Field Evaluation of Atmotube Pro VOC sensor

Background

- From 3/31/2021 to 4/21/2021, six **Atmotube Pro** sensors were deployed at South Coast AQMD's "G-Street" air monitoring station and run side-by-side with a reference total volatile organic compounds (VOCs) instrument (Thermo Fisher Scientific, Model 55i)

- **Atmotube Pro (*6 units tested*):**
  - VOC sensor: Metal Oxide; non-FEM (Sensirion SGPC3)
    - TVOC output range: 0 – 60 ppm
    - Typical accuracy: 15% of measured value
    - Measurement interval: 2 seconds
  - Each unit also reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), temperature (°C), RH (%), pressure (mbar), VOC (ppm)
  - Unit cost: $199 (https://atmotube.com/products/atmotube-pro)
  - Time resolution: 1-min
  - Units IDs: SL1, SL2, SL3, SL6, SL7 and SL8

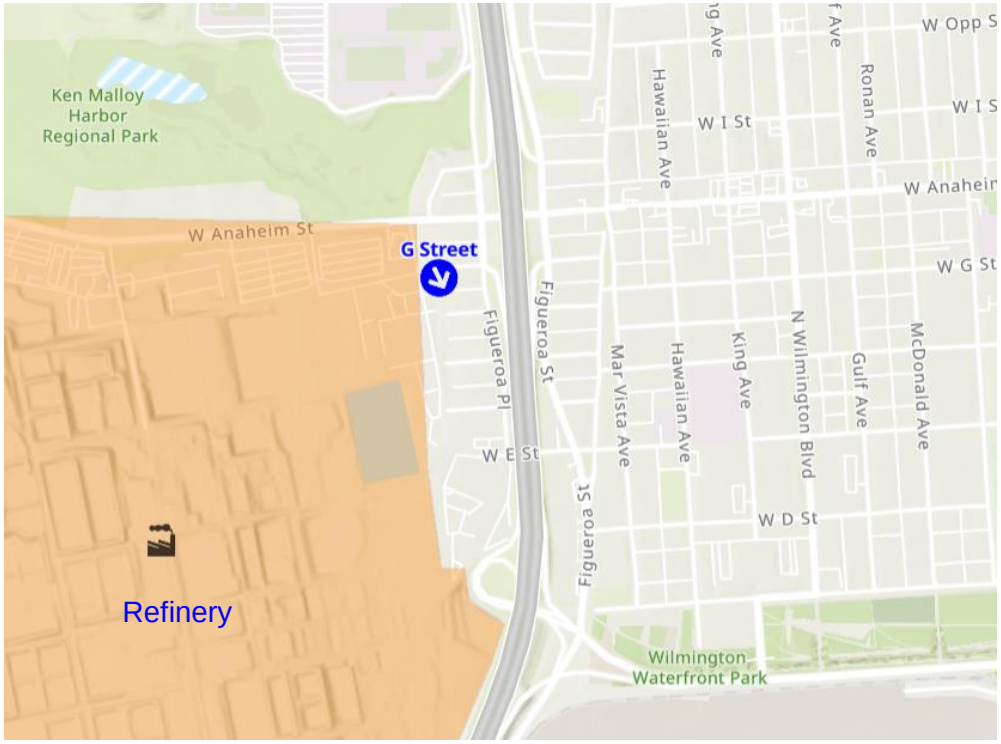
- **Thermo 55i (*reference instrument*):**
  - GC-FID
  - Measures: methane (CH_4) and non-methane hydrocarbons (NMHC)
  - Unit cost: ~$25,000
  - Time resolution: 1-min
  - Specifications:
    - Measurement ranges: 0-50 ppm
    - Limit of detection (LOD): 50 ppb
    - Analysis time: ~ 70 seconds
    - Accuracy: ±1% of range
    - Repeatability: ±2% of measured value or 50 ppb (whichever is larger)
    - Drift: ±2% of span over 24 hours
    - Ambient operating temperature: 15 – 35 °C
    - Sample temperature: ambient to 35 °C

Atmotube Pro

Thermo 55i

Background: Air Monitoring Site

- South Coast AQMD's "G-Street" air monitoring station is located in Wilmington, east of a petroleum refinery and west of a major freeway (I-110) – an ideal site to conduct air monitoring of VOCs



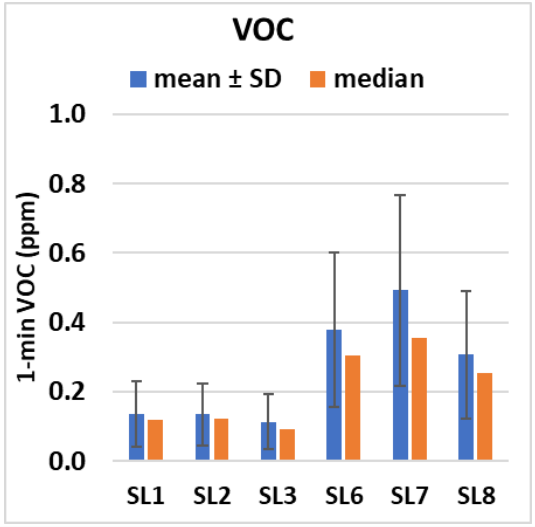
Sensor Data validation & recovery

- Values below LOD of 50 ppb and calibration spike data were eliminated from the reference instrument data-set; data were used as is for all sensors

Sensor Units	Sensor Usage History	VOC Deployment Period	Data Recovery (3/31/21 - 4/21/21)
NEW Triplicate: SL1, SL2 and SL3	Received on 3/9/2021	Deployed at "G-street" station on 3/25/2021	SL1: ~ 68% (only had data from 4/7/21 to 4/21/21) SL2: ~ 100% SL3: ~ 100%
OLD Triplicate: SL6, SL7 and SL8	Received in early 2020	Deployed at "G-Street" station on 3/31/2021	SL6: ~ 100% SL7: ~ 98% SL8: ~ 100%

Note: Comparisons were made separately for the two triplicates because of different sensor usage history

Atmotube Pro; intra-model variability

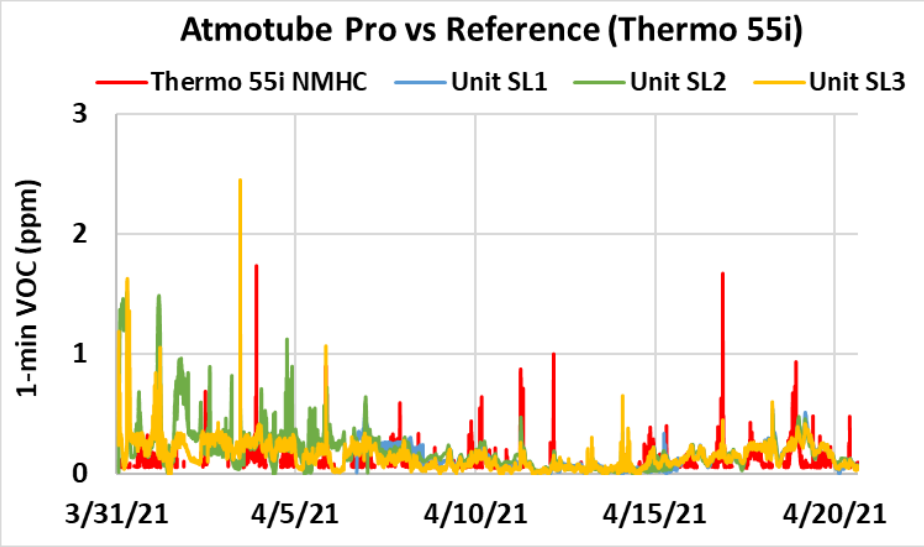


- Absolute intra-model variability for the VOC measurements was ~ 0.16 ppm (calculated as the standard deviation of the sensor means)
- Relative intra-model variability for the VOC measurements was ~ 60% (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

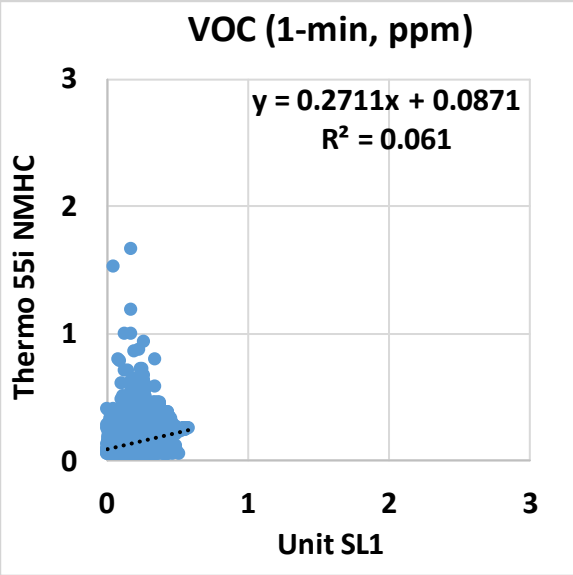
Note: Intra-model variability was calculated using only valid sensor data

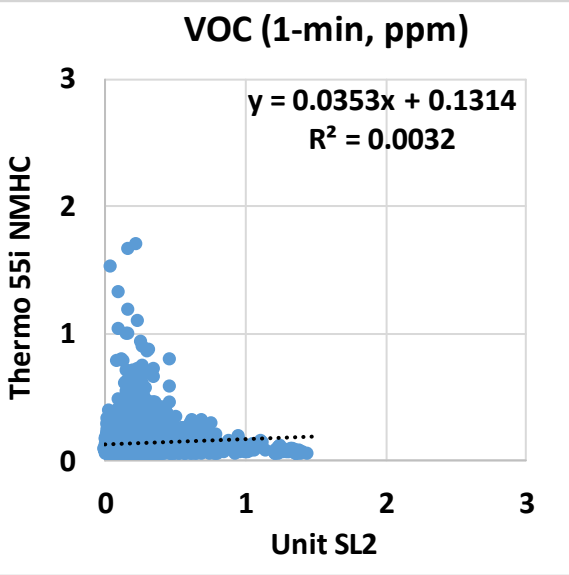
Units SL1, SL2 and SL3
(NEW Sensors)

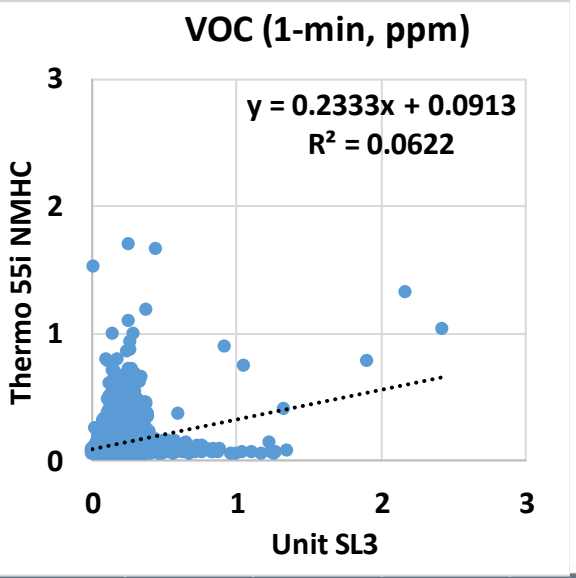
Atmotube Pro vs Thermo 55i NMHC (VOC; 1-min)



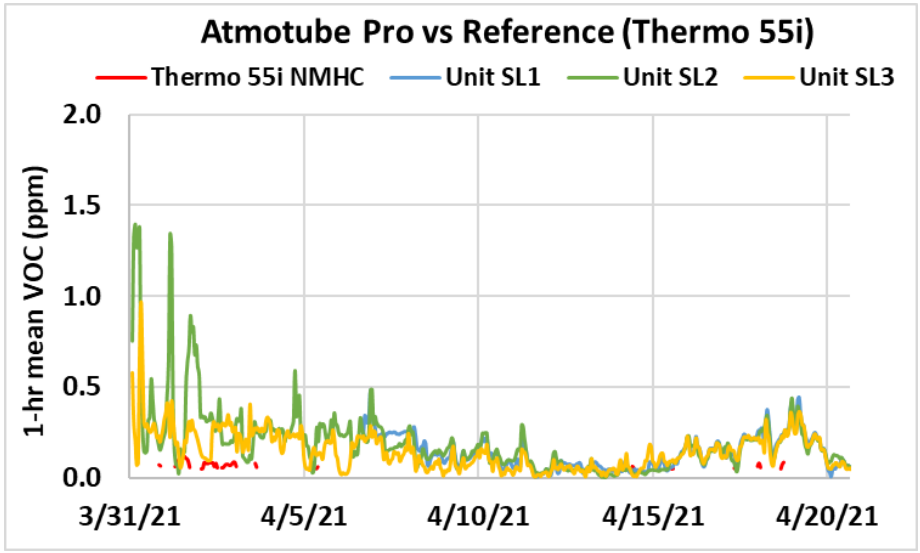
- The Atmotube Pro sensors did not correlate well with the corresponding Thermo 55i VOC (NMHC) data
- Overall, the Atmotube Pro sensors overestimated the VOC (NMHC) concentration as measured by the Thermo 55i
- The Atmotube Pro sensors did not seem to track the VOC (NMHC) diurnal variations as recorded by the Thermo 55i







Atmotube Pro vs Thermo 55i NMHC (VOC; 1-hr mean)



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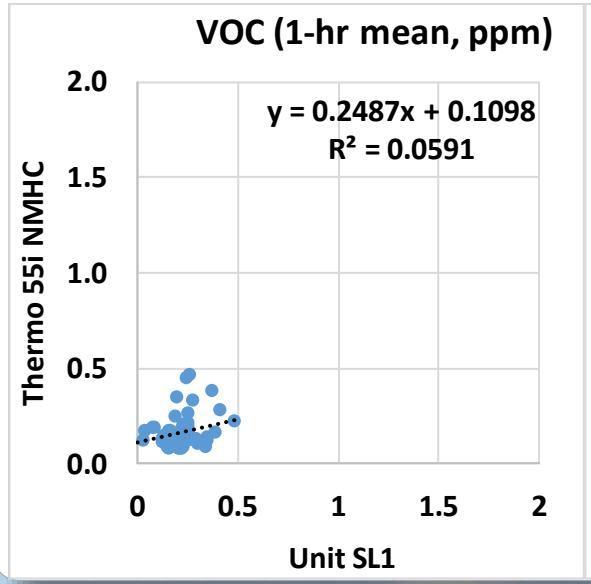

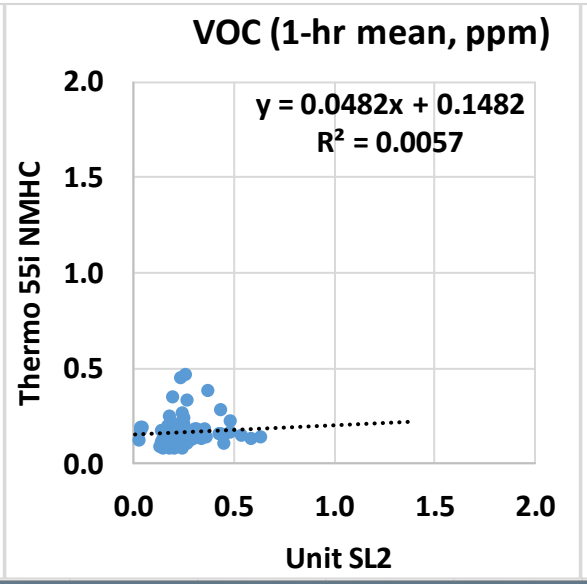

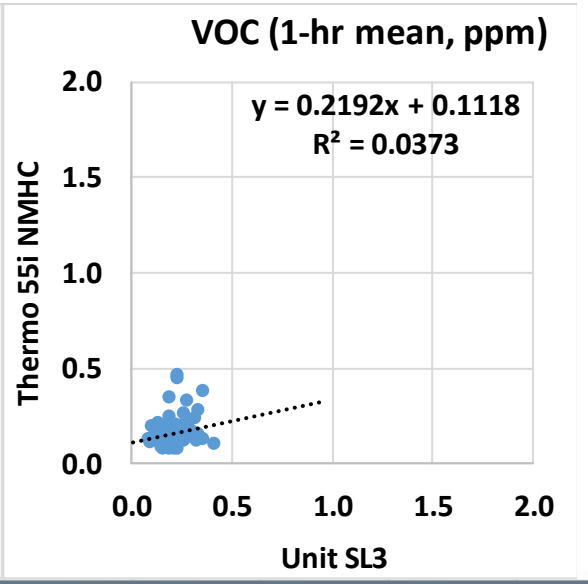

Co-location data summary: using only 1-minute data above LOD

Sensor (1-MIN)	Thermo 55i Channel	Slope	Intercept	R^2	MAE (ppm)	MBE (ppm)	RMSE (ppm)
SL1	NMHC	0.27	0.09	0.06	0.11	0.06	0.22
SL1	CH_4	0.83	2.10	0.13	2.08	-2.08	2.91
SL1	THC	0.81	2.42	0.04	2.39	-2.39	3.89
SL2	NMHC	0.04	0.13	0.003	0.14	0.10	0.27
SL2	CH_4	0.13	2.20	0.01	2.03	-2.03	2.51
SL2	THC	0.15	2.58	0.004	2.38	-2.38	3.17
SL3	NMHC	0.23	0.09	0.06	0.10	0.07	0.18
SL3	CH_4	0.56	2.14	0.08	2.08	-2.08	2.56
SL3	THC	0.60	2.49	0.03	2.41	-2.41	3.21

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

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

Root Mean Square Error (RMSE): another metric to calculate measurement error

Note: Total Hydrocarbon (THC) is calculated as the sum of Methane (CH_4) and Nonmethane Hydrocarbon (NMHC). This table includes data points that are above the 50 ppb LOD

Co-location data summary: using all 1-minute non-negative Thermo 55i data

Sensor (1-MIN)	Thermo 55i Channel	Slope	Intercept	R^2	MAE (ppm)	MBE (ppm)	RMSE (ppm)
SL1	NMHC	0.36	-0.01	0.18	0.11	0.096	0.19
SL1	CH_4	0.83	2.10	0.13	2.08	-2.08	2.91
SL1	THC	1.20	2.09	0.16	2.12	-2.12	2.98
SL2	NMHC	0.05	0.03	0.02	0.17	0.16	0.31
SL2	CH_4	0.13	2.20	0.01	2.03	-2.03	2.51
SL2	THC	0.18	2.23	0.01	2.07	-2.07	2.56
SL3	NMHC	0.22	0.006	0.11	0.12	0.11	0.19
SL3	CH_4	0.56	2.14	0.08	2.08	-2.08	2.56
SL3	THC	0.78	2.15	0.096	2.12	-2.12	2.61

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

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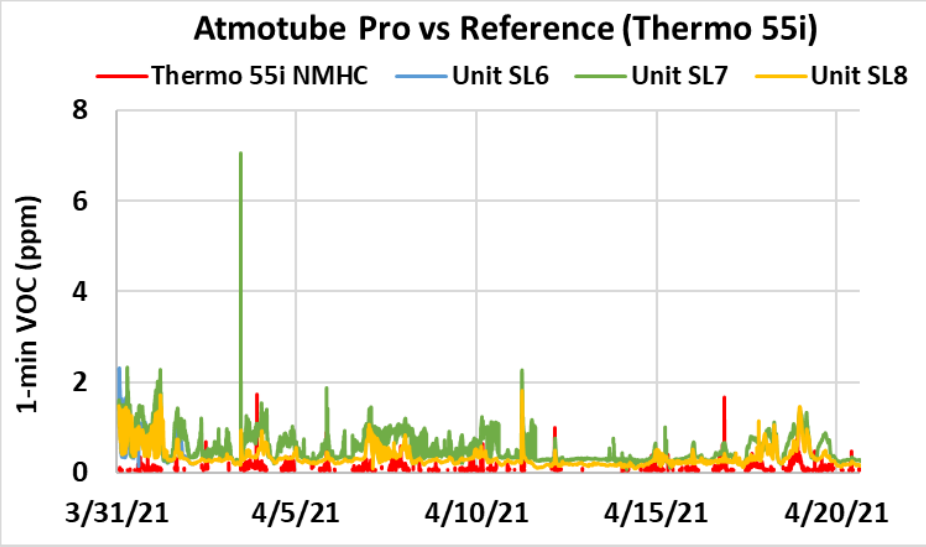
Root Mean Square Error (RMSE): another metric to calculate measurement error

Note: Total Hydrocarbon (THC) is calculated as the sum of Methane (CH_4) and Nonmethane Hydrocarbon (NMHC). This table includes all data points from the Thermo 55i

Units SL6, SL7 and SL8
(OLD Sensors)

Atmotube Pro vs Thermo 55i NMHC (VOC; 1-min)



- The Atmotube Pro sensors did not correlate well with the corresponding Thermo 55i VOC (NMHC) data
- Overall, the Atmotube Pro sensors overestimated the VOC (NMHC) concentration as measured by the Thermo 55i
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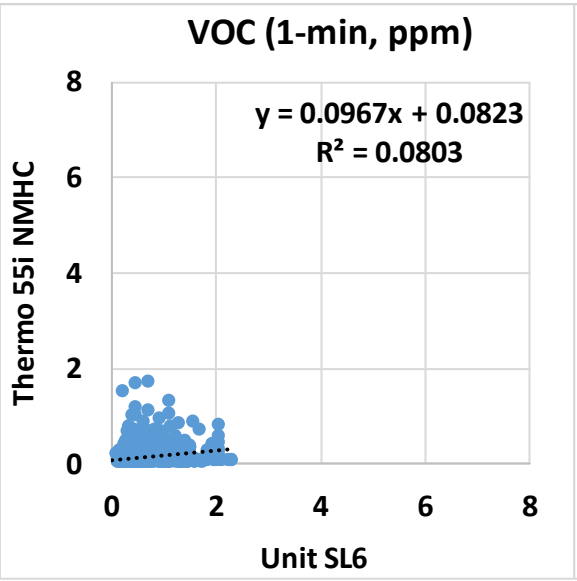
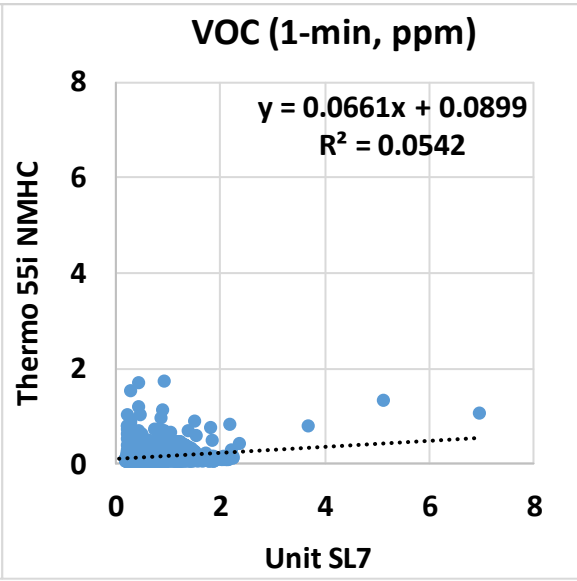
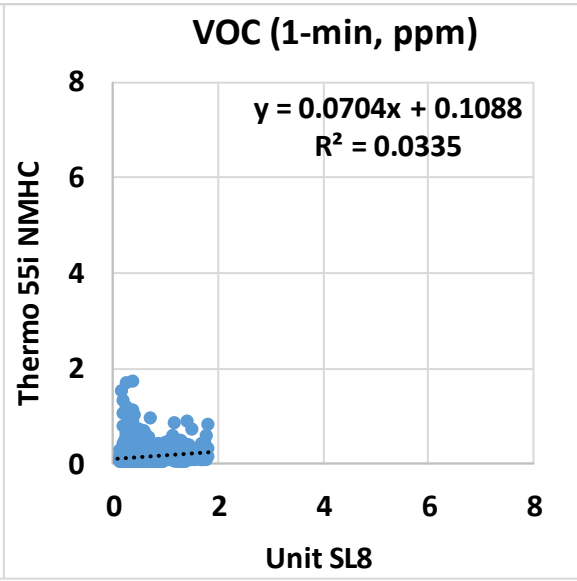
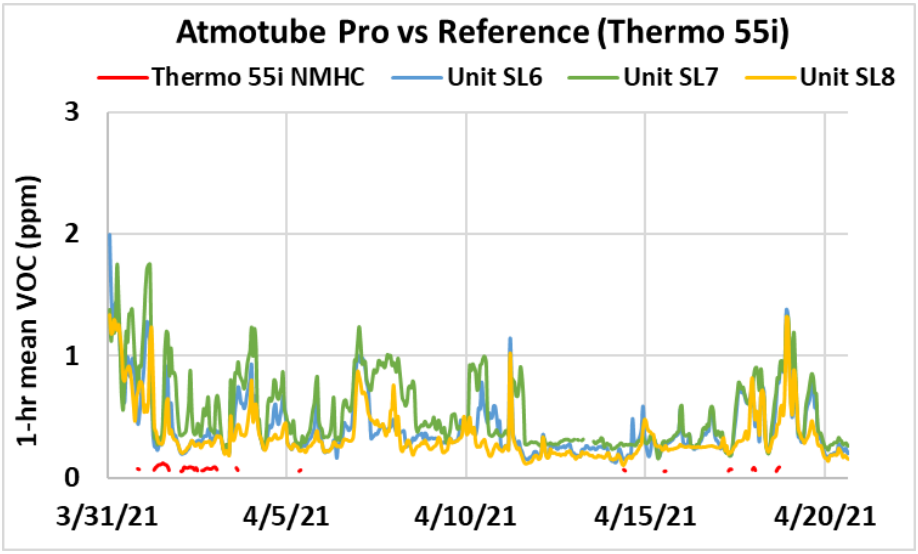






Atmotube Pro vs Thermo 55i NMHC (VOC; 1-hr mean)



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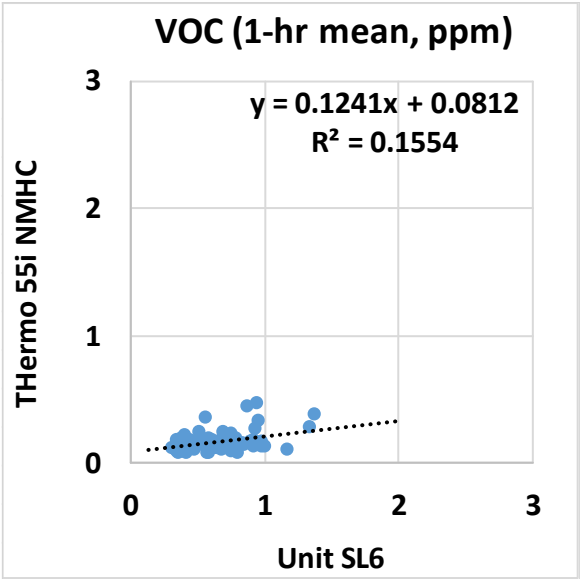

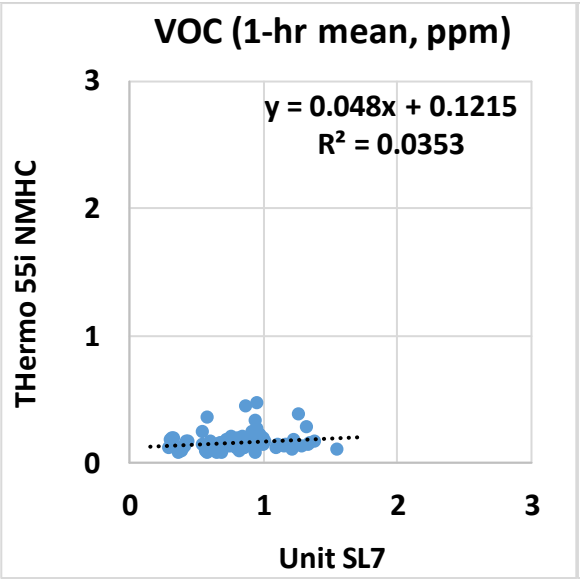

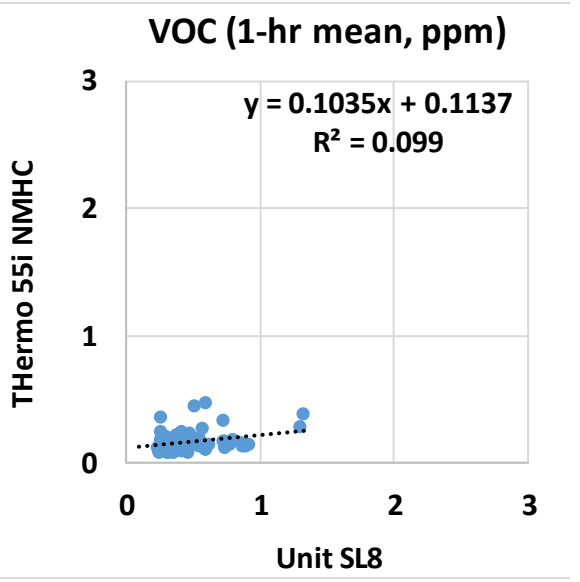

Co-location data summary: using only 1-minute data above LOD

Sensor (1-MIN)	Thermo 55i Channel	Slope	Intercept	R^2	MAE (ppm)	MBE (ppm)	RMSE (ppm)
SL6	NMHC	0.10	0.08	0.08	0.46	0.46	0.70
SL6	CH_4	0.30	2.10	0.12	1.81	-1.81	2.24
SL6	THC	0.27	2.45	0.04	2.02	-2.02	2.72
SL7	NMHC	0.07	0.09	0.05	0.62	0.62	0.92
SL7	CH_4	0.26	2.09	0.13	1.68	-1.68	2.10
SL7	THC	0.22	2.45	0.04	1.86	-1.86	2.52
SL8	NMHC	0.07	0.11	0.03	0.31	0.30	0.51
SL8	CH_4	0.22	2.15	0.05	1.88	-1.88	2.33
SL8	THC	0.15	2.55	0.01	2.18	-2.18	2.92

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

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Root Mean Square Error (RMSE): another metric to calculate measurement error

Note: Total Hydrocarbon (THC) is calculated as the sum of Methane (CH_4) and Nonmethane Hydrocarbon (NMHC). This table includes data points that are above the 50 ppb LOD

Co-location data summary: using all 1-minute non-negative Thermo 55i data

Sensor (1-MIN)	Thermo 55i Channel	Slope	Intercept	R^2	MAE (ppm)	MBE (ppm)	RMSE (ppm)
SL6	NMHC	0.12	-0.01	0.17	0.38	0.38	0.55
SL6	CH_4	0.30	2.10	0.12	1.81	-1.81	2.24
SL6	THC	0.42	2.09	0.15	1.85	-1.85	2.29
SL7	NMHC	0.09	-0.01	0.15	0.51	0.51	0.73
SL7	CH_4	0.26	2.09	0.13	1.68	-1.68	2.10
SL7	THC	0.35	2.08	0.15	1.72	-1.72	2.15
SL8	NMHC	0.09	0.007	0.07	0.31	0.31	0.46
SL8	CH_4	0.22	2.15	0.05	1.88	-1.88	2.33
SL8	THC	0.31	2.16	0.06	1.92	-1.92	2.38

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

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

Root Mean Square Error (RMSE): another metric to calculate measurement error

Note: Total Hydrocarbon (THC) is calculated as the sum of Methane (CH_4) and Nonmethane Hydrocarbon (NMHC). This table includes all data points from the Thermo 55i

VOC Testing Summary

- The Atmotube Pro sensors' VOC data recovery from all units tested was close to 100% except for Unit SL1
- The absolute intra-model variability for the Atmotube Pro sensors measurements was ~0.16 ppm
- The VOC concentrations measured by the Atmotube Pro sensors did not correlate well with the corresponding Thermo 55i VOC (NMHC) measurements
- The sensors overestimated the VOC (NMHC) concentrations as measured by the Thermo 55i reference instrument
- No sensor calibration was performed by South Coast AQMD prior to the beginning of this field co-location test

Limitations and Disclaimer

While the Thermo 55i reference instrument offers high time resolution, automated and continuous VOC monitoring, several limitations may exist:

- The VOC species measured at the “G-street” air monitoring station are representative of the source mix at that specific location and may not be present in other areas
- The reference instrument used for this testing (Thermo 55i) does not report specific responses to individual VOC species
- The reference instrument used for this testing (Thermo 55i) was calibrated using a single non-methane organic compound (propane), following the manufacturer’s recommendations and standard operating procedure. The Thermo 55i may show a different response when the chemical structure of the ambient VOC sample is different from the gas used to calibrate the VOC analyzer
- The Thermo 55i has a manufacturer-specified limit of detection of 50 ppb. Ambient VOC concentrations are usually very low, and often less than 50 ppb, which limits the number of valid data points from this VOC analyzer that can be used for comparison
- The VOC sensors may have been calibrated by the manufacturer to one or more specific VOC species and may show different responses when the chemical structure of the ambient VOC sample is different from the gas(es) the manufacturer used to calibrate the VOC sensor, and when the relative humidity and other environmental conditions are different from those experienced during these co-location measurements