Field Evaluation
Ecomesure EcomSmart

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 03/10/2022 to 05/10/2022, three **Ecomesure EcomSmart (hereinafter EcomSmart)** multi-sensor units were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) and Federal Reference Method (FRM) instruments measuring the same pollutants.

- EcomSmart (*3 units tested*):
  - Gas Sensors: Electrochemical (Alphasense, non-FEM)
  - $PM_{2.5}$ – Optical (Tera Sensors NextPM, non-FEM)
  - Each unit measures: O_3 (ppb), NO_2 (ppb), CO (ppb), $PM_{1.0}$ (µg/m^3), $PM_{2.5}$ (µg/m^3), PM_{10}(µg/m^3), T (°C), RH (%)
  - Unit cost: $4,550 as-tested + $480/year platform subscription fee
  - Time resolution: 1-min
  - Units IDs: 0531, 0532, and 0533

- South Coast AQMD Reference instruments:
  - O_3 instrument (Teledyne T400, hereinafter FEM T400); cost: ~$7,000
    - Time resolution; 1-min
  - CO instrument (Horiba APMA 370, hereinafter FRM Horiba); cost: ~$10,000
    - Time resolution; 1-min
  - NO/NO_2 instrument (Teledyne T200, hereinafter FRM T200); cost: ~$11,000
    - Time resolution: 1-min
  - PM Instrument (GRIMM EDM 180; FEM $PM_{2.5}$, hereinafter FEM GRIMM); cost: $25,000 and up
    - Time resolution: 1-min
  - PM instrument (Teledyne API T640; FEM $PM_{2.5}$, hereinafter FEM T640); cost: $21,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min

FEM GRIMM

FEM T640

FEM T400

FRM Horiba

FRM T200

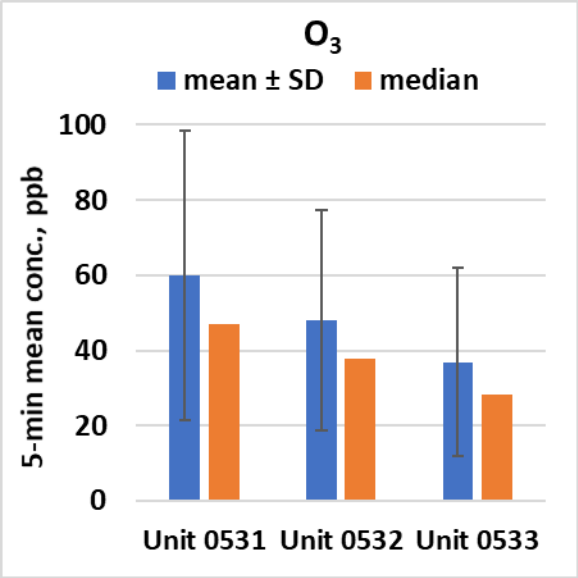
Ozone (O_3)
in Ecomesure EcomSmart

Data validation & recovery

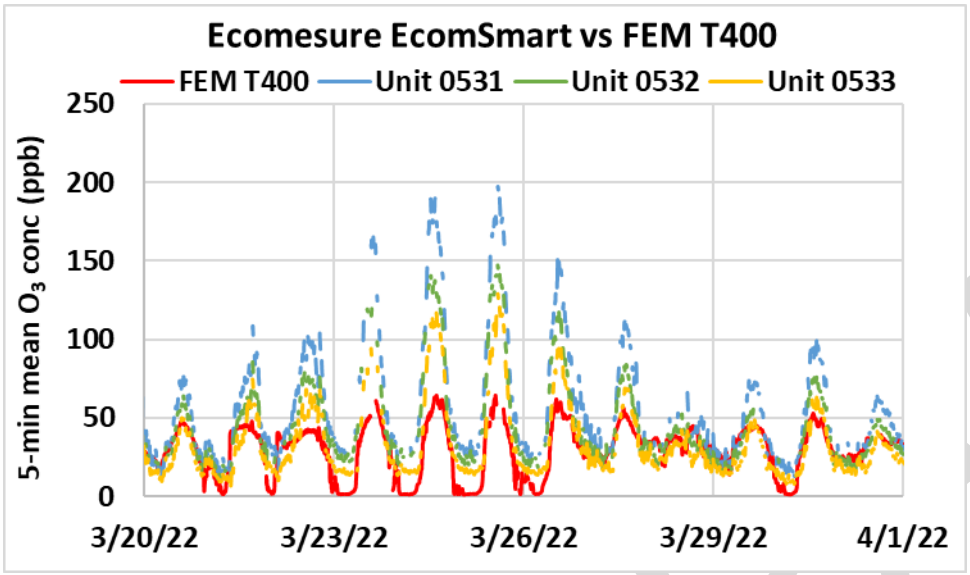
- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values, and invalid data-points were eliminated from the data-set)
- Data recovery for O_3 from Unit 0531, Unit 0532 and Unit 0533 was ~ 96.3%, ~ 96.2% and ~ 96.1%, respectively

Ecomesure EcomSmart; Intra-model variability

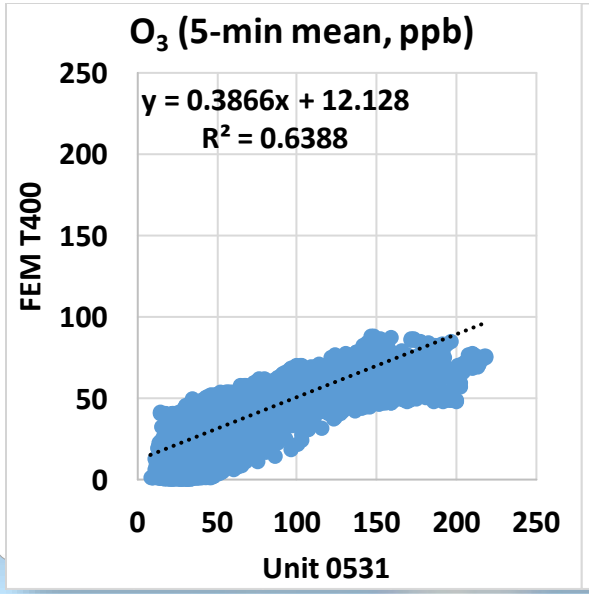
- Absolute intra-model variability was ~ 9.4 ppb for the ozone measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 19.4% for the ozone measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

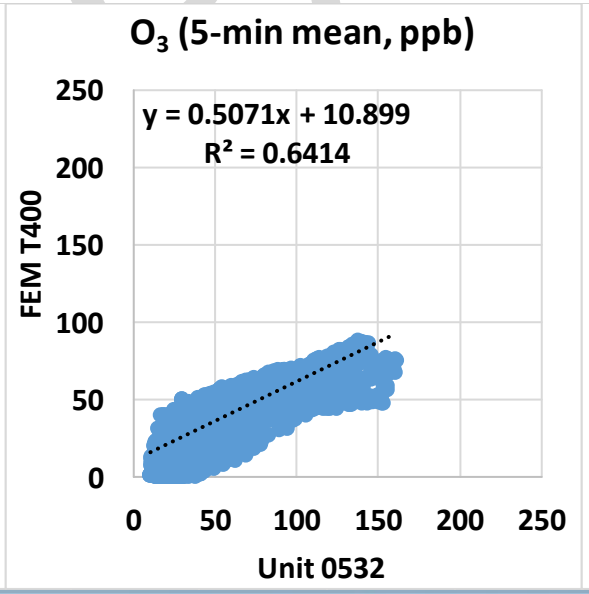


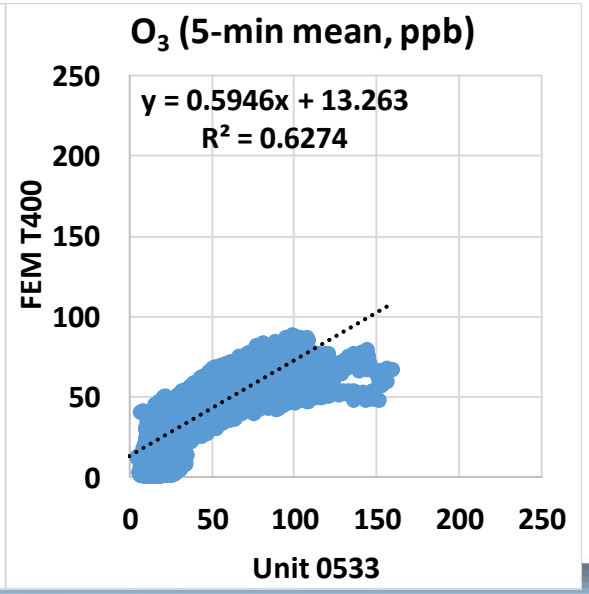
EcomSmart vs FEM T400 (Ozone; 5-min mean)



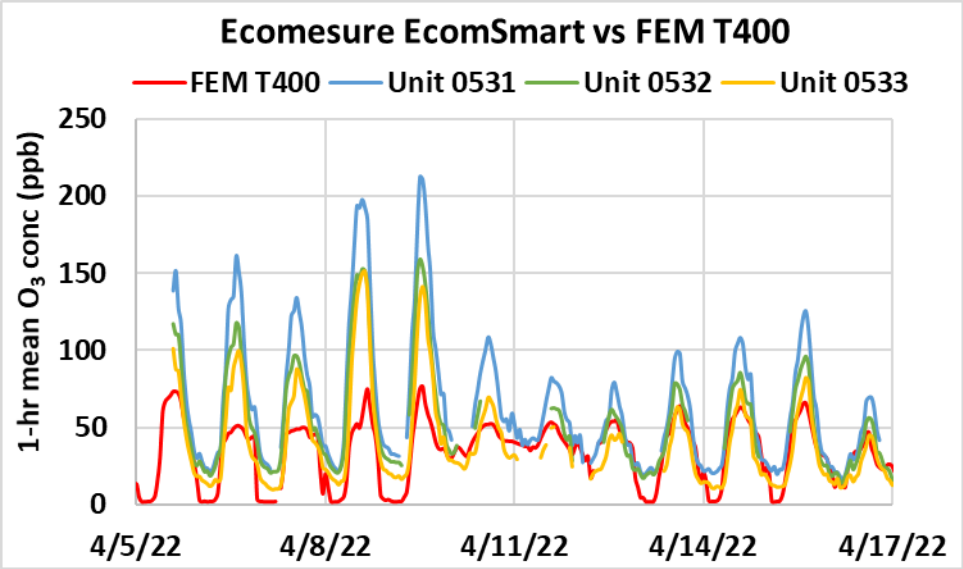
- The EcomSmart sensors showed moderate correlation with the corresponding FEM T400 ozone data ($0.62 < R^2 < 0.65$)
- Overall, the EcomSmart sensors overestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The EcomSmart sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



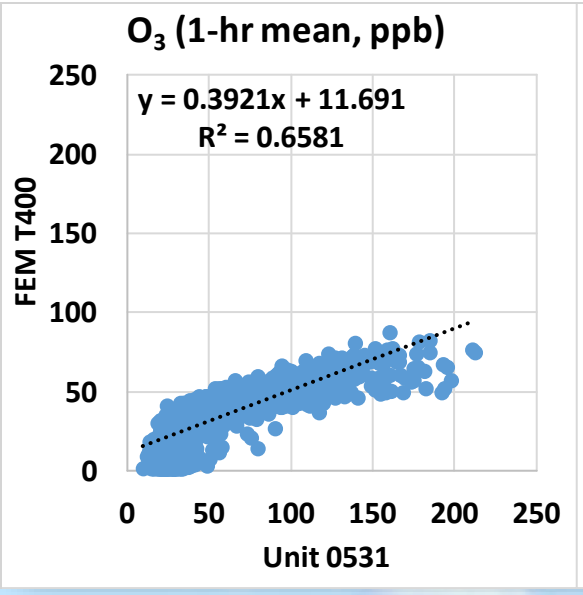


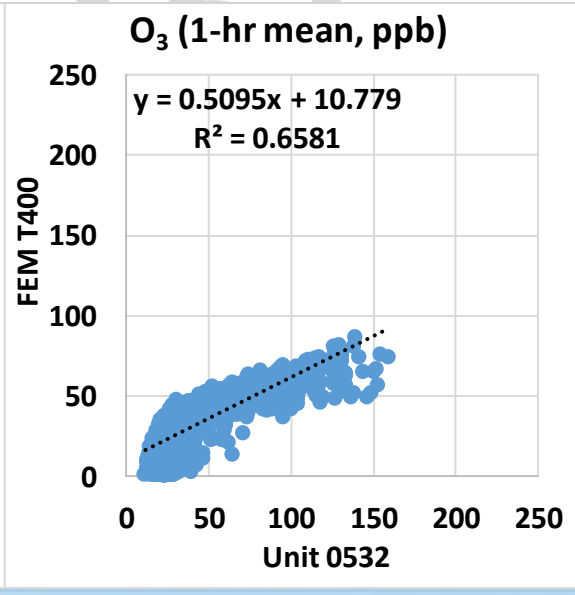


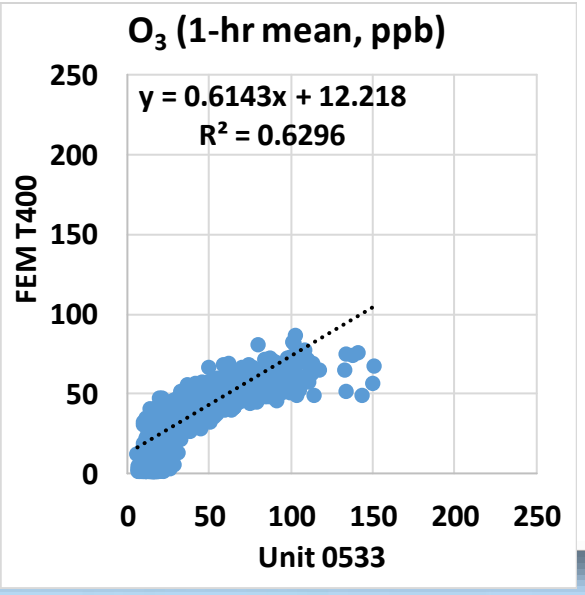
EcomSmart vs FEM T400 (Ozone; 1-hr mean)



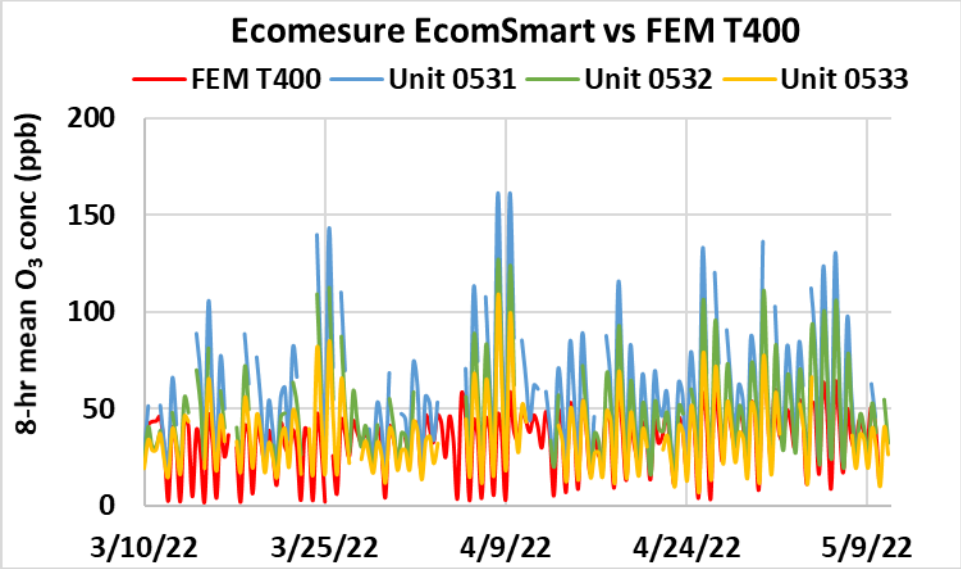
- The EcomSmart sensors showed moderate correlation with the corresponding FEM T400 ozone data ($0.62 < R^2 < 0.66$)
- Overall, the EcomSmart sensors overestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The EcomSmart sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



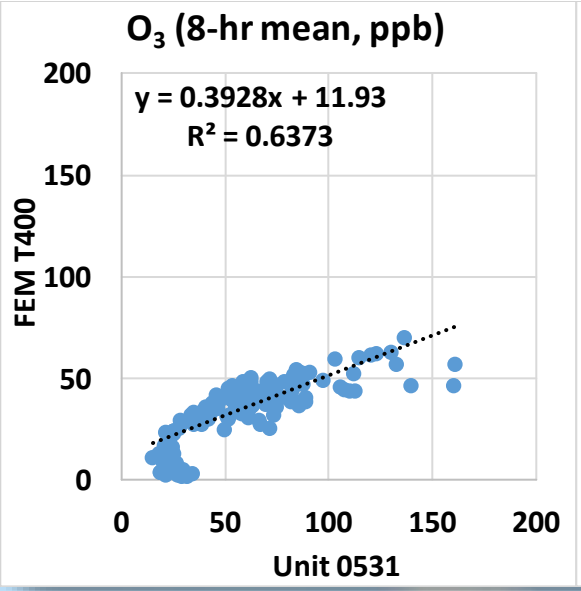


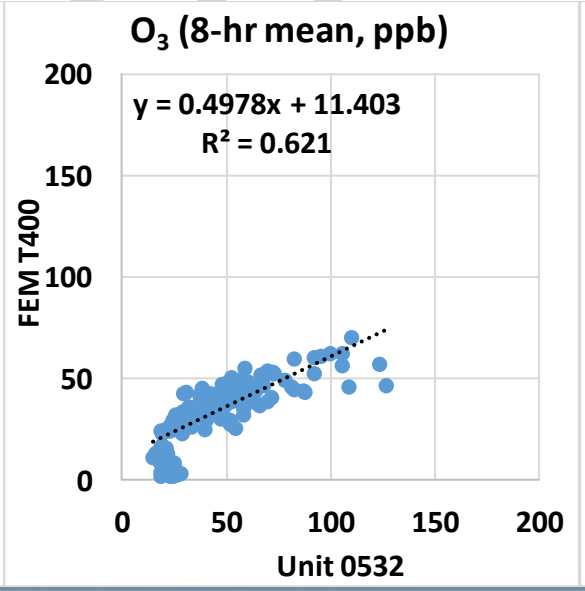


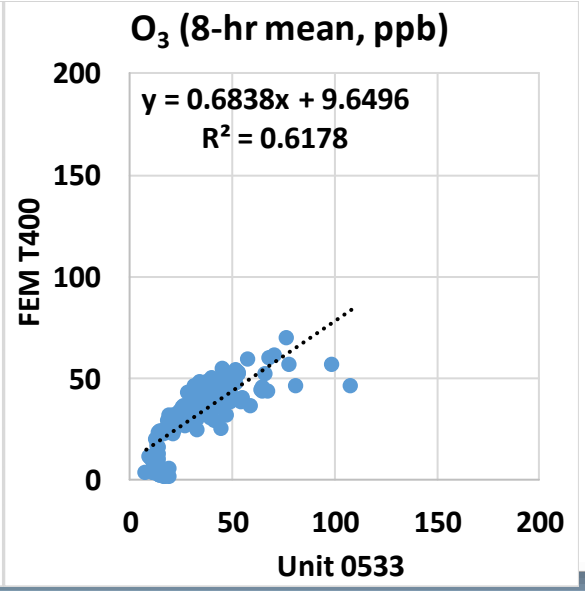
EcomSmart vs FEM T400 (Ozone; 8-hr mean)



- The EcomSmart sensors showed moderate correlation with the corresponding FEM T400 ozone data ($0.61 < R^2 < 0.64$)
- Overall, the EcomSmart sensors overestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The EcomSmart sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument







Summary: Ozone

	Average of 3 Sensors, Ozone		EcomSmart vs FEM T400, Ozone						FEM T400, Ozone (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FEM T400 Average	FEM T400 SD	Range during the field evaluation
5-min	52.8	33.5	0.63 to 0.64	0.39 to 0.59	10.9 to 13.3	1.4 to 24.7	11.4 to 25.7	15.2 to 36.1	34.9	18.5	1.1 to 89.0
1-hr	54.9	34.0	0.63 to 0.66	0.39 to 0.61	10.8 to 12.2	1.2 to 24.9	10.9 to 25.6	14.6 to 36.0	33.6	18.5	1.3 to 87.2
8-hr	54.9	27.6	0.62 to 0.64	0.39 to 0.68	9.6 to 11.9	1.3 to 24.9	8.3 to 25.0	7.9 to 29.8	33.8	15.6	2.0 to 70.4

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

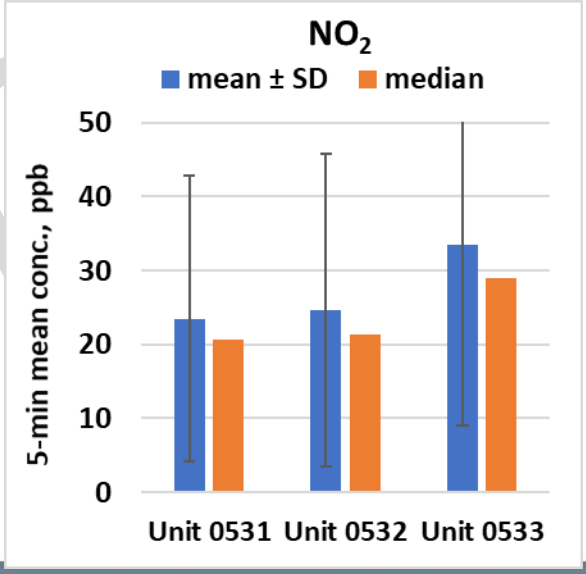
Nitrogen Dioxide (NO_2) in Ecomesure EcomSmart

Data validation & recovery

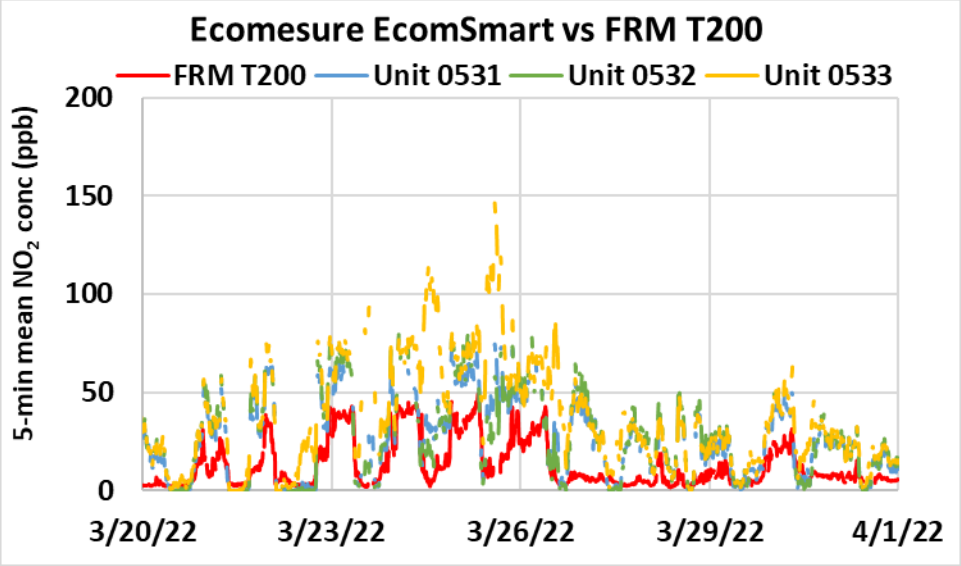
- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values, and invalid data-points were eliminated from the data-set)
- Data recovery for NO_2 from Unit 0531, Unit 0532 and Unit 0533 was ~ 96.3%, ~ 96.2% and ~ 96.1%, respectively

Ecomesure EcomSmart; Intra-model variability

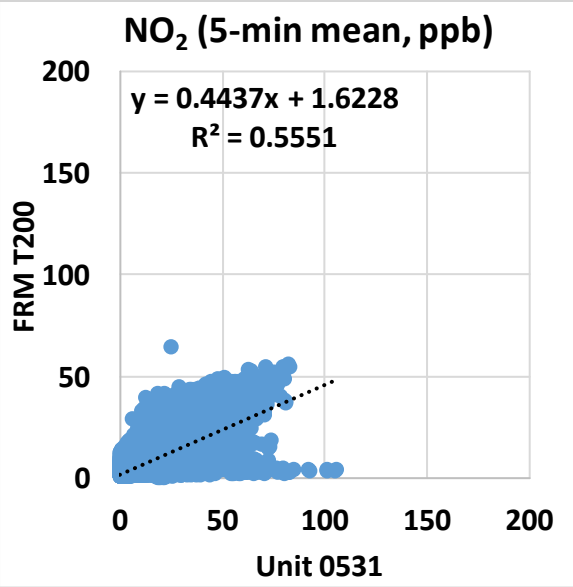
- Absolute intra-model variability was ~ 4.5 ppb for the NO_2 measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 16.5% for the NO_2 measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

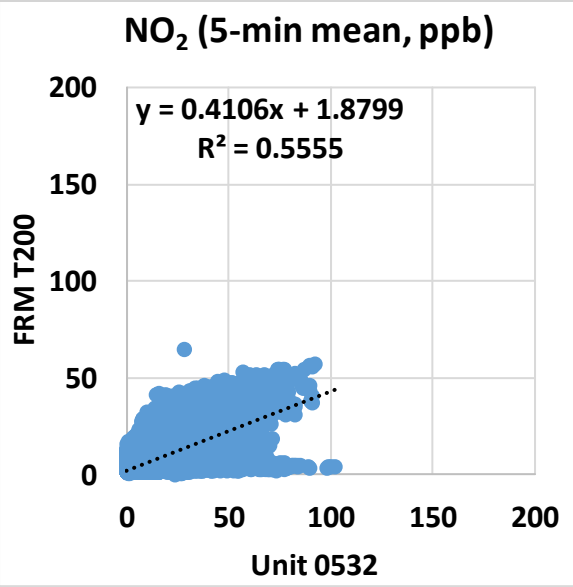


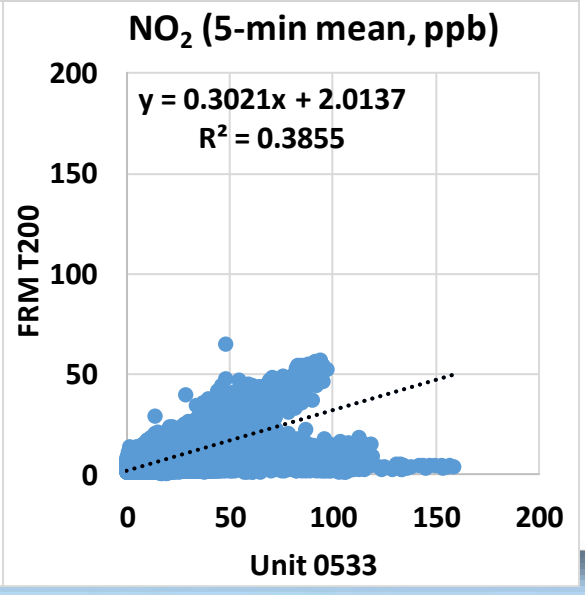
EcomSmart vs FRM T200 (NO_2; 5-min mean)



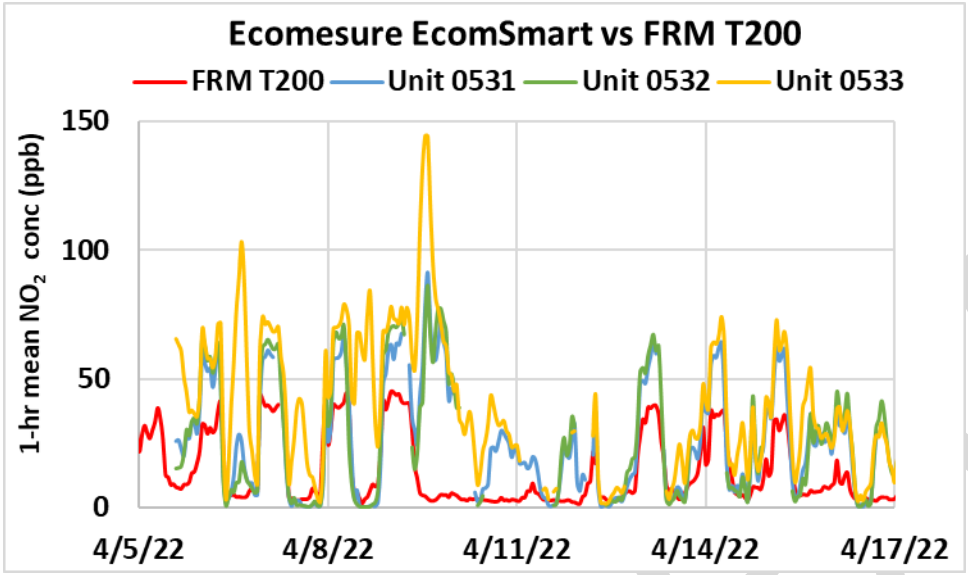
- The EcomSmart sensors showed weak to moderate correlations with the corresponding FRM T200 NO_2 data ($0.38 < R^2 < 0.56$)
- Overall, the EcomSmart sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The EcomSmart sensors sometimes seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



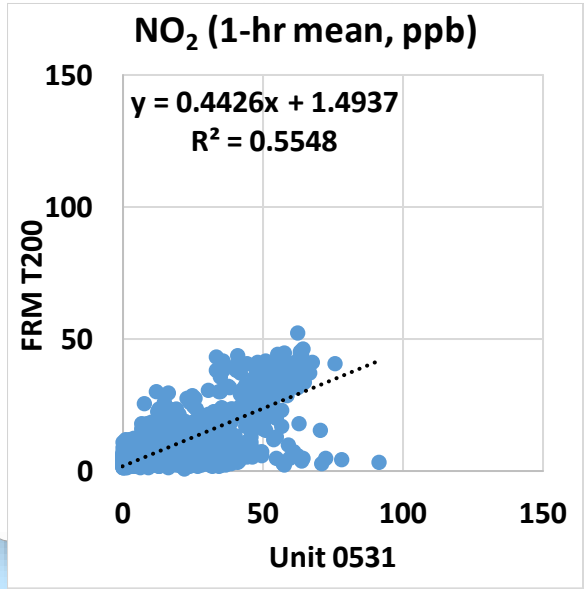


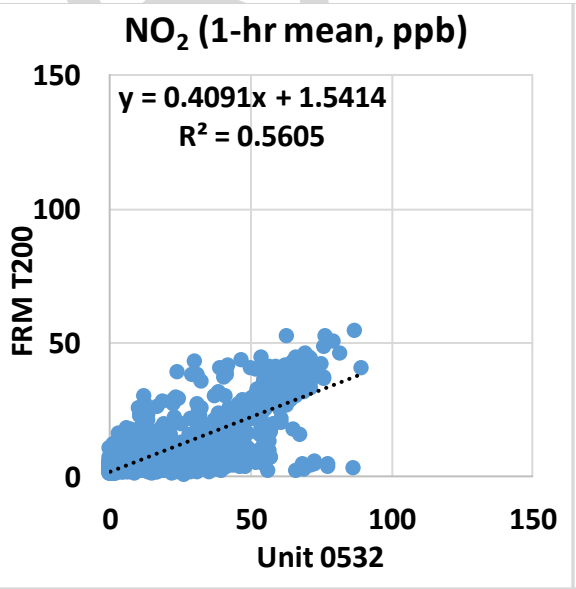


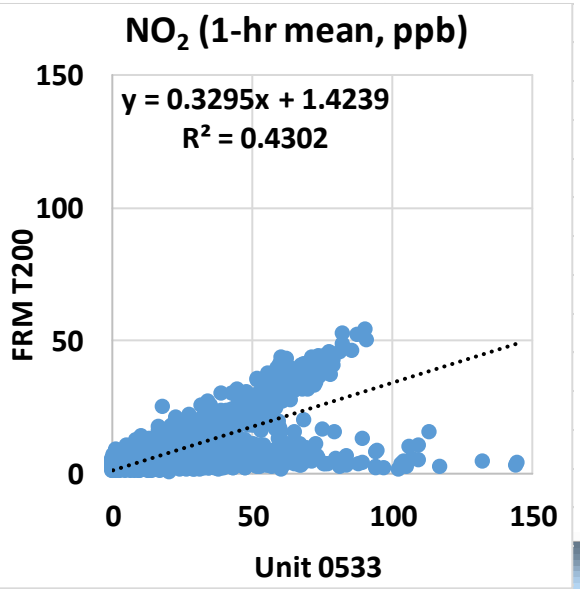
EcomSmart vs FRM T200 (NO_2; 1-hr mean)



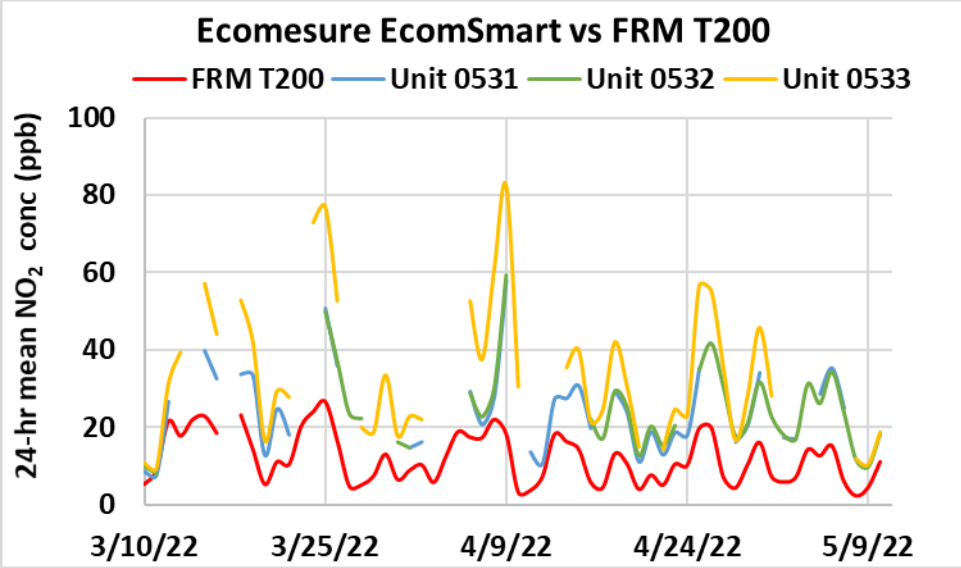
- The EcomSmart sensors showed weak to moderate correlations with the corresponding FRM T200 NO_2 data ($0.43 < R^2 < 0.57$)
- Overall, the EcomSmart sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The EcomSmart sensors sometimes seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



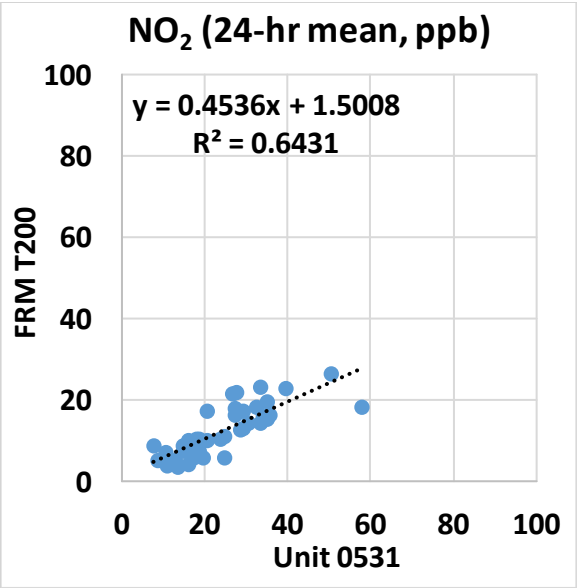


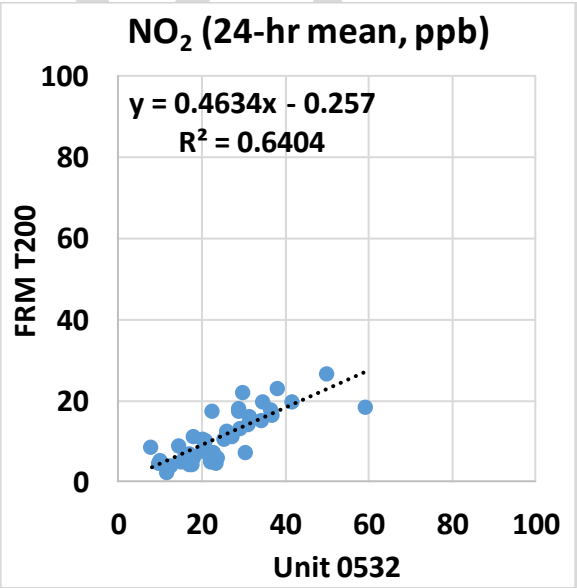


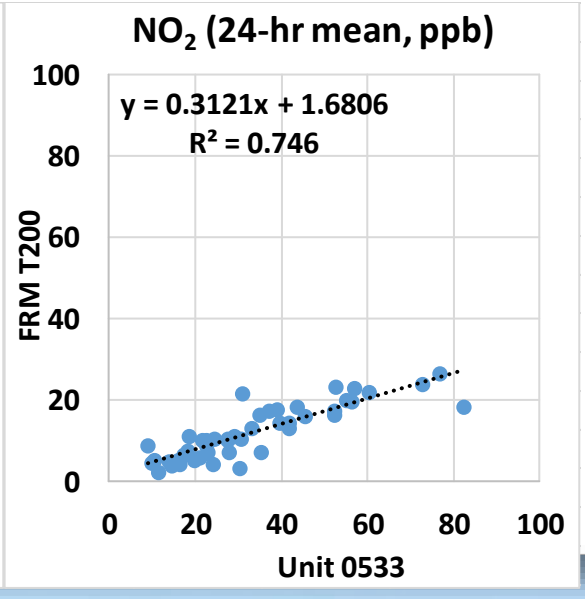
EcomSmart vs FRM T200 (NO_2; 24-hr mean)



- The EcomSmart sensors showed moderate to strong correlations with the corresponding FRM T200 NO_2 data ($0.64 < R^2 < 0.75$)
- Overall, the EcomSmart sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The EcomSmart sensors seemed to track the daily NO_2 variations as recorded by the FRM T200 instrument







Summary: NO_2

	Average of 3 Sensors, NO_2		EcomSmart vs FRM T200, NO_2						FRM T200, NO_2 (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FRM T200 Average	FRM T200 SD	Range during the field evaluation
5-min	24.6	24.3	0.39 to 0.56	0.30 to 0.44	1.6 to 2.0	11.2 to 20.9	13.3 to 21.6	17.3 to 28.5	12.0	11.6	0.6 to 65.0
1-hr	23.8	19.7	0.43 to 0.56	0.33 to 0.44	1.4 to 1.5	11.5 to 20.7	13.3 to 21.3	17.2 to 27.6	12.5	11.7	0.8 to 54.7
24-hr	24.7	10.8	0.64 to 0.75	0.31 to 0.46	-0.3 to 1.7	11.8 to 21.6	11.8 to 21.6	13.6 to 25.1	12.1	6.4	2.4 to 26.7

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

Carbon Monoxide (CO) in Ecomesure EcomSmart

Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values, and invalid data-points were eliminated from the data-set)
- Data recovery for CO from Unit 0531, Unit 0532 and Unit 0533 was ~ 96.3%, ~ 96.2% and ~ 96.1%, respectively

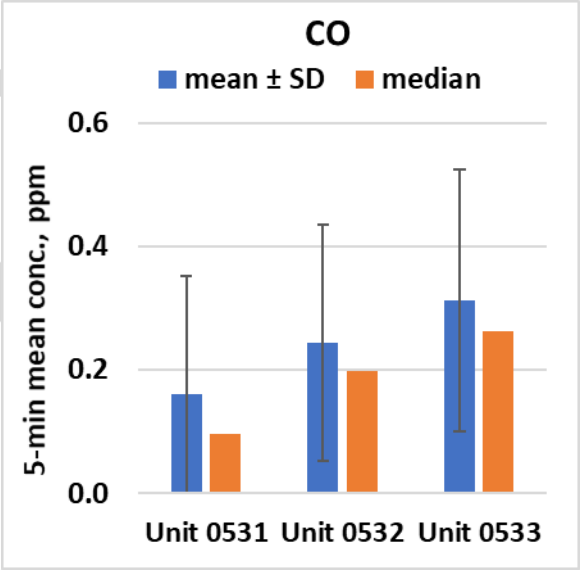
Ecomesure EcomSmart; Intra-model variability

- Absolute intra-model variability was ~ 0.06 ppm for the CO measurements

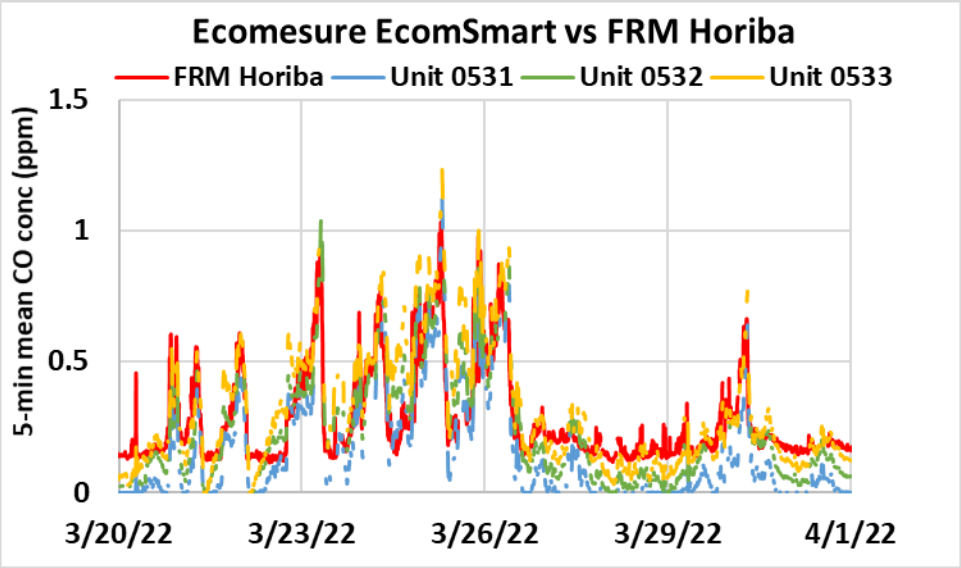
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 26.2% for the CO measurements

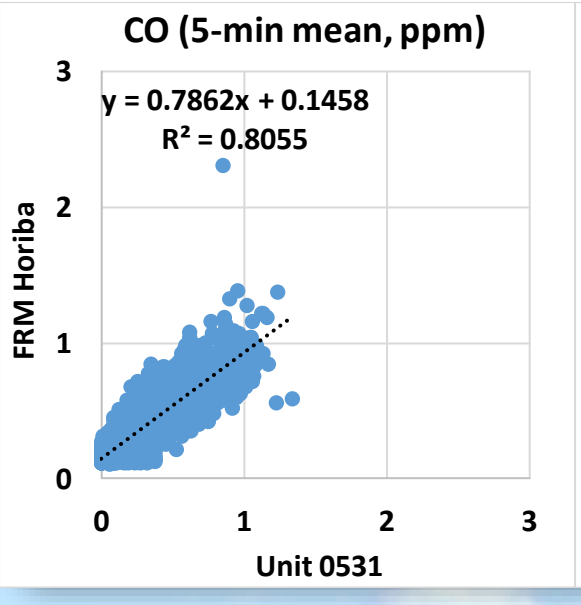
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

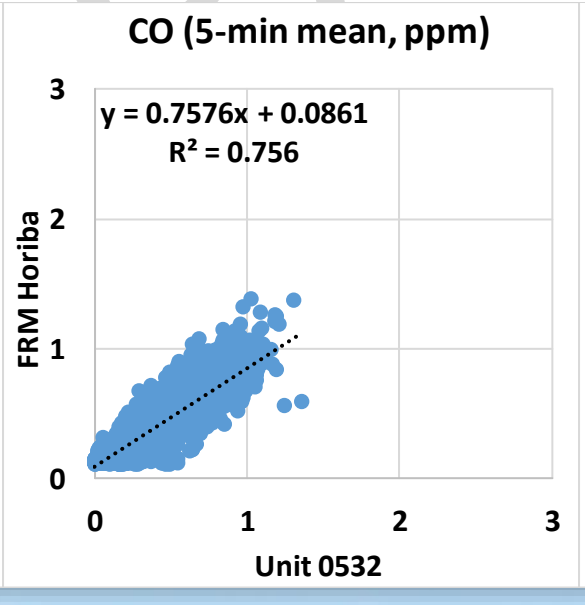


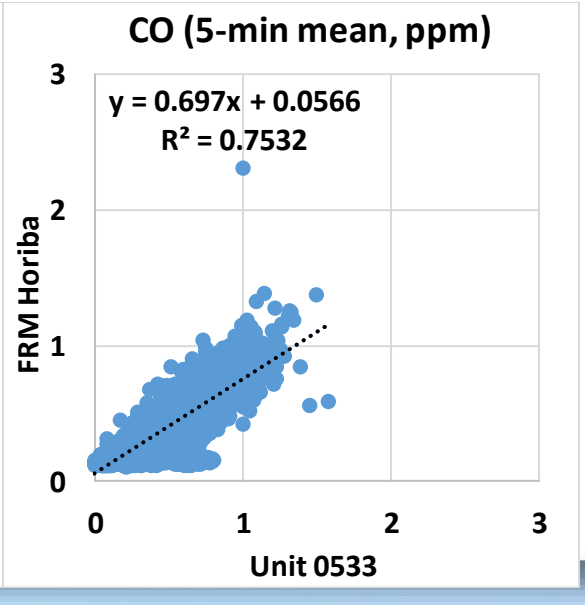
EcomSmart vs FRM Horiba (CO; 5-min mean)



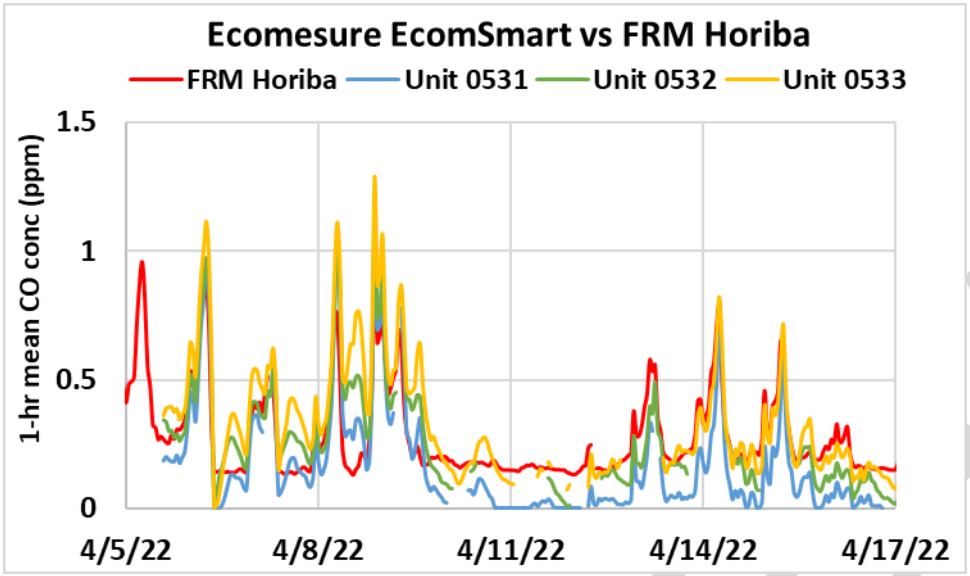
- The EcomSmart sensors showed strong correlations with the corresponding FRM Horiba CO data ($0.75 < R^2 < 0.81$)
- Overall, the EcomSmart sensors underestimated the CO concentration as measured by the FRM Horiba instrument
- The EcomSmart sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument



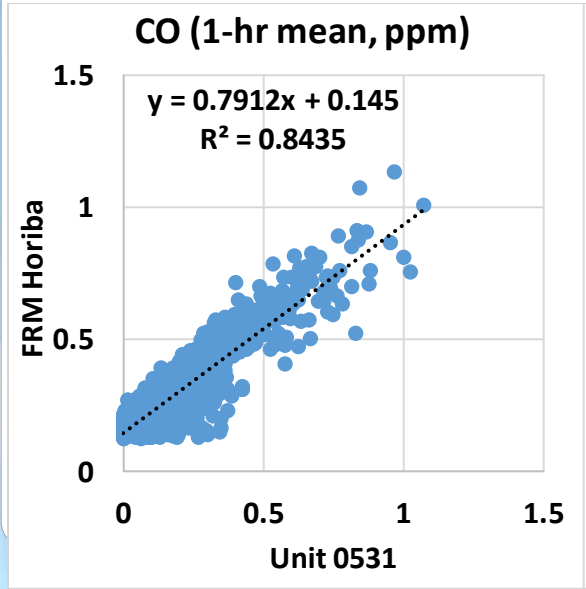


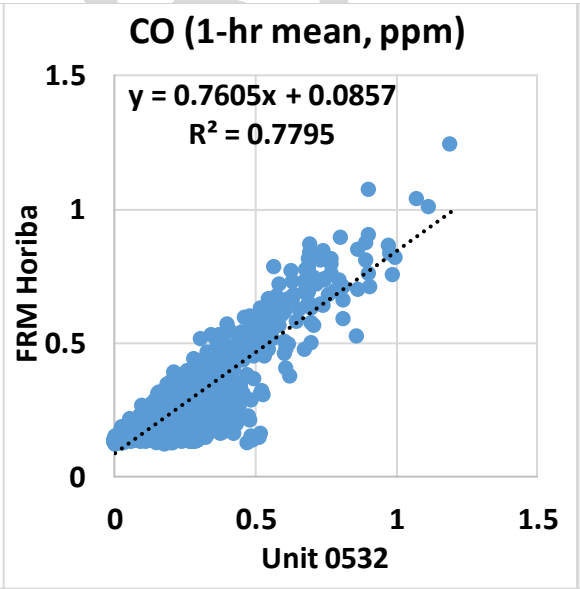


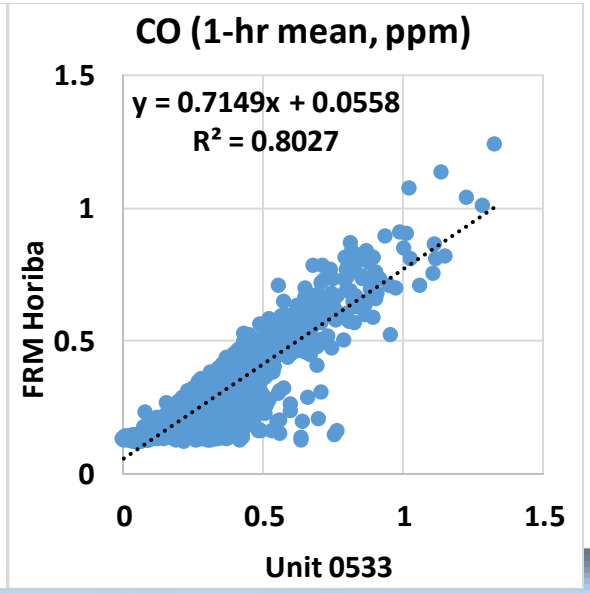
EcomSmart vs FRM Horiba (CO; 1-hr mean)



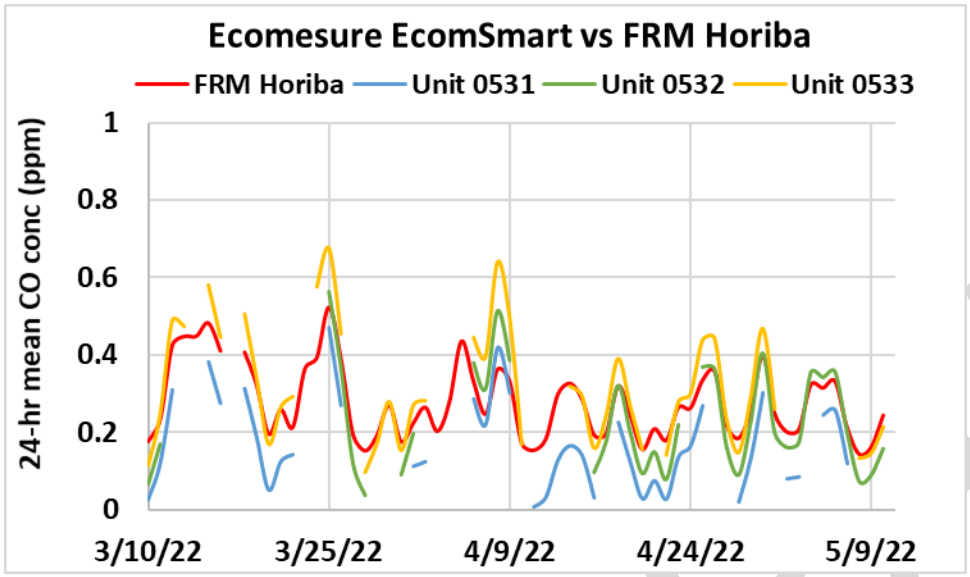
- The EcomSmart sensors showed strong correlations with the corresponding FRM Horiba CO data ($0.77 < R^2 < 0.85$)
- Overall, the EcomSmart sensors underestimated the CO concentration as measured by the FRM Horiba instrument
- The EcomSmart sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument



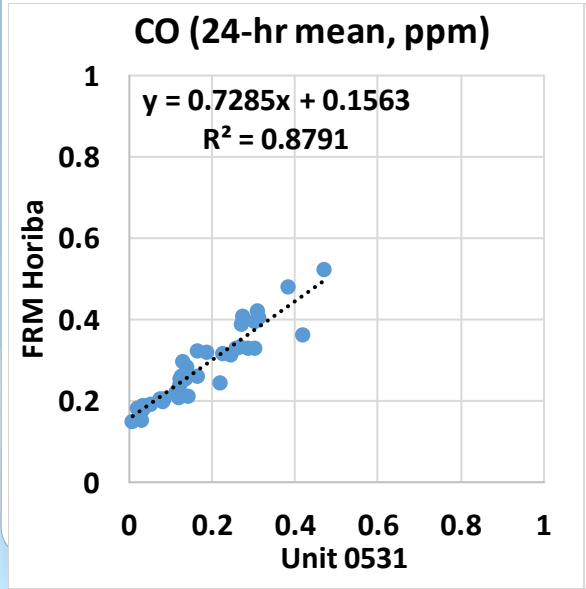


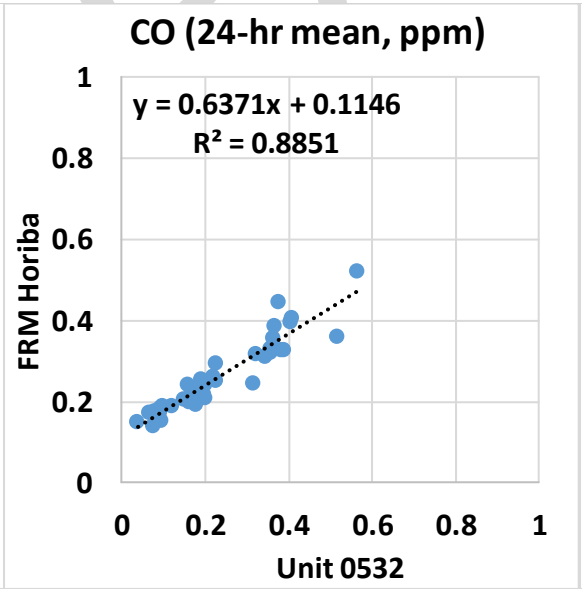


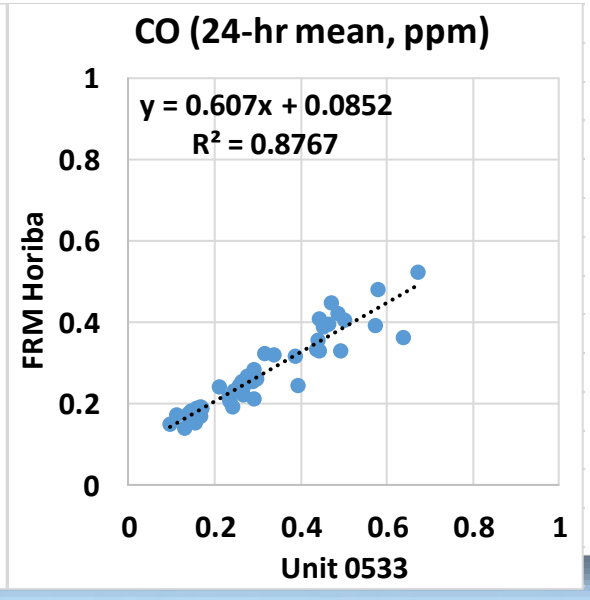
EcomSmart vs FRM Horiba (CO; 24-hr mean)



- The EcomSmart sensors showed strong correlations with the corresponding FRM Horiba CO data ($0.87 < R^2 < 0.89$)
- Overall, the EcomSmart sensors underestimated the CO concentration as measured by the FRM Horiba instrument
- The EcomSmart sensors seemed to track the daily CO variations as recorded by the FRM Horiba instrument







Summary: CO

	Average of 3 Sensors, CO		EcomSmart vs FRM Horiba, CO						FRM CO, Horiba (ppm)		
	Average (ppm)	SD (ppm)	R^2	Slope	Intercept	MBE[1] (ppm)	MAE[2] (ppm)	RMSE[3] (ppm)	FRM Horiba Average	FRM Horiba SD	Range during the field evaluation
5-min	0.24	0.20	0.75 to 0.81	0.70 to 0.79	0.06 to 0.15	-0.11 to 0.04	0.08 to 0.13	0.10 to 0.14	0.28	0.17	0.11 to 2.32
1-hr	0.24	0.19	0.78 to 0.84	0.71 to 0.79	0.06 to 0.15	-0.11 to 0.03	0.07 to 0.12	0.09 to 0.13	0.28	0.17	0.12 to 1.25
24-hr	0.24	0.13	0.88 to 0.89	0.61 to 0.73	0.09 to 0.16	-0.11 to 0.04	0.06 to 0.12	0.10 to 0.14	0.28	0.09	0.14 to 0.52

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

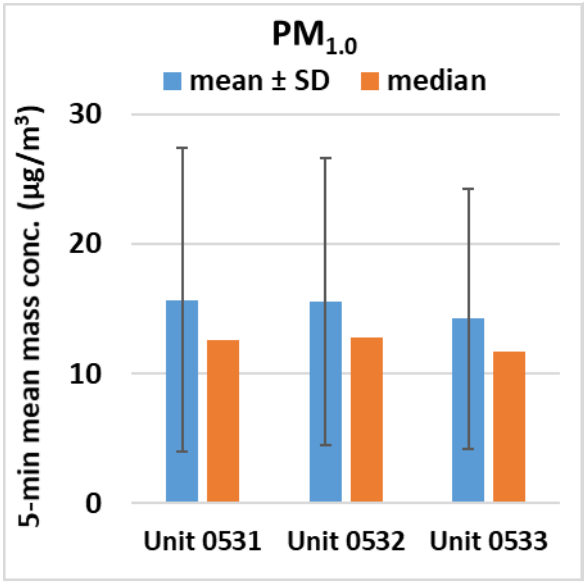
Particulate Matter (PM) in Ecomesure EcomSmart

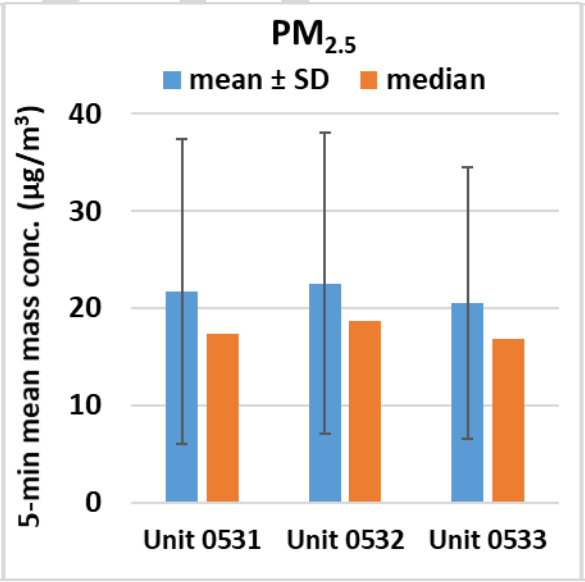
Data validation & recovery

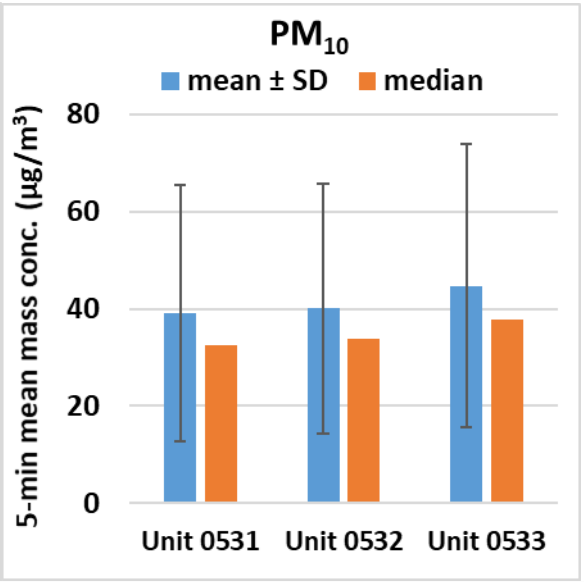
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from Unit 0531, Unit 0532 and Unit 0533 was ~96.3%, ~96.2% and ~96.1%, respectively for all PM measurements

EcomSmart; intra-model variability

- Absolute intra-model variability was ~0.65, ~0.83 and ~2.45 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~4.3%, ~3.8% and ~5.9% for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

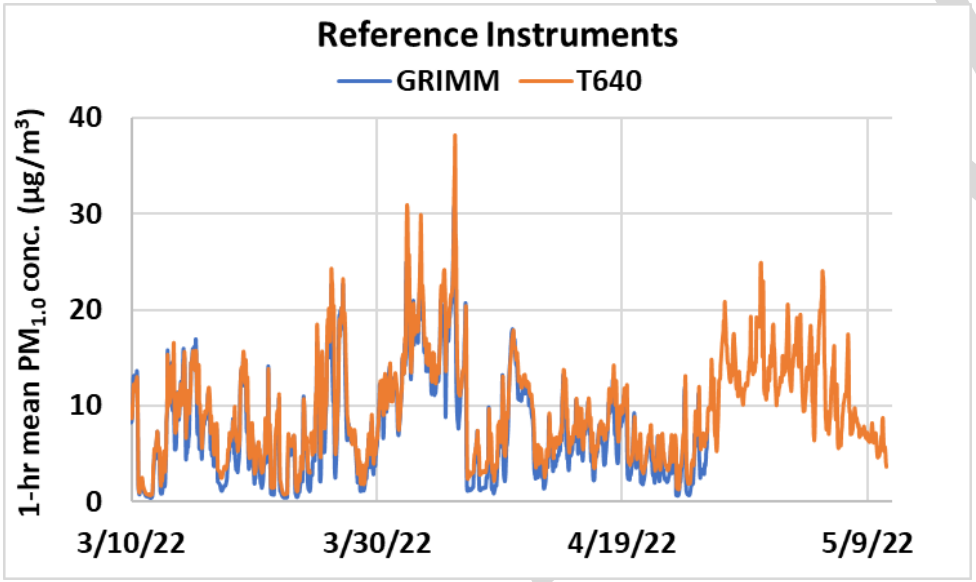


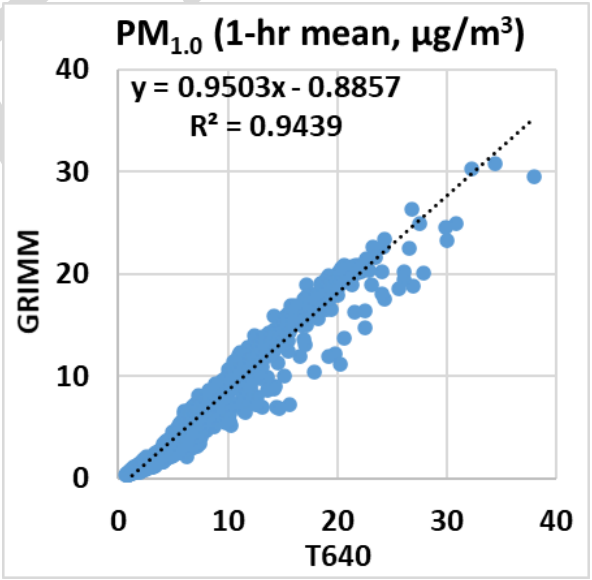




Reference Instruments: $PM_{1.0}$ GRIMM and T640

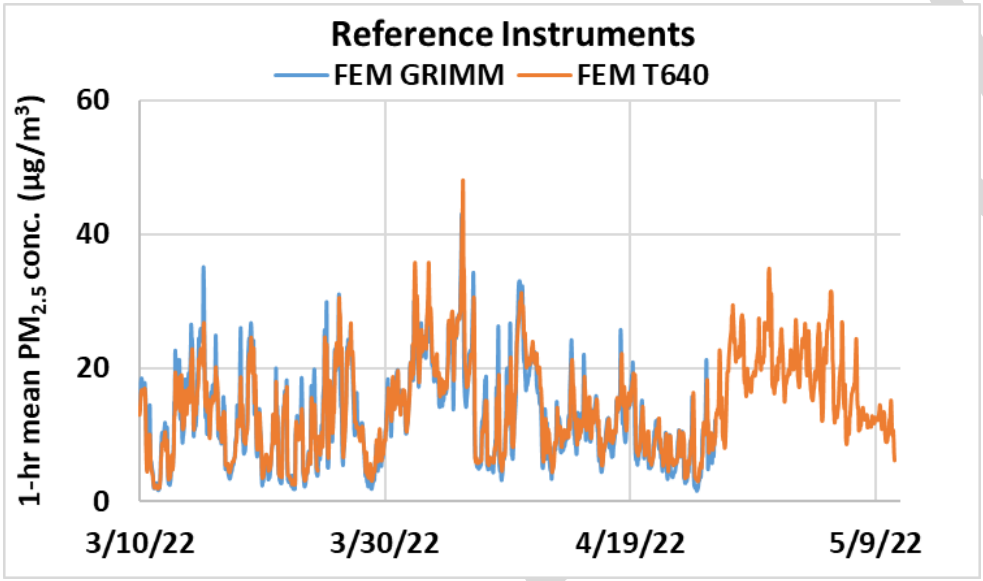
- Data recovery for $PM_{1.0}$ from GRIMM and T640 was ~ 100%.
- Very strong correlations between the reference instruments for $PM_{1.0}$ measurements (R^2 ~ 0.94) were observed.

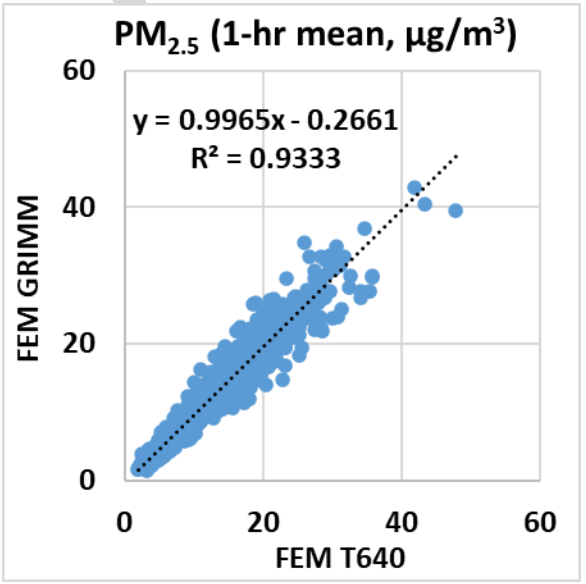




Reference Instruments: $PM_{2.5}$ FEM GRIMM and FEM T640

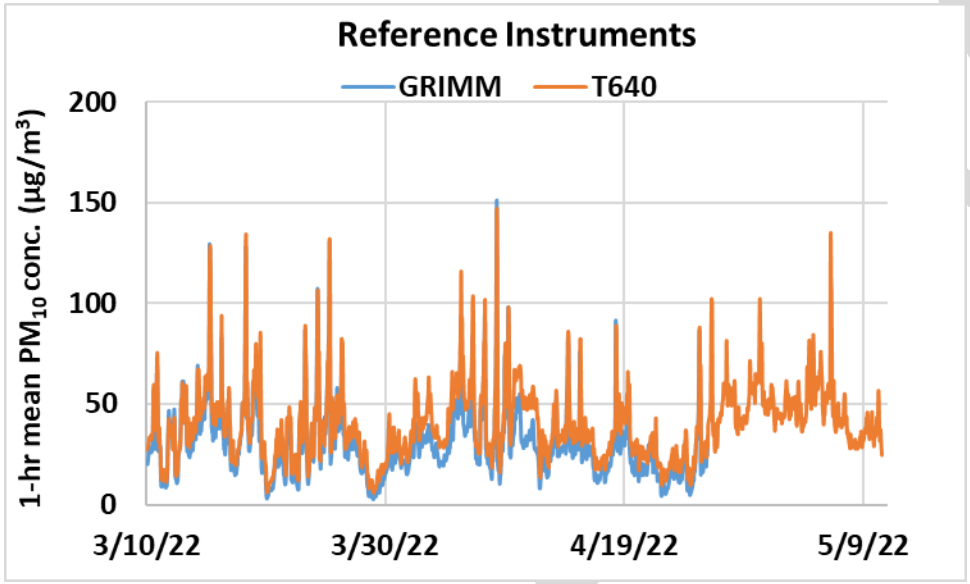
- Data recovery for $PM_{2.5}$ from FEM GRIMM and FEM T640 was ~ 100%.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~0.93) were observed.

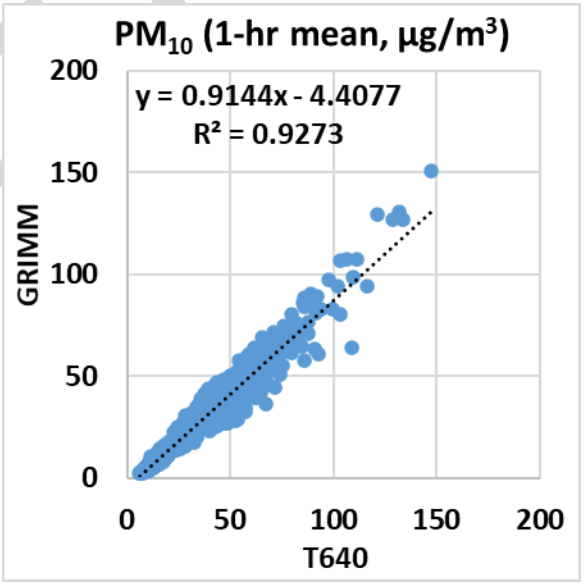




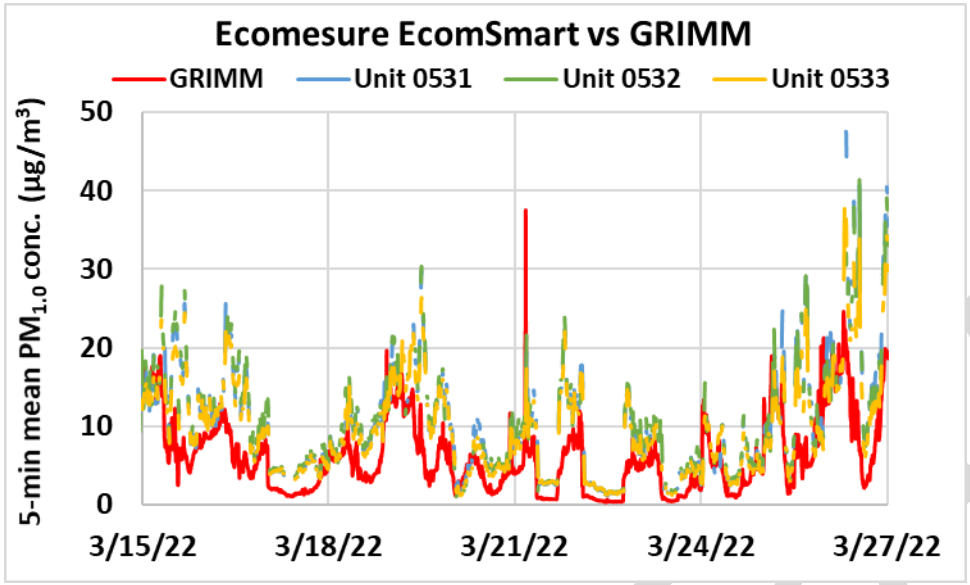
Reference Instruments: PM_{10} GRIMM and T640

- Data recovery for PM_{10} from GRIMM and T640 was ~ 100%.
- Very strong correlations between the reference instruments for PM_{10} measurements (R^2 ~0.93) were observed.

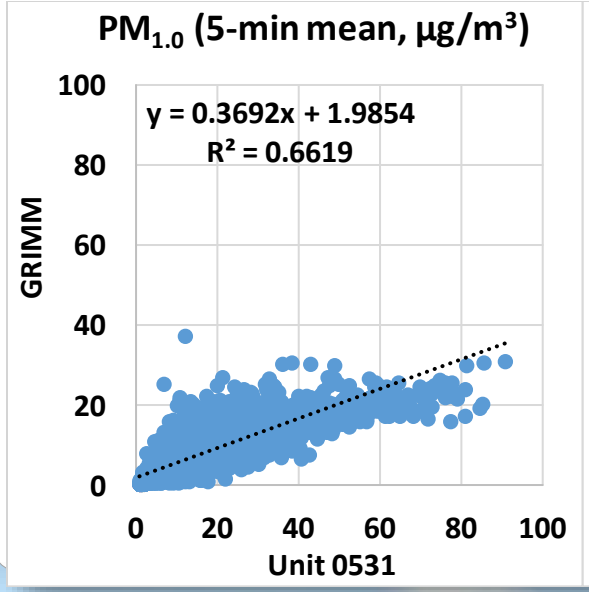


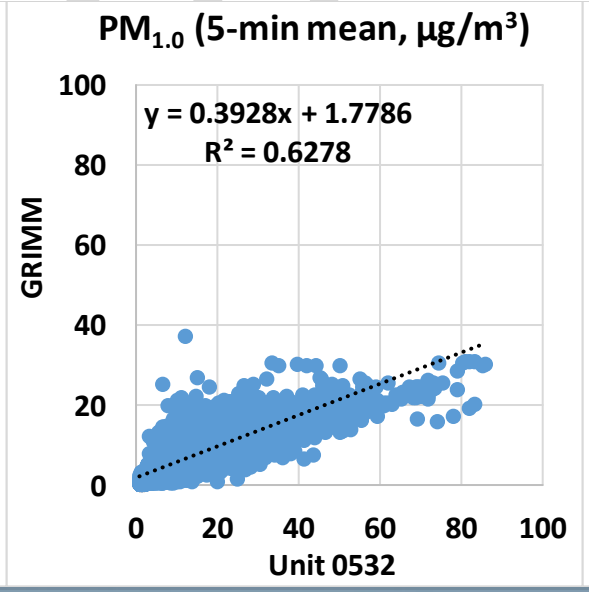


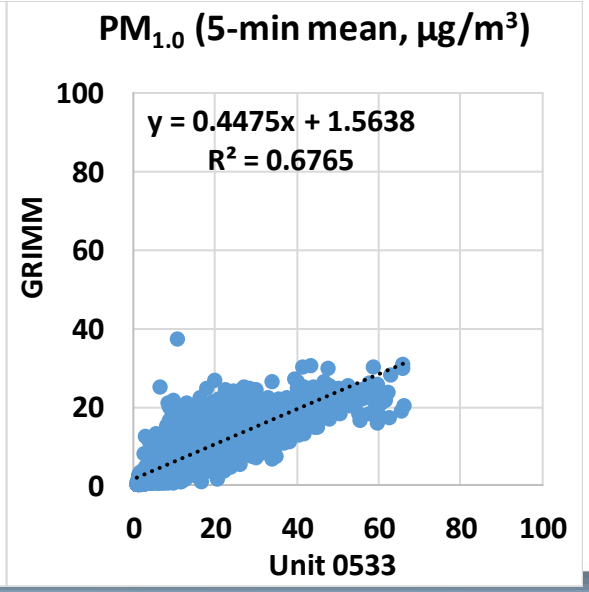
EcomSmart vs GRIMM ($PM_{1.0}$; 5-min mean)



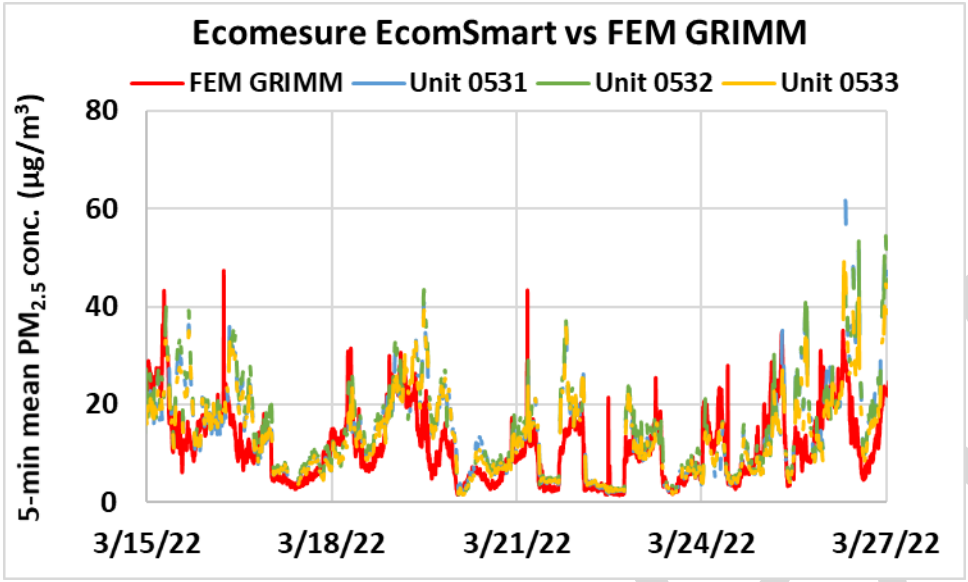
- The EcomSmart sensors showed moderate correlations with the corresponding GRIMM data ($0.62 < R^2 < 0.68$)
- Overall, the EcomSmart sensors overestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The EcomSmart sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



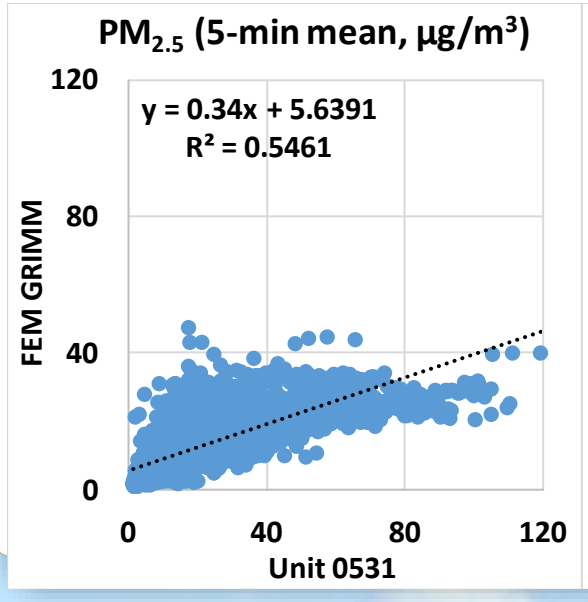


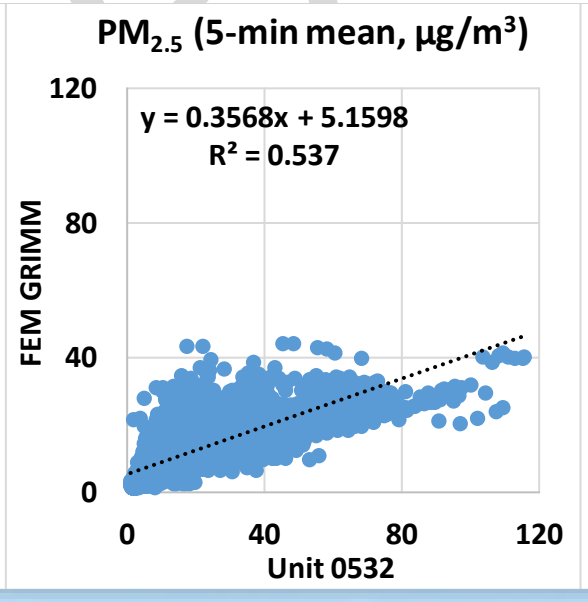


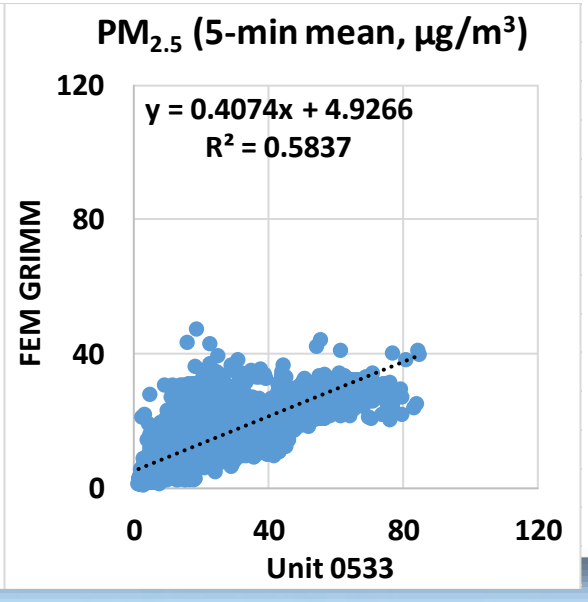
EcomSmart vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



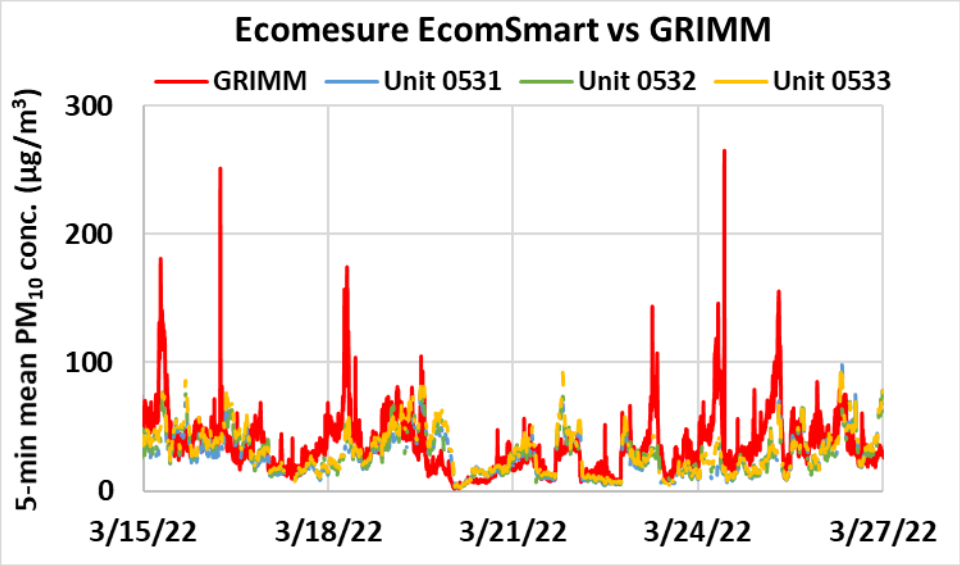
- The EcomSmart sensors showed moderate correlations with the corresponding FEM GRIMM data ($0.53 < R^2 < 0.59$)
- Overall, the EcomSmart sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The EcomSmart sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



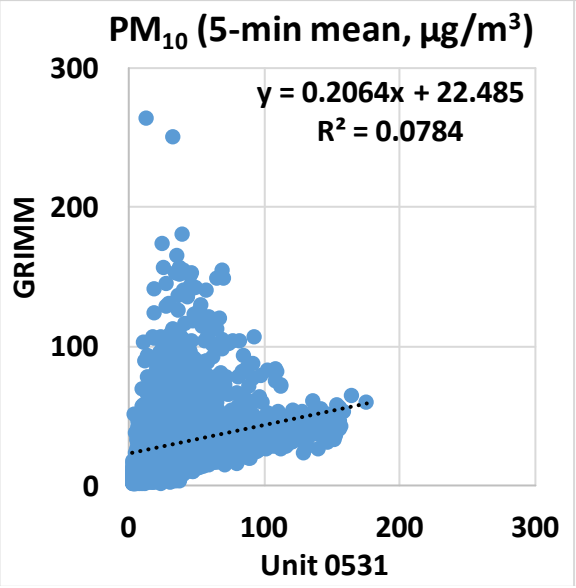


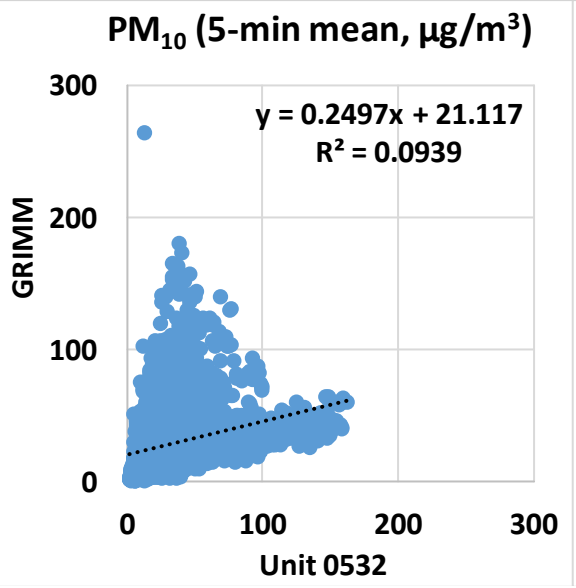


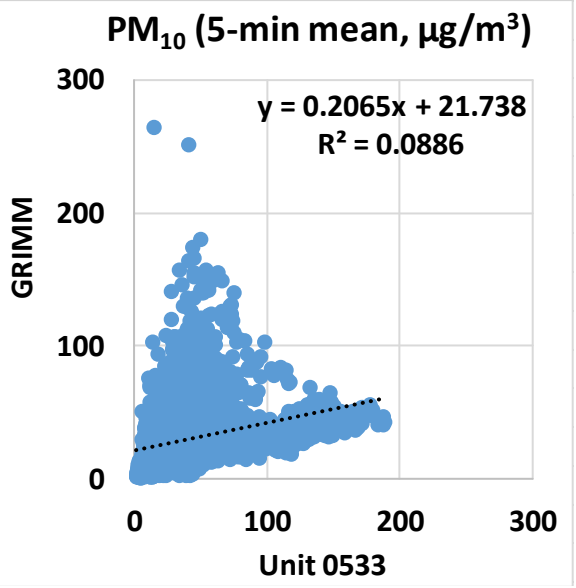
EcomSmart vs GRIMM (PM_{10}; 5-min mean)



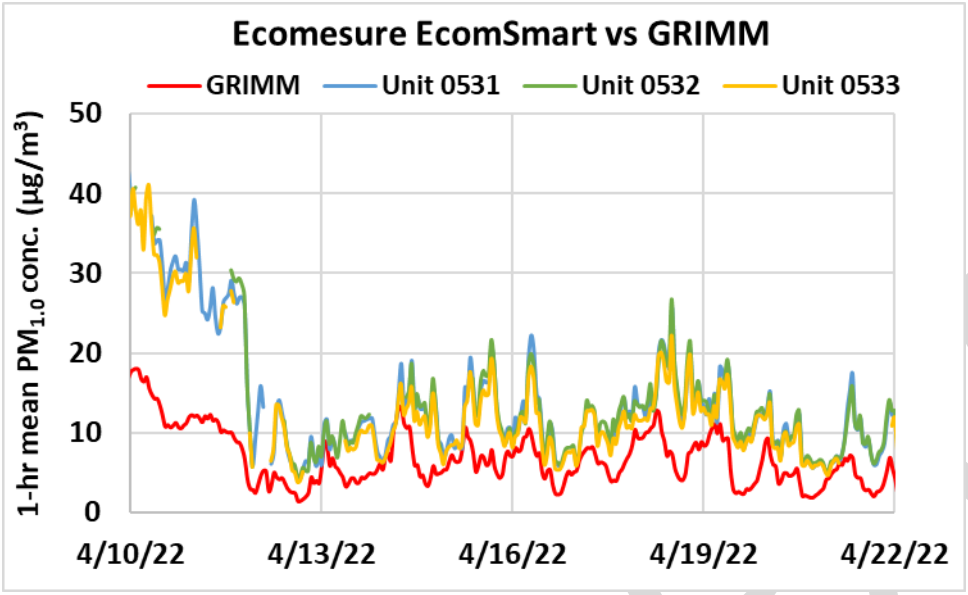
- The EcomSmart sensors did not correlate with the corresponding GRIMM data ($0.07 < R^2 < 0.10$)
- Overall, the EcomSmart sensors overestimated the PM_{10} mass concentrations as measured by GRIMM
- The EcomSmart sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



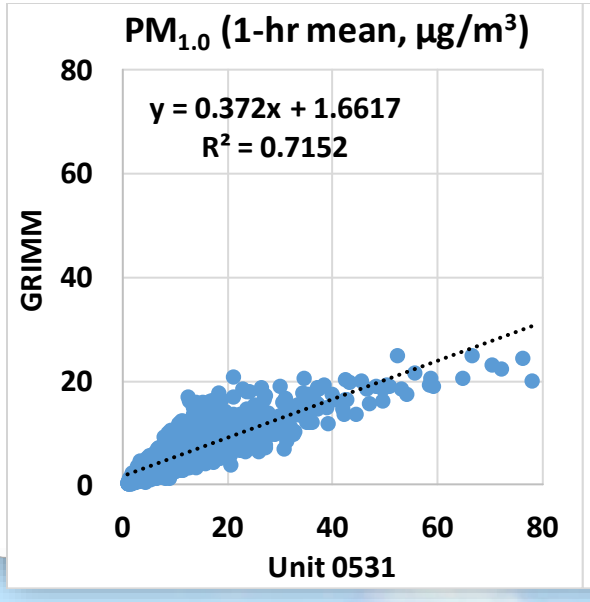


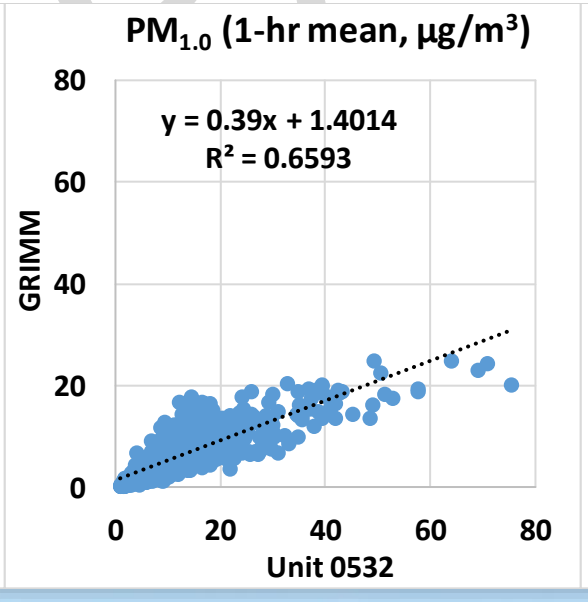


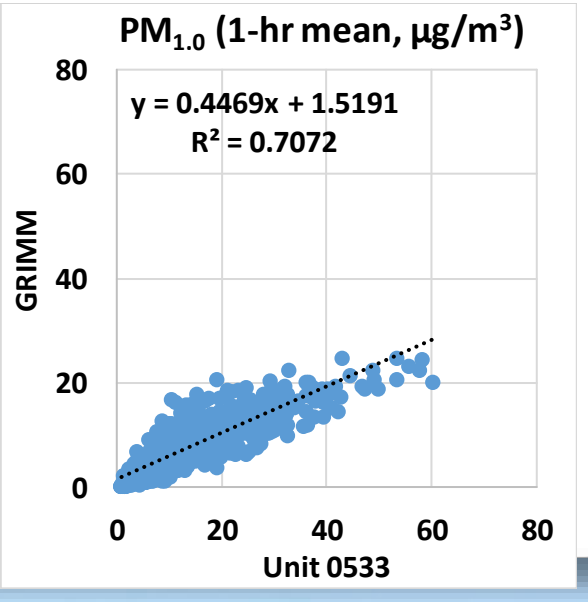
EcomSmart vs GRIMM ($PM_{1.0}$; 1-hr mean)



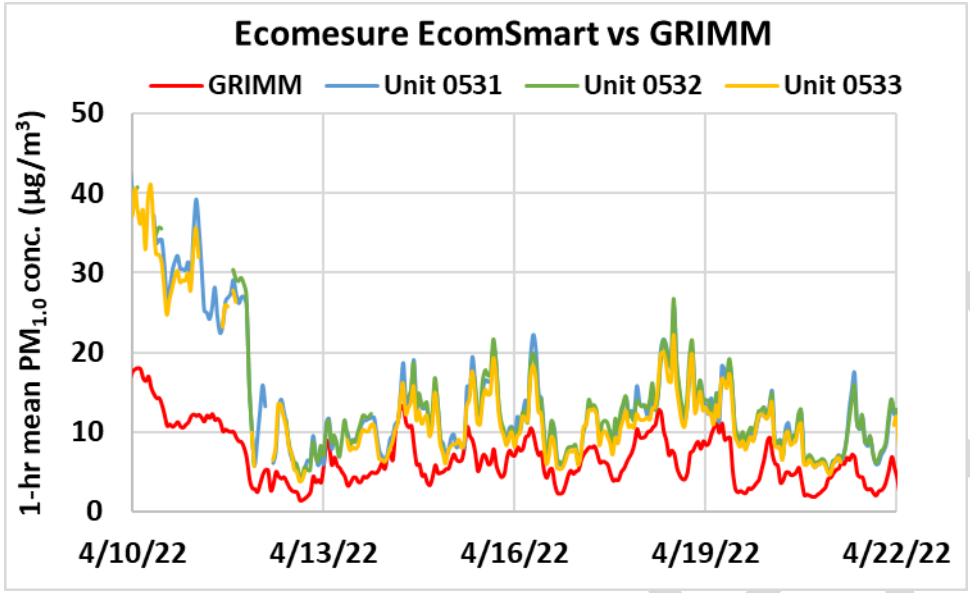
- The EcomSmart sensors showed moderate to strong correlations with the corresponding GRIMM data ($0.65 < R^2 < 0.72$)
- Overall, the EcomSmart sensors overestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The EcomSmart sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



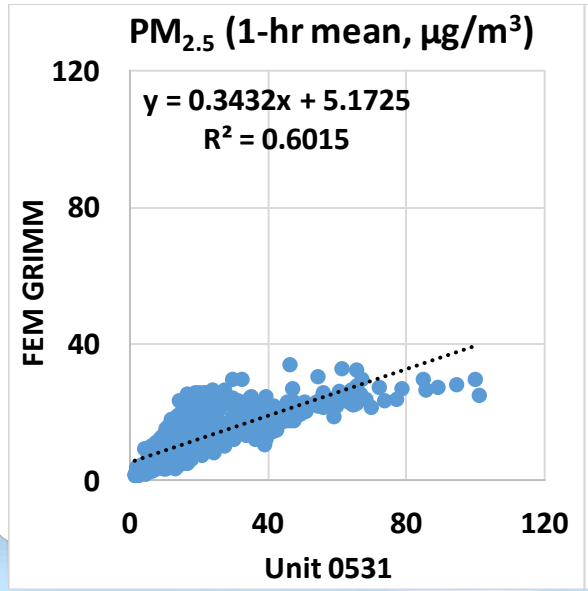


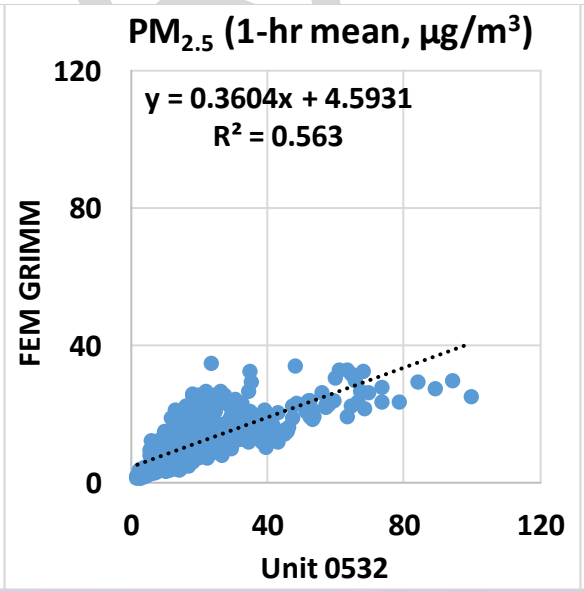


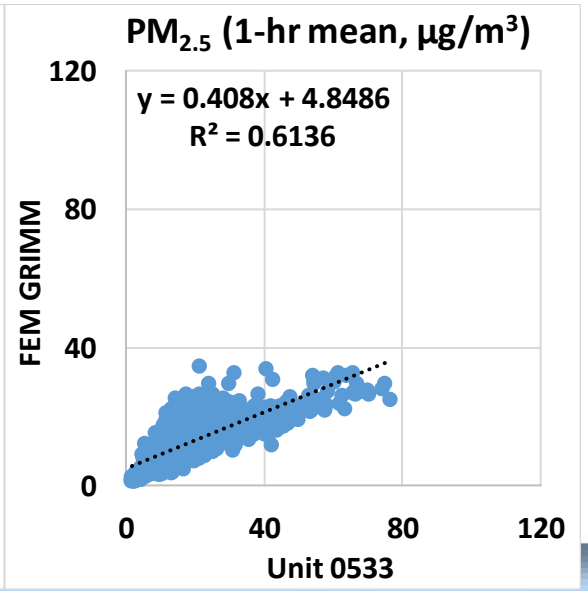
EcomSmart vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



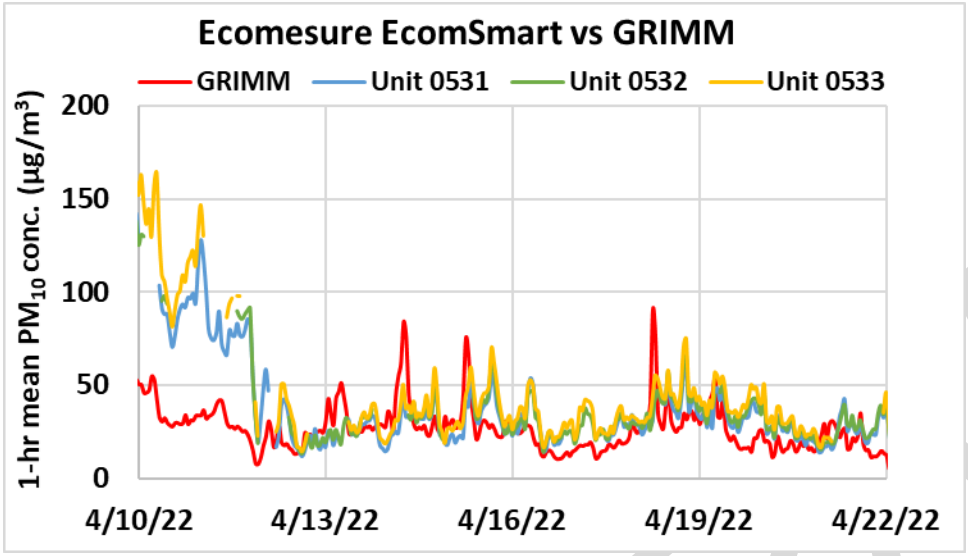
- The EcomSmart sensors showed moderate correlations with the corresponding FEM GRIMM data ($0.56 < R^2 < 0.62$)
- Overall, the EcomSmart sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The EcomSmart sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



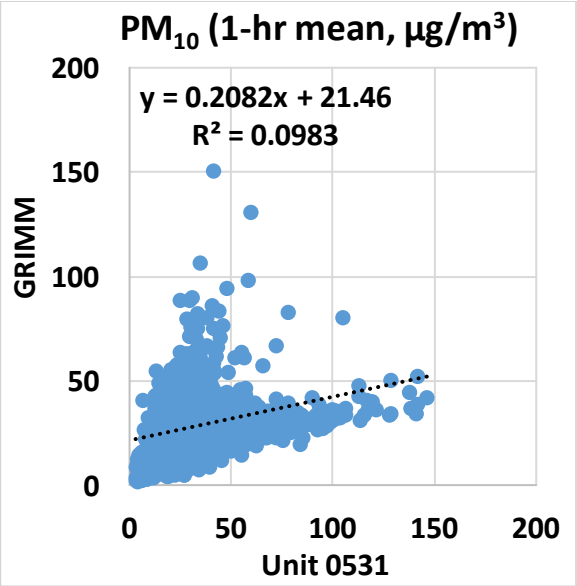


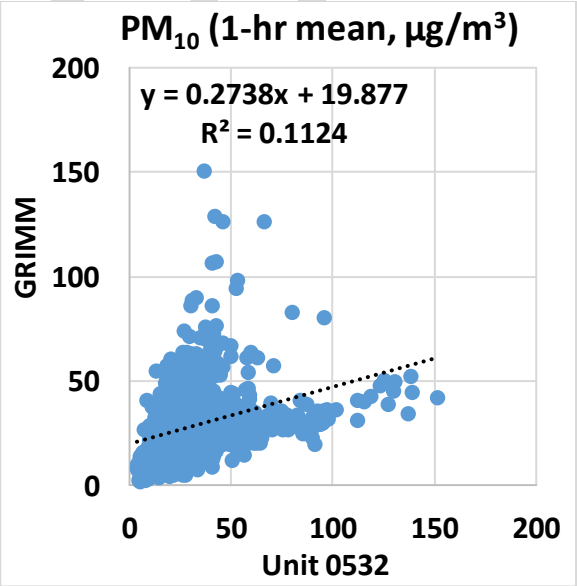


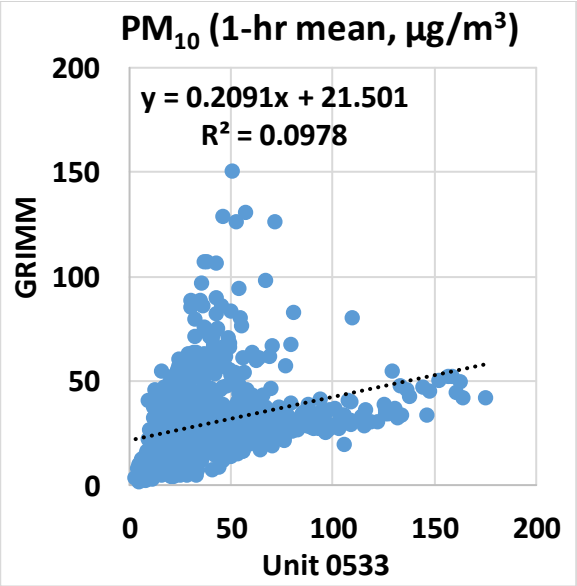
EcomSmart vs GRIMM (PM_{10}; 1-hr mean)



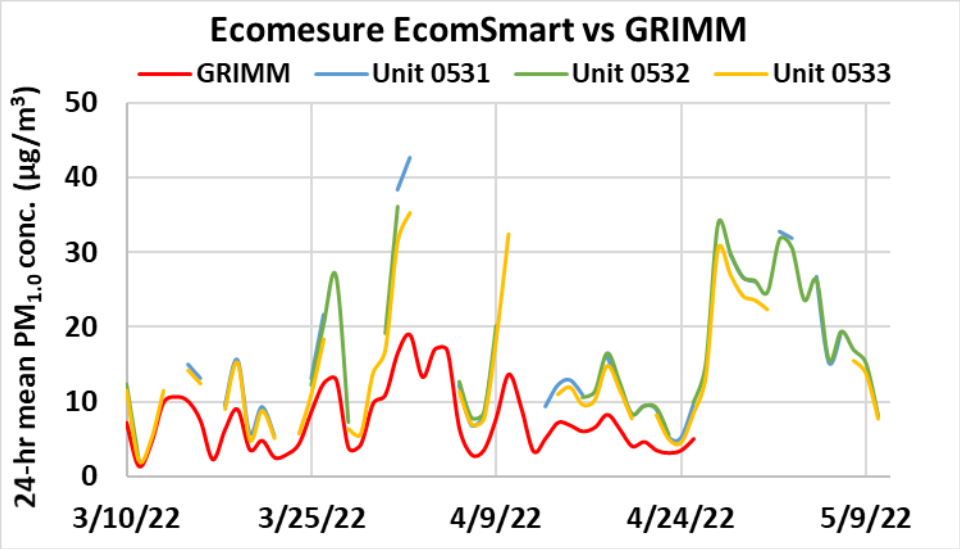
- The EcomSmart sensors showed no to very weak correlations with the corresponding GRIMM data ($0.09 < R^2 < 0.12$)
- Overall, the EcomSmart sensors overestimated the PM_{10} mass concentrations as measured by GRIMM
- The EcomSmart sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



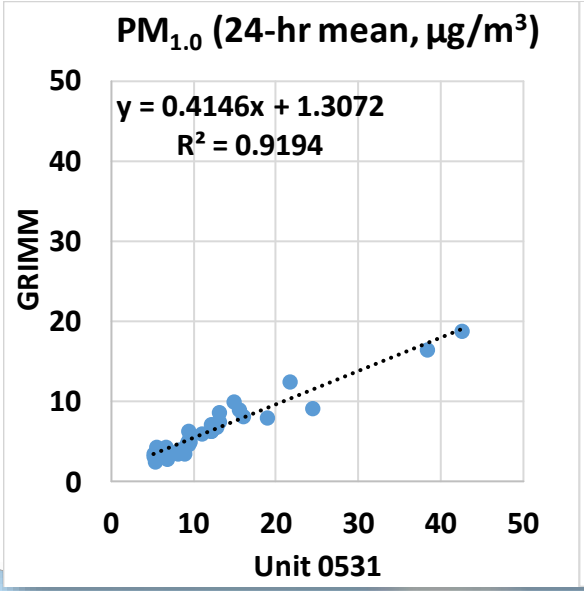


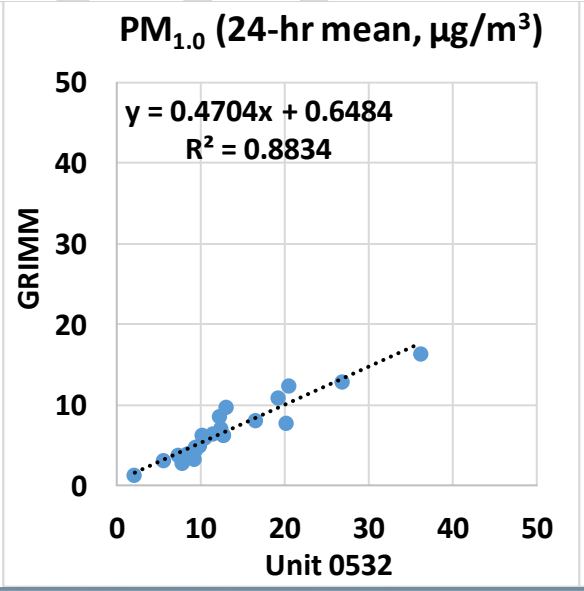


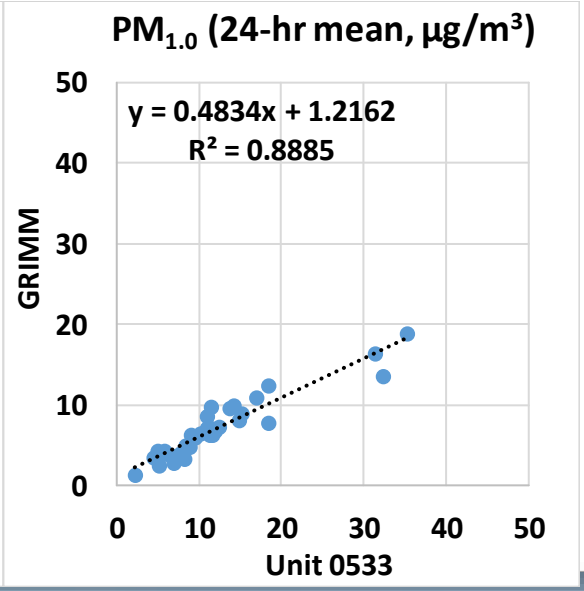
EcomSmart vs GRIMM ($PM_{1.0}$; 24-hr mean)



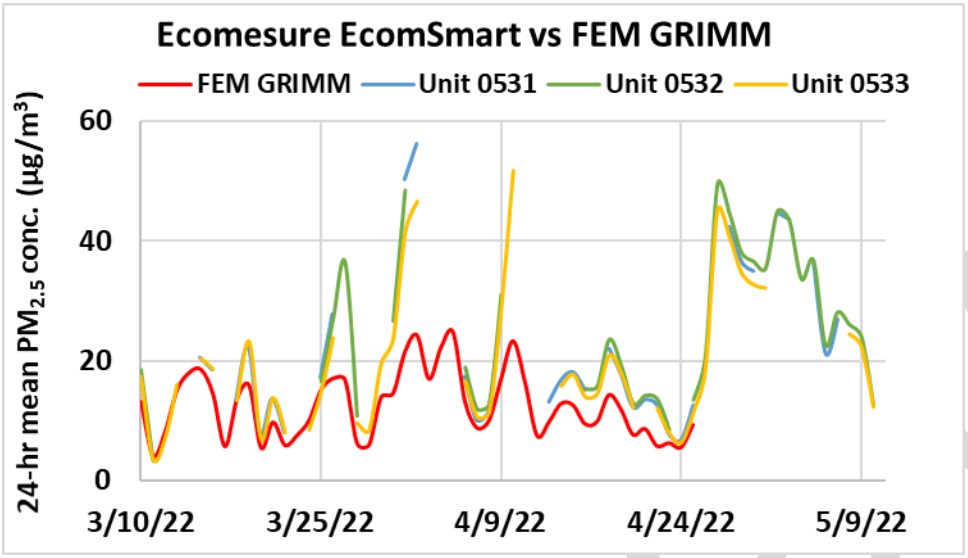
- The EcomSmart sensors showed strong to very strong correlations with the corresponding GRIMM data ($0.88 < R^2 < 0.92$)
- Overall, the EcomSmart sensors overestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The EcomSmart sensors seemed to track the $PM_{1.0}$ daily variations as recorded by GRIMM



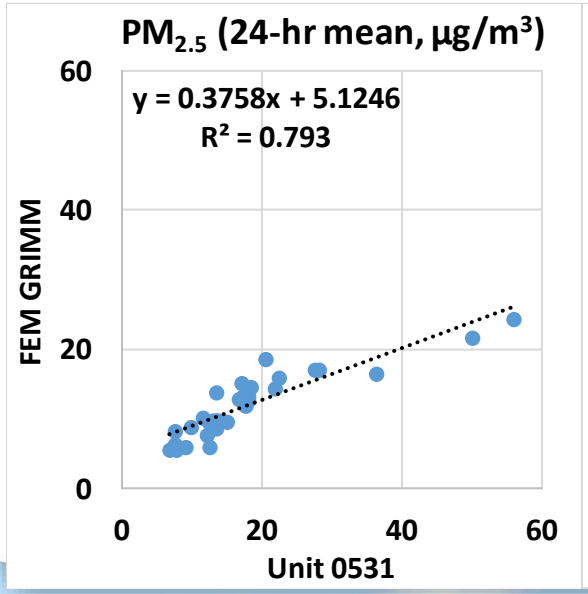


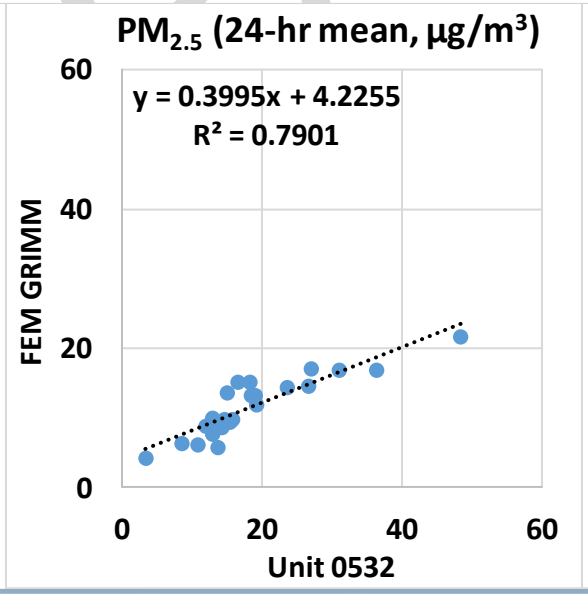


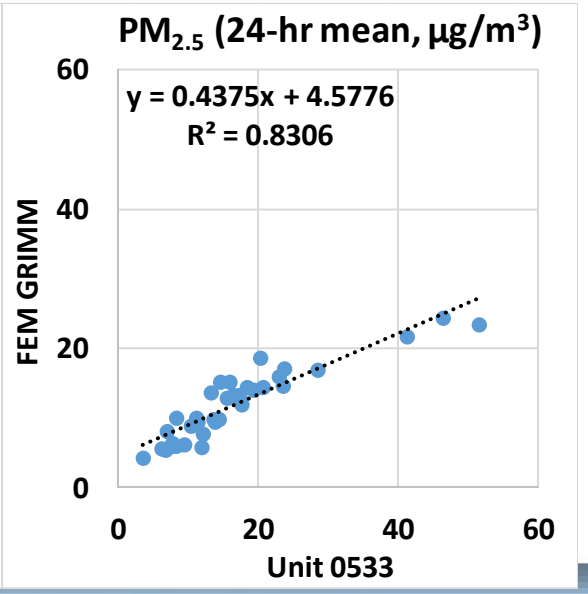
EcomSmart vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



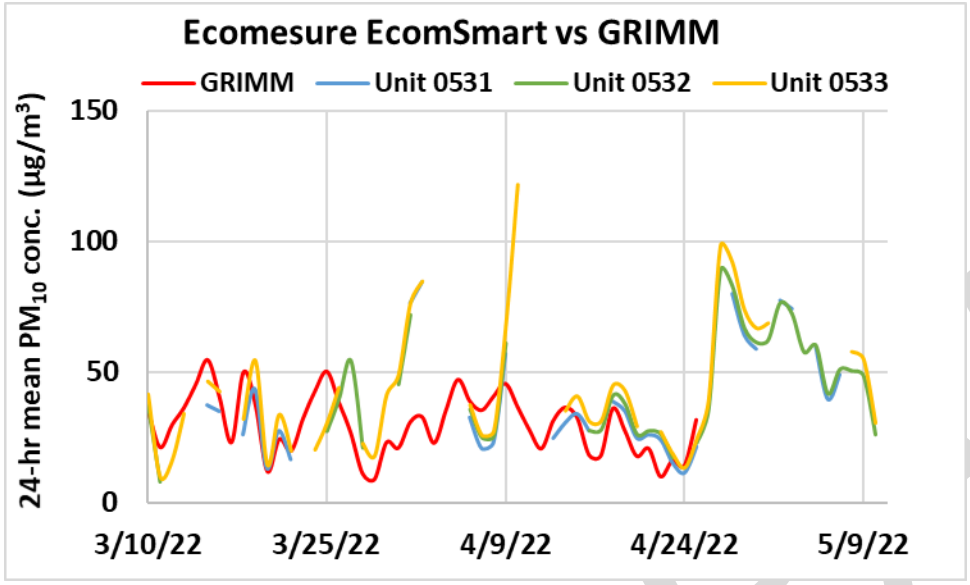
- The EcomSmart sensors showed strong correlations with the corresponding FEM GRIMM data ($0.79 < R^2 < 0.84$)
- Overall, the EcomSmart sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The EcomSmart sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM GRIMM



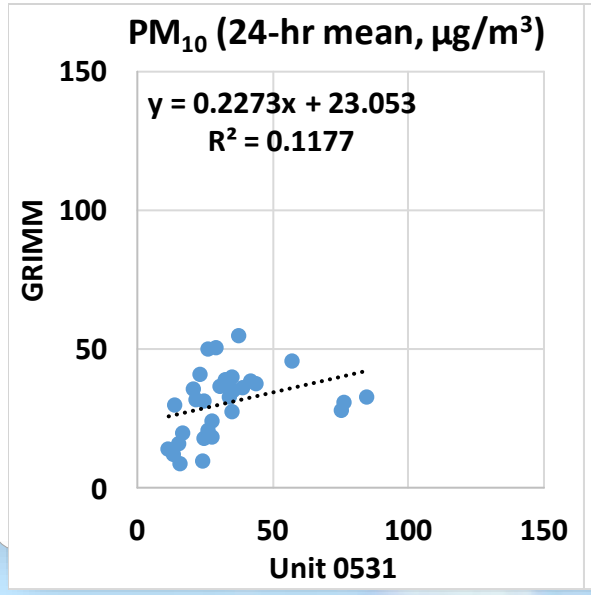


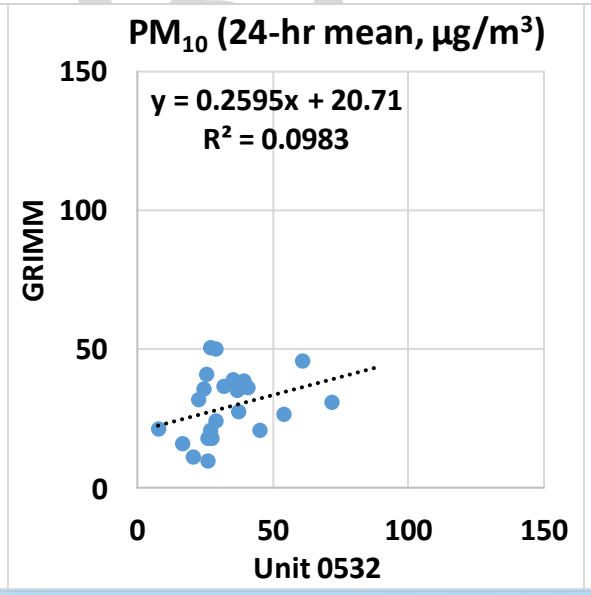


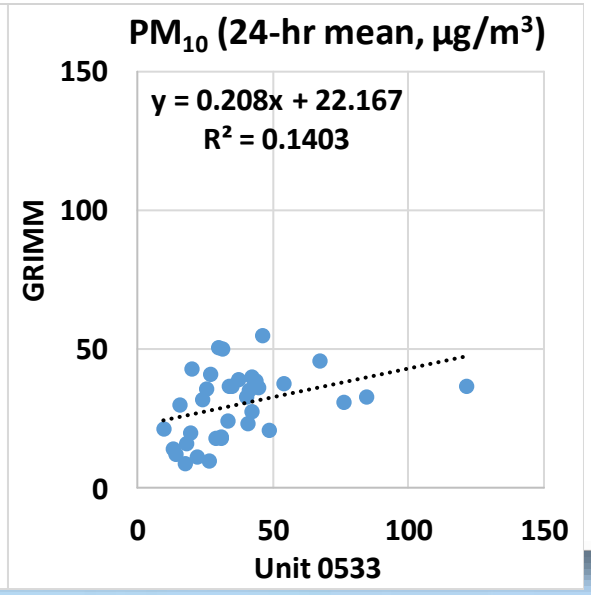
EcomSmart vs GRIMM (PM_{10}; 24-hr mean)



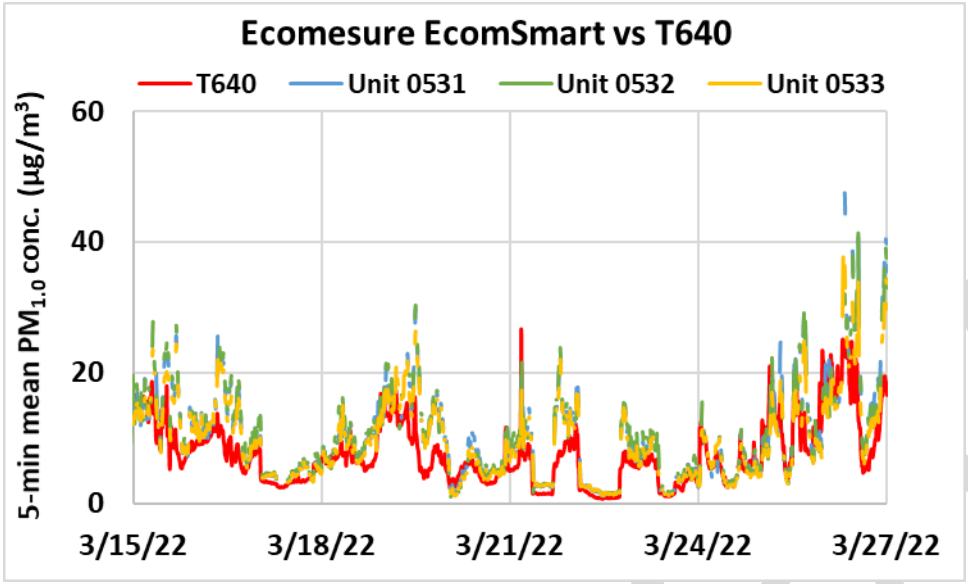
- The EcomSmart sensors showed no to very weak correlations with the corresponding GRIMM data ($0.09 < R^2 < 0.15$)
- Overall, the EcomSmart sensors overestimated the PM_{10} mass concentrations as measured by GRIMM
- The EcomSmart sensors did not seem to track the PM_{10} daily variations as recorded by GRIMM



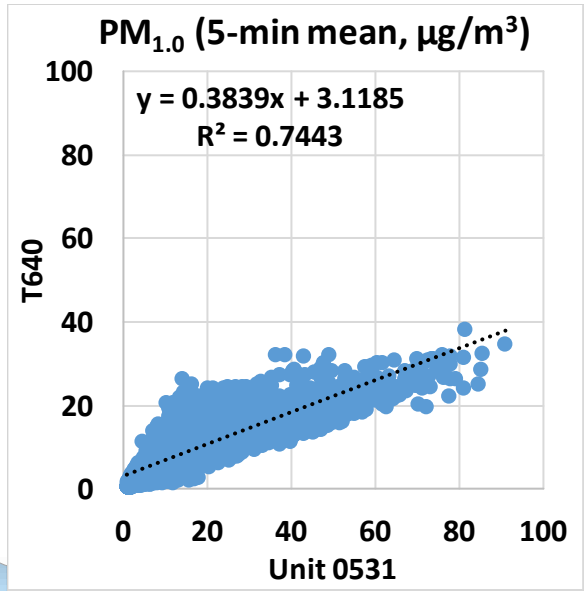


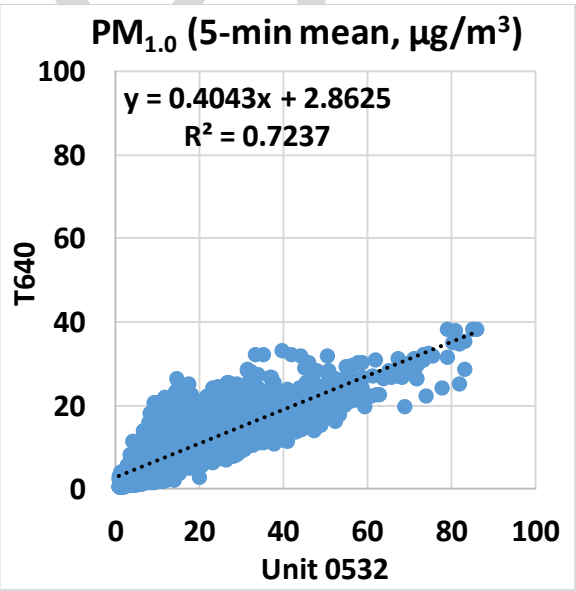


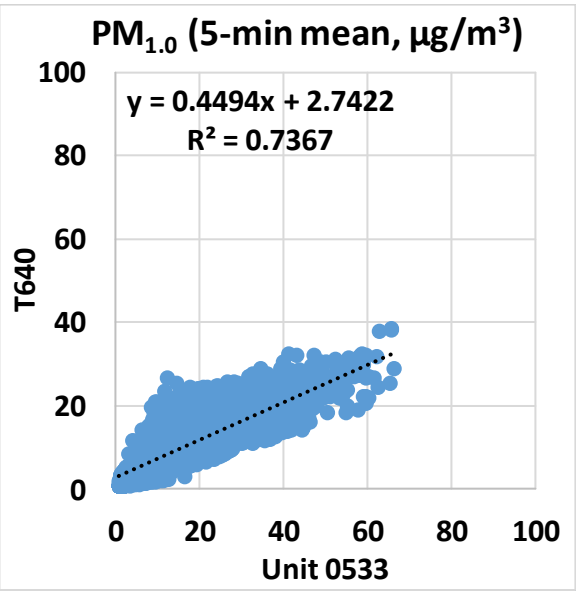
EcomSmart vs T640 ($PM_{1.0}$; 5-min mean)



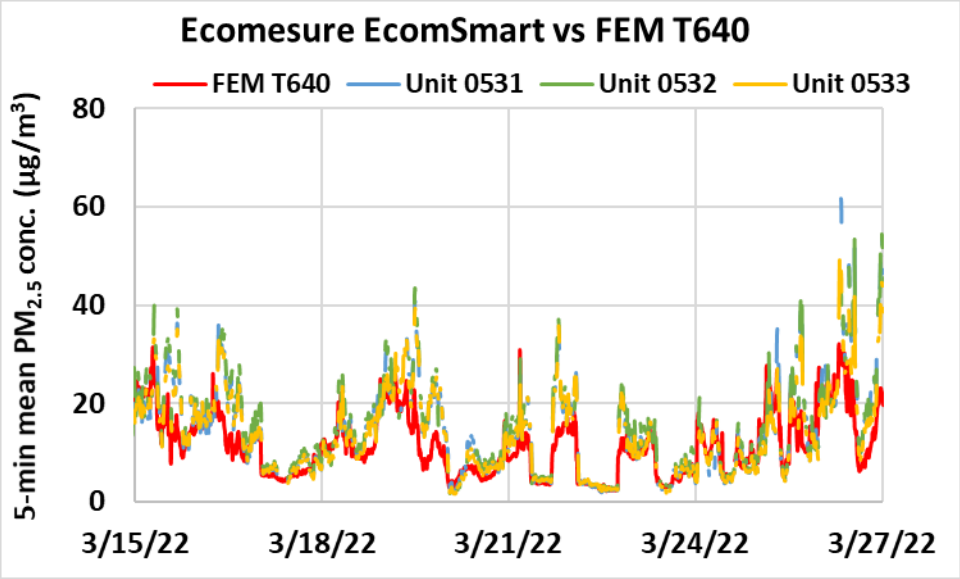
- The EcomSmart sensors showed strong correlations with the corresponding T640 data ($0.72 < R^2 < 0.75$)
- Overall, the EcomSmart sensors overestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The EcomSmart sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



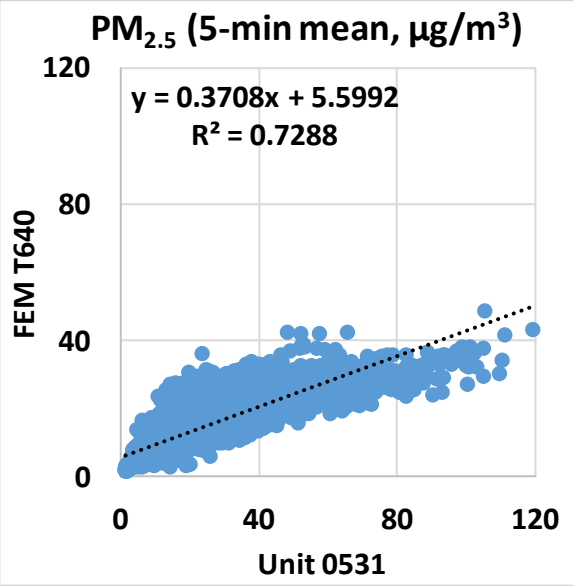


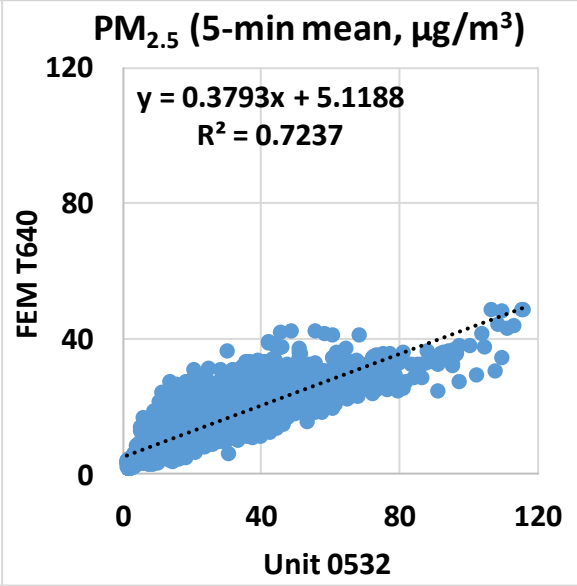


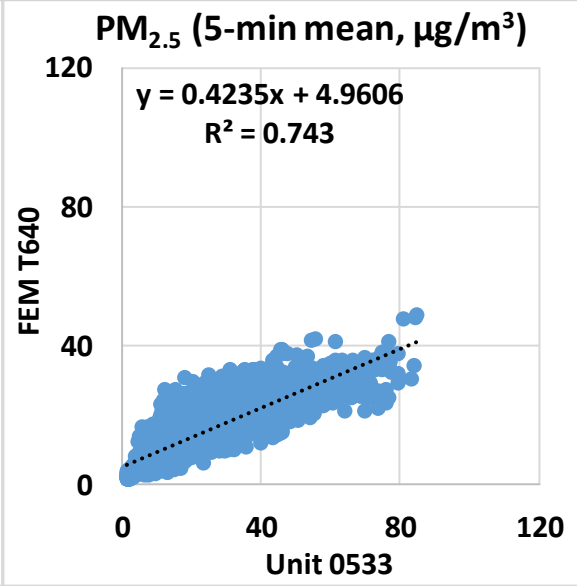
EcomSmart vs FEM T640 ($PM_{2.5}$; 5-min mean)



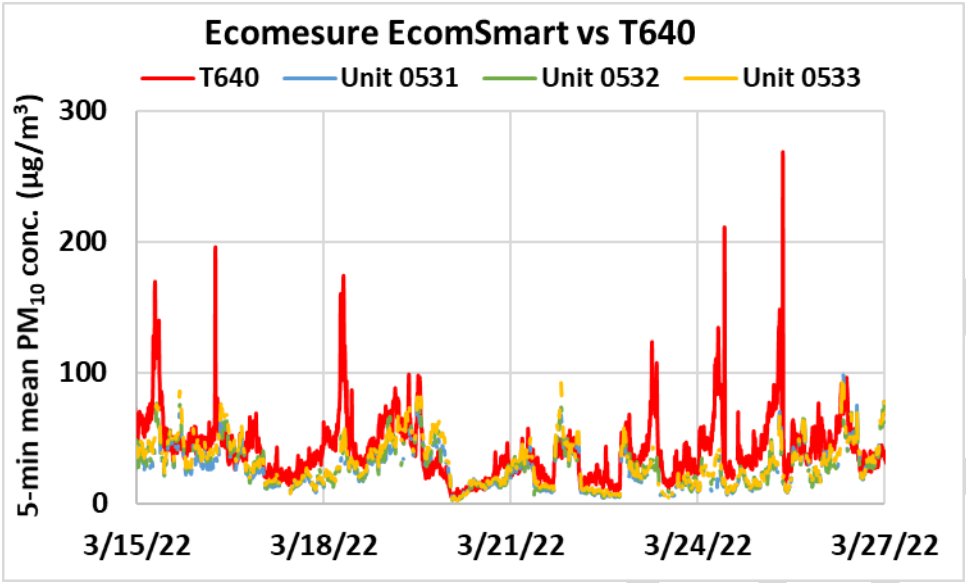
- The EcomSmart sensors showed strong correlations with the corresponding FEM T640 data ($0.72 < R^2 < 0.75$)
- Overall, the EcomSmart sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The EcomSmart sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



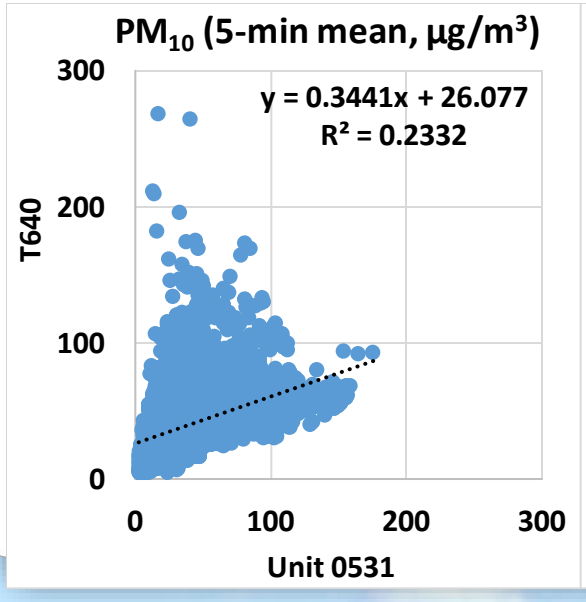


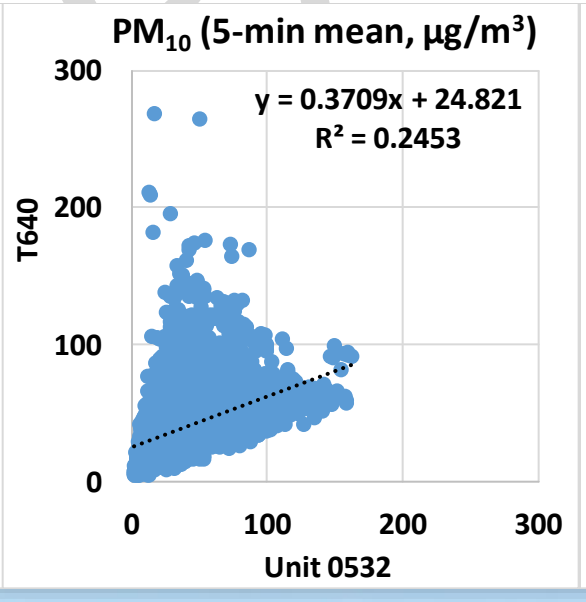


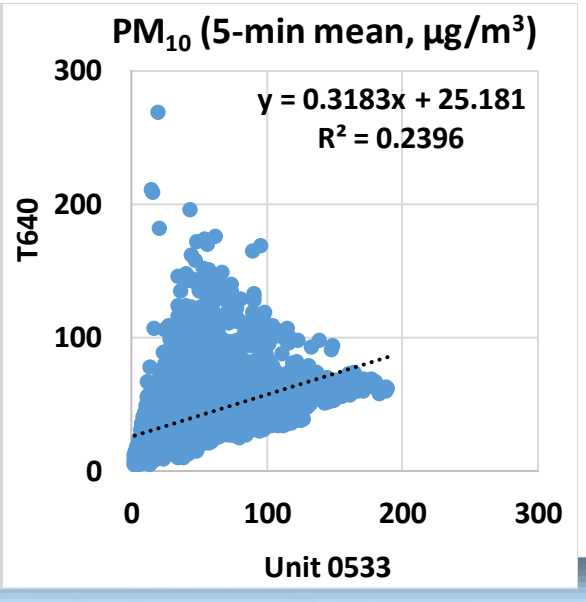
EcomSmart vs T640 (PM_{10}; 5-min mean)



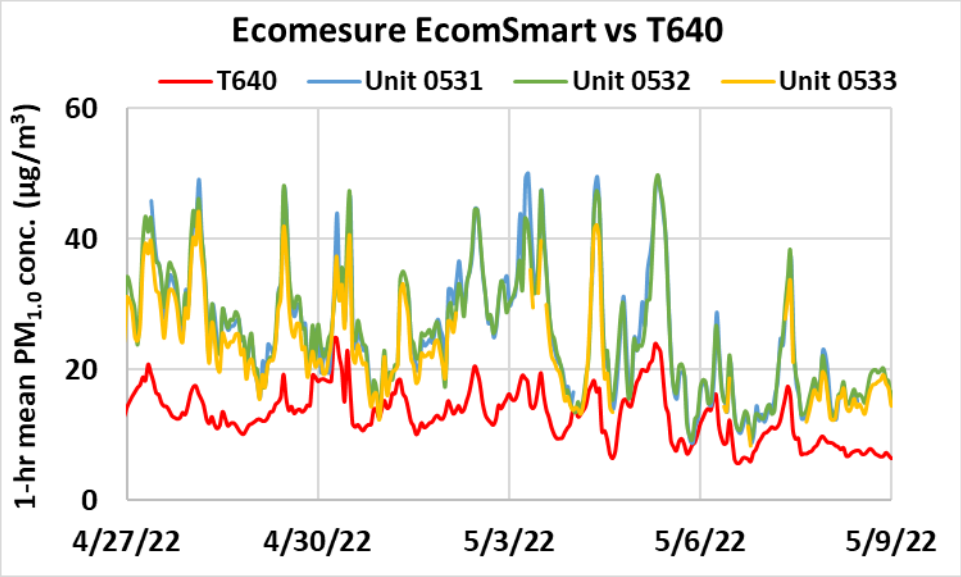
- The EcomSmart sensors showed very weak correlations with the corresponding T640 data ($0.23 < R^2 < 0.25$)
- Overall, the EcomSmart sensors overestimated the PM_{10} mass concentrations as measured by T640
- The EcomSmart sensors did not seem to track the PM_{10} diurnal variations as recorded by T640



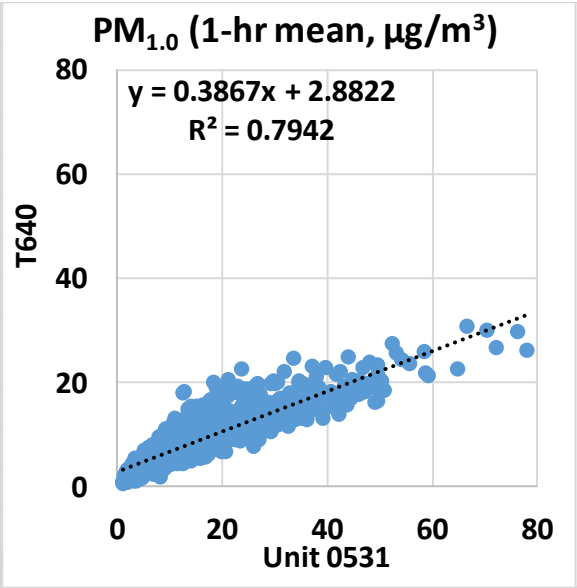


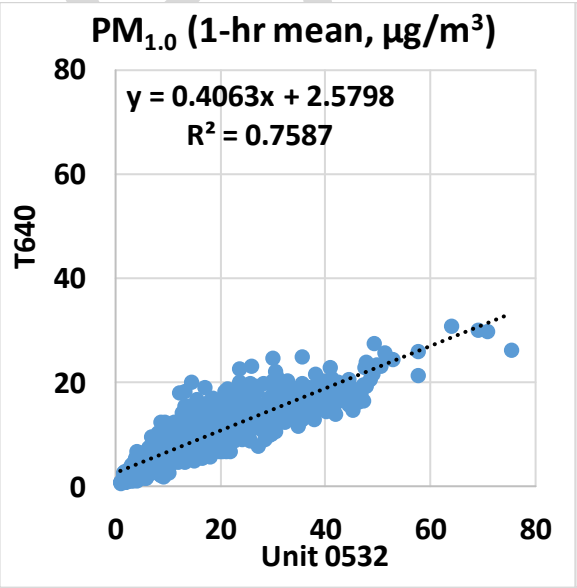


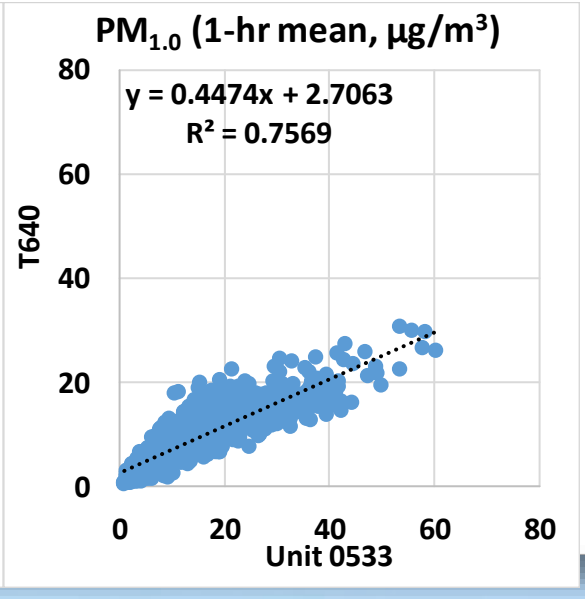
EcomSmart vs T640 ($PM_{1.0}$; 1-hr mean)



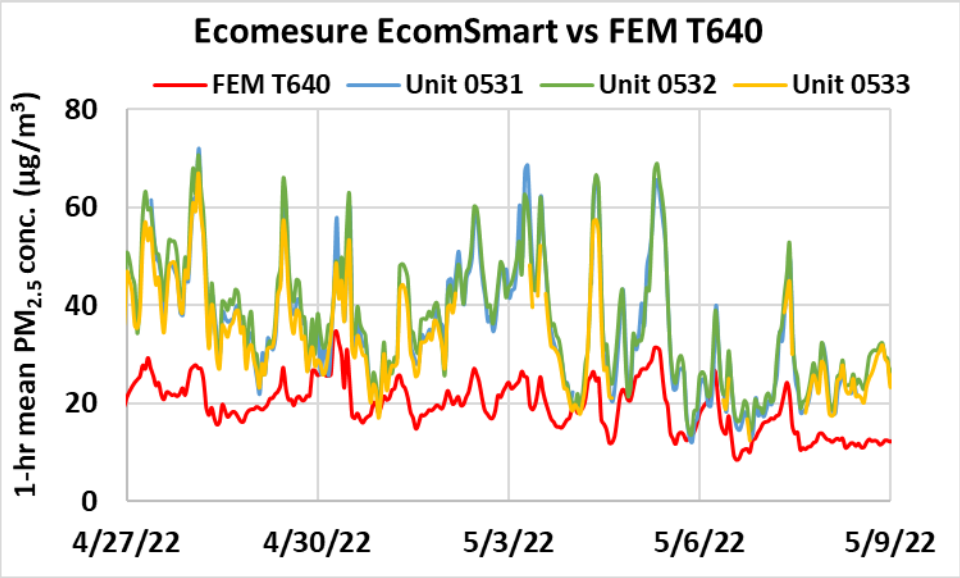
- The EcomSmart sensors showed strong correlations with the corresponding T640 data ($0.75 < R^2 < 0.80$)
- Overall, the EcomSmart sensors overestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The EcomSmart sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



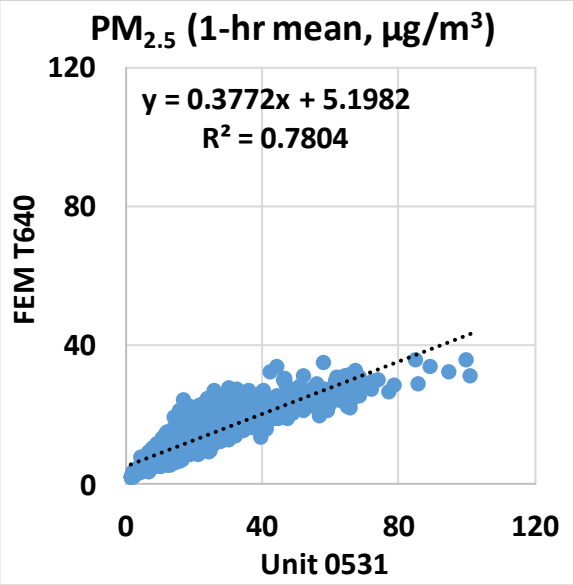


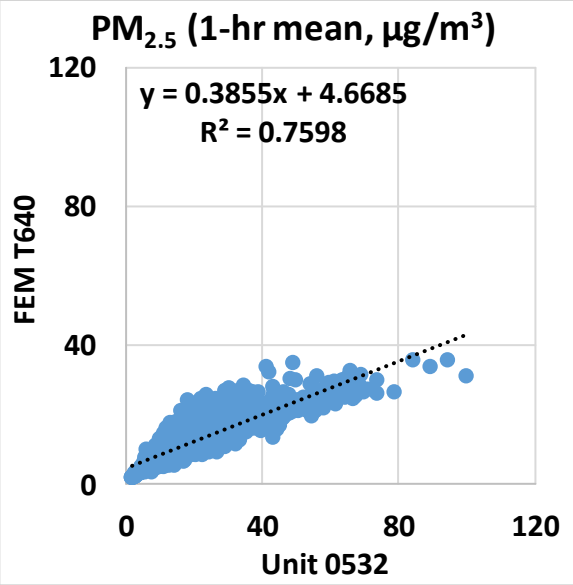


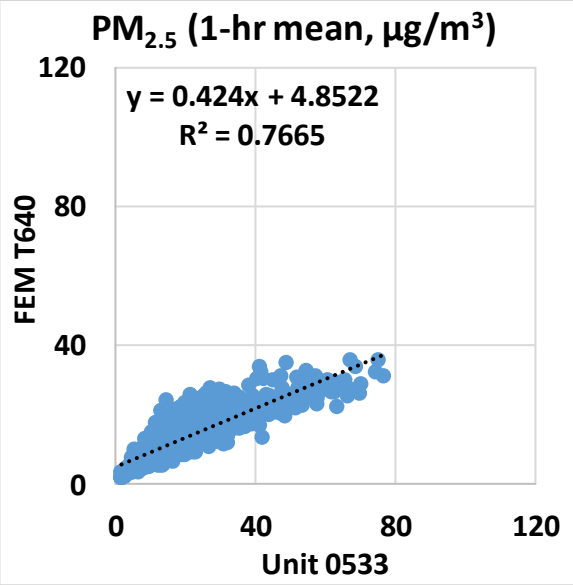
EcomSmart vs FEM T640 ($PM_{2.5}$; 1-hr mean)



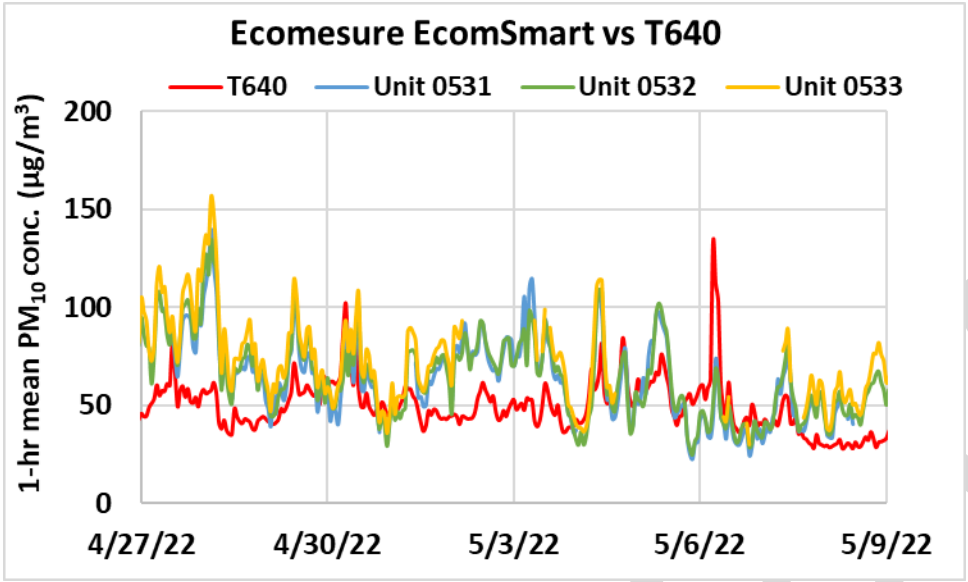
- The EcomSmart sensors showed strong correlations with the corresponding FEM T640 data ($0.75 < R^2 < 0.79$)
- Overall, the EcomSmart sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The EcomSmart sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



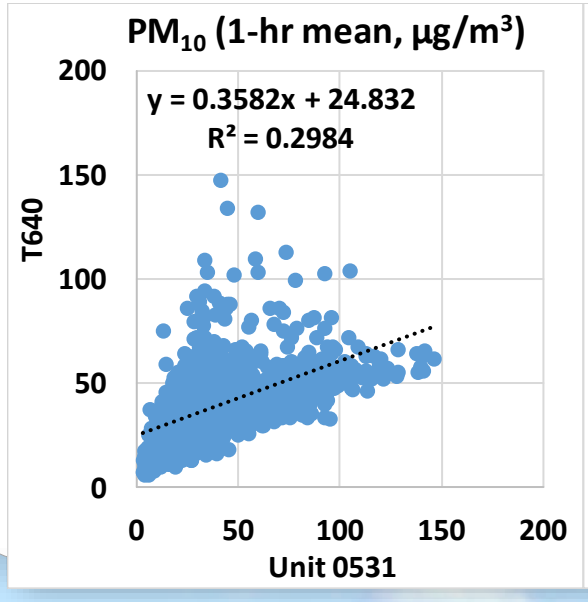


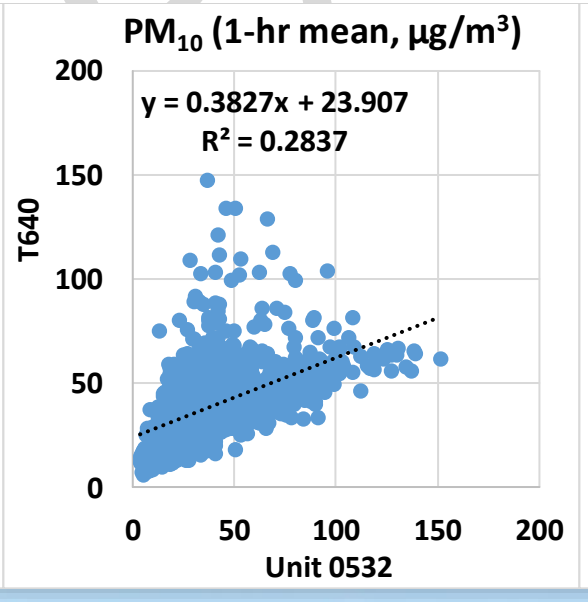


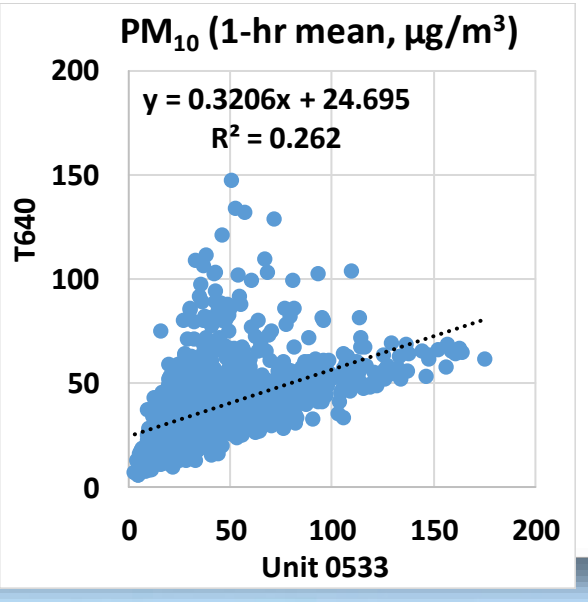
EcomSmart vs T640 (PM_{10}; 1-hr mean)



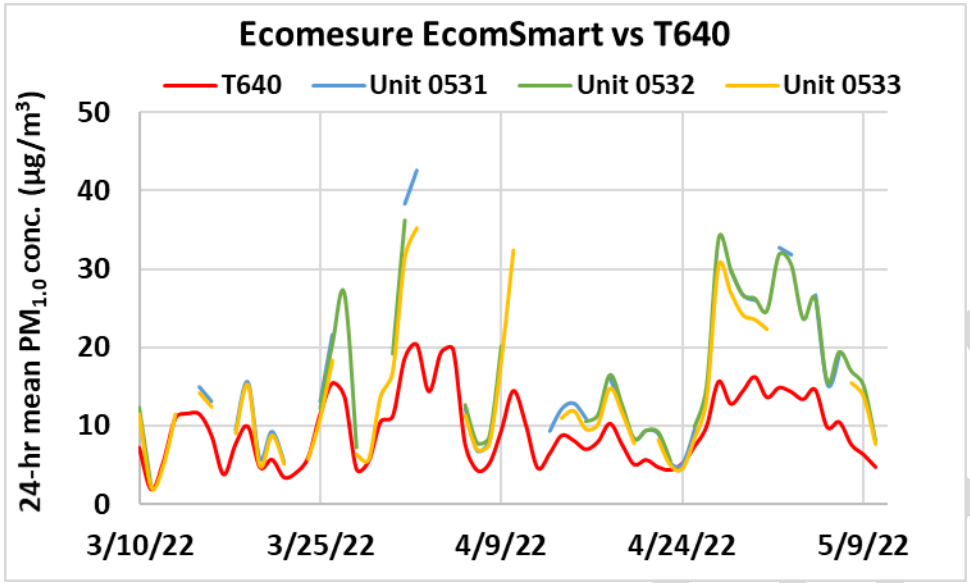
- The EcomSmart sensors showed very weak correlations with the corresponding T640 data ($0.26 < R^2 < 0.30$)
- Overall, the EcomSmart sensors overestimated the PM_{10} mass concentrations as measured by T640
- The EcomSmart sensors did not seem to track the PM_{10} diurnal variations as recorded by T640



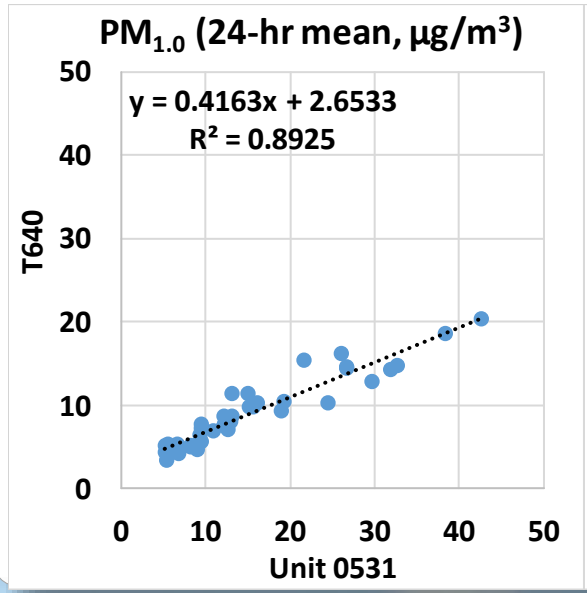


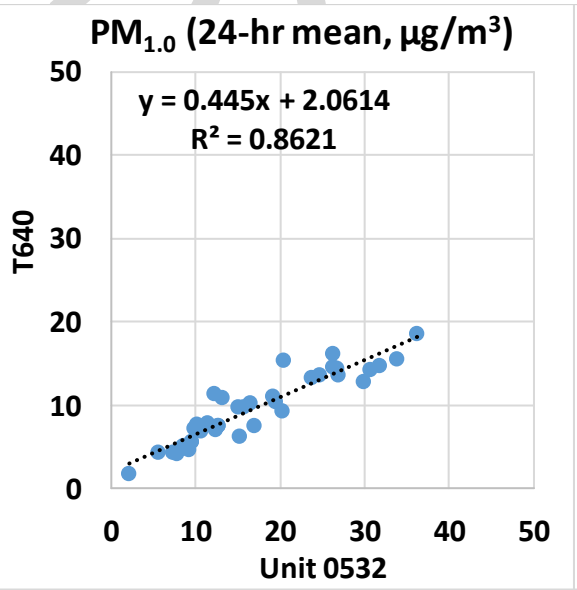


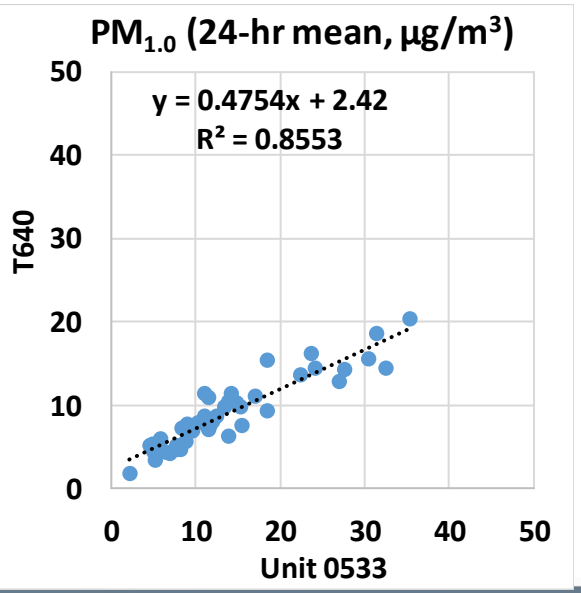
EcomSmart vs T640 ($PM_{1.0}$; 24-hr mean)



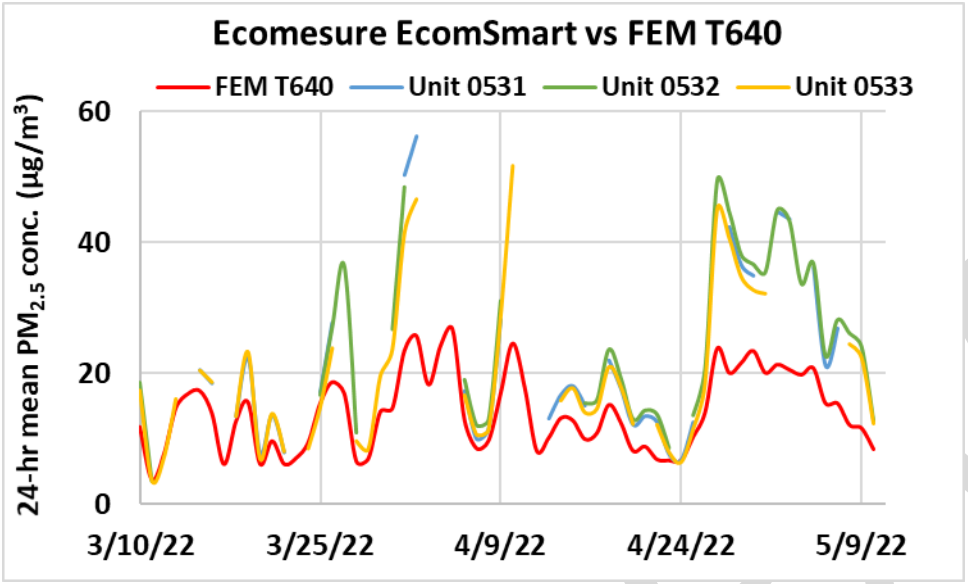
- The EcomSmart sensors showed strong correlations with the corresponding T640 data ($0.85 < R^2 < 0.90$)
- Overall, the EcomSmart sensors overestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The EcomSmart sensors seemed to track the $PM_{1.0}$ daily variations as recorded by T640



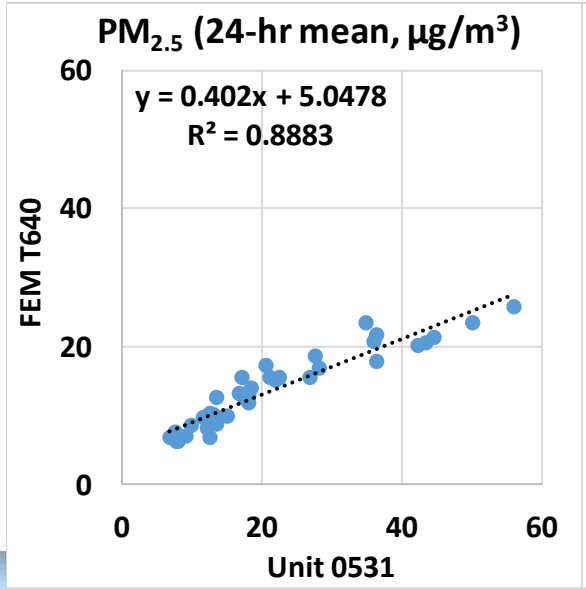


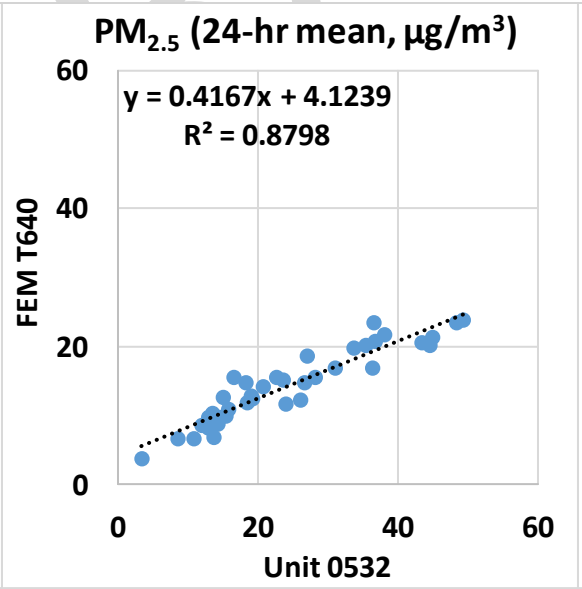


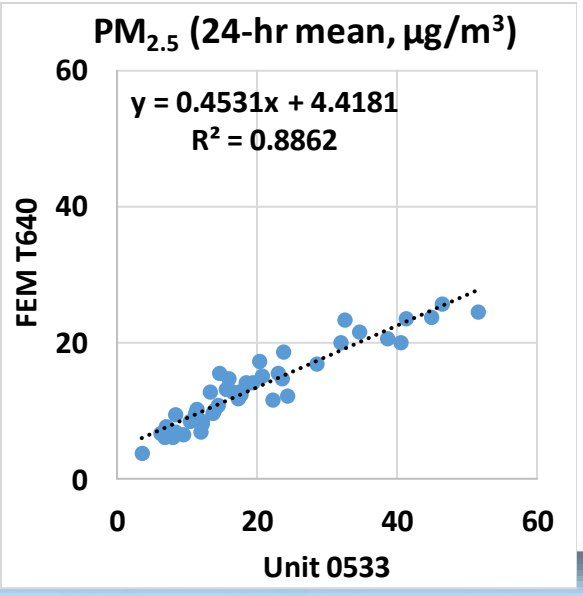
EcomSmart vs FEM T640 ($PM_{2.5}$; 24-hr mean)



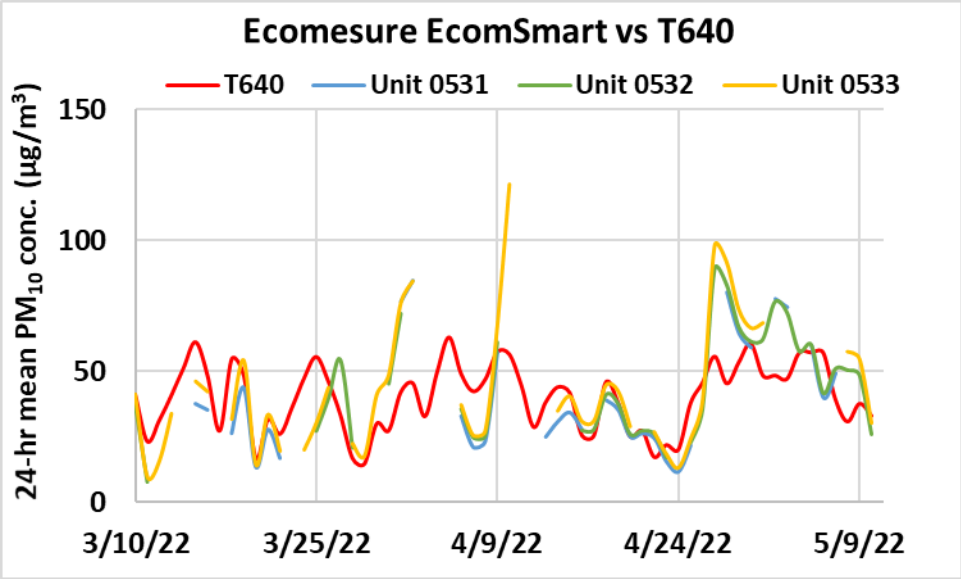
- The EcomSmart sensors showed strong correlations with the corresponding FEM T640 data ($0.87 < R^2 < 0.89$)
- Overall, the EcomSmart sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The EcomSmart sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640



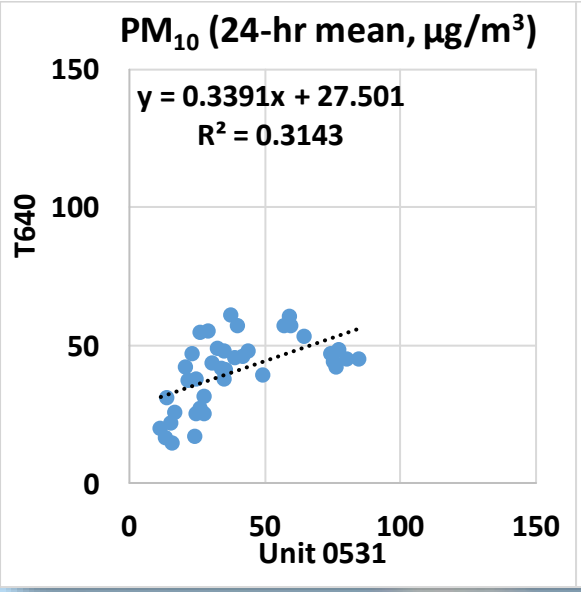


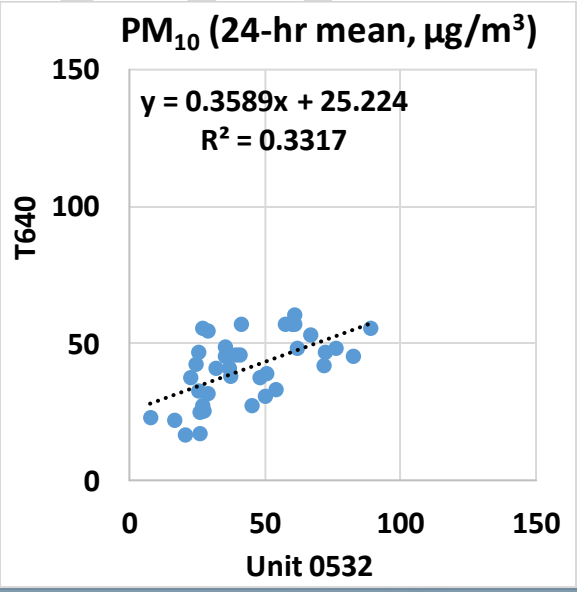


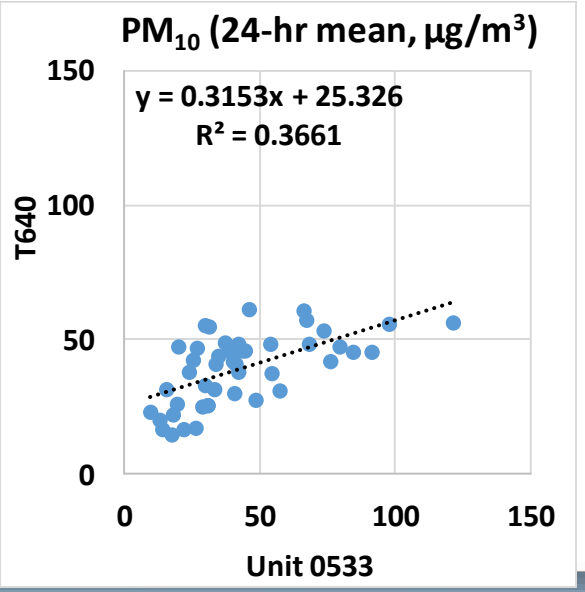
EcomSmart vs T640 (PM_{10}; 24-hr mean)



- The EcomSmart sensors showed weak correlations with the corresponding T640 data ($0.31 < R^2 < 0.37$)
- Overall, the EcomSmart sensors overestimated the PM_{10} mass concentrations as measured by T640
- The EcomSmart sensors did not seem to track the PM_{10} daily variations as recorded by T640







Summary: PM

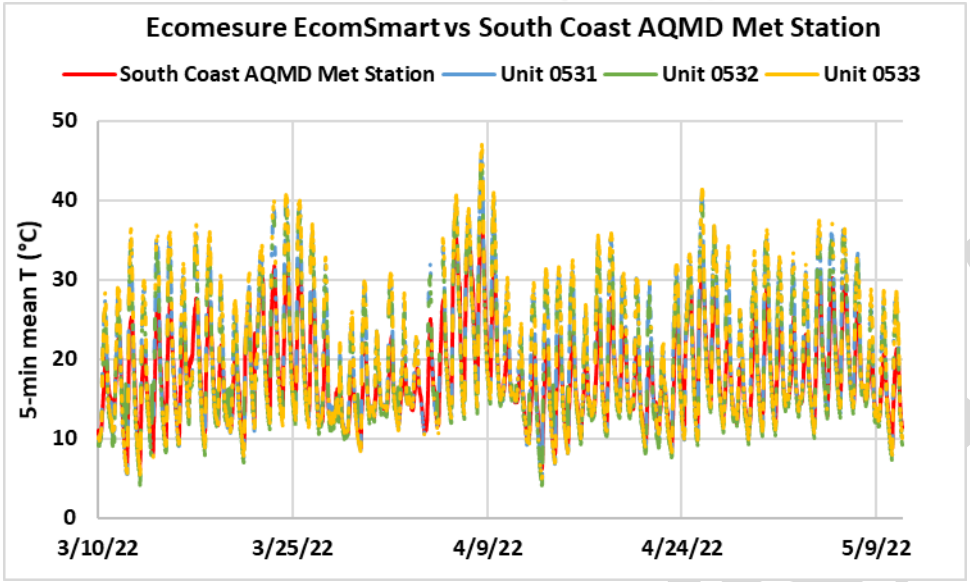
	Average of 3 Sensors, $PM_{1.0}$		EcomSmart vs GRIMM & T640, $PM_{1.0}$						GRIMM & T640 ($PM_{1.0}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	15.5	11.1	0.63 to 0.74	0.37 to 0.45	1.6 to 3.1	5.2 to 6.8	5.6 to 7.1	8.1 to 10.5	7.4 to 9.5	5.5	0.3 to 38.4
1-hr	15.3	10.8	0.66 to 0.79	0.37 to 0.45	1.4 to 2.9	5.1 to 7.0	5.4 to 7.1	7.9 to 10.4	7.4 to 9.5	5.4 to 5.5	0.4 to 37.9
24-hr	15.4	8.8	0.86 to 0.92	0.41 to 0.48	0.6 to 2.7	4.8 to 7.3	4.9 to 7.3	6.4 to 8.9	7.4 to 9.5	4.3 to 4.5	1.4 to 20.3
	Average of 3 Sensors, $PM_{2.5}$		EcomSmart vs FEM GRIMM & FEM T640, $PM_{2.5}$						FEM GRIMM & FEM T640 ($PM_{2.5}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	22.0	15.3	0.54 to 0.74	0.37 to 0.42	4.9 to 5.6	5.7 to 9.1	7.0 to 9.6	10.8 to 13.9	12.5 to 14.1	7.2 to 7.3	1.2 to 60.1
1-hr	21.8	14.9	0.56 to 0.78	0.38 to 0.42	4.6 to 5.2	5.6 to 9.4	6.7 to 9.6	10.5 to 13.7	12.5 to 14.1	7.1 to 7.2	1.5 to 47.9
24-hr	22.0	12.2	0.79 to 0.89	0.38 to 0.45	4.1 to 5.1	5.0 to 10.0	5.2 to 10.1	8.0 to 12.4	12.5 to 14.1	5.4 to 5.9	3.8 to 26.7
	Average of 3 Sensors, PM_{10}		EcomSmart vs GRIMM & T640, PM_{10}						GRIMM & T640 (PM_{10}, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	41.9	27.2	0.08 to 0.25	0.21 to 0.37	21.1 to 26.1	0.1 to 9.2	16.7 to 20.3	23.3 to 29.8	30.0 to 40.1	18.8 to 19.3	1.7 to 268.7
1-hr	41.7	26.7	0.10 to 0.30	0.21 to 0.38	20.0 to 24.8	0.9 to 8.8	15.8 to 19.6	21.7 to 28.8	30.0 to 40.1	17.7 to 18.2	2.3 to 150.8
24-hr	41.8	21.7	0.10 to 0.37	0.21 to 0.36	20.7 to 27.5	-1.7 to 7.3	12.2 to 14.8	15.4 to 21.9	30.0 to 40.1	11.4 to 12.6	8.9 to 62.8

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

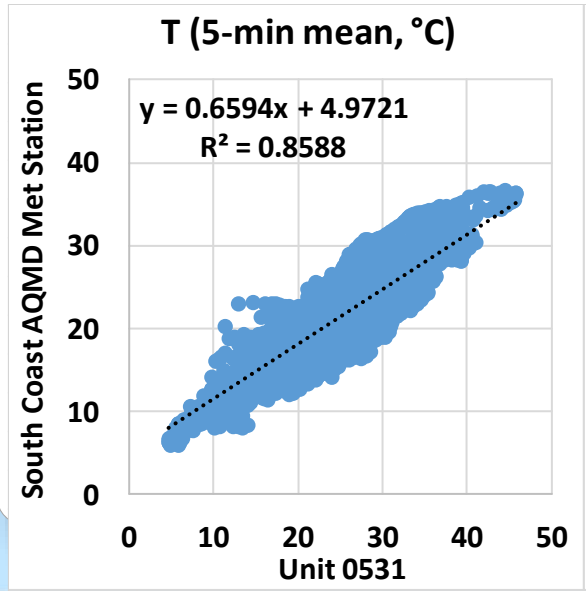
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

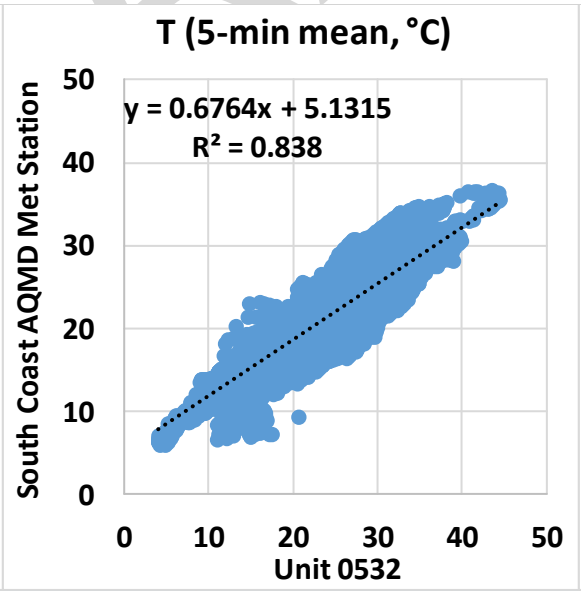
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

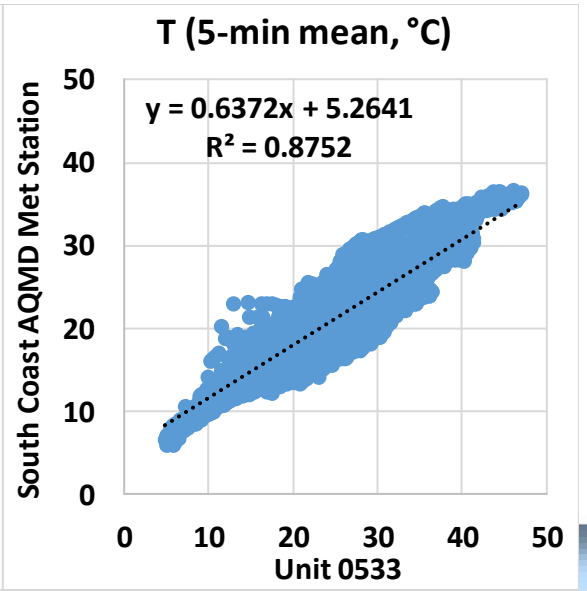
EcomSmart vs South Coast AQMD Met Station (Temp; 5-min mean)



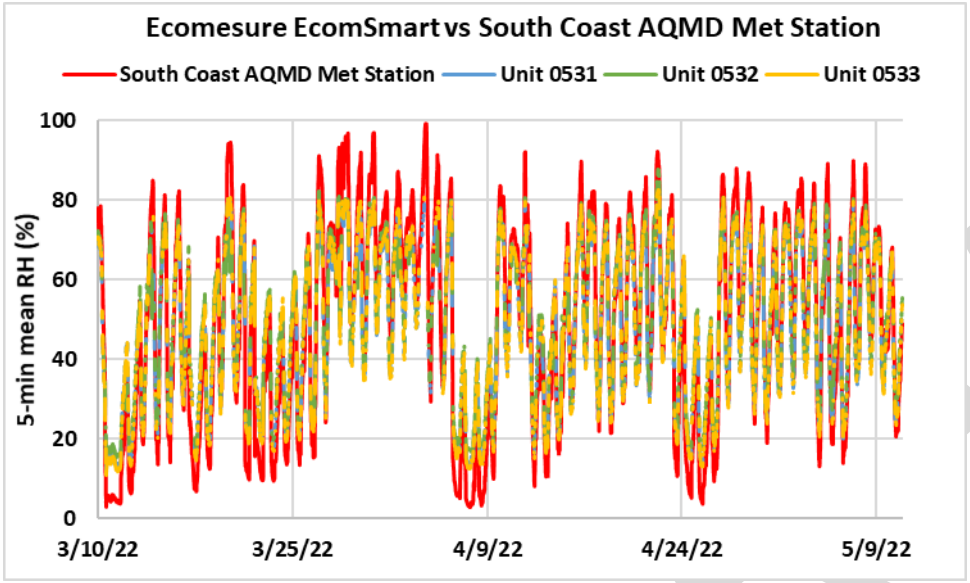
- The EcomSmart sensors showed strong correlations with the corresponding South Coast AQMD Met Station data ($0.83 < R^2 < 0.88$)
- Overall, the EcomSmart sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The EcomSmart sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station



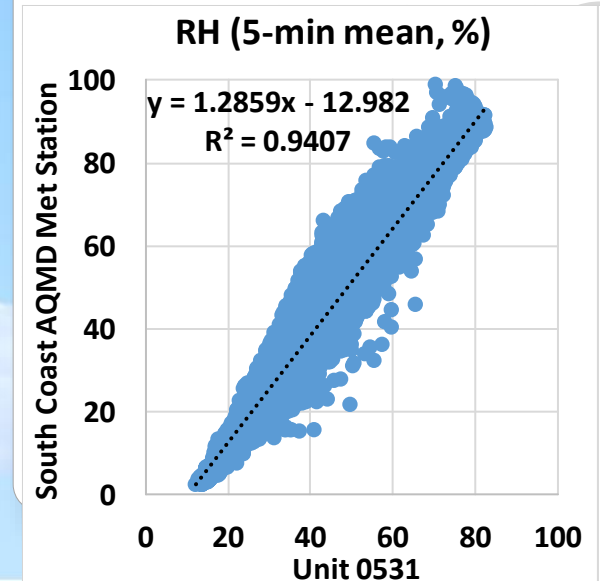


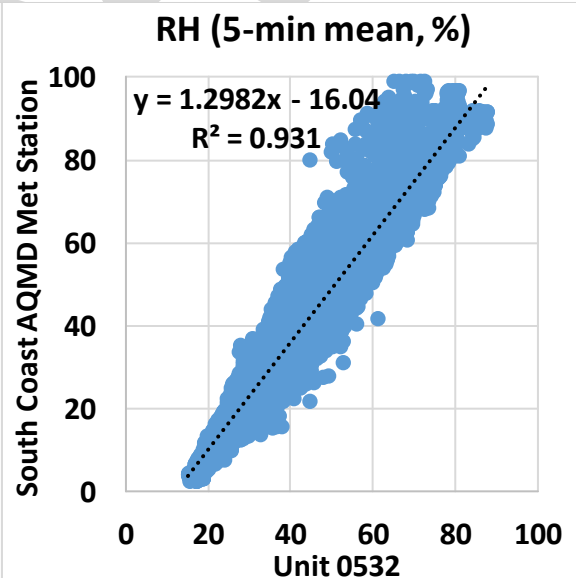


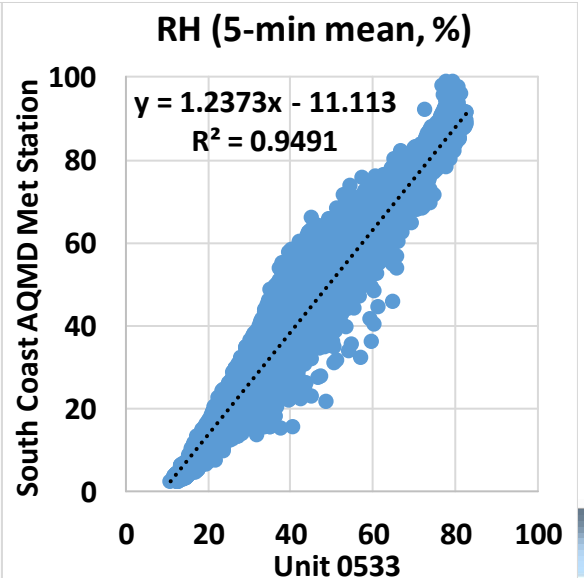
EcomSmart vs South Coast AQMD Met Station (RH; 5-min mean)



- EcomSmart sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.93 < R^2 < 0.95$)
- Overall, the EcomSmart sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station
- The EcomSmart sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The three **EcomSmart** sensors' data recovery for all gases (O_3, NO_2 and CO) and all PM fractions was ~96%.
- The absolute intra-model variability for O_3, NO_2 and CO was ~9.4 ppb, ~4.5 ppb, and ~0.06 ppm, respectively. Absolute intra-model variability was ~0.65, ~0.83 and ~2.45 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- Reference instruments: very strong correlations between GRIMM and T640 for $PM_{1.0}$ (R^2 ~ 0.94, 1-hr mean); very strong correlations between FEM GRIMM and FEM T640 for $PM_{2.5}$ (R^2 ~ 0.93, 1-hr mean) and very strong correlations between GRIMM and T640 for PM_{10} (R^2 ~ 0.93, 1-hr mean) mass concentration measurements
- During the <u>entire</u> field deployment testing period:
  - Ozone sensors showed moderate correlation with the FEM T400 instrument ($0.62 < R^2 < 0.65$, 5-min mean) and generally overestimated the corresponding FEM T400 data
  - NO_2 sensors showed weak to moderate correlations with the FRM T200 instrument ($0.38 < R^2 < 0.56$, 5-min mean) and overestimated the corresponding FRM T200 data
  - CO sensors showed strong correlations with the FRM Horiba instrument ($0.75 < R^2 < 0.81$, 5-min mean) and underestimated the corresponding FRM data
  - The EcomSmart sensors showed moderate to strong correlations with the corresponding reference $PM_{1.0}$ data ($0.65 < R^2 < 0.80$, 1-hr mean); moderate to strong correlations with the corresponding reference $PM_{2.5}$ data ($0.56 < R^2 < 0.79$, 1-hr mean) and no to very weak correlations with the corresponding reference PM_{10} data ($0.09 < R^2 < 0.30$; 1-hr mean). The sensors overestimated $PM_{1.0}$, $PM_{2.5}$ PM_{10} and mass concentrations as measured by GRIMM and T640
  - Temperature and relative humidity sensors showed strong and very strong correlations with the South Coast AQMD Met Station T and RH data, respectively (R^2 ~ 0.86 for T and R^2 ~ 0.94 for RH) and overestimated the T and underestimated the RH data as recorded by the South Coast AQMD Met Station
- No sensor calibration was performed by South Coast AQMD staff for this evaluation.
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under controlled T and RH conditions, and known target and interferent pollutants concentrations.
- These results are still preliminary