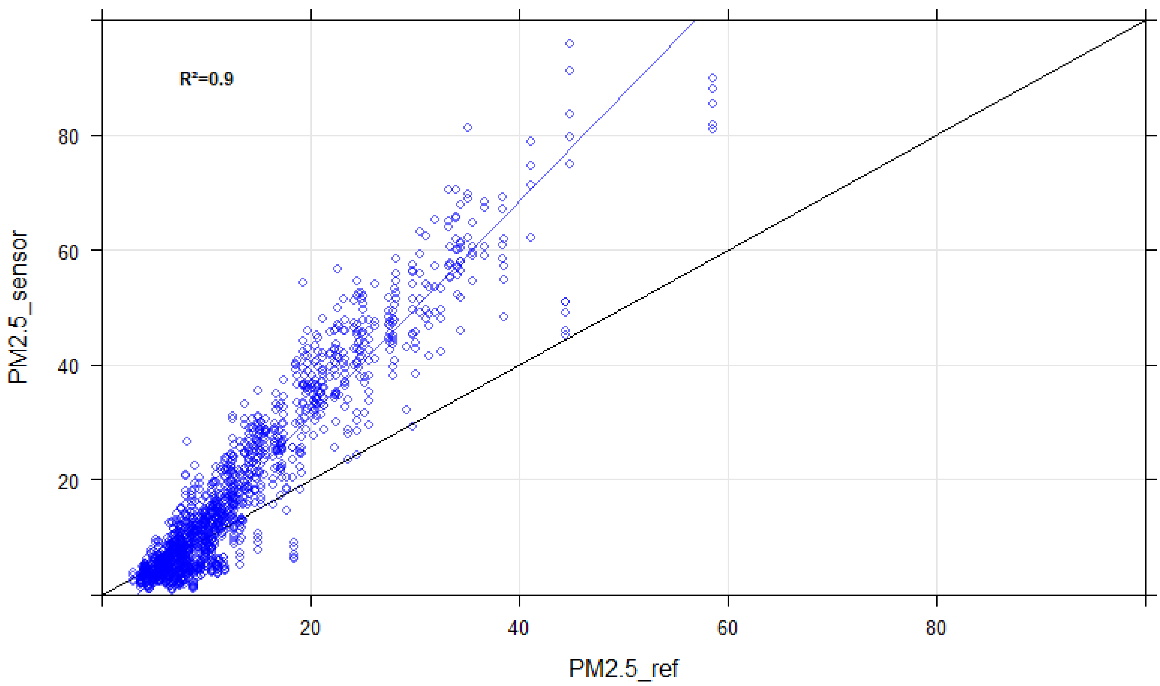


Figure 83: $PM_{2.5}$ scatterplot for all Plantower daily averages in µg/m³



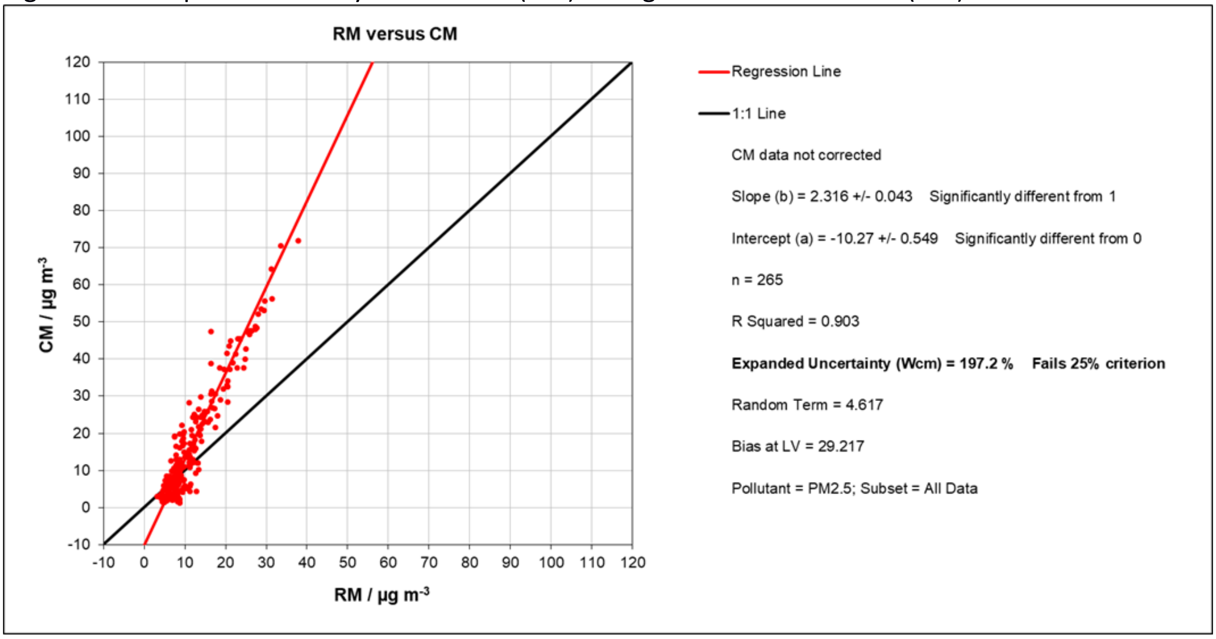
+$PM_{2.5}$ 95% confidence interval around 30 µg/m³

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

+$PM_{2.5}$ comparison with gravimetric reference

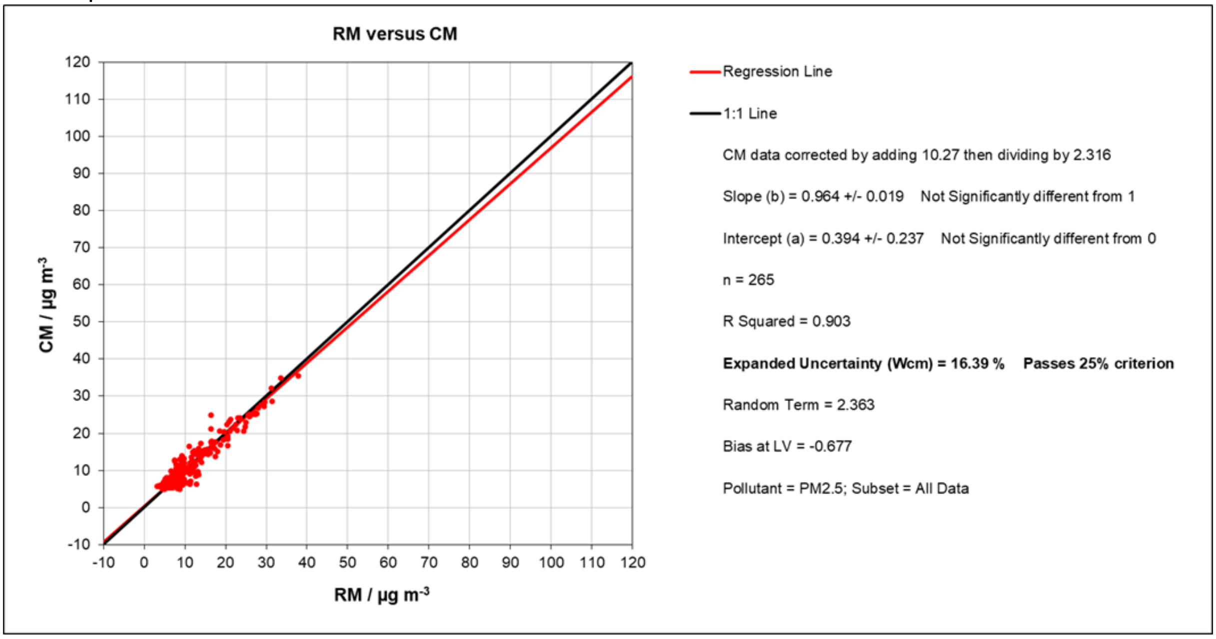
When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an R^2 of 0.90 and an expanded uncertainty of 197%. The bias at the limit value was about 29 µg/m³.

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 µg/m^3 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 µg/m^3 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 PM_{10} sensor data vs Fidas reference

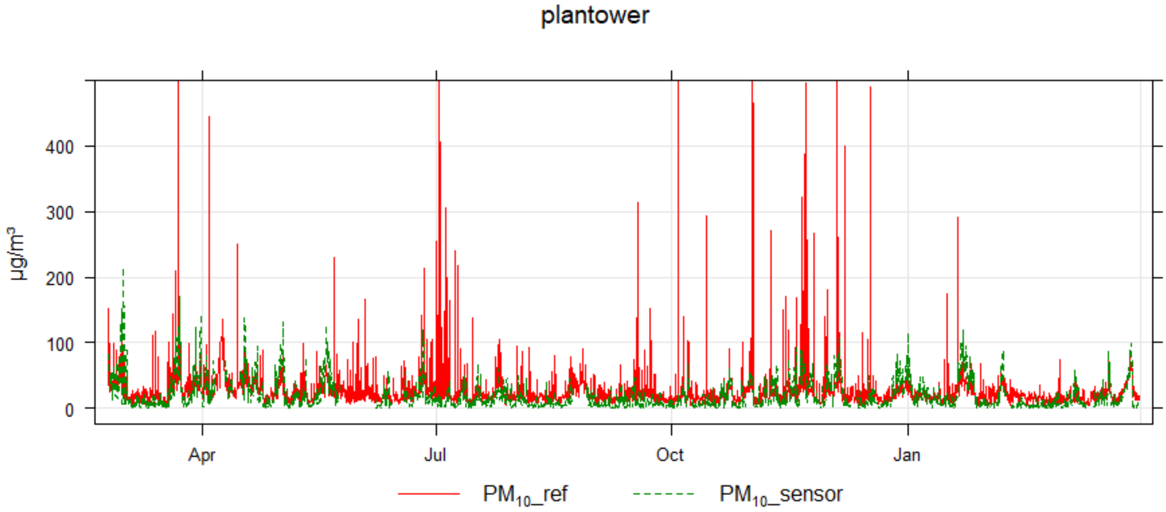


Figure 87: Dailyy average of all valid Plantower PM_{10} sensor data vs Fidas reference

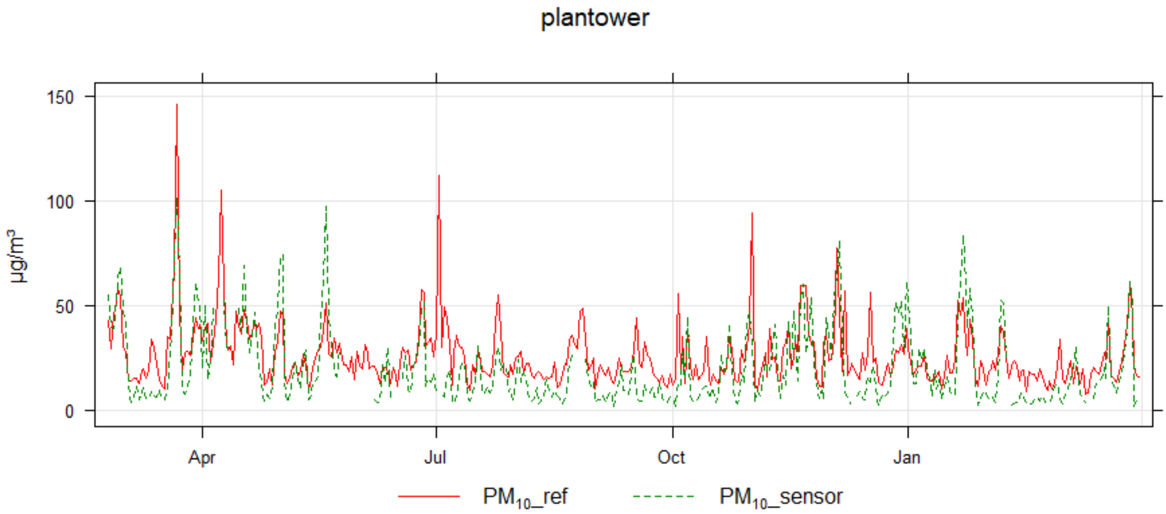
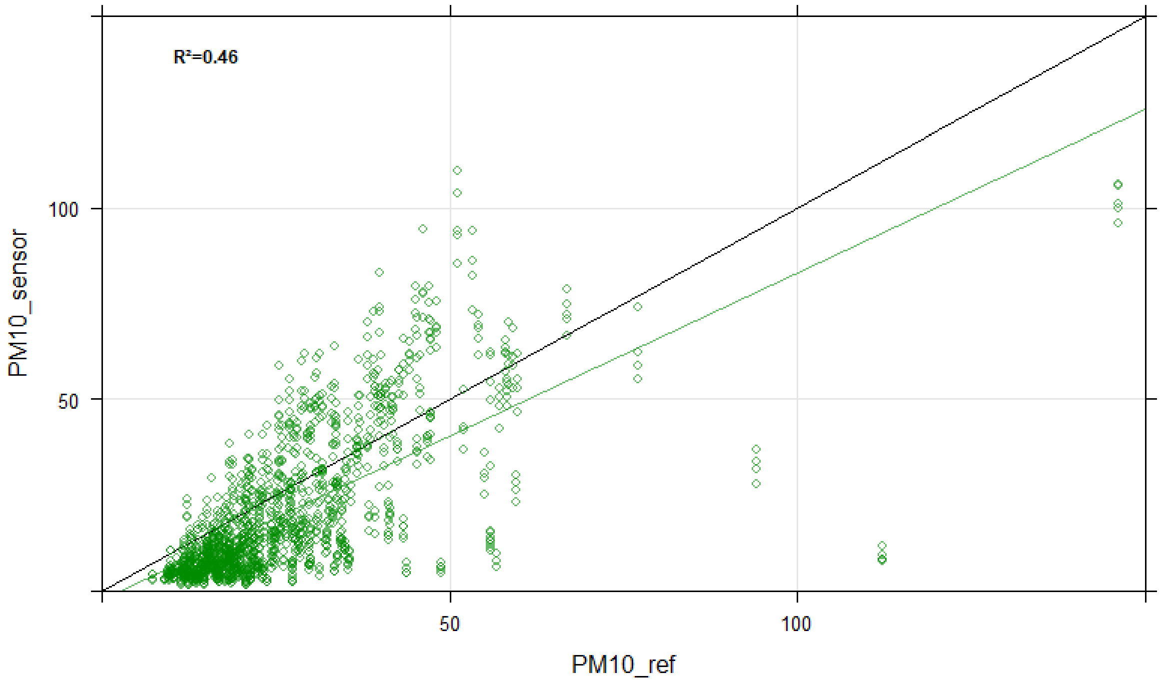


Figure 88: PM_{10} scatterplot for all Plantower daily averages in µg/m³



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

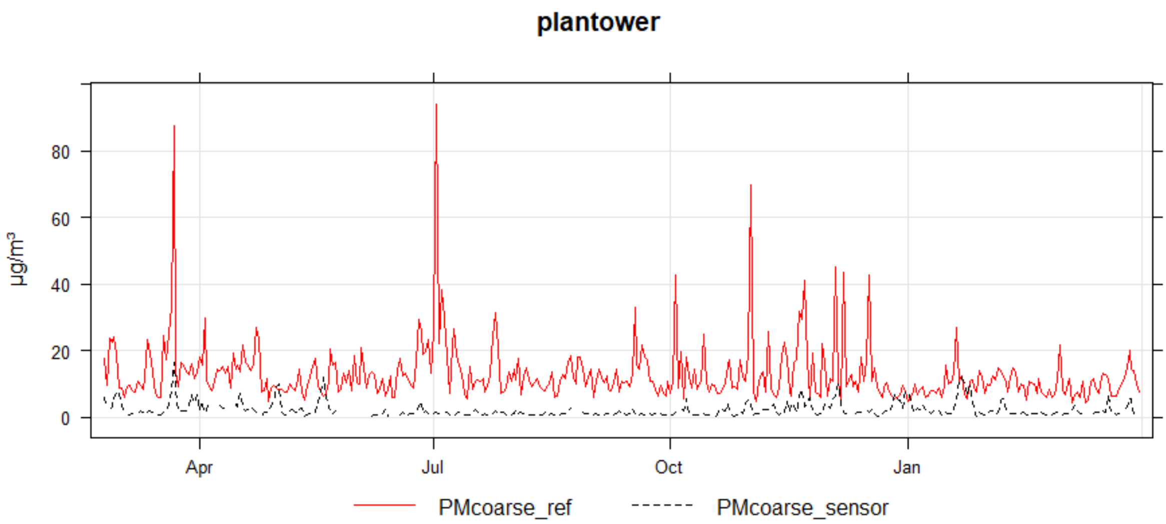
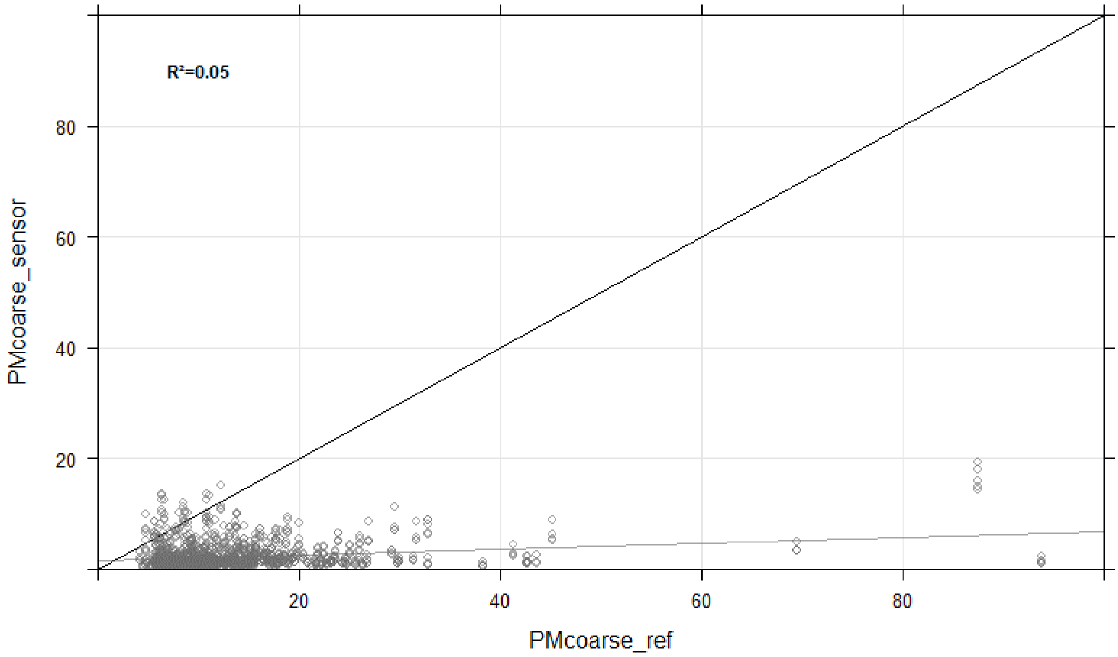
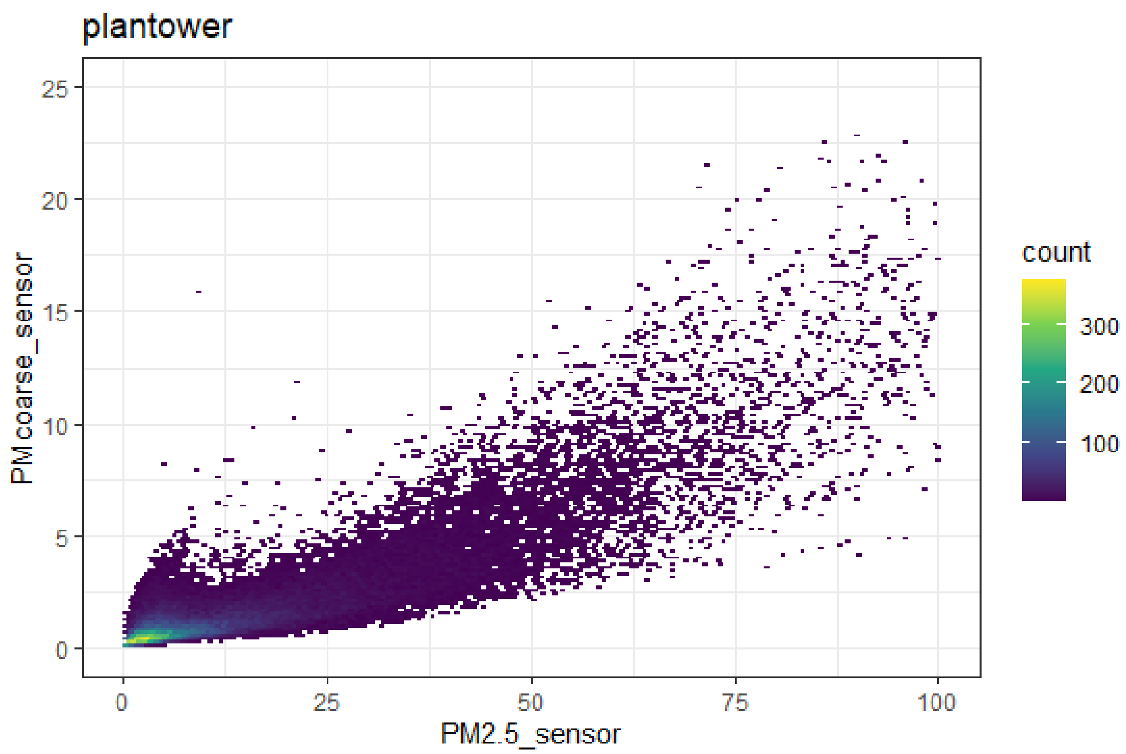


Figure 90: PM_{coarse} scatterplot for all Plantower daily averages in µg/m³



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 µg/m³



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

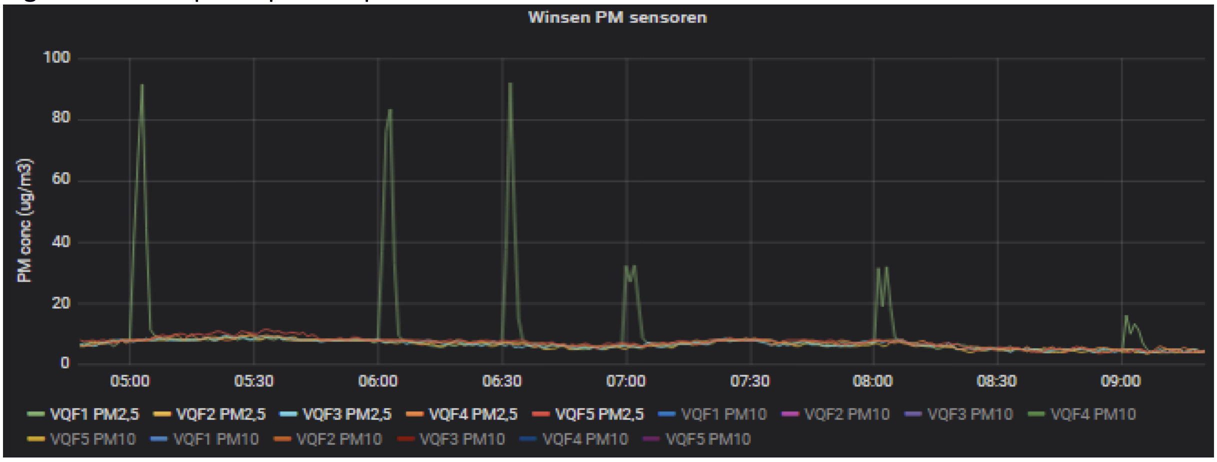


Figure 93: Periods of elevated signal starting around noon for Winsen unit 2

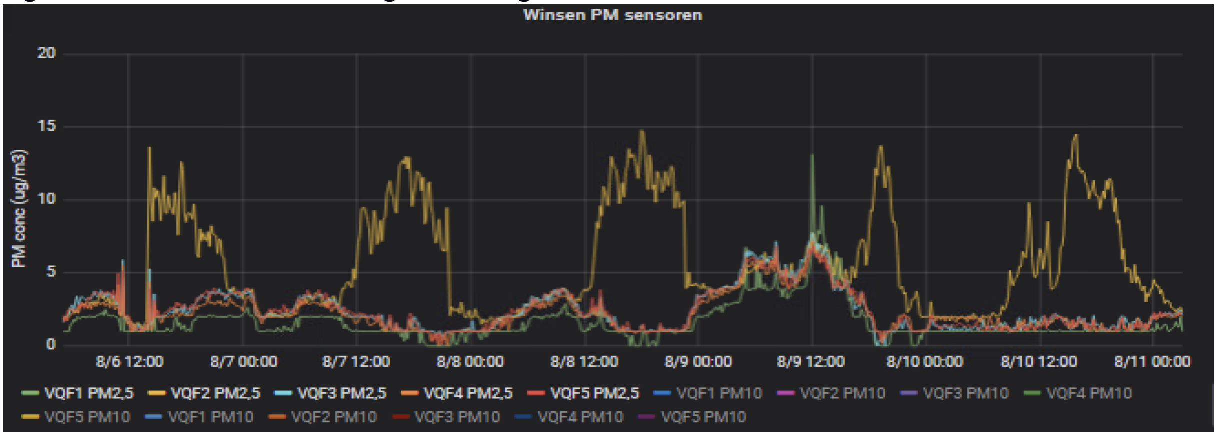
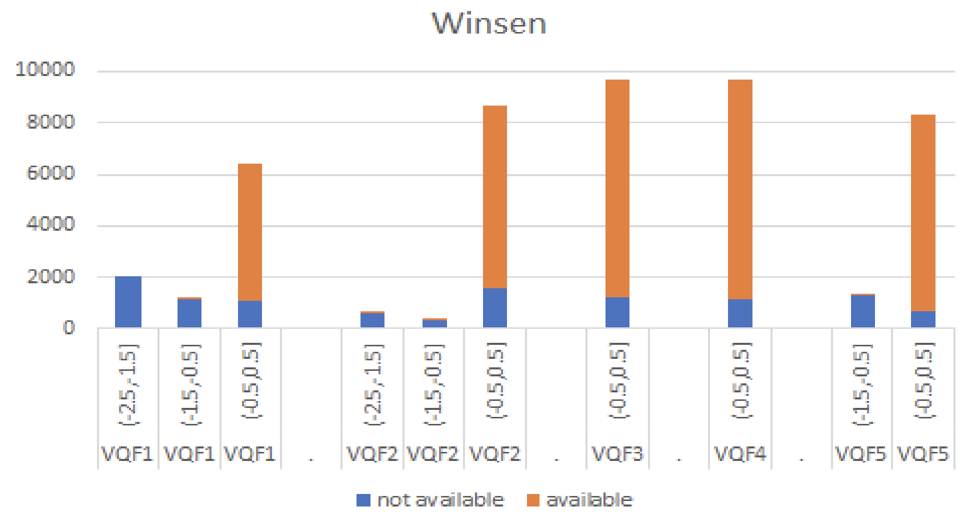


Figure 94: Overview of available hourly data per validation code (-2 :invalid / -1: suspicious /0: valid) for the different units



+$PM_{2.5}$ 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

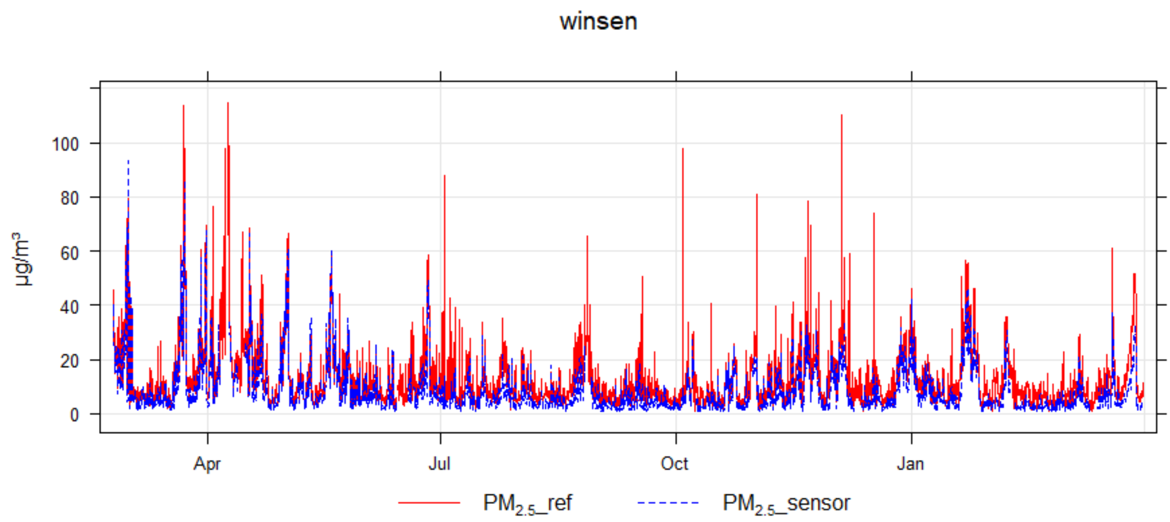


Figure 96: Hourly average of all individual Winsen $PM_{2.5}$ sensor data vs Fidas reference

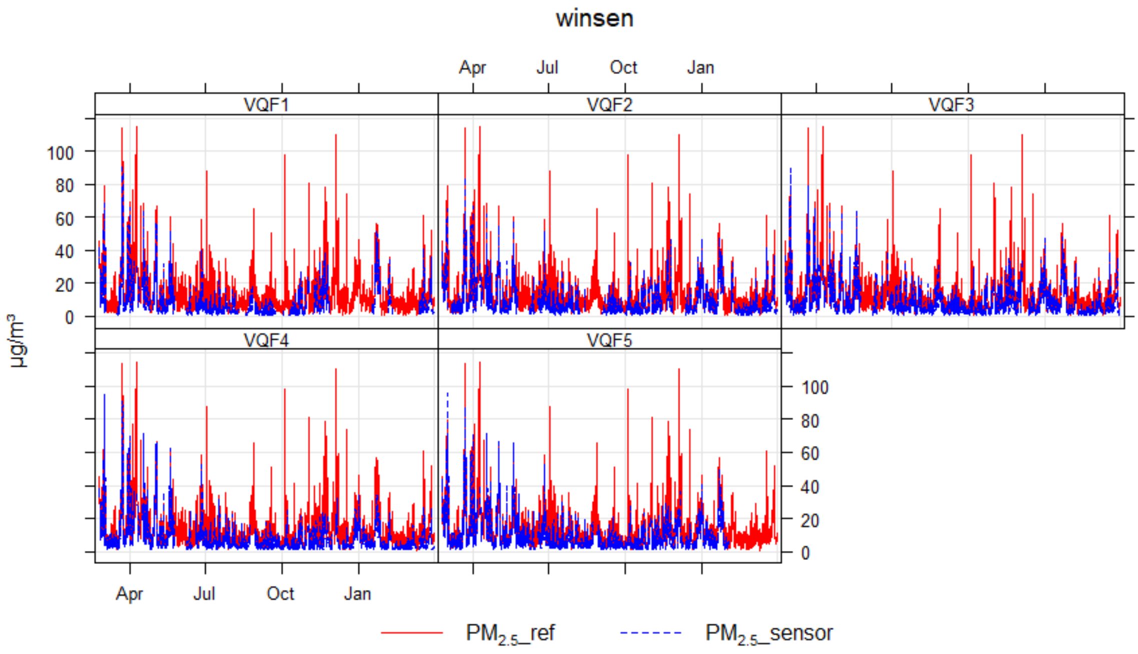


Figure 97: Density plot of all hourly $PM_{2.5}$ Winsen sensor data vs $PM_{2.5}$ Fidas (in µg/m³)

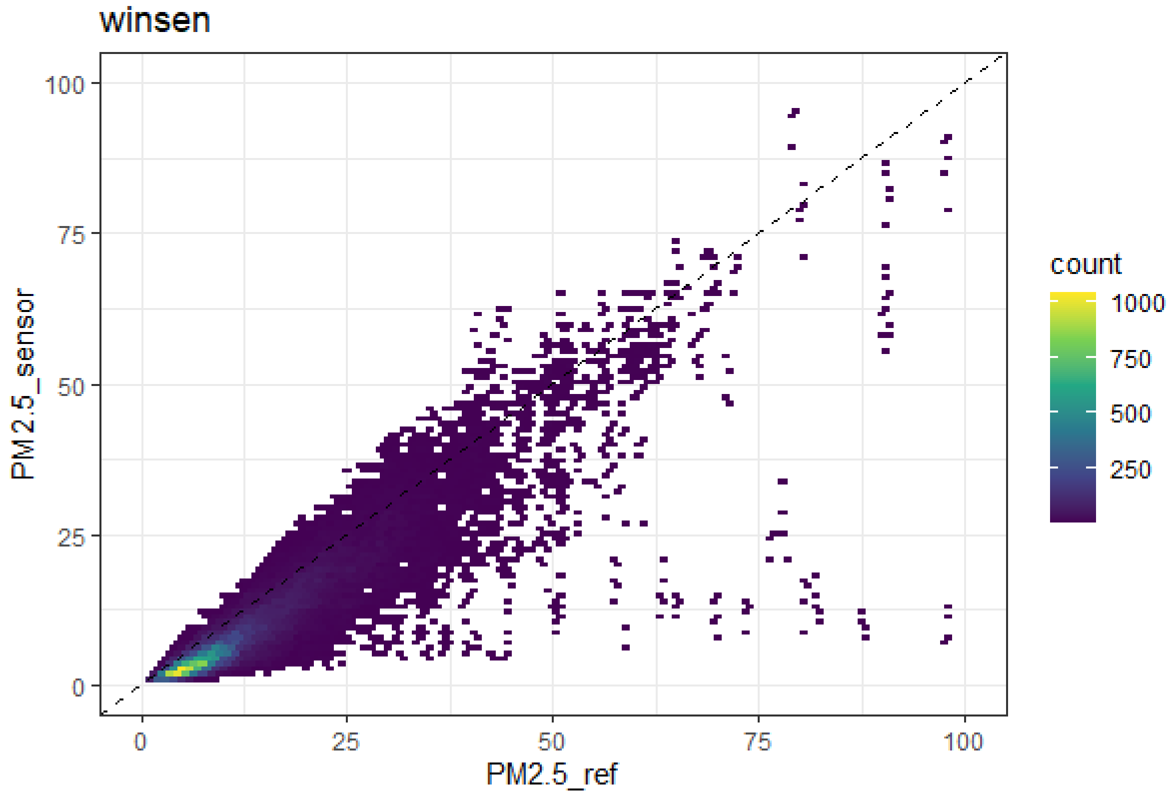


Figure 98: $PM_{2.5}$ scatterplot for all Winsen sensor 5-min averages (left) and all hourly averages (right) in µg/m³

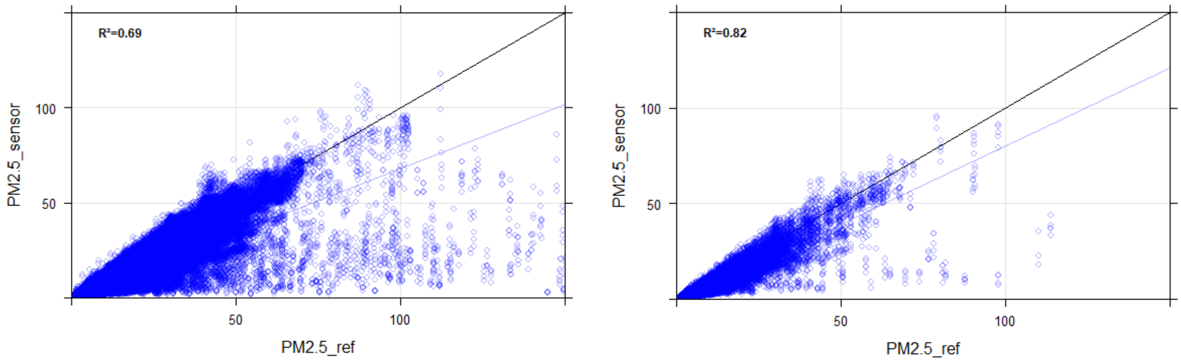
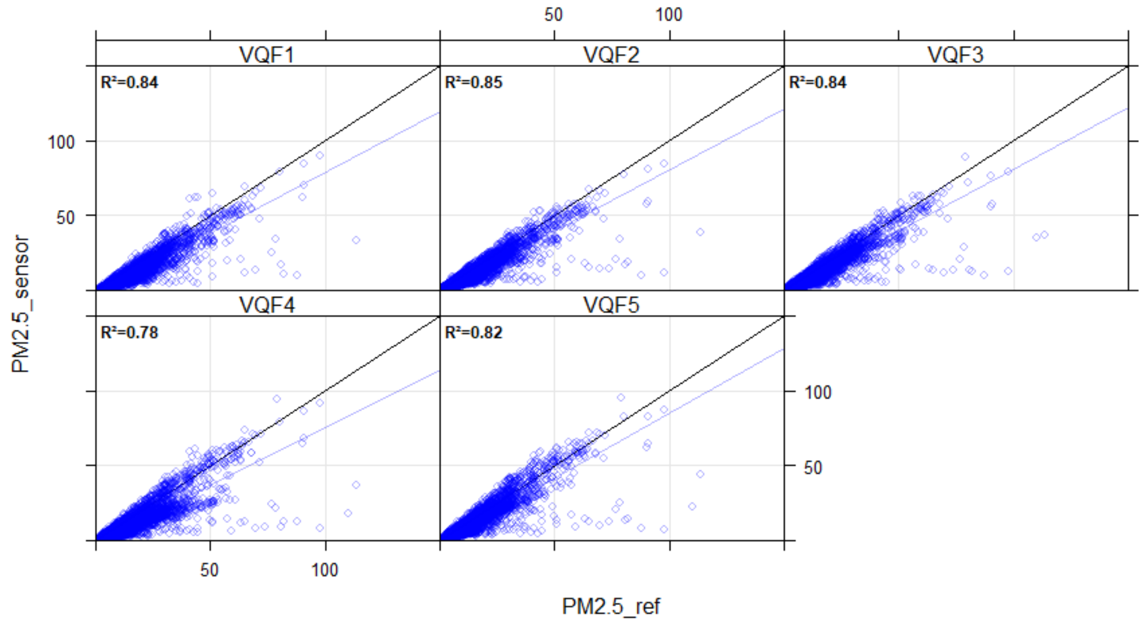
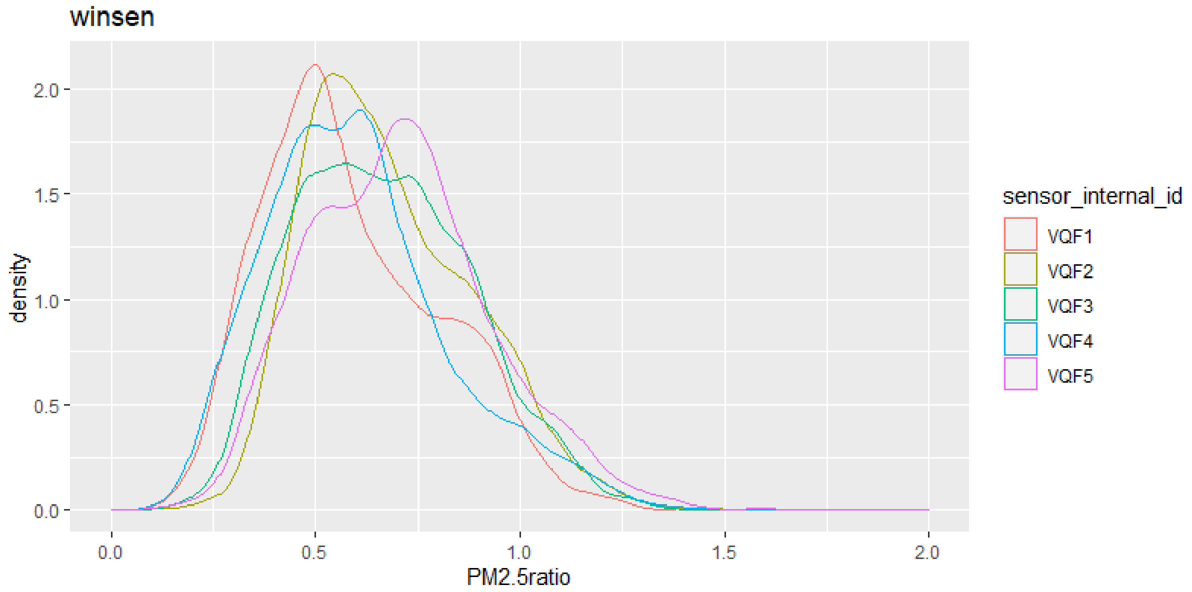


Figure 99: $PM_{2.5}$ scatterplots for hourly Winsen averages per sensor in µg/m³



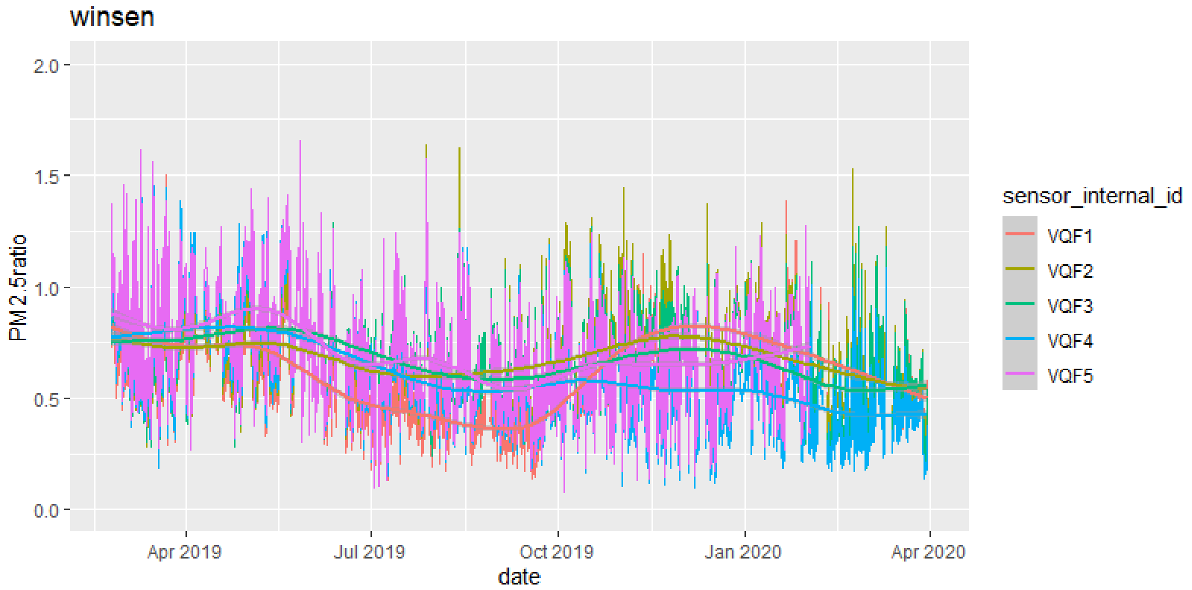
The sensor/Fidas ratios also show the general underestimation and relatively good comparability between the different units.

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 $PM_{2.5}$ 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

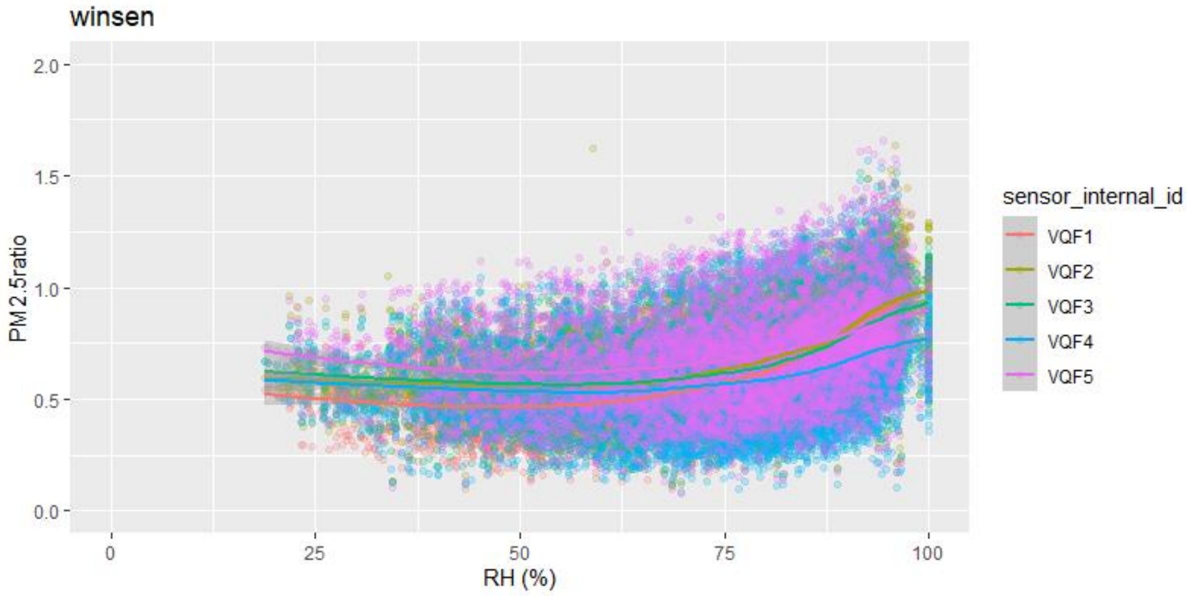
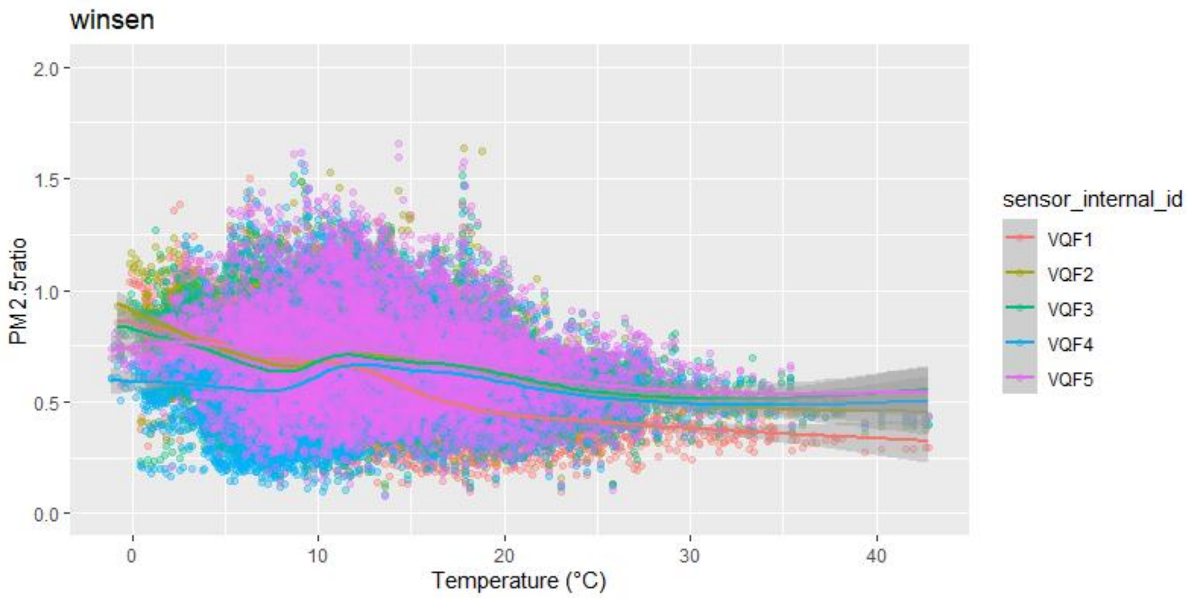


Figure 103: Hourly $PM_{2.5}$ ratio (Winsen sensor/Fidas) in function of temperature



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

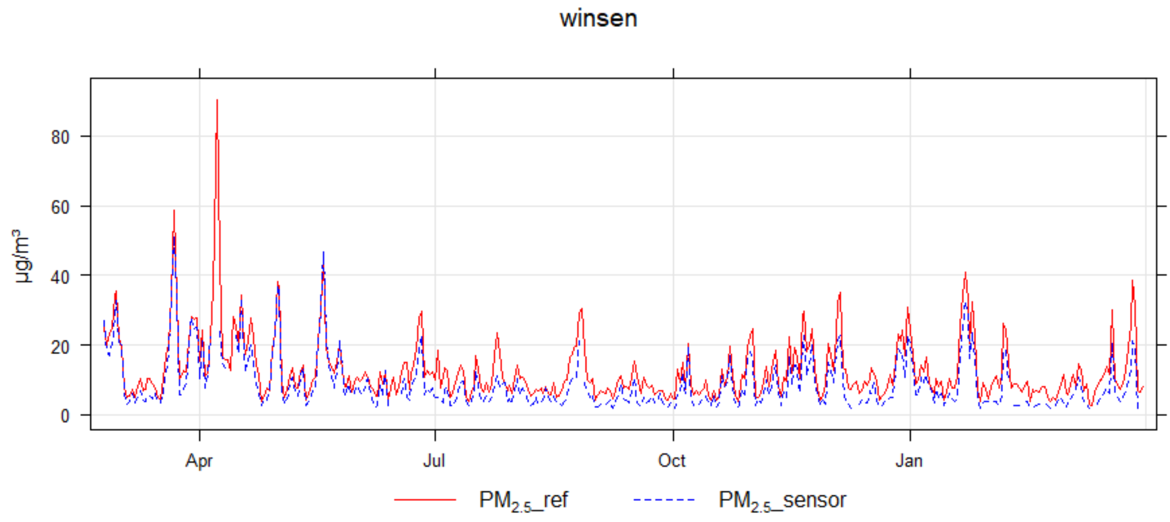
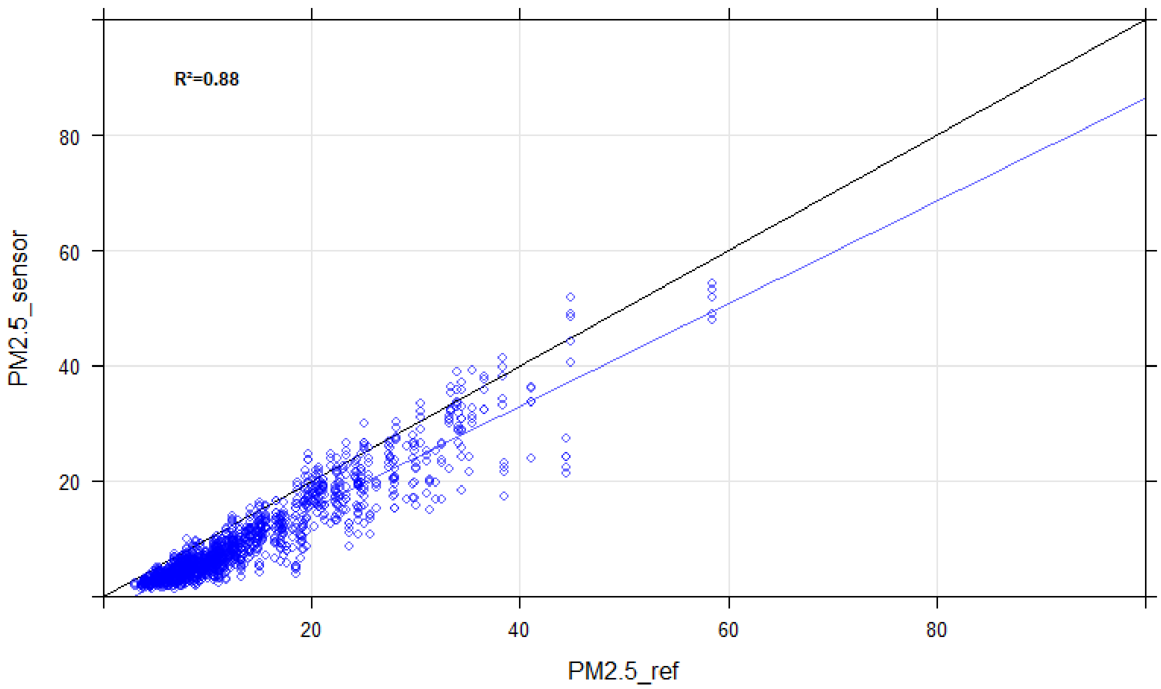


Figure 105: $PM_{2.5}$ scatterplot for all Winsen daily averages in µg/m³



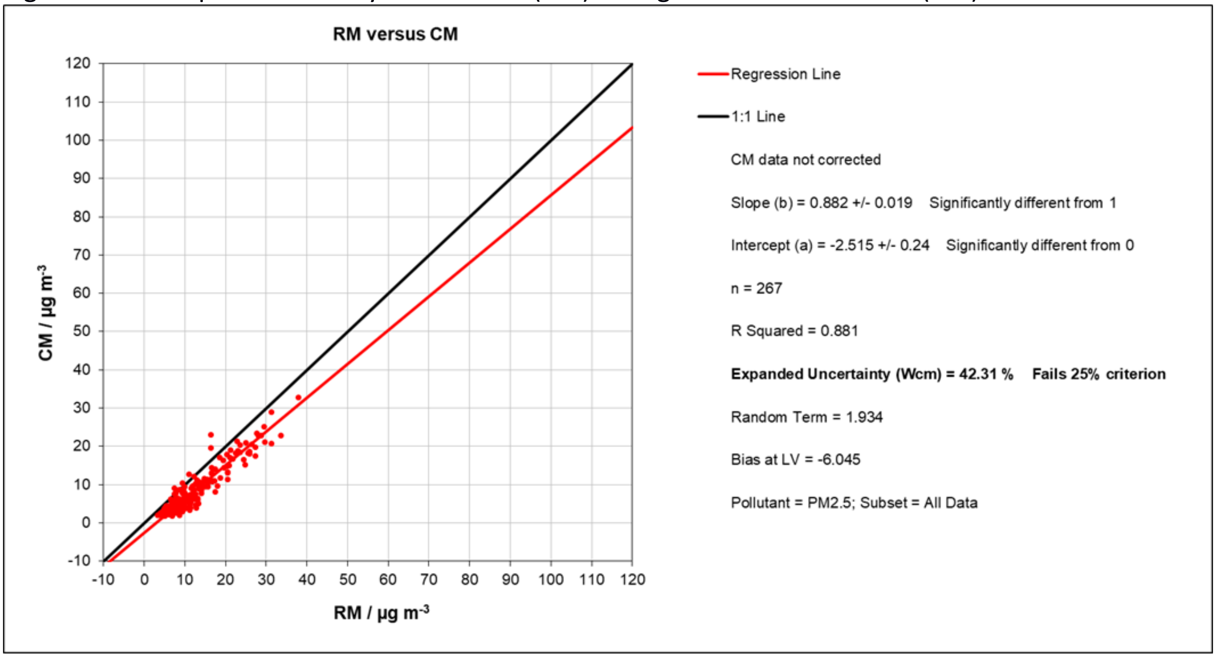
+$PM_{2.5}$ 95% confidence interval around 30 µg/m³

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

+$PM_{2.5}$ comparison with gravimetric reference

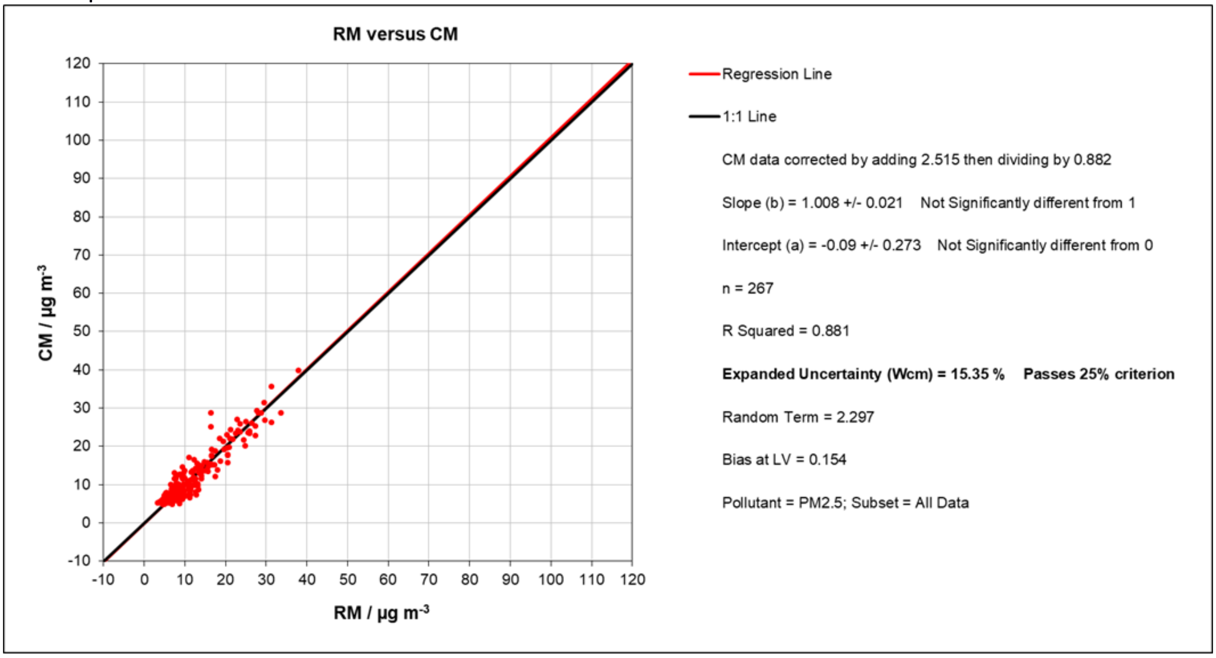
When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an R^2 of 0.88 and an expanded uncertainty of 42%. The bias at the limit value was about -6 µg/m³.

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 µg/m^3 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 µg/m^3 or 15.7%.

+PM_{10} 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 PM_{10} sensor data vs Fidas reference

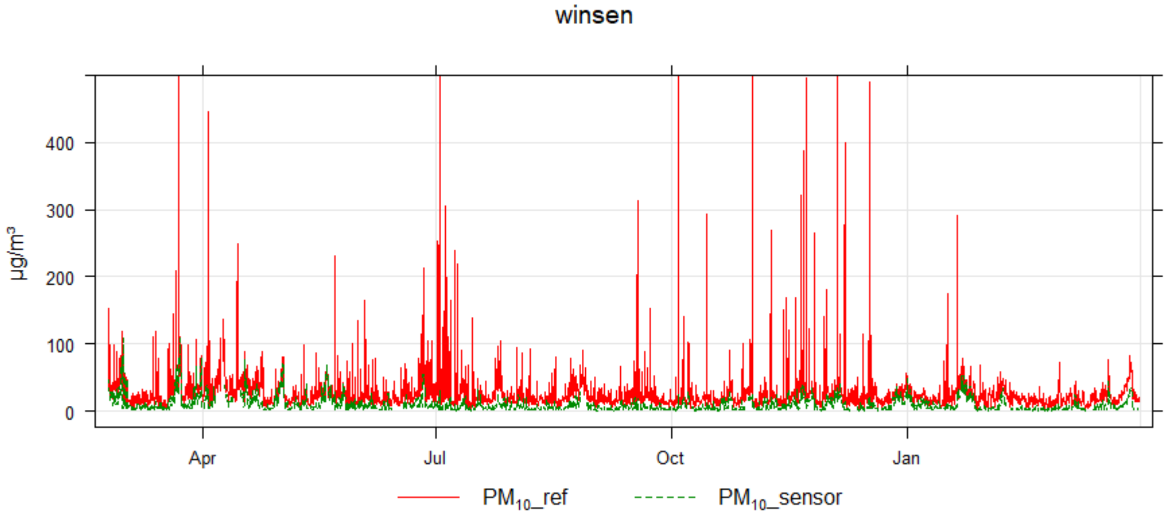


Figure 109: Daily average of all valid Winsen PM_{10} sensor data vs Fidas reference

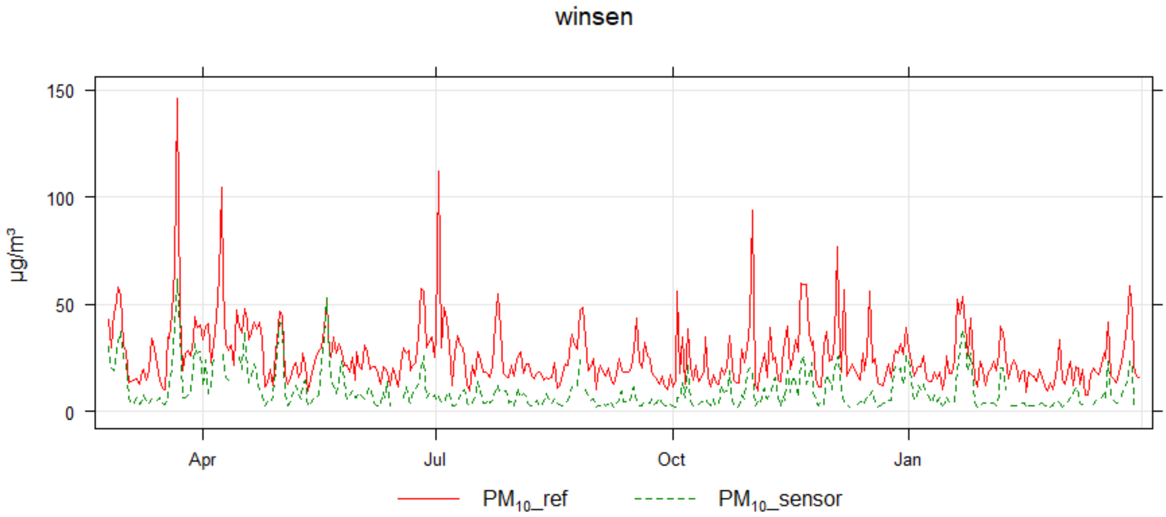
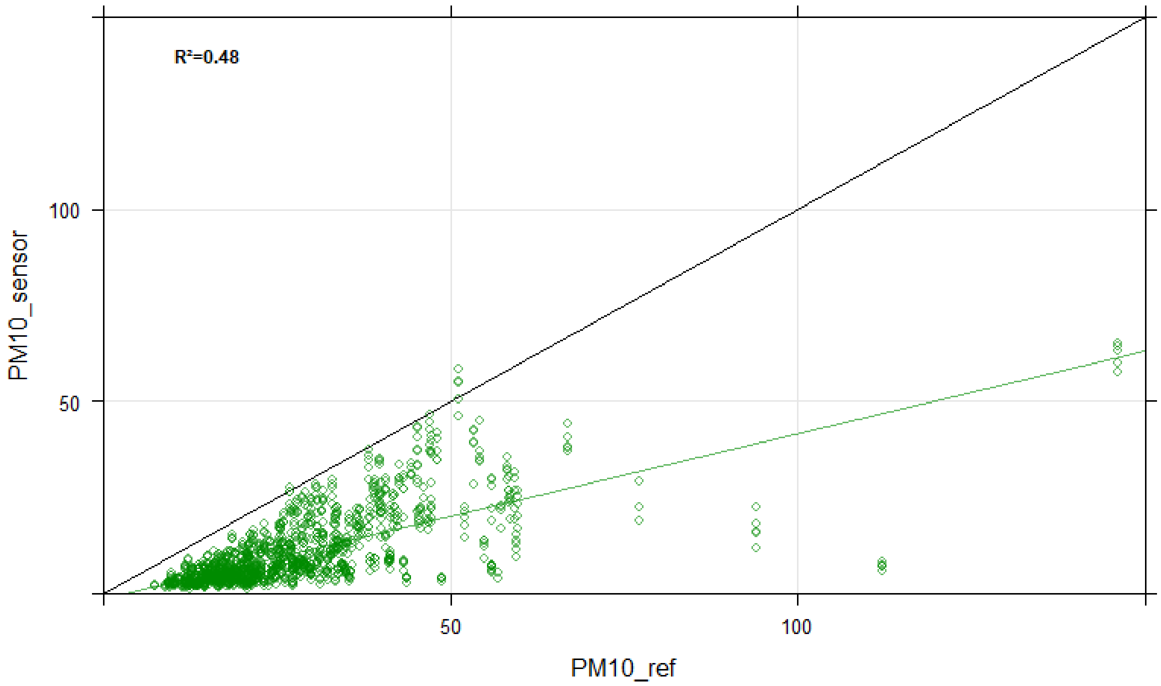


Figure 110: PM_{10} scatterplot for all Dylos daily averages in µg/m³



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

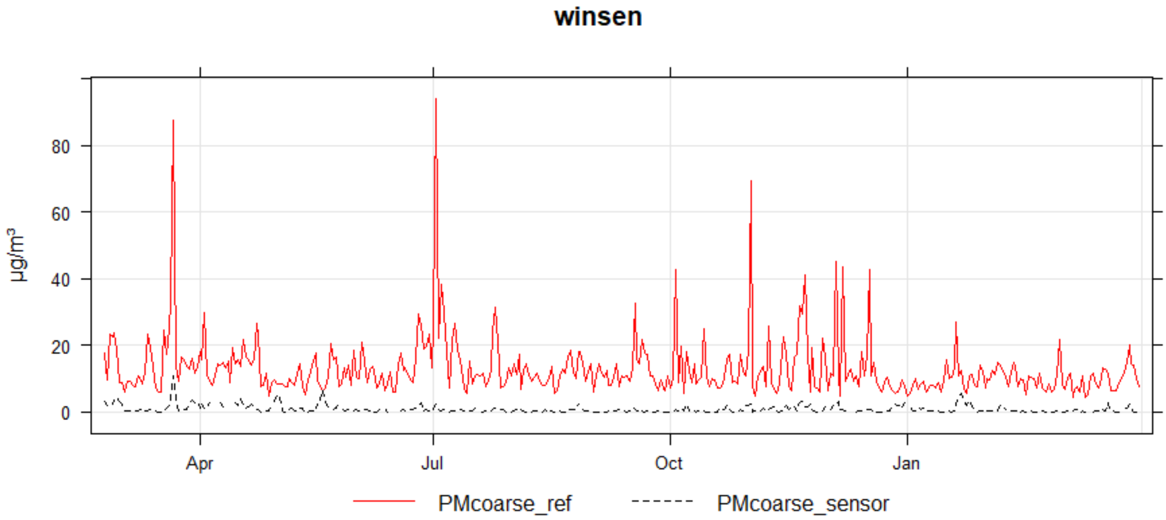
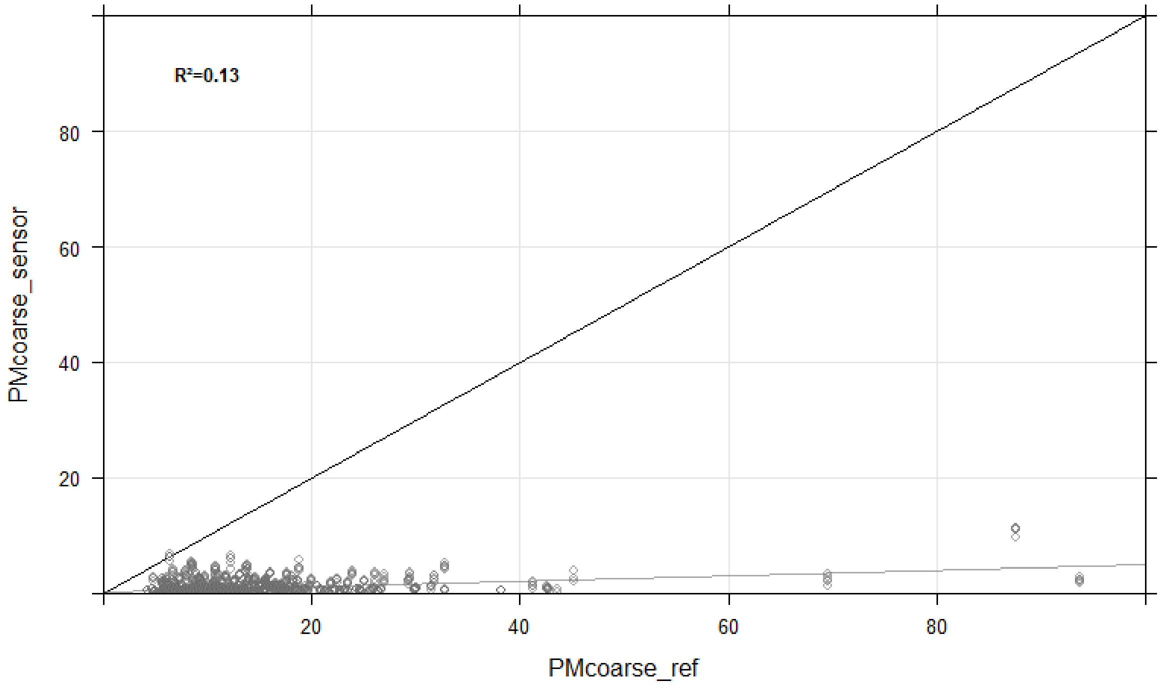
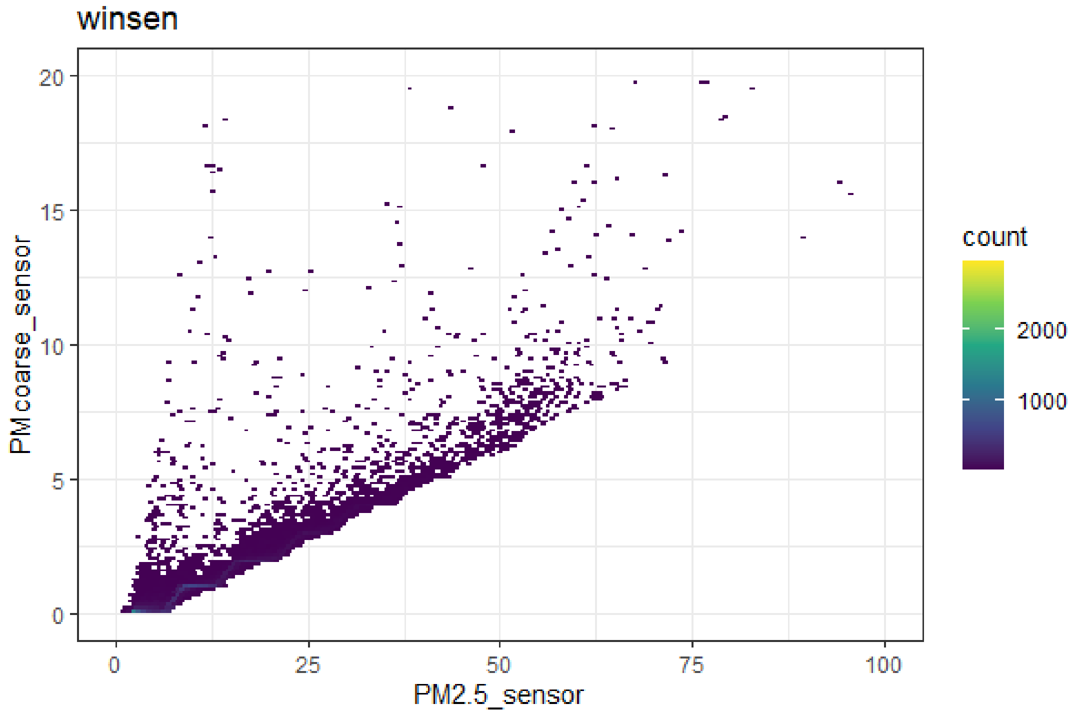


Figure 112: PM_{coarse} scatterplot for all Winsen daily averages in µg/m³



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 µg/m³

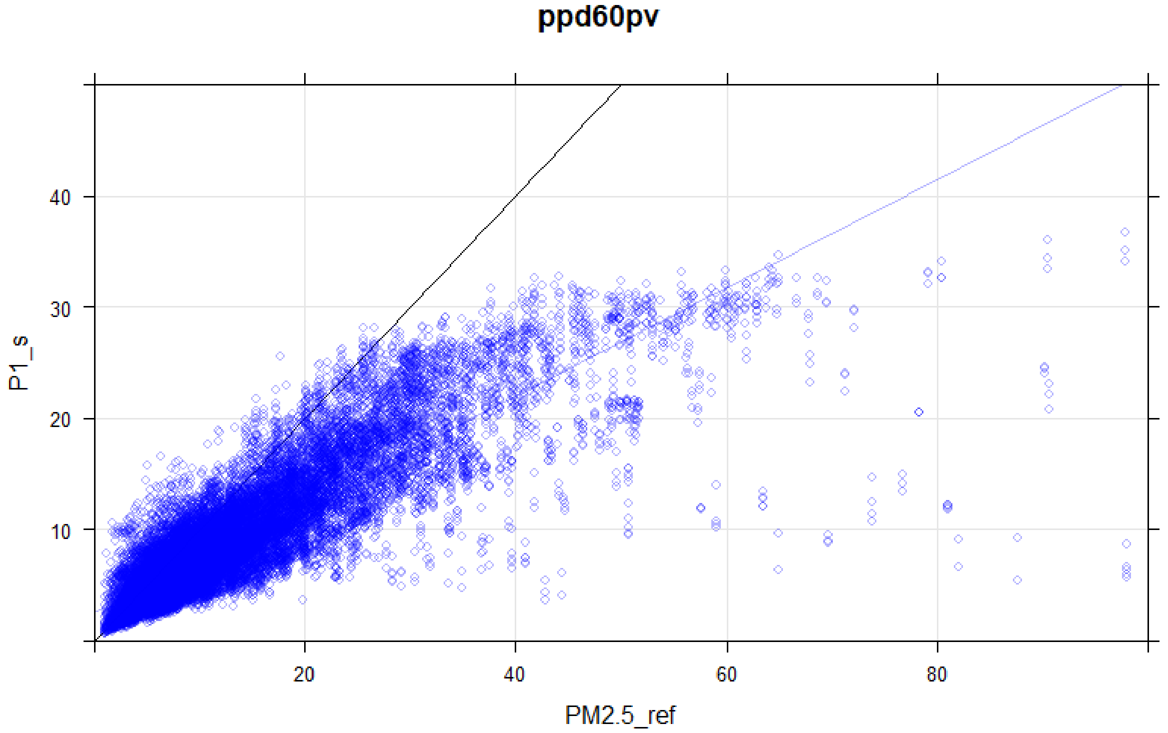


Shinyei PPD60PV

+Required calibration

According to the spec sheet the PPD60PV requires a non-linear calibration 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



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).

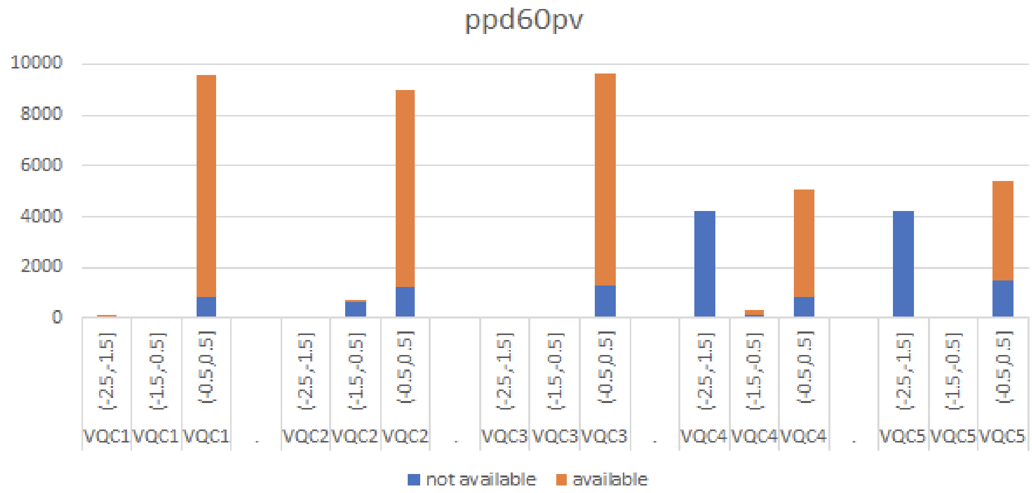
P1<26.8: $PM_{2.5}$ = P1_s/0.67
P1>=26.8: $PM_{2.5}$ = 40+(P1_s-26.8)/0.17

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

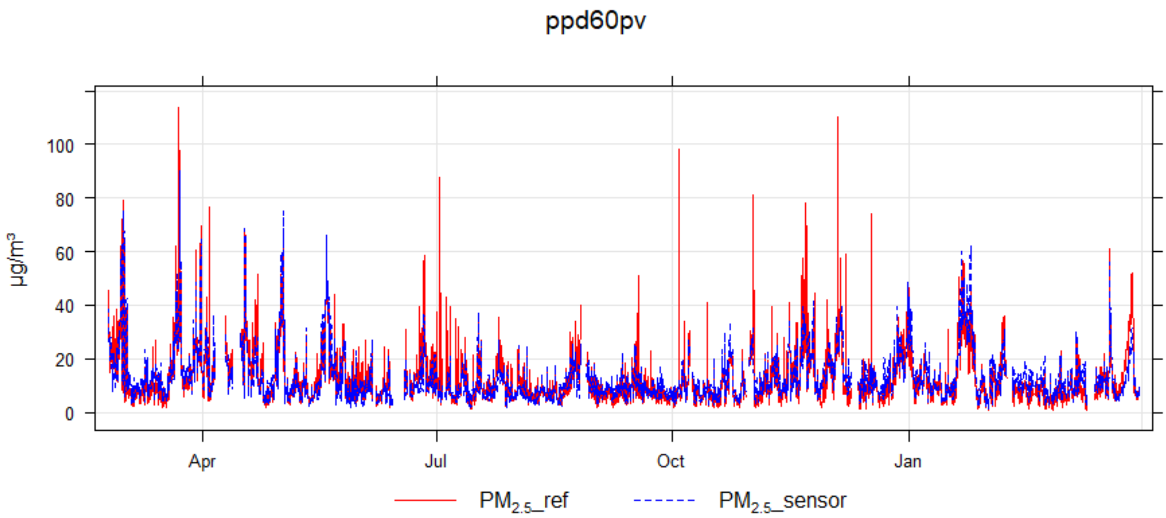


Figure 117: Hourly average of all individual PPD $PM_{2.5}$ sensor data vs Fidas reference

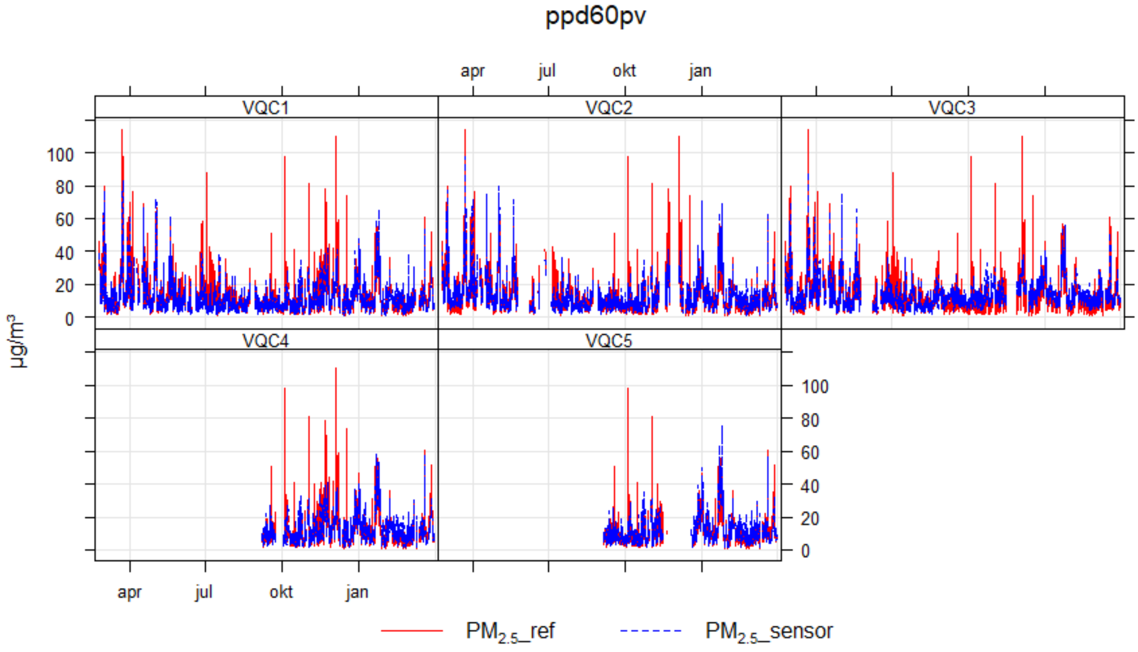


Figure 118: Density plot of all hourly $PM_{2.5}$ PPD sensor data vs $PM_{2.5}$ Fidas (in µg/m³)

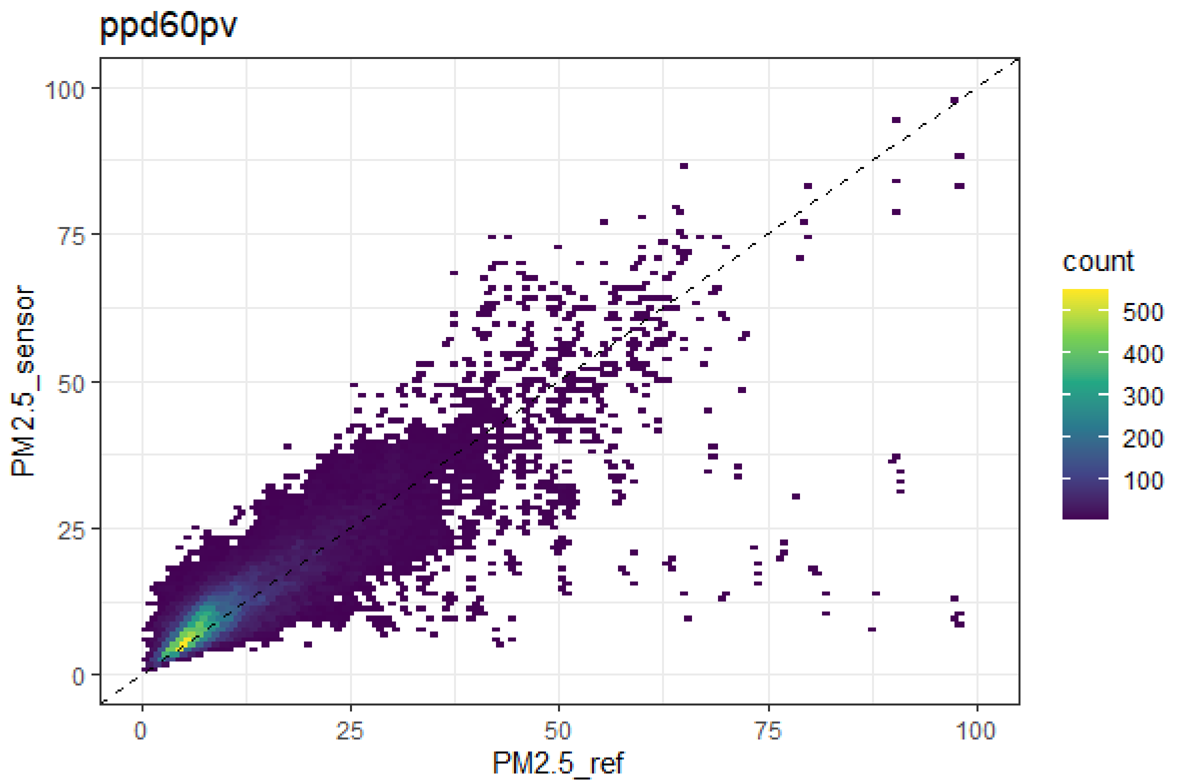


Figure 119: $PM_{2.5}$ scatterplot for all PPD sensor 5-min averages (left) and all hourly averages (right) in µg/m³

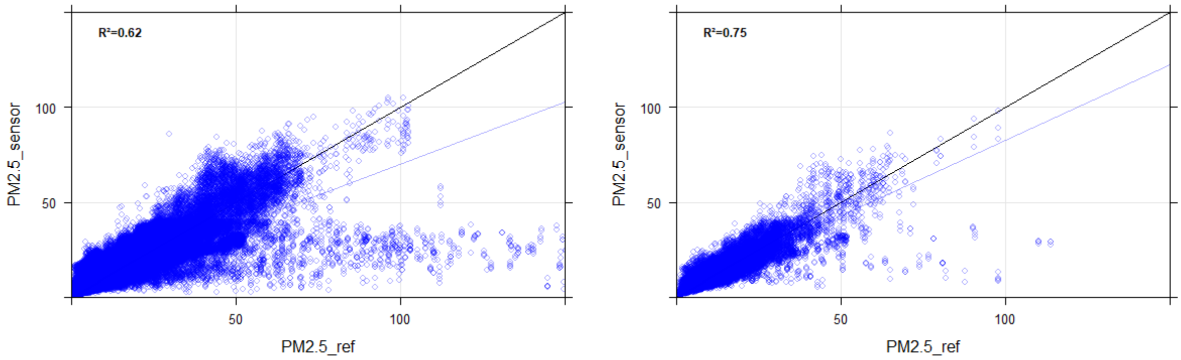
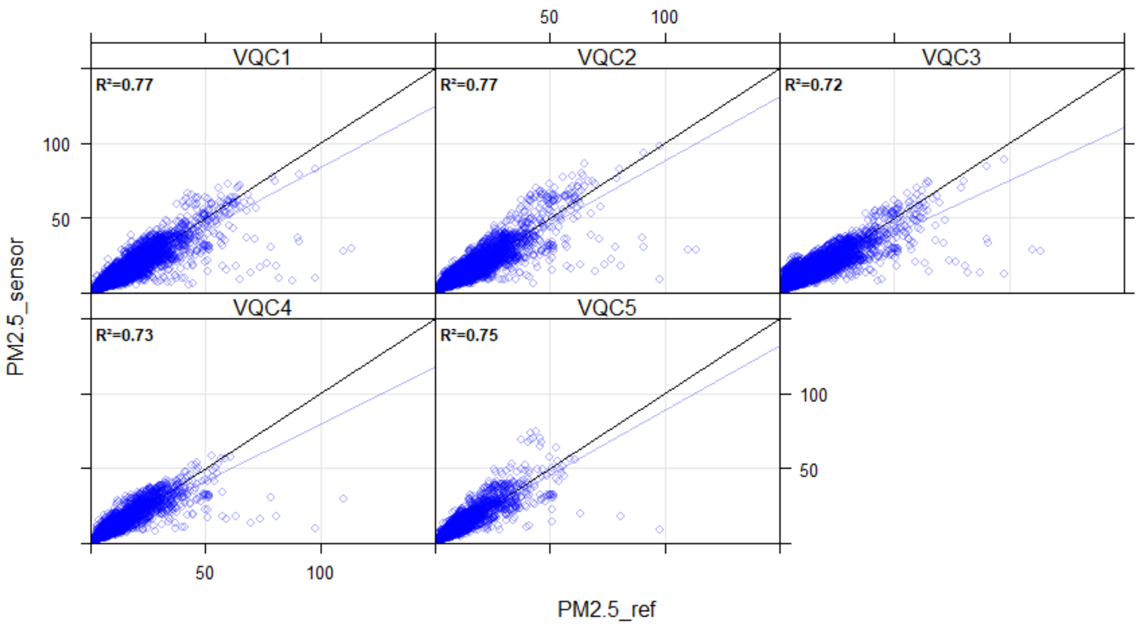
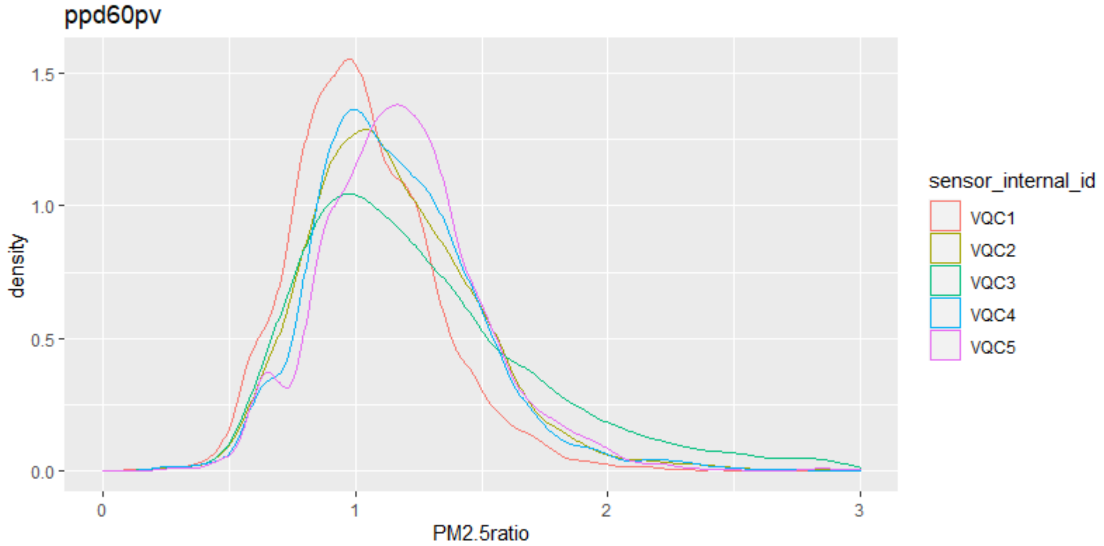


Figure 120: $PM_{2.5}$ scatterplots for hourly PPD averages per sensor in µg/m³



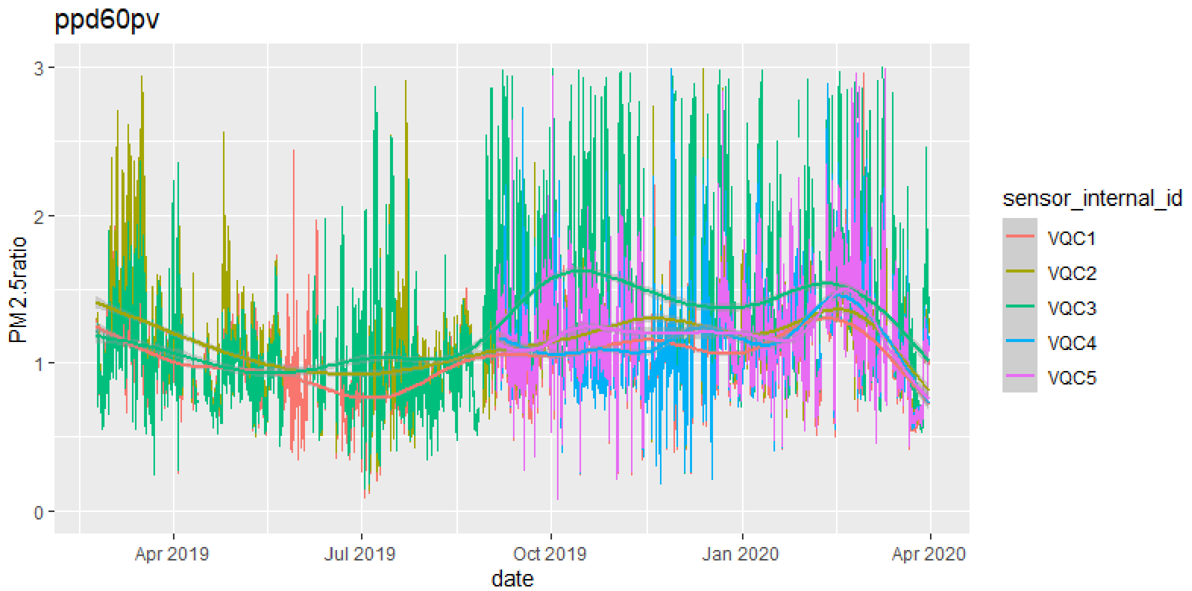
The sensor/Fidas ratios show a good comparability between units and a distribution around 1.

Figure 121: Distribution of hourly $PM_{2.5}$ ratio (PPD sensor/Fidas)



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



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

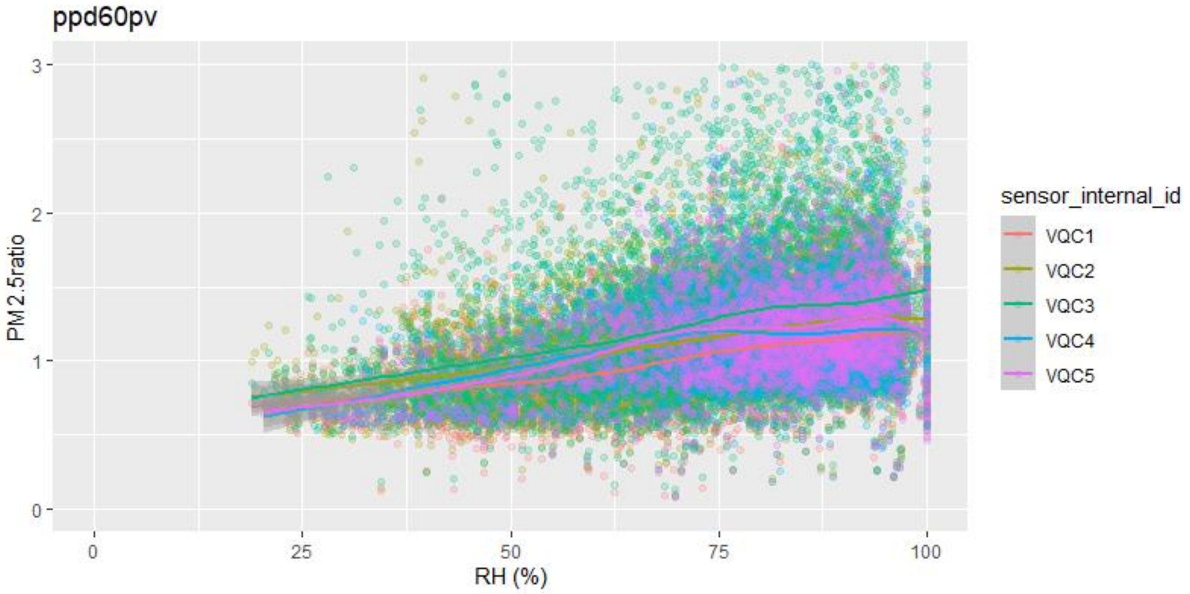
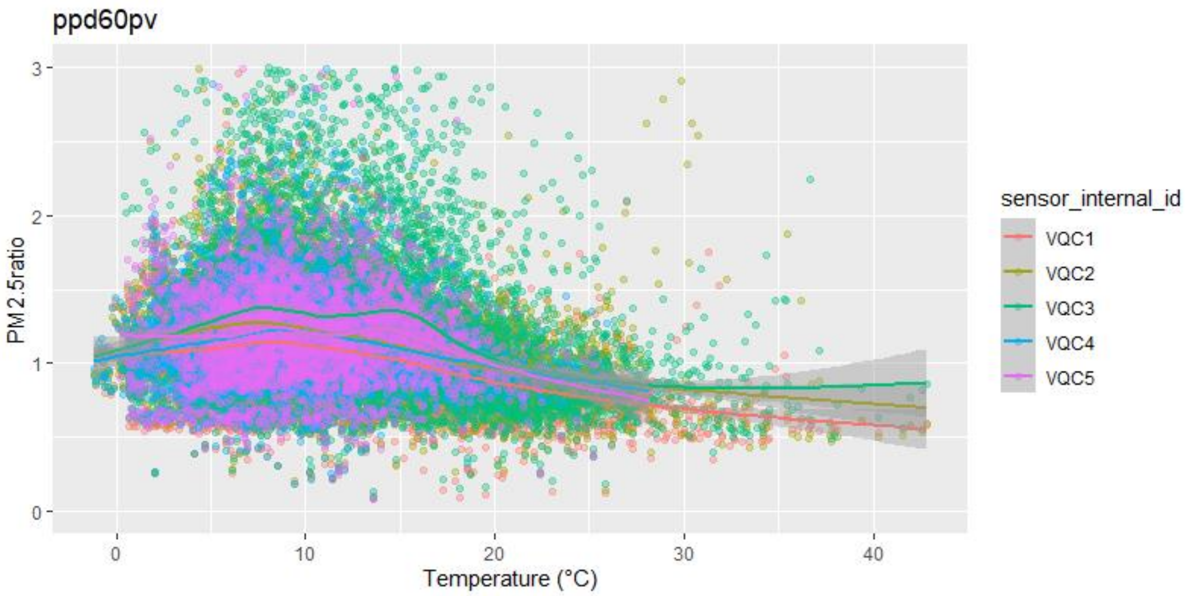


Figure 124: Hourly $PM_{2.5}$ ratio (PPD sensor/Fidas) in function of temperature



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 125: Daily average of all valid PPD $PM_{2.5}$ sensor data vs Fidas reference

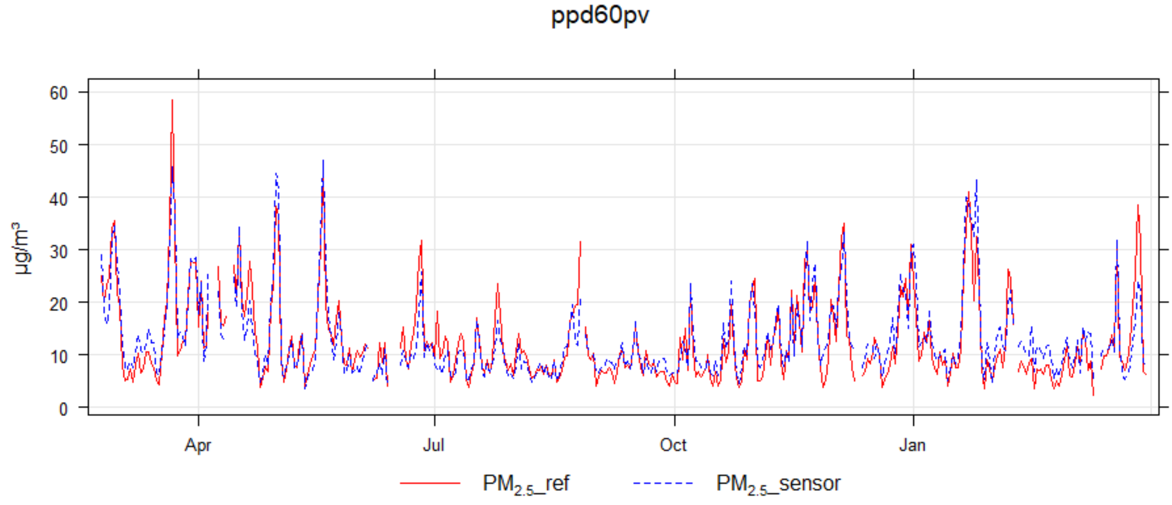
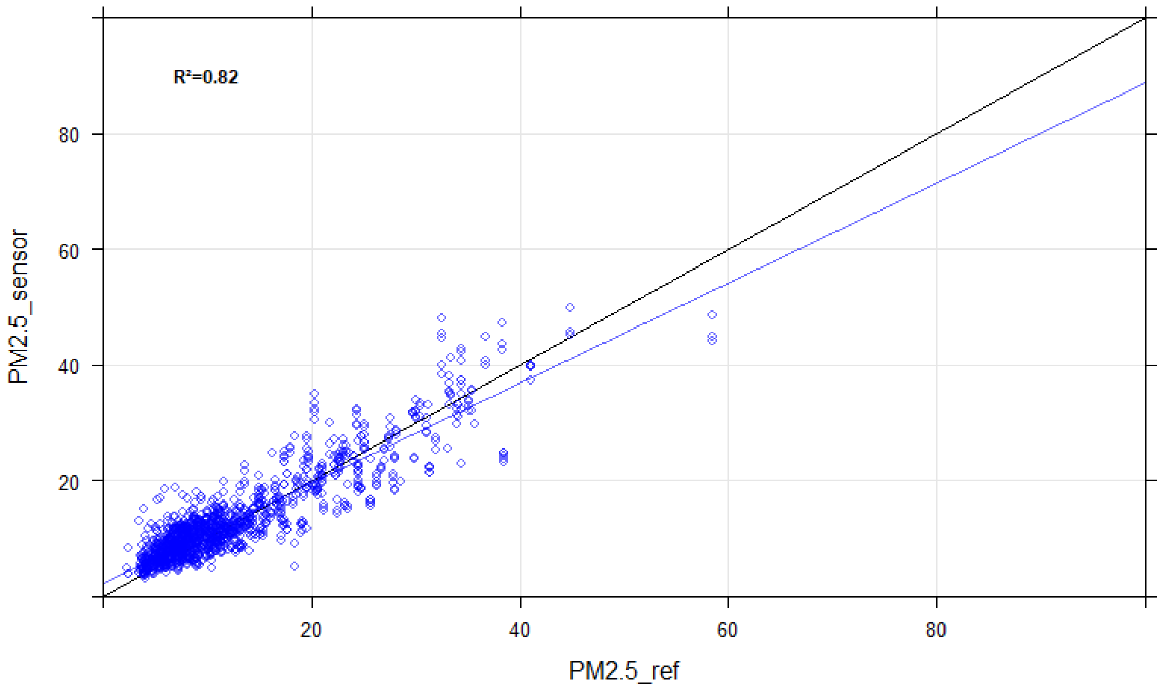


Figure 126: $PM_{2.5}$ scatterplot for all PPD daily averages in µg/m³



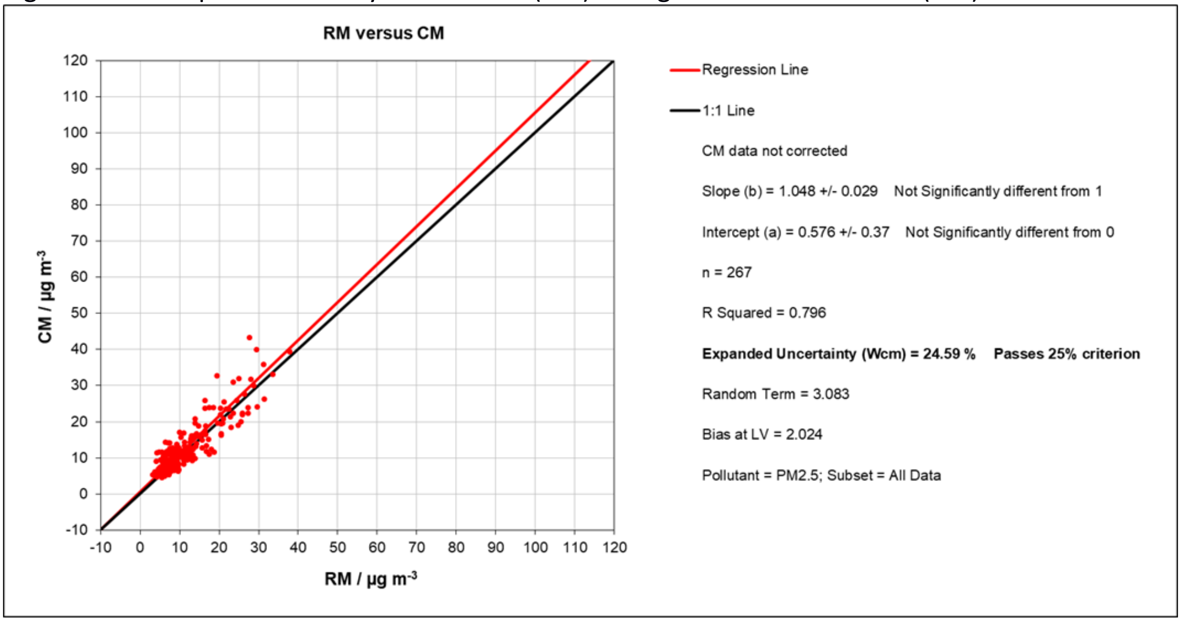
+$PM_{2.5}$ 95% confidence interval around 30 µg/m³

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

+$PM_{2.5}$ comparison with gravimetric reference

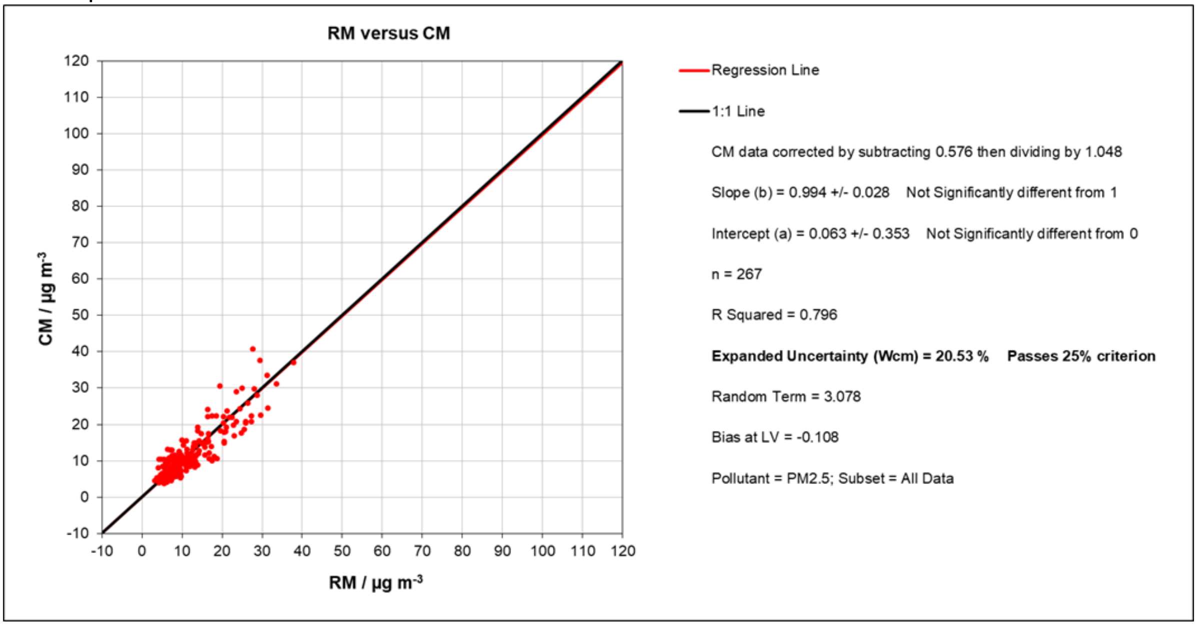
When comparing the daily overall average with the $PM_{2.5}$ gravimetric data we find an R^2 of 0.80 and an expanded uncertainty of 24.6%. The bias at the limit value was about 2 µg/m³.

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 µg/m^3 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 µg/m^3 or 14.2%.

+PM_{10} 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)

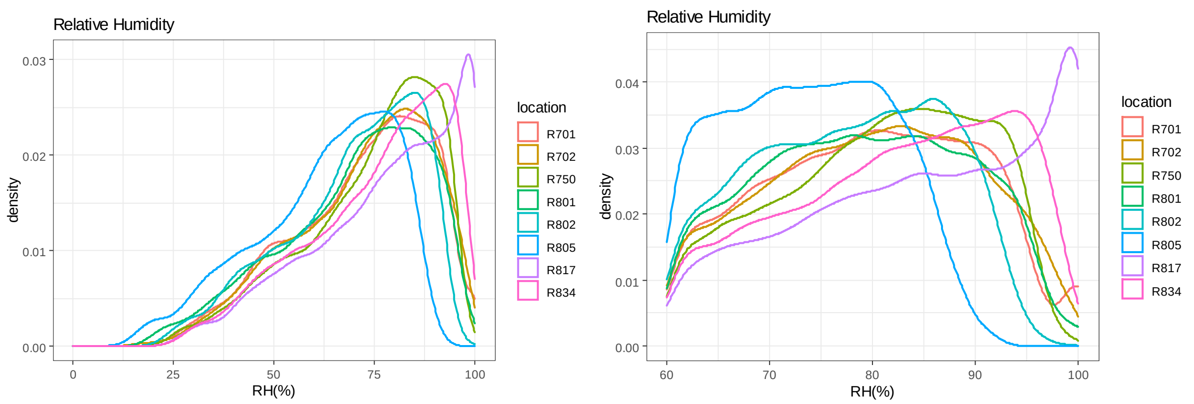


Figure 130: Monitoring site R750 (Zelzate)

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)	R^2 (day)
R701	0.42	0.47
R834	0.57	0.76
R817	0.58	0.75
R750	0.59	0.76
R801	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

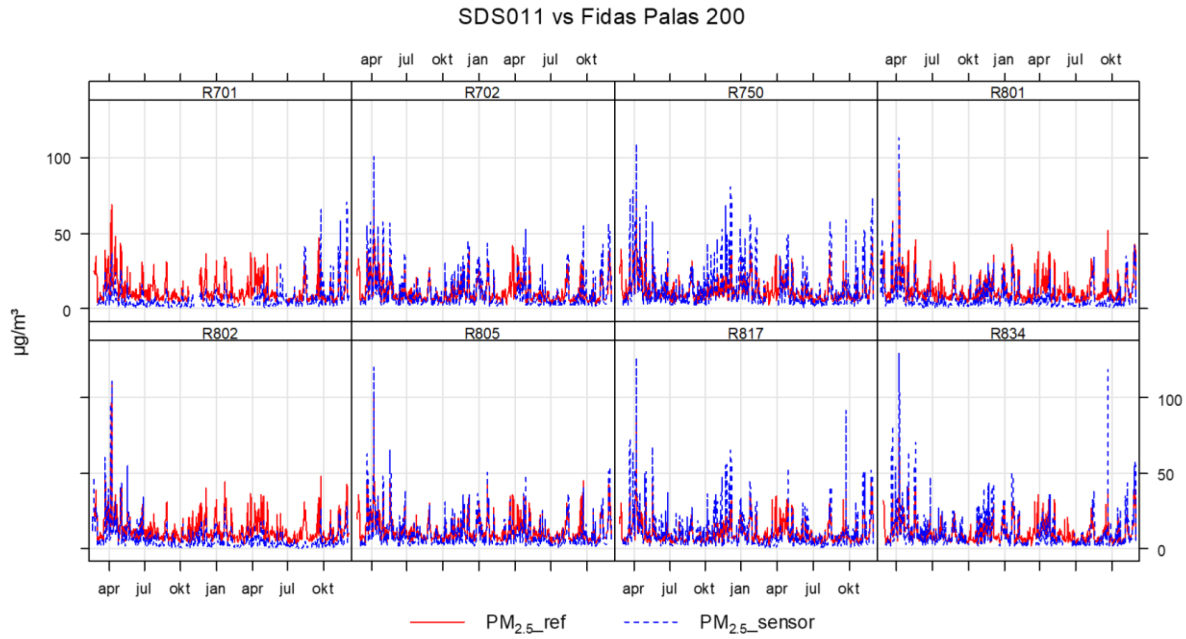
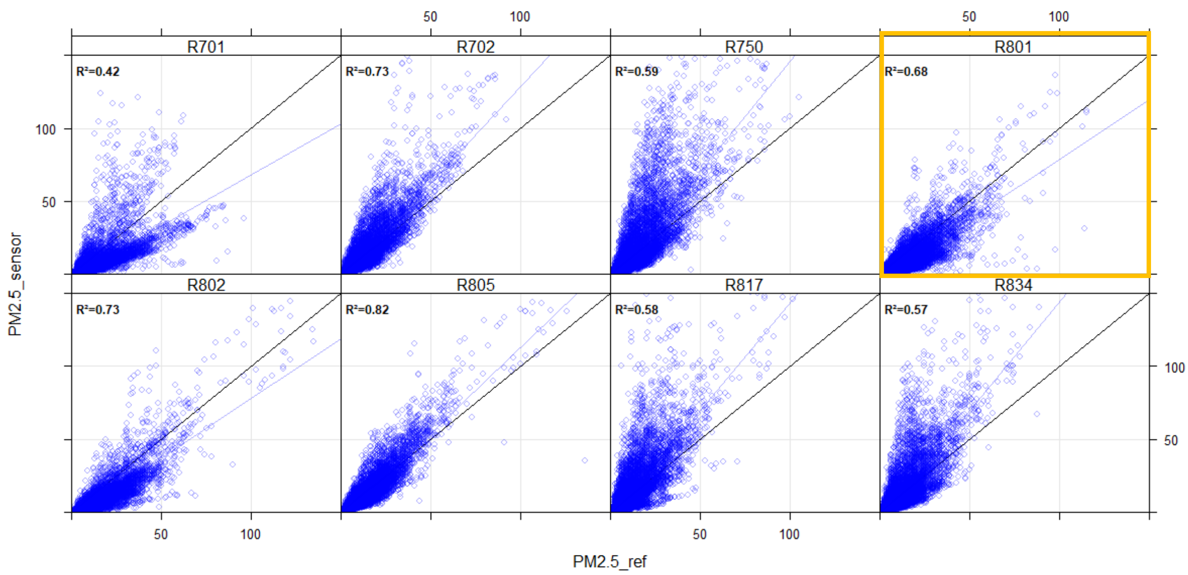


Figure 135: Scatterplot of the SDS011 sensors vs Fidas reference at the 8 locations (R801=Vaquums field test site)



+Sensor/reference ratio, linear regression and expanded uncertainty around 30 µg/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

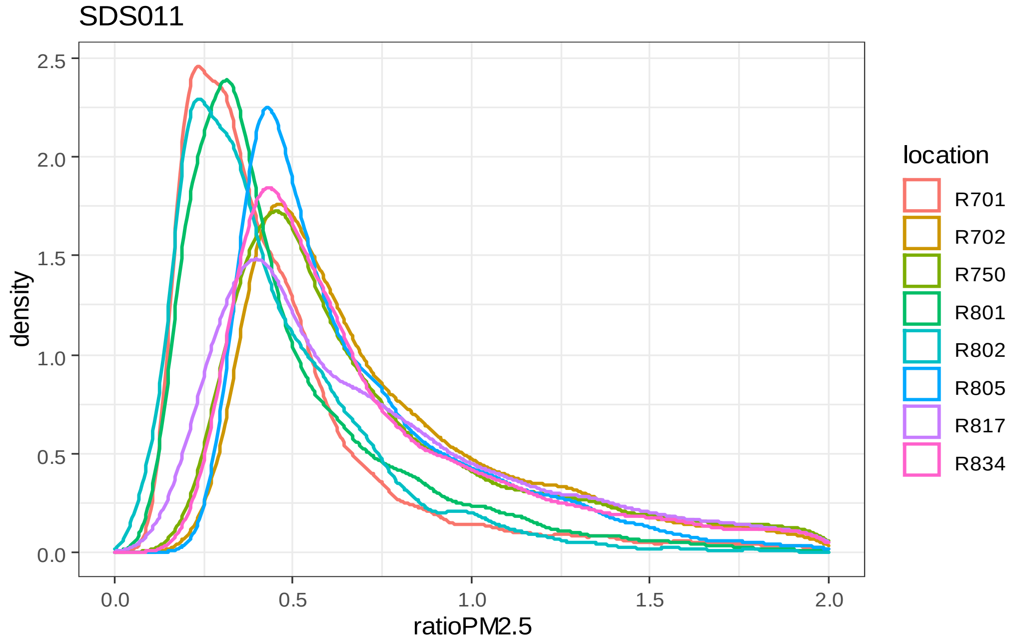
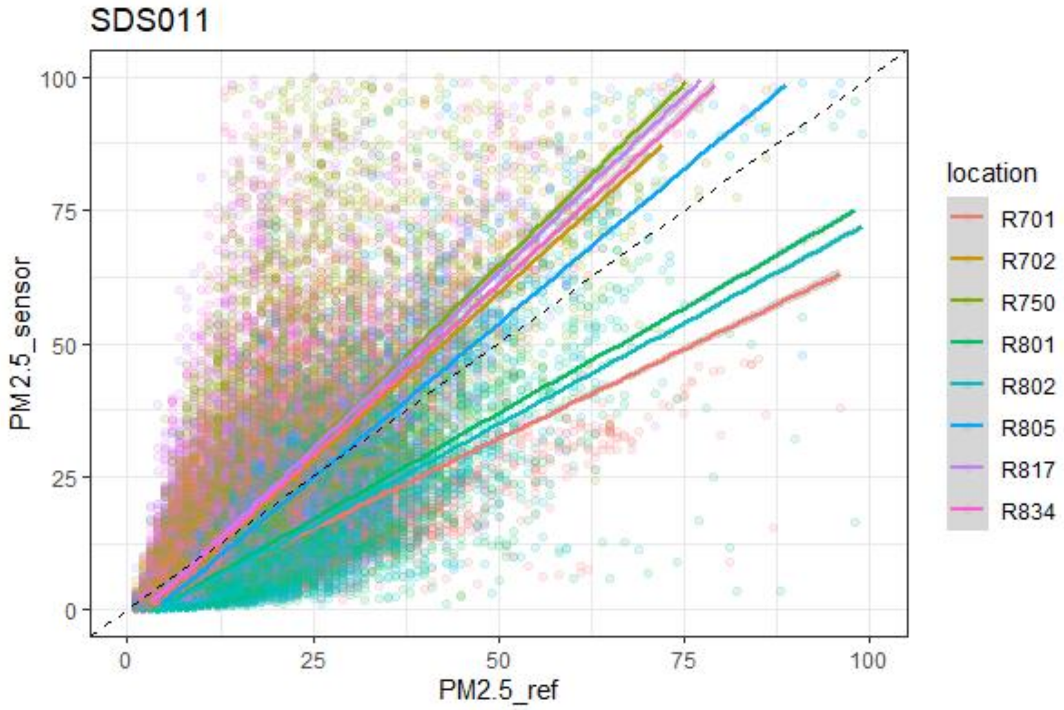
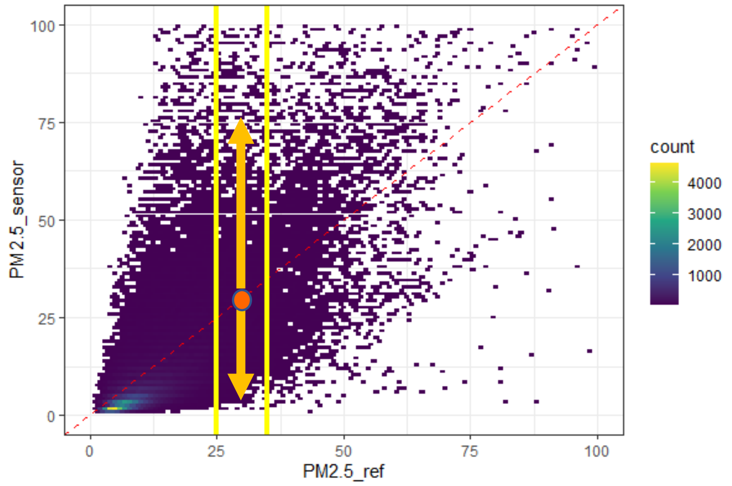


Figure 137: Linear regressions for the 8 different sites



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.

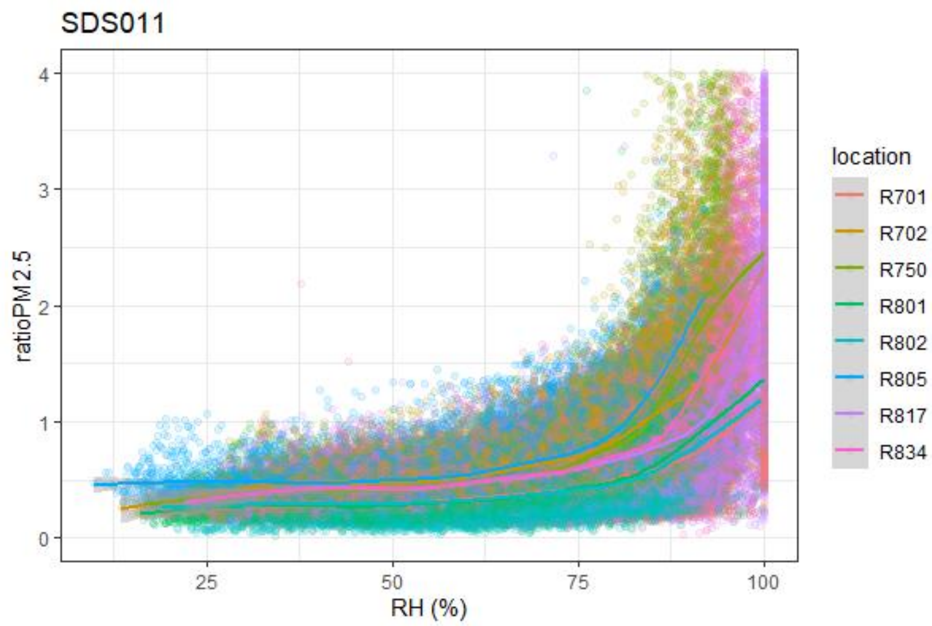
Figure 138: Estimate of the expanded uncertainty around 30 µg/m³



	P95 (hour) µg/m³	P95 (day) µg/m³
R805	17.9	19.0
R801	21.7	18.4
R802	23.5	21.0
R701	25.3	22.8
R702	36.3	19.5
R834	39.0	21.5
R817	58.2	35.2
R750	66.8	37.6

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

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[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

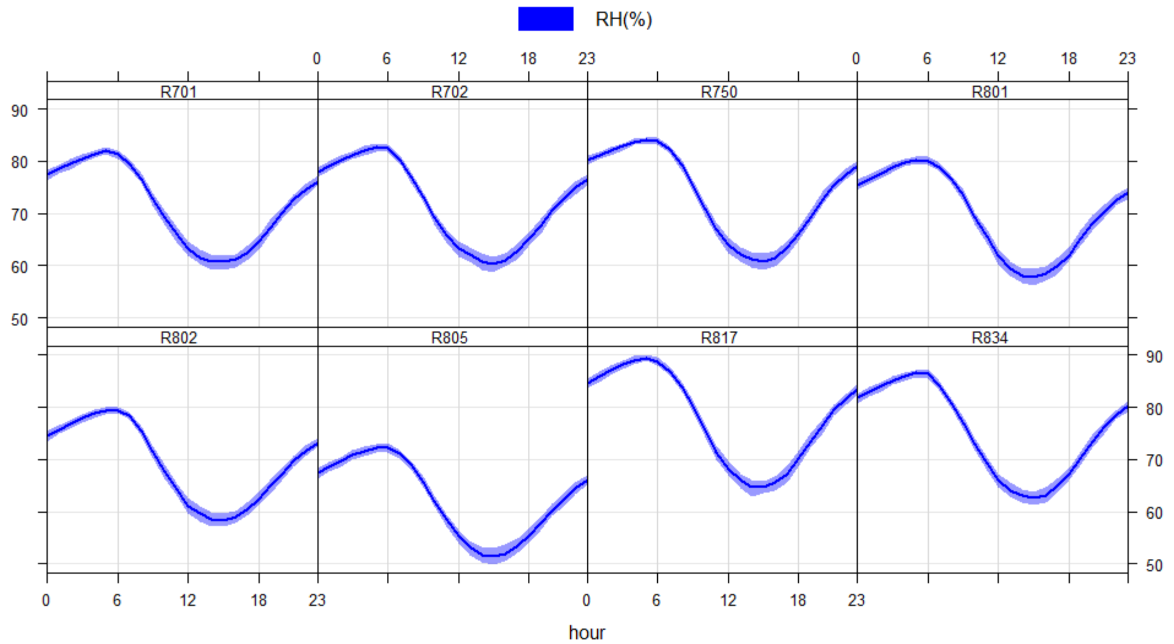
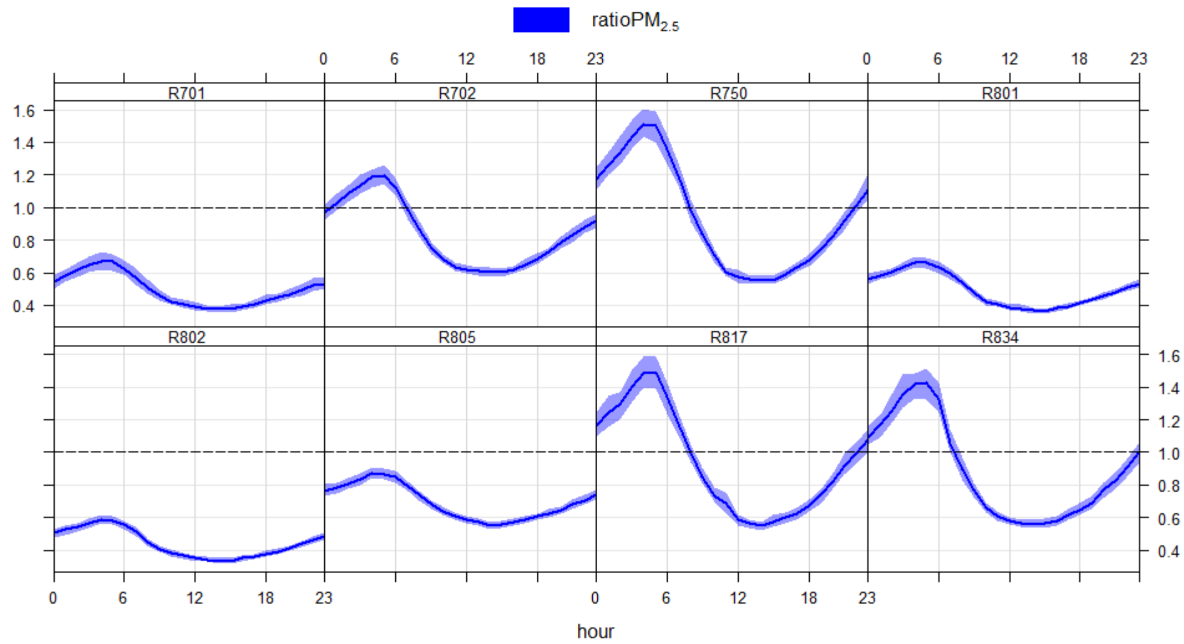
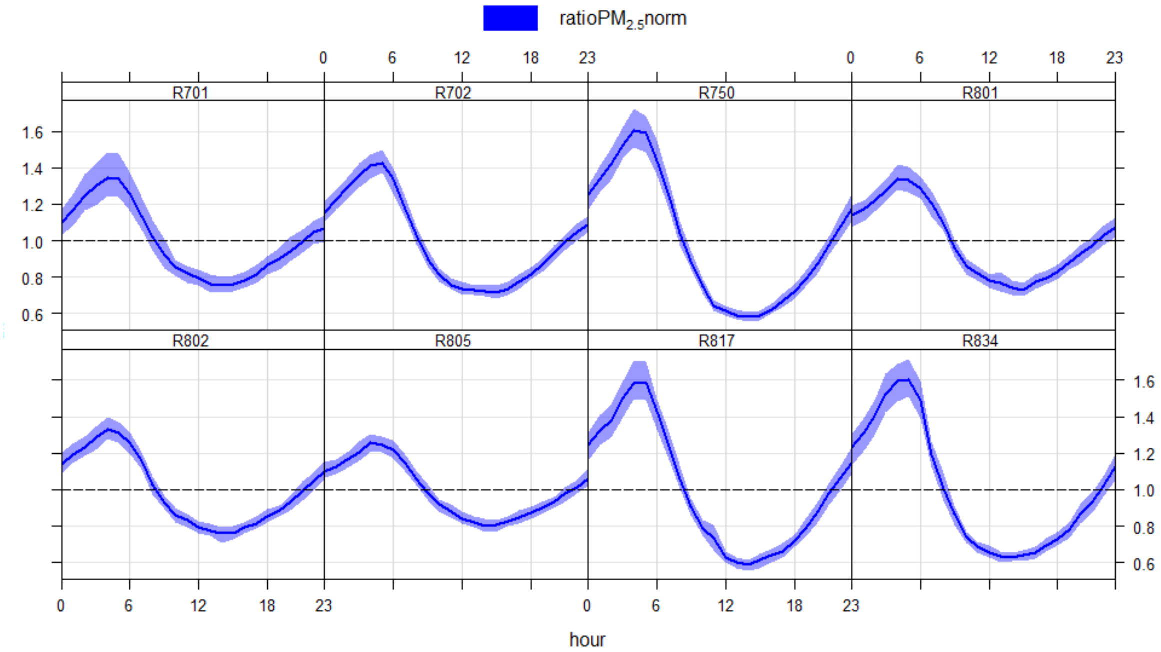


Figure 141: Diurnal pattern of the sensor/reference ratio for the 8 different sites



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.

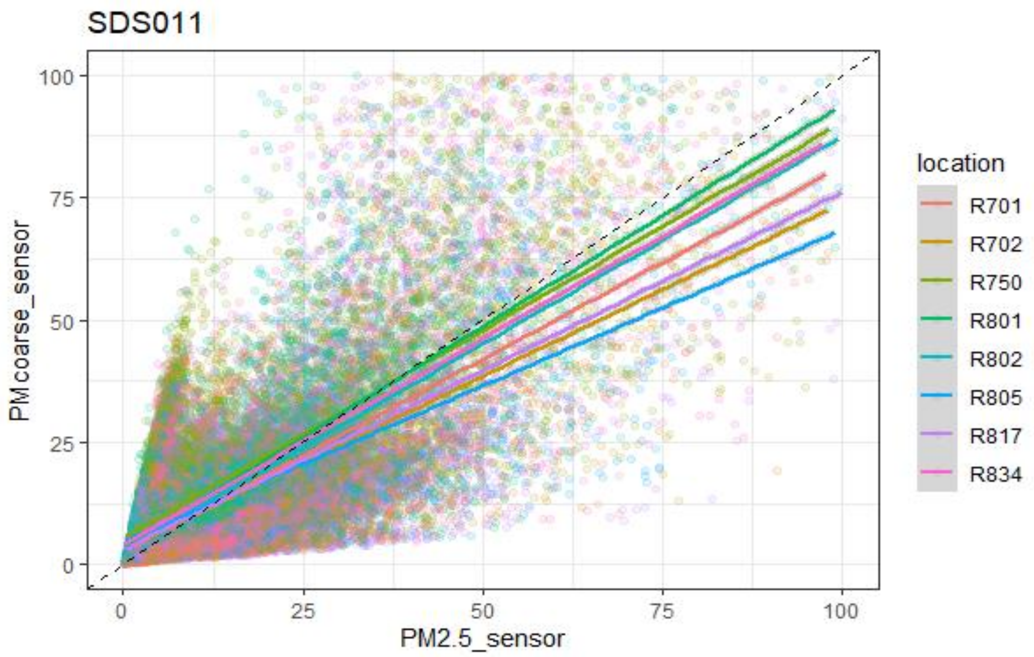
Figure 142: Diurnal pattern of the normalized sensor/reference ratio for the 8 different sites



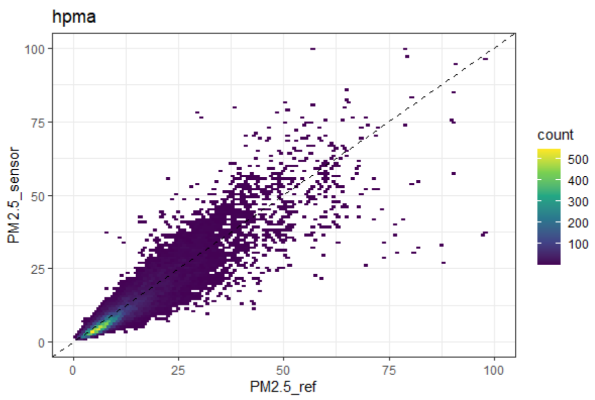
+PM$_{coarse}$ vs PM$_{2.5}$ scatterplot

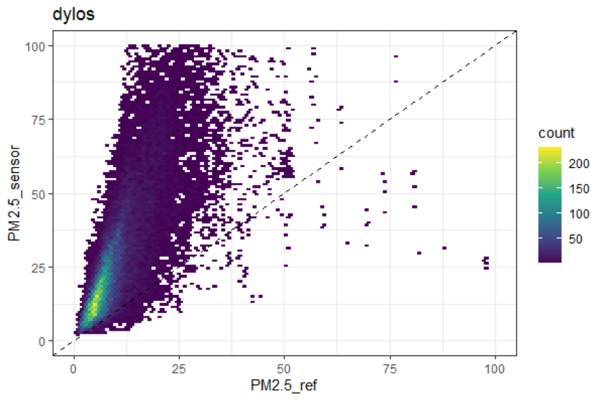
Just like in the different sensor sections we also plotted the PM$_{coarse}$ vs the PM$_{2.5}$ signal of the sensor (Figure *143*). Although the linear relation between sites (or sensors) appears to vary a bit, it is obvious that all share the same upper and lower limit. This could imply that plotting 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).

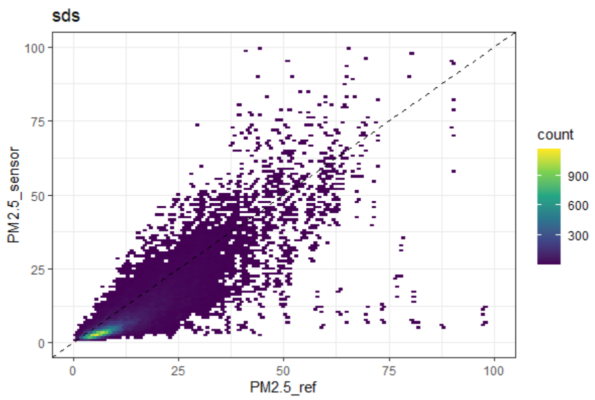
Figure 143: Scatterplot of PM$_{coarse}$ vs PM$_{2.5}$ for all 8 sites

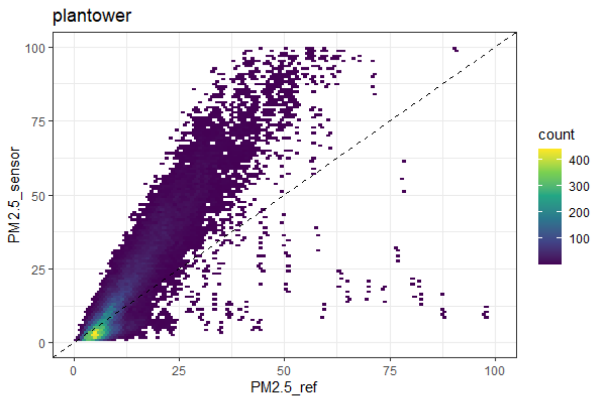


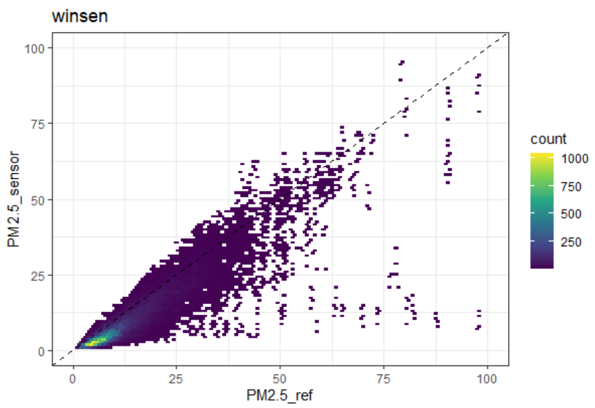
Annex 1: $PM_{2.5\_sensor}$ vs $PM_{2.5\_ref}$ scatterplots

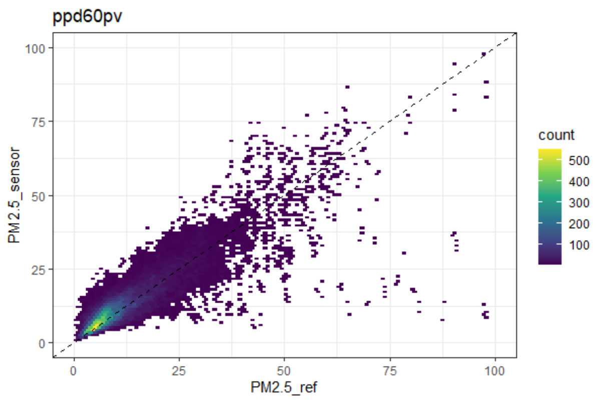






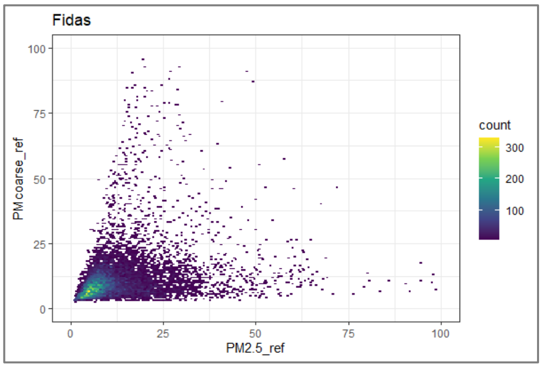


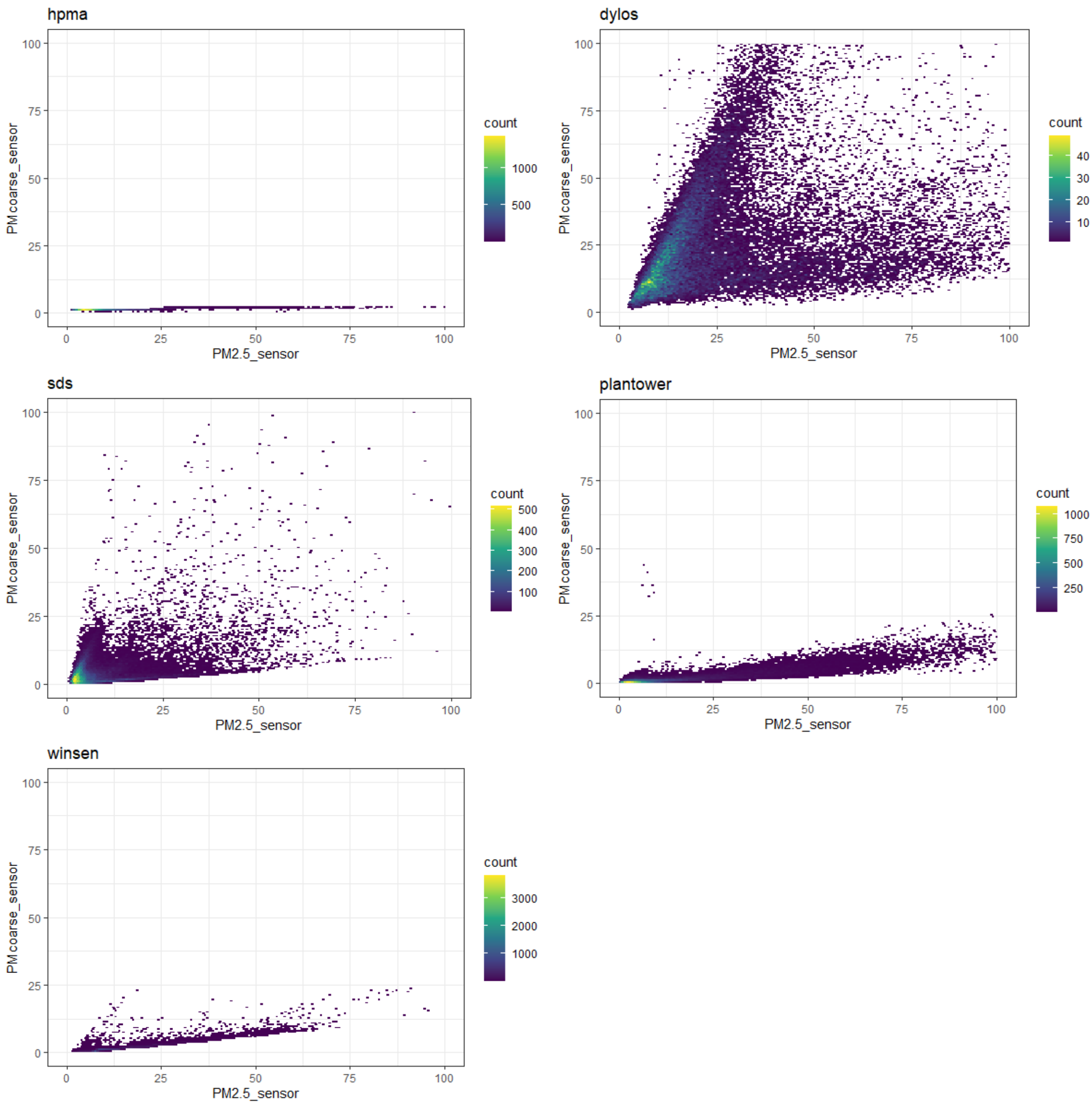




Annex 2: PM_{coarse} vs $PM_{2.5}$ scatterplots

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] https://www.rdocumentation.org/packages/openair/versions/0.4-17/topics/modStats

VAQUUMS

Honeywell HPMA 115S0

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
		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**
		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**
		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
hour	**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
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	**Pmcoarse**	**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	r	COE	IOA
		all	254488	0.01	-11.93	11.93	-0.92	0.92	41.74	-0.53	-0.49	0.25
hour	**Pmcoarse**	**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	**Pmcoarse**	**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

VAQUUMS

Dylos DC1700

5min	**PM2.5**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQN1	67429	0.39	17.63	18.00	1.50	1.53	33.84	0.75	-1.68	-0.25
		VQN2	72748	0.26	26.50	26.81	2.03	2.05	47.53	0.71	-2.48	-0.42
		VQN3	74802	0.16	28.81	28.99	2.27	2.28	47.89	0.73	-2.84	-0.48
		VQN4	86799	0.17	30.05	30.35	2.40	2.43	51.06	0.73	-3.12	-0.51
		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**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQN1	251	0.33	17.96	18.10	1.50	1.51	31.07	0.85	-2.00	-0.33
		VQN2	268	0.20	25.89	26.15	1.95	1.97	41.13	0.80	-2.83	-0.48
		VQN3	275	0.12	28.30	28.32	2.21	2.21	41.93	0.82	-3.26	-0.53
		VQN4	323	0.12	29.53	29.73	2.33	2.35	45.01	0.83	-3.63	-0.57
		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**	**r**	**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**	**COE**	**IOA**
		VQN1	5675	0.40	36.00	37.80	1.53	1.61	69.91	0.40	-2.43	-0.42
		VQN2	6103	0.34	48.99	51.10	1.89	1.97	94.14	0.37	-2.88	-0.48
		VQN3	6266	0.26	54.12	55.43	2.13	2.18	88.83	0.42	-3.28	-0.53
		VQN4	7379	0.25	53.81	55.64	2.12	2.19	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	352	0.27	51.58	51.83	2.05	2.06	75.80	0.58	-4.29	-0.62
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1469	0.27	48.88	49.20	1.93	1.94	72.54	0.61	-3.82	-0.58
5min	**Pmcoarse**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**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**	**r**	**COE**	**IOA**
		VQN1	5675	0.44	18.40	20.39	1.56	1.73	42.24	0.27	-2.37	-0.41
		VQN2	6103	0.40	22.56	25.32	1.74	1.95	54.37	0.23	-2.34	-0.40
		VQN3	6266	0.34	25.37	27.21	2.00	2.15	48.65	0.31	-2.67	-0.46
		VQN4	7379	0.35	23.77	26.07	1.84	2.02	45.51	0.33	-2.40	-0.41
		VQN5	8059	0.36	25.14	26.97	1.98	2.12	48.13	0.32	-2.71	-0.46
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	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	r	COE	IOA
		all	1469	0.36	22.89	23.56	1.80	1.85	35.71	0.37	-3.53	-0.56

Nova Fitness SDS011

5min	**PM2.5**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	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	-0.21	0.36	8.23	0.79	0.39	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	COE	IOA
		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**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	6537	0.76	-2.67	4.52	-0.20	0.34	6.76	0.86	0.43	0.71
		VQA2	6969	0.76	-2.74	4.72	-0.21	0.36	6.96	0.85	0.38	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**	**r**	**COE**	**IOA**
		VQA1	283	0.85	-2.77	3.89	-0.21	0.29	5.00	0.91	0.44	0.72
		VQA2	305	0.83	-2.83	4.07	-0.21	0.31	5.25	0.90	0.39	0.69
		VQA3	367	0.49	-4.90	5.29	-0.39	0.42	6.37	0.88	0.16	0.58
		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**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	78112	0.51	-10.28	13.65	-0.40	0.53	42.56	0.45	0.00	0.50
		VQA2	83177	0.47	-10.99	13.98	-0.42	0.54	42.23	0.48	-0.02	0.49
		VQA3	100681	0.40	-12.74	14.40	-0.50	0.57	47.56	0.35	-0.08	0.46
		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**	**COE**	**IOA**
		VQA1	6537	0.49	-10.31	13.55	-0.40	0.52	28.77	0.46	-0.02	0.49
		VQA2	6969	0.46	-11.03	13.90	-0.43	0.54	28.17	0.48	-0.05	0.47
		VQA3	8427	0.38	-12.76	14.36	-0.50	0.56	29.83	0.42	-0.11	0.44
		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**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	283	0.51	-10.46	11.96	-0.40	0.46	14.92	0.75	-0.12	0.44
		VQA2	305	0.47	-11.22	12.48	-0.43	0.48	15.43	0.73	-0.21	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
		all	1645	0.46	-11.77	12.86	-0.45	0.50	16.11	0.70	-0.24	0.38
5min	**Pmcoarse**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	78112	0.25	-7.62	9.83	-0.60	0.78	35.88	0.43	-0.26	0.37
		VQA2	83177	0.23	-8.25	10.01	-0.65	0.79	35.51	0.50	-0.26	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
		all	444344	0.29	-7.58	9.67	-0.59	0.75	37.55	0.40	-0.22	0.39
hour	**Pmcoarse**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	6537	0.24	-7.65	9.77	-0.60	0.77	23.50	0.32	-0.31	0.35
		VQA2	6969	0.22	-8.29	9.96	-0.65	0.78	22.89	0.37	-0.31	0.34
		VQA3	8427	0.27	-7.95	9.80	-0.61	0.75	24.36	0.24	-0.28	0.36
		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**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQA1	283	0.23	-7.69	8.58	-0.61	0.68	11.07	0.51	-0.62	0.19
		VQA2	305	0.23	-8.39	8.99	-0.66	0.70	11.44	0.49	-0.68	0.16
		VQA3	367	0.23	-8.05	9.25	-0.62	0.71	12.38	0.27	-0.67	0.16
		VQA4	339	0.32	-6.70	8.34	-0.52	0.64	10.93	0.43	-0.54	0.23
		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

Plantower 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	102473	0.73	2.60	6.33	0.21	0.50	10.86	0.82	0.14	0.57
		VQE5	96989	0.75	5.20	7.95	0.41	0.62	13.29	0.82	-0.06	0.47
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	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	5.19	7.77	0.41	0.61	12.26	0.91	-0.06	0.47
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	35367	0.73	5.15	7.89	0.40	0.61	12.53	0.90	-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	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1558	0.86	5.13	7.01	0.40	0.54	10.53	0.95	-0.09	0.46
5min	**PM10**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		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	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	421910	0.55	-5.90	14.67	-0.23	0.56	49.57	0.26	-0.06	0.47
hour	**PM10**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		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	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	35367	0.55	-5.93	14.32	-0.23	0.55	30.48	0.39	-0.07	0.47
day	**PM10**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		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	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1558	0.59	-5.94	11.54	-0.23	0.44	15.35	0.68	-0.10	0.45
5min	**Pmcoarse**	**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	96989	0.09	-11.41	11.73	-0.86	0.88	43.64	0.11	-0.41	0.29
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	421910	0.12	-11.06	11.50	-0.83	0.86	43.30	0.12	-0.38	0.31
hour	**Pmcoarse**	**sensor_id**	**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	-0.86	0.88	26.65	0.12	-0.48	0.26
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	35367	0.11	-11.08	11.48	-0.83	0.86	26.48	0.12	-0.45	0.28
day	**Pmcoarse**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**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	-0.86	0.86	14.62	0.21	-1.05	-0.02
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1558	0.08	-11.07	11.19	-0.83	0.84	14.50	0.22	-0.98	0.01

Winsen ZH03B

5min	PM2.5	sensor_id	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		VQF1	63276	0.61	-4.89	5.09	-0.34	0.35	8.32	0.85	0.40	0.70
		VQF2	84398	0.80	-3.55	3.81	-0.27	0.29	7.20	0.85	0.50	0.75
		VQF3	100211	0.75	-3.45	3.71	-0.28	0.30	6.98	0.85	0.49	0.75
		VQF4	101226	0.64	-4.38	4.71	-0.35	0.38	8.16	0.81	0.36	0.68
		VQF5	90965	0.81	-3.02	3.59	-0.24	0.28	7.40	0.82	0.52	0.76
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	440076	0.73	-3.80	4.13	-0.29	0.32	7.59	0.83	0.46	0.73
hour	**PM2.5**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQF1	5310	0.60	-4.88	5.06	-0.34	0.35	6.72	0.92	0.39	0.70
		VQF2	7085	0.80	-3.54	3.76	-0.27	0.29	5.42	0.92	0.50	0.75
		VQF3	8384	0.75	-3.46	3.69	-0.28	0.30	5.30	0.92	0.48	0.74
		VQF4	8479	0.63	-4.38	4.69	-0.35	0.37	6.56	0.88	0.35	0.68
		VQF5	7619	0.81	-3.02	3.55	-0.24	0.28	5.33	0.91	0.51	0.76
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	36877	0.72	-3.80	4.10	-0.29	0.32	5.86	0.91	0.45	0.73
day	**PM2.5**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQF1	244	0.66	-4.91	4.92	-0.34	0.34	5.75	0.94	0.30	0.65
		VQF2	315	0.86	-3.55	3.61	-0.27	0.28	4.37	0.95	0.44	0.72
		VQF3	363	0.82	-3.52	3.60	-0.28	0.28	4.31	0.95	0.43	0.71
		VQF4	368	0.66	-4.44	4.60	-0.35	0.36	5.60	0.91	0.26	0.63
		VQF5	328	0.88	-3.11	3.42	-0.24	0.27	4.14	0.95	0.45	0.73
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1618	0.78	-3.86	3.99	-0.30	0.31	4.85	0.94	0.38	0.69
5min	**PM10**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQF1	63276	0.24	-18.65	18.80	-0.64	0.64	52.34	0.35	-0.22	0.39
		VQF2	84398	0.28	-16.01	16.11	-0.61	0.61	49.71	0.38	-0.15	0.42
		VQF3	100211	0.27	-15.56	15.65	-0.61	0.62	47.53	0.35	-0.18	0.41
		VQF4	101226	0.21	-16.70	16.87	-0.65	0.66	49.80	0.32	-0.25	0.38
		VQF5	90965	0.31	-15.62	15.86	-0.59	0.60	52.19	0.32	-0.12	0.44
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	440076	0.26	-16.37	16.52	-0.62	0.63	50.15	0.34	-0.18	0.41
hour	**PM10**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQF1	5310	0.23	-18.63	18.76	-0.64	0.64	34.07	0.45	-0.27	0.37
		VQF2	7085	0.27	-16.00	16.08	-0.61	0.61	31.43	0.46	-0.19	0.40
		VQF3	8384	0.26	-15.59	15.68	-0.61	0.62	30.54	0.44	-0.22	0.39
		VQF4	8479	0.20	-16.73	16.87	-0.65	0.66	31.74	0.42	-0.29	0.36
		VQF5	7619	0.30	-15.64	15.86	-0.59	0.60	32.38	0.41	-0.17	0.42
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	36877	0.25	-16.38	16.51	-0.62	0.62	31.89	0.44	-0.22	0.39
day	**PM10**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQF1	244	0.21	-18.41	18.41	-0.64	0.64	21.52	0.71	-0.69	0.15
		VQF2	315	0.23	-15.91	15.91	-0.60	0.60	19.17	0.71	-0.52	0.24
		VQF3	363	0.21	-15.71	15.73	-0.61	0.61	18.85	0.70	-0.55	0.23
		VQF4	368	0.16	-16.79	16.81	-0.65	0.65	19.95	0.68	-0.63	0.18
		VQF5	328	0.25	-15.71	15.76	-0.59	0.60	19.21	0.67	-0.52	0.24
		default	n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
		all	1618	0.21	-16.40	16.42	-0.62	0.62	19.66	0.69	-0.57	0.21
5min	**Pmcoarse**	**sensor_id**	**n**	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**r**	**COE**	**IOA**
		VQF1	63276	0.04	-13.75	13.83	-0.93	0.94	45.03	0.43	-0.48	0.26
		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	-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	-12.58	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	15.39	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
		all	1618	0.01	-12.54	12.54	-0.93	0.93	15.55	0.37	-1.21	-0.09

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**	**sensor_id**	**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