Performance Evaluation Results for the Inaugural Set of VOC Air Quality Sensors Tested Under the AQ-SPEC VOC Laboratory Sensor Testing Protocol

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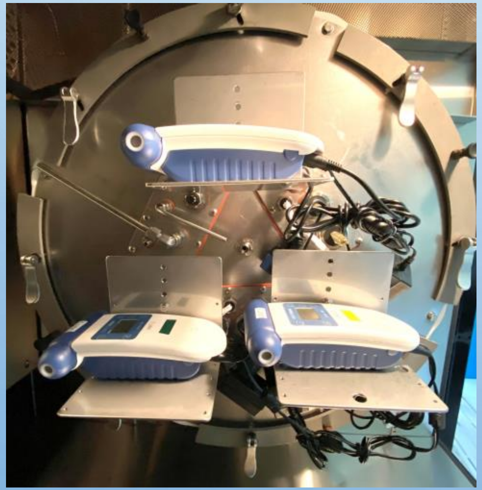
Chamber System and VOC Reference Instruments

Chamber

- 0.1 m^3 test volume
- Stainless steel
- Leak tight power, data and sampling probe passthroughs
- Dry, gas- and particle-free, T/RH conditioned air

AQ-SPEC
VOC Environmental Chamber



VOC Sensor placement

VOC Reference Instruments

- Direct methane and non-methane hydrocarbon analyzer (Thermo Fisher Scientific, Model 55i; **Thermo 55i**)
  - 70 seconds measurement cycle time
  - Measurement Range: 0-50 ppm
- Gas Chromatograph with Flame Ionization Detection (Agilent 6890N Network Gas Chromatograph, **GC-FID**)
  - ~ 20 min measurement cycle time
  - Measurement Range: <2 to 400 ppb per species

VOC Test Gases

- Benzene-only
- 4-species VOC Mixture: equal concentration of 1,3-butadiene, benzene, ethane and tetrachloroethylene

Initial Set of Sensors Evaluated

	Aeroqual S500-PID	Sensirion SGP40	Smart Citizen Kit v2.1
Unit Price	\$3,120 (sensor body + sensor head)	\$80	\$119
Units	ppm	Index expressed as ppm isobutylene, raw signal	ppm
Operation Principle/raw sensor	Photoionization Detection (Aeroqual PID)	Metal Oxide (Sensirion SGP40)	Metal Oxide (AMS CCS811)
Measurement Range	0 – 30 ppm	0.3 – 30 ppm of Ethanol in clean air	0 – 1.187 ppm
Limit of Detection	0.01 ppm	< 0.05 ppm for ethanol	
Accuracy/Linearity	< 0.02 ppm ± 10%		
Measurement Interval (min)	1	1	1
Built-in Compensation		RH	

Laboratory VOC Sensor Testing Procedure

Testing Phases	Knowledge Outcome
Phase 1: Transient Event Detection	• Peak detection rate
Phase 2: Initial Concentration Ramping	• Linearity and accuracy
Phase 3: Effect of T and RH	• Climate susceptibility
Phase 4: Effect of Gaseous Interferents	• Interferent susceptibility
Phase 5: Outdoor Simulation	• Explanatory factors
Phase 6: Final Concentration Ramping	• Short-term change in Response

To evaluate the sensor's ability to

- Respond to transient events with reasonable response time
- Report accurate VOC concentrations when compared to reference instruments
- Respond to environmental (T, RH) and gaseous (CO, CO_2, O_3) interferents

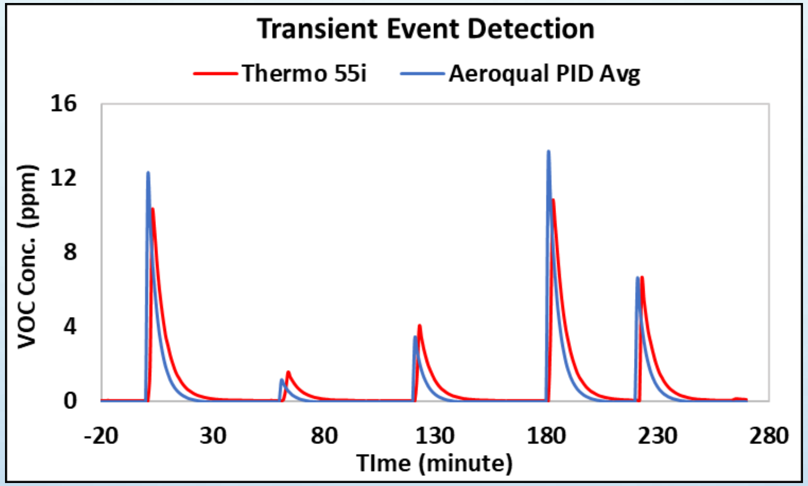
And to investigate

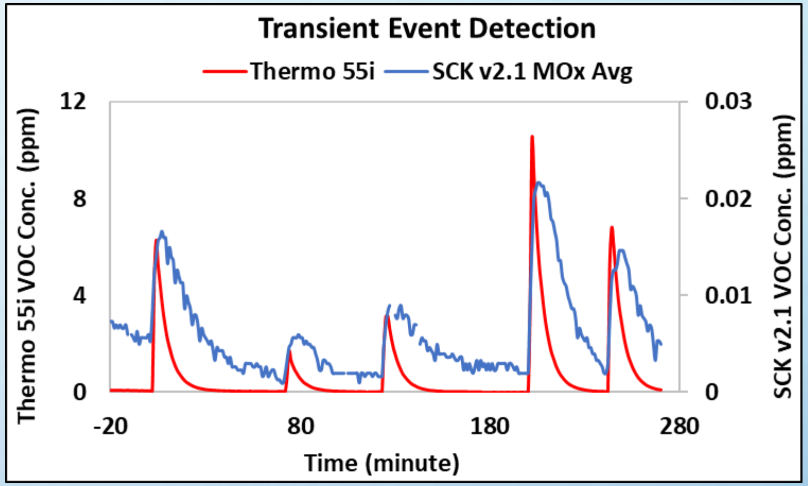
- Drivers for sensor signal through ANOVA analysis
- Changes in sensor response after they have been subjected to various climate conditions and gaseous interferents

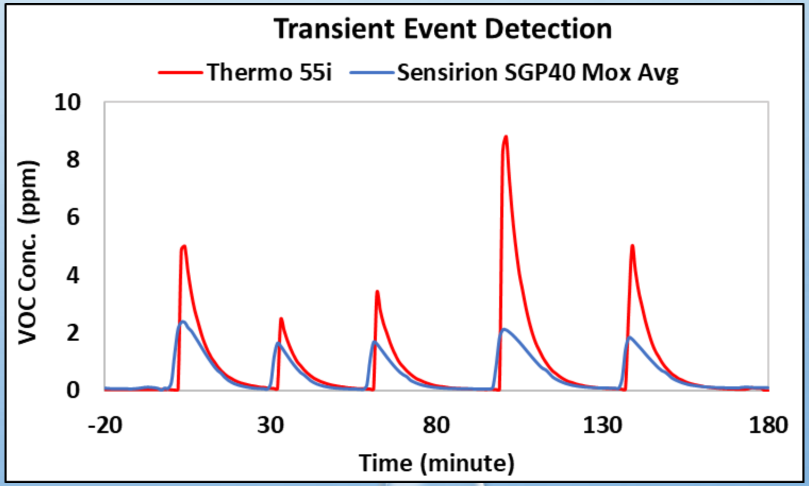
NOTE: Only VOC blend results are shown in this presentation

Phase 1 – Transient Event Detection

- Sensors can generally detect 100% of the VOC peaks generated
- Sensors generally detected peaks as fast as the Thermo 55i detected peaks

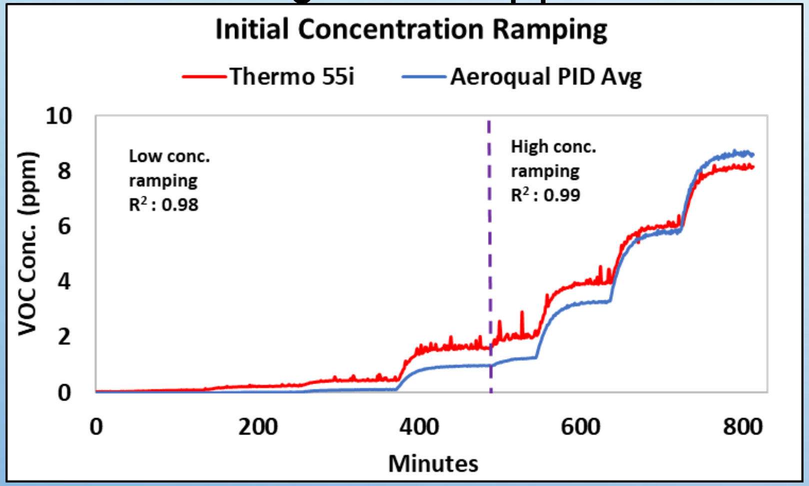


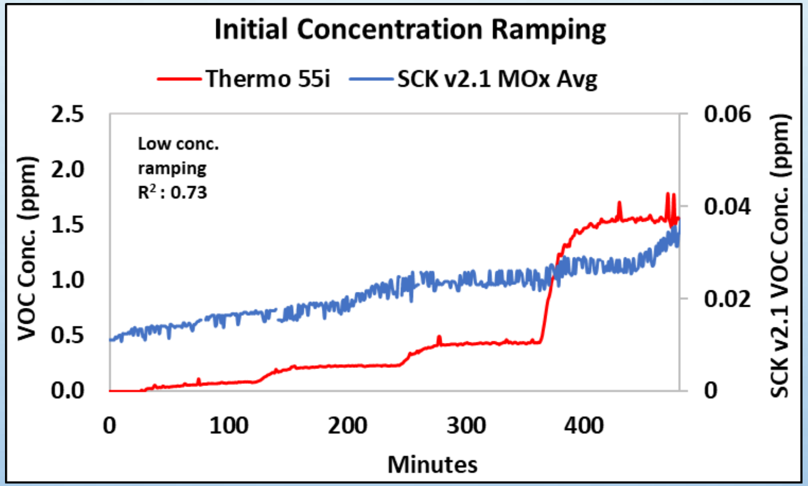


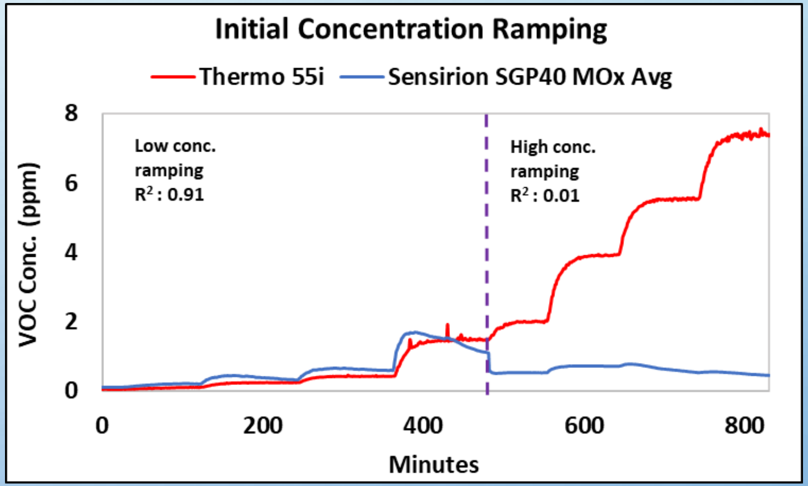


Phase 2 – Initial Concentration Ramping

- Aeroqual S500-PID sensors tracked the VOC concentrations in the range of 0-8 ppm
- The SCK v2.1 and Sensirion SGP40 sensors did not track well with the VOC conc. > 1 ppm







Phase 2 – Initial Concentration Ramping

Accuracy

- Aeroqual S500-PID: relative errors decreased with increasing VOC concentrations
- SCK sensors showed high relative errors at all concentrations tested.
- Sensirion SGP40: relatively lower errors at low VOC concentrations (< 2 ppm); relative errors increased with increasing VOC above 2 ppm

Initial Conc. Ramping Sensor Relative Errors (%) Against Thermo 55i			
Nominal VOC CONC. (ppm)	Aeroqual PID	SCK v2.1 MOx	Sensirion SGP40 MOx
0.06	-100.0	-88	81.8
0.2	-89.3	-91	28.0
0.4	-76.0	-93	37.2
1.6	-40.4	-98	-23.5
2	-42.9		-75.0
4	-19.5		-82.1
6	-4.9		-90.9
8	4.9		-94.6

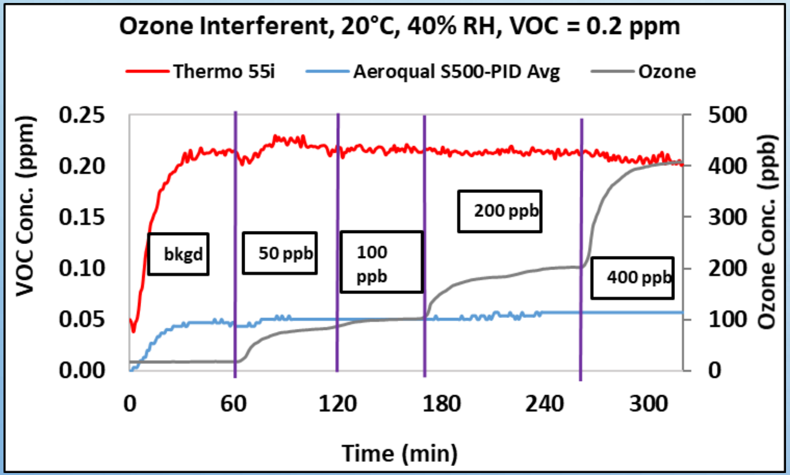
Phase 3 – Effect of Temperature and RH

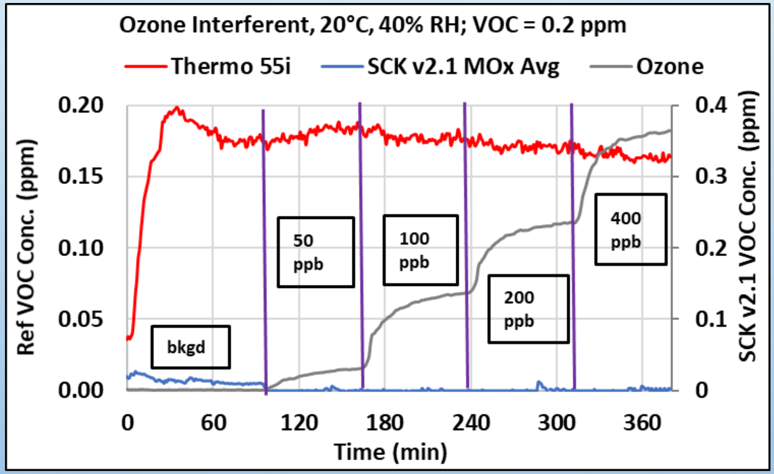
	Aeroqual S500-PID; Mean Bias Error (ppm)				
	T interference with constant RH @ 40%	RH interference with constant T @ 20°C			
RH (%) / T (°C)	40	25	40	65	80
20	-0.4	0.2	-0.4	-0.9	-1.2
10	0				
30	-0.8				
20	-0.3				

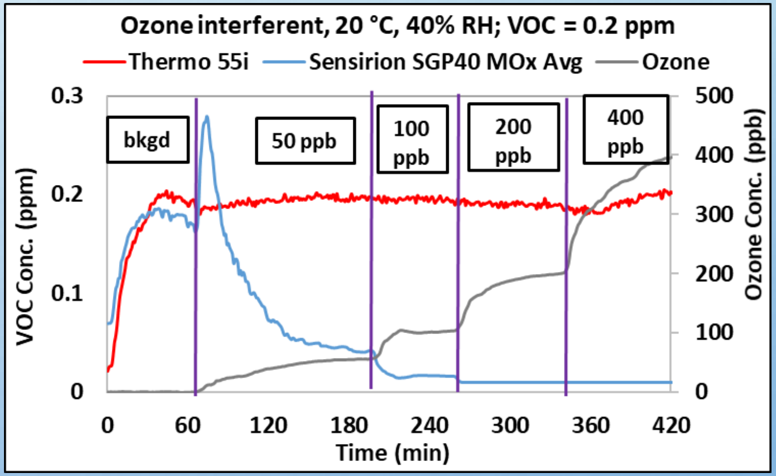
	Sensirion SGP40; Mean Bias Error (ppm)				
	T interference with constant RH @ 40%	RH interference with constant T @ 20°C			
RH (%) / T (°C)	40	25	40	65	80
20	-3.9	-3.2	-3	-3.2	-3.6
10	-4.1				
30	-3.5				
20	-3.9				

Phase 4 – Effect of Interferent Gases: Ozone

- The Aeroqual S500-PID sensors response did not vary with ozone concentration
- The SCK v2.1 sensors showed mostly zeroes after the addition of ozone.
- The Sensirion SGP40 sensors' VOC concentration decreased as ozone concentration increased.



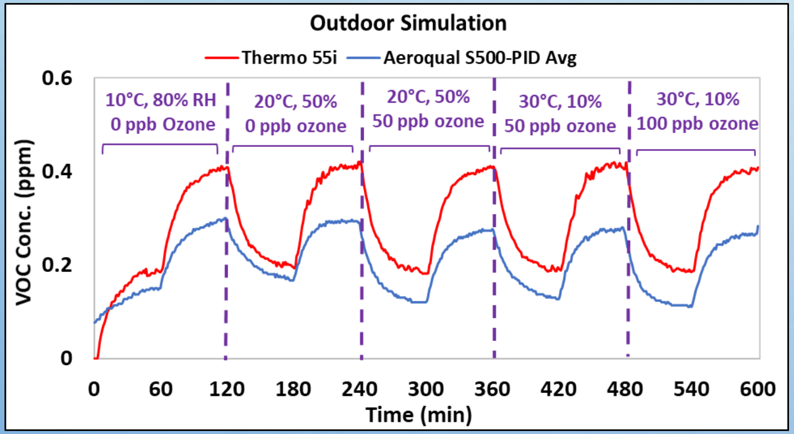


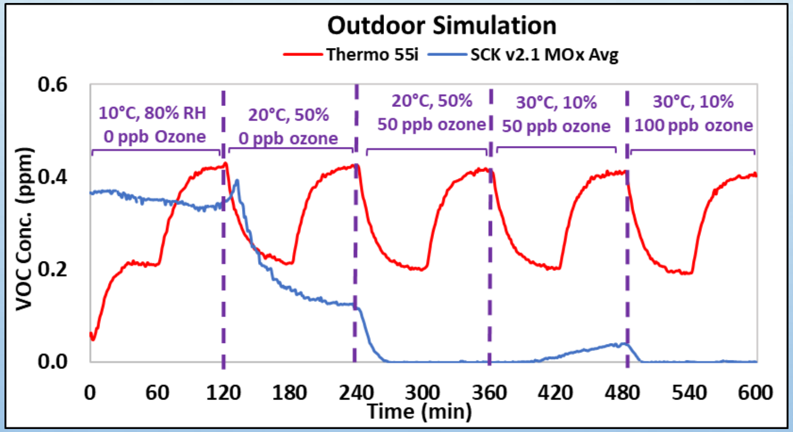


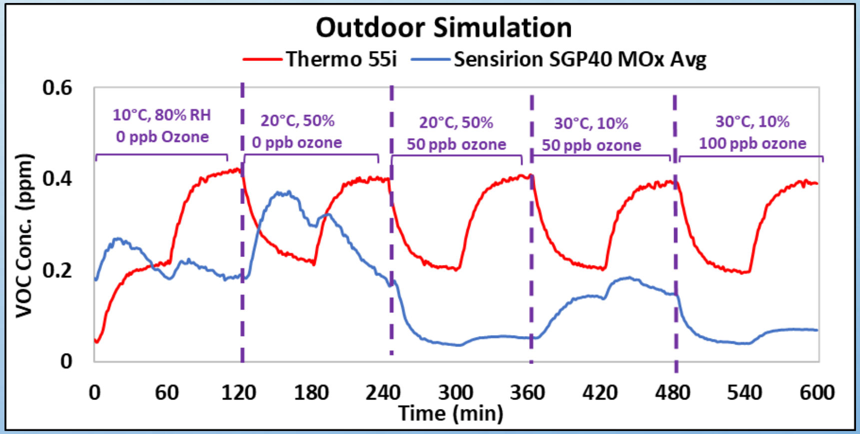
Phase 5 – Outdoor Simulation

- The Aeroqual S500-PID sensors tracked well with the VOC variations

- The SCK v2.1 and the Sensirion SGP40 sensors did not track as well with VOC variations
- The SCK v2.1 sensors and Sensirion SGP40 sensors' response decreased significantly with the addition of ozone



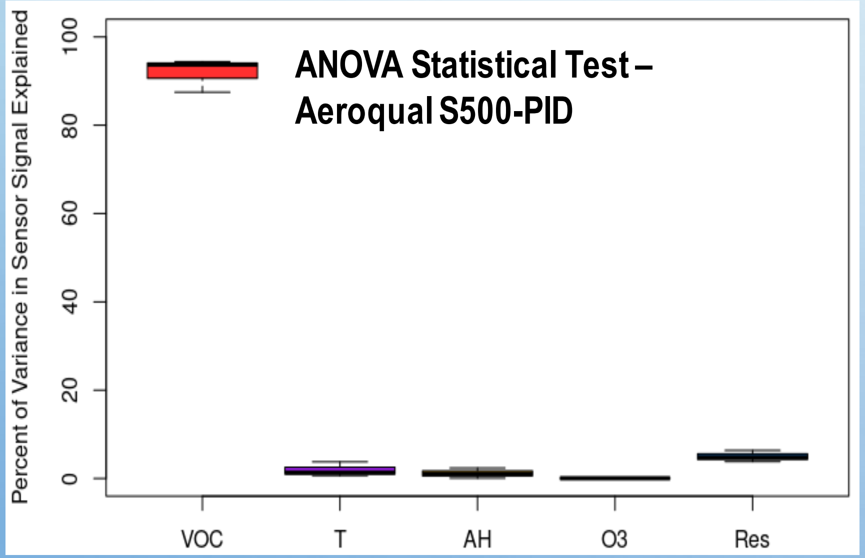


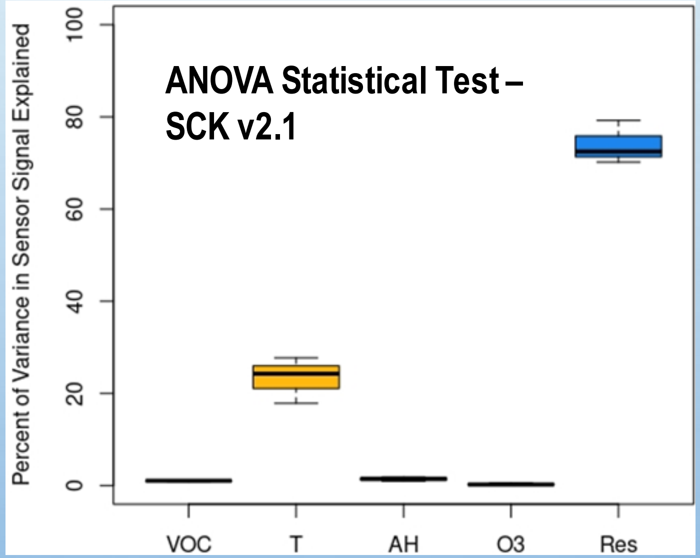


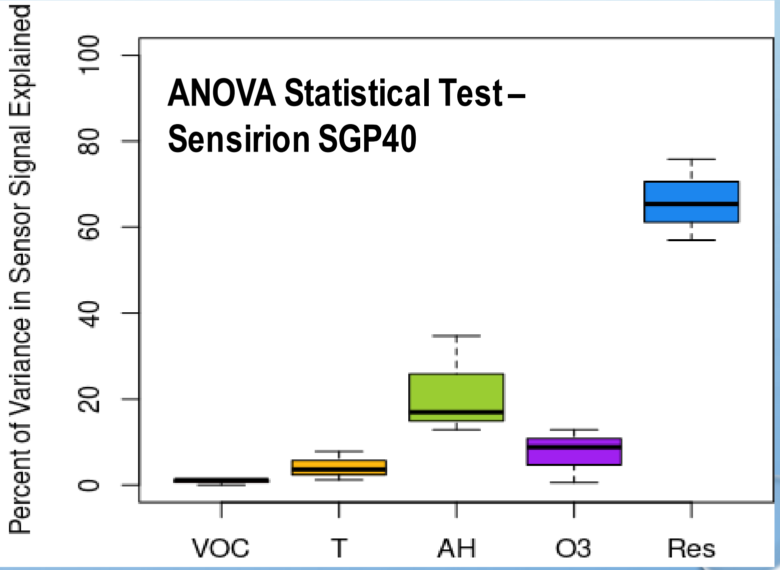
Phase 5 – Outdoor Simulation - ANOVA

- The VOC concentration accounted for ~92% of the variance in the ANOVA statistical test for the Aeroqual S500-PID sensors.

- Temperature explained about 23% of the variance for the SCK v2.1 sensors and humidity explained about 21% of the sensor response for the Sensirion SGP40 sensors.
- Both the SCK v2.1 and Sensirion SGP40 sensors did not seem to be specifically sensitive to VOC variations according to the ANOVA statistical tests.

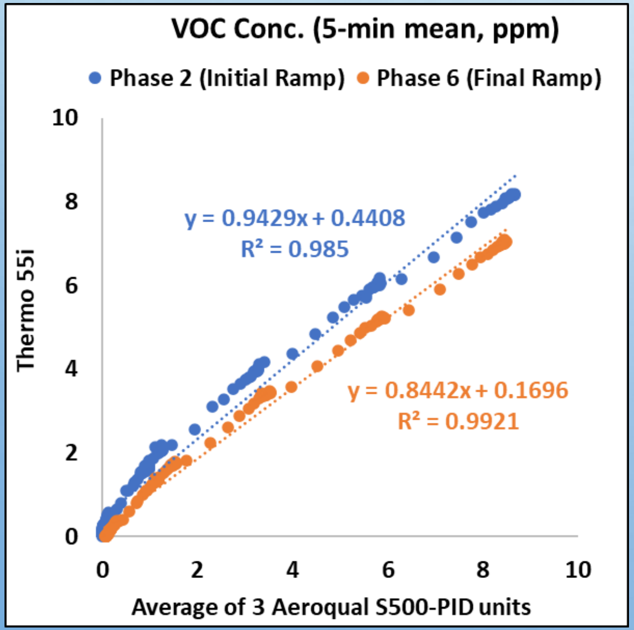


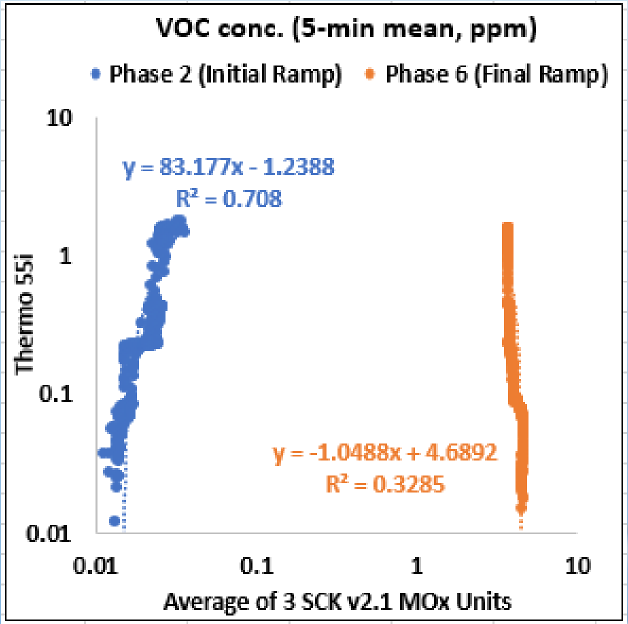


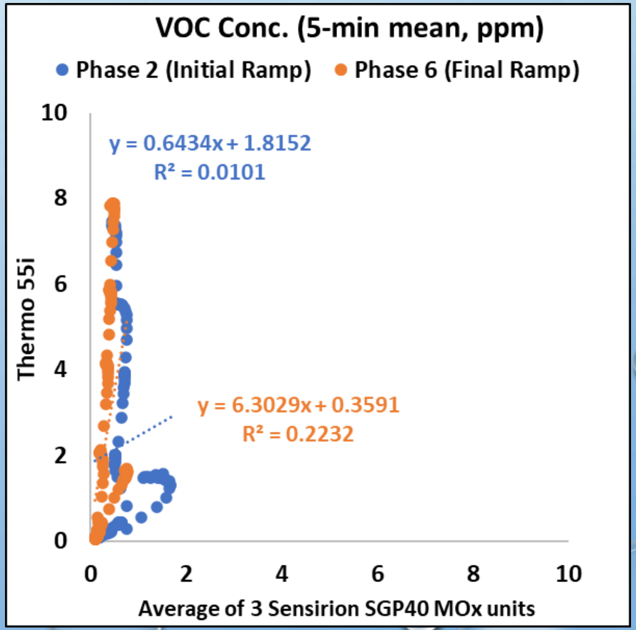


Phase 6 – Final Concentration Ramping/Drift

- The Aeroqual S500-PID sensors showed similar behavior between initial and final concentration rampings.
- The SCK v2.1 sensors generally underestimated VOC during the initial ramping but showed overestimation during the final ramping.
- The Sensirion SPG40 sensor response was less sensitive to VOC variations in the final concentration ramping than in the initial ramping.







Recap and Future Work

Recap:

- VOC sensors can show drastically different responses to the same test procedure and species
- The PID sensor tested showed less interference from T, RH or gases compared to the MOx sensors tested
- Sensors that are primarily responsive to VOC in these tests have the potential for fenceline and ambient air monitoring

Future Work:

- Next in queue for VOC sensor testing:
  - PurpleAir PA-II FLEX VOC (MOx)
  - SENSIT SPOD (PID)
  - SGS SmartSense (PID)
- VOC sensor testing in the field

Thank You!

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