Laboratory Evaluation:

Smart Citizen Kit v2.1

South Coast
AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

Three **Smart Citizen Kit v2.1** (hereinafter **SCK 2.1**) sensors (units IDs: 7FD1, 3423, 4E34) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (09/19/2019 to 11/19/2019) under ambient environmental conditions and have been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity. The same three SCK 2.1 units were tested both in the field (1st stage of testing) and in the laboratory (2nd stage of testing).

SCK 2.1 (*3 units tested*):

- Particle sensor: optical; non-FEM (model PMS 5003, Plantower)
- Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), temperature (°C), RH (%), pressure (Pa), noise level (dBA) and ambient light (Lux), VOC (ppb), equivalent carbon dioxide (ppm)
- Unit cost: $119 (Smart Citizen Starter Kit)
- Time resolution: 1-min
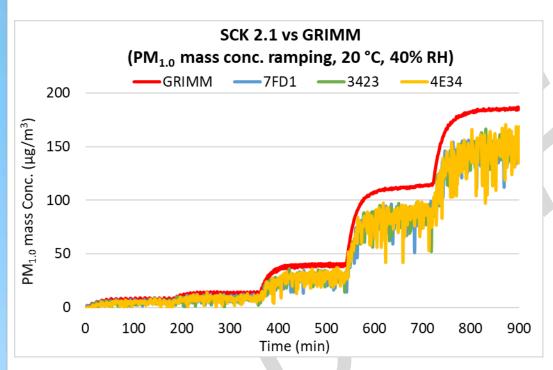- Units IDs: 7FD1, 3423, 4E34

GRIMM (*reference method*):

- Optical particle counter
- FEM $PM_{2.5}$
- Uses proprietary algorithms to calculate $PM_{1.0}$, $PM_{2.5}$, and PM_{10} mass conc. from particle number measurements
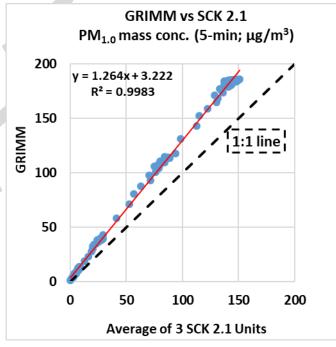- Cost: ~$25,000
- Time resolution: 1-min

FEM GRIMM

Evaluation results for PM$_{1.0}$ mass concentration

SCK 2.1 vs GRIMM

SCK 2.1 vs GRIMM ($PM_{1.0}$ mass conc.)

SCK 2.1 vs GRIMM
($PM_{1.0}$ mass conc. ramping, 20 °C, 40% RH)

— GRIMM — 7FD1 — 3423 — 4E34

Coefficient of Determination

GRIMM vs SCK 2.1
$PM_{1.0}$ mass conc. (5-min; $\mu g/m^3$)

$y = 1.264x + 3.222$
$R^2 = 0.9983$

1:1 line

- The SCK 2.1 sensors tracked well with the concentration variation as recorded by the GRIMM in the concentration range of 0 - ~200 $\mu g/m^3$.

- The SCK 2.1 sensors showed very strong correlations with the GRIMM $PM_{1.0}$ mass conc. ($R^2 > 0.99$)

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SCK 2.1 vs GRIMM $PM_{1.0}$ Accuracy

- Accuracy (20°C and 40% RH)

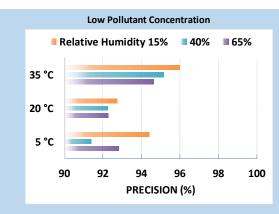| Steady state #	Sensor Mean ($\mu g/m^3$)	GRIMM ($\mu g/m^3$)	Accuracy (%)
1	4.7	7.5	62.8
2	8.5	12.9	65.5
3	28.0	39.6	70.6
4	86.6	114.1	75.9
5	147.8	185.5	79.7

- The SCK 2.1 sensors underestimated GRIMM $PM_{1.0}$ mass concentrations at 20 °C and 40% RH. The accuracy of the SCK 2.1 sensors increased (from ~63% to 80%) as $PM_{1.0}$ mass concentrations increased.
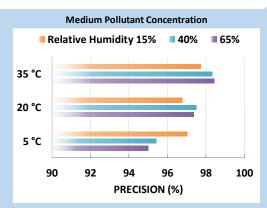
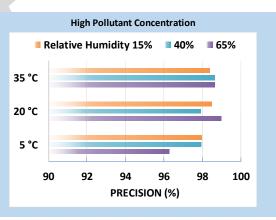# SCK v2.1: Data Recovery and Intra-model Variability

- Data recovery for $PM_{1.0}$ mass concentration from all units was 100%

- Low $PM_{1.0}$ measurement variations were observed between the SCK v2.1 sensors

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SCK 2.1 PM$_{1.0}$: Precision

- Precision (Effect of PM$_{1.0}$ conc., Temperature and Relative Humidity)
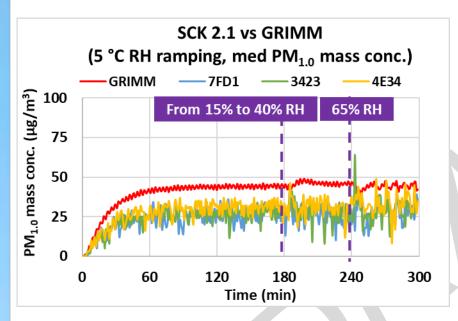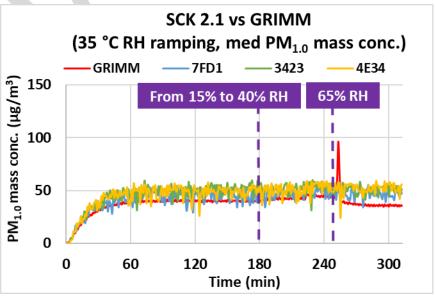

- Overall, the SCK 2.1 sensors showed high precision for all combinations of low, medium and high PM$_{1.0}$ conc., T, and RH.

- Precision was relatively higher at higher PM$_{1.0}$ mass concentrations.

SCK 2.1 PM$_{1.0}$: Climate Susceptibility

SCK 2.1 vs GRIMM
(5 °C RH ramping, med PM$_{1.0}$ mass conc.)

Legend: GRIMM, 7FD1, 3423, 4E34

From 15% to 40% RH — 65% RH

y-axis: PM$_{1.0}$ mass conc. (μg/m^3)
x-axis: Time (min)

**Low Temp – RH ramping
(medium conc.)**

**High Temp – RH ramping
(medium conc.)**

SCK 2.1 vs GRIMM
(35 °C RH ramping, med PM$_{1.0}$ mass conc.)

Legend: GRIMM, 7FD1, 3423, 4E34

From 15% to 40% RH — 65% RH

y-axis: PM$_{1.0}$ mass conc. (μg/m^3)
x-axis: Time (min)
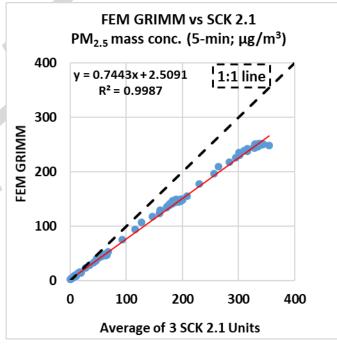
Evaluation results for PM$_{2.5}$ mass concentration

SCK 2.1 vs FEM GRIMM

SCK 2.1 vs FEM GRIMM (PM$_{2.5}$ mass conc.)

Coefficient of Determination

SCK 2.1 vs FEM GRIMM
(PM$_{2.5}$ mass conc. ramping, 20 °C, 40% RH)
— FEM GRIMM — 7FD1 — 3423 — 4E34

FEM GRIMM vs SCK 2.1
PM$_{2.5}$ mass conc. (5-min; µg/m^3)

$y = 0.7443x + 2.5091$
$R^2 = 0.9987$

1:1 line

- The SCK 2.1 sensors tracked well with the concentration variation as recorded by the FEM GRIMM in the concentration range of 0 - ~250 µg/m^3.

- The SCK 2.1 sensors showed very strong correlations with the FEM GRIMM PM$_{2.5}$ mass conc. (R^2 > 0.99)

SCK 2.1 vs FEM GRIMM PM$_{2.5}$ Accuracy

- Accuracy (20°C and 40% RH)

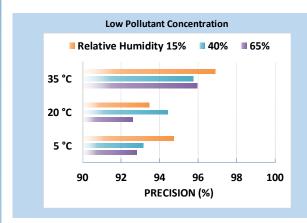| Steady state #	Sensor Mean (µg/m³)	FEM GRIMM (µg/m³)	Accuracy (%)
1	9.3	8.7	92.7
2	17.6	14.8	81.4
3	63.0	48.1	69.0
4	195.3	149.4	69.2
5	340.2	250.3	64.1

- The SCK 2.1 sensors overestimated FEM GRIMM PM$_{2.5}$ mass concentrations at 20 °C and 40% RH. The accuracy of the SCK 2.1 sensors decreased (from ~ 93% to 64%) as PM$_{2.5}$ mass concentrations increased.
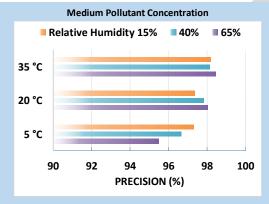
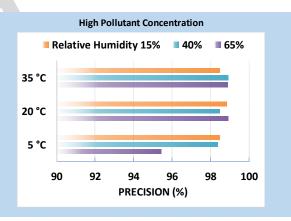# SCK v2.1: Data Recovery and Intra-model Variability

- Data recovery for PM$_{2.5}$ mass concentration from all units was 100%

- Low PM$_{2.5}$ measurement variations were observed between the SCK v2.1 sensors

SCK 2.1 vs FEM GRIMM
($PM_{2.5}$; 1-min mean)

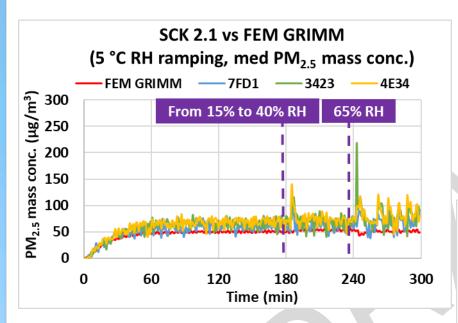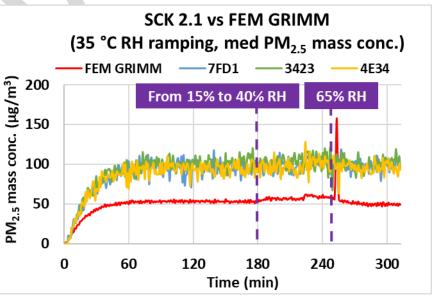- Precision (Effect of $PM_{2.5}$ conc.,Temperature and Relative Humidity)

- Overall, the SCK 2.1 sensors showed high precision for all combinations of low, medium and high $PM_{2.5}$ conc., T, and RH.

- Precision was relatively higher at higher $PM_{2.5}$ mass concentrations.

SCK 2.1 vs PM$_{2.5}$: Climate Susceptibility

SCK 2.1 vs FEM GRIMM
(5 °C RH ramping, med PM$_{2.5}$ mass conc.)

— FEM GRIMM   — 7FD1   — 3423   — 4E34

From 15% to 40% RH   65% RH

PM$_{2.5}$ mass conc. (µg/m³)

Time (min)

**Low Temp – RH ramping
(medium conc.)**

**High Temp – RH ramping
(medium conc.)**

SCK 2.1 vs FEM GRIMM
(35 °C RH ramping, med PM$_{2.5}$ mass conc.)

— FEM GRIMM   — 7FD1   — 3423   — 4E34

From 15% to 40% RH   65% RH

PM$_{2.5}$ mass conc. (µg/m³)

Time (min)

Discussion

- **Accuracy**: Overall, the accuracy of the SCK 2.1 sensors increased (from ~63% to 80%) as $PM_{1.0}$ mass concentrations increased; the accuracy decreased (from ~ 93% to 64%) as $PM_{2.5}$ mass concentration increased. The SCK 2.1 sensors underestimated the corresponding $PM_{1.0}$ measurements and overestimated the corresponding $PM_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.

- **Precision**: The SCK 2.1 sensors showed high precision for all test combinations (PM concentrations, T and RH) for $PM_{1.0}$ and $PM_{2.5}$ mass concentrations

- **Intra-model variability**: Low intra-model variability was observed among the SCK 2.1 sensors for $PM_{1.0}$ and $PM_{2.5}$ mass concentrations.

- **Data Recovery:** Data recovery for $PM_{1.0}$ and $PM_{2.5}$ mass concentration was 100% from all SCK 2.1 units

- **Coefficient of Determination**: The SCK 2.1 sensors showed very strong correlation/linear response with the corresponding GRIMM $PM_{1.0}$ and FEM GRIMM $PM_{2.5}$ measurement data ($R^2 > 0.99$).

- **Climate susceptibility**: For most of the temperature and relative humidity combination, the climate condition had minimal effect on the SCK 2.1 sensors' precision; the sensors showed spiked conc. change at the RH change points at 5 °C and showed significant concentration variation at 5 °C/65% RH.