Calibration, pressure and temperature sensitivity of Vaisala GMM 220A CO_2 sensors

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Objective: Calibrate and test performance of four Vaisala CARBOCAP® Carbon Dioxide Module GMM 220A sensors that measure CO_2 mixing ratios. The following characteristics were tested: sensor individual zero offset and span (Section 2), temperature sensitivity (Section 3), pressure sensitivity (Section 4), sensor noise (Section 5) and sensor drift over 24 hours (Section 6). The sensors tested were GMM 220 #59, #60, #66, and #67. All sensors are used in the soil respiration set-up of APBI 244 / GEOB 204 at UBC.

1. Calibration Setup

Four of the soil chambers equipped with a CARBOCAP® Carbon Dioxide Module of the GMM 220A series sensors (#59, #60, #66, and #67) were placed within a sealed aluminum container with a volume of 0.13 m^3 in the calibration lab. #59 and #600 had the version Std 4.15, #66, and #67 were running the version Std 4.10. All four sensors were sampled with a frequency of 1 sec using the voltage output of the GMM 220A (directly connected to board) on a CR1000 logger (Campbell Scientific, Inc.) in the container. 5-second averages were stored in the CR1000 data logger. A pressure transducer (Vaisala PTB 427) and a temperature / relative humidity sensor (Vaisala HMP 45) probe were also operated in the container and connected to the CR1000 data logger. A total of 5 fans mixed the air in the container (Figure 1, left). The container was sealed with a lid, and in some experiments the lid was secured with brackets to prevent diffusion when pressure changes occurred (Figure 1, right).

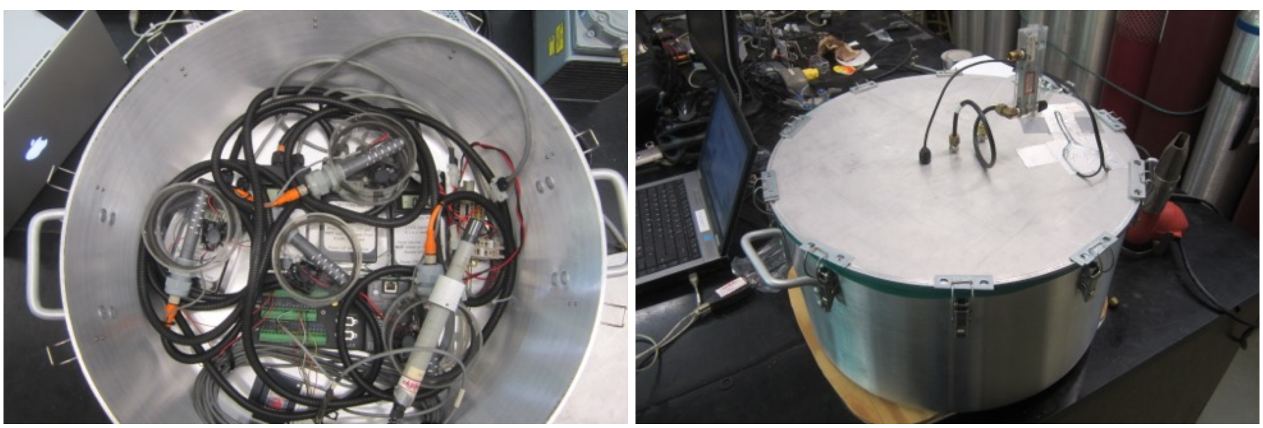

Figure 1 – Calibration container with soil chambers (left) and container when sealed (right). Inlets for gas injection and cables are fed through top (right).

2. Determination of zero and span

To determine zero and span of all sensors, the container was connected to a Li-7000 (in temperature controlled box) in a closed flow loop that was enforced by a pump. Li-7000 digital output was stored at 2 Hz on a PC. The container was initially filled at a slightly above room-ambient CO_2 mixing ratio (580 ppm), while over a period of 4.67 days it was reduced from 580 ppm to 470 ppm at a roughly constant rate of 1 ppm hr^{-1} though a small leak. Pressure was on average 102.744 kPa (range: 103.322, 102.450 kPa), air temperature in the container ranged between 23.8°C and 25.8°C during the four days.

To determine the zero offset, the same container, connected to the Li-7000 was filled with pure N_2 and the sealed container was run for 20 minutes (air temperature: 25.1°C, pressure: 103.358 kPa), while the Li-7000 connected through the loop confirmed that CO_2 mixing ratios stayed at 0 ppm.

For further analysis of the span, 5-minute averages were calculated from the 2-Hz data of the Li-7000 and the 5 second data of the GMM 220 sensors. The average zero reading (in mV) was determined over the 20 min with the N_2 gas in the container (Table 1). This value was subtracted from the readings, and a linear fit (forced to zero) was established between the CO_2 mixing ratio measured by the Li-7000 and the Sensor reading in mV minus the zero offset determined before. Regressions are shown in Figure 2. Table 1 summarizes the offset and slope.

Table 1 – Zero offset and slope (ppm/mV) of the four sensors

	Measurement at zero ppm [N_2] (mV)	Measurement at zero ppm [N_2] std-dev (mV)	Slope (ppm / mV)	Inverse slope (mV / ppm)	Offset (ppm)
Sensor #59	9.69769	7.24016	0.8214	1.2174	-11.8056
Sensor #60	9.03533	4.84961	1.9479	0.5134	-4.6386
Sensor #66	2.61549	1.29552	0.9167	1.0908	-2.8531
Sensor #67	129.348	6.35710	0.7554	1.3237	-171.2239

The following calibration coefficients were derived:

Sensor #59 : CO_2 (ppm) = 0.82145 ppm/mV * Signal in mV - 11.8056 ppm
Sensor #60 : CO_2 (ppm) = 1.94785 ppm/mV * Signal in mV - 4.63861 ppm
Sensor #66 : CO_2 (ppm) = 0.91672 ppm/mV * Signal in mV - 2.85309 ppm
Sensor #67 : CO_2 (ppm) = 0.75543 ppm/mV * Signal in mV - 171.224 ppm

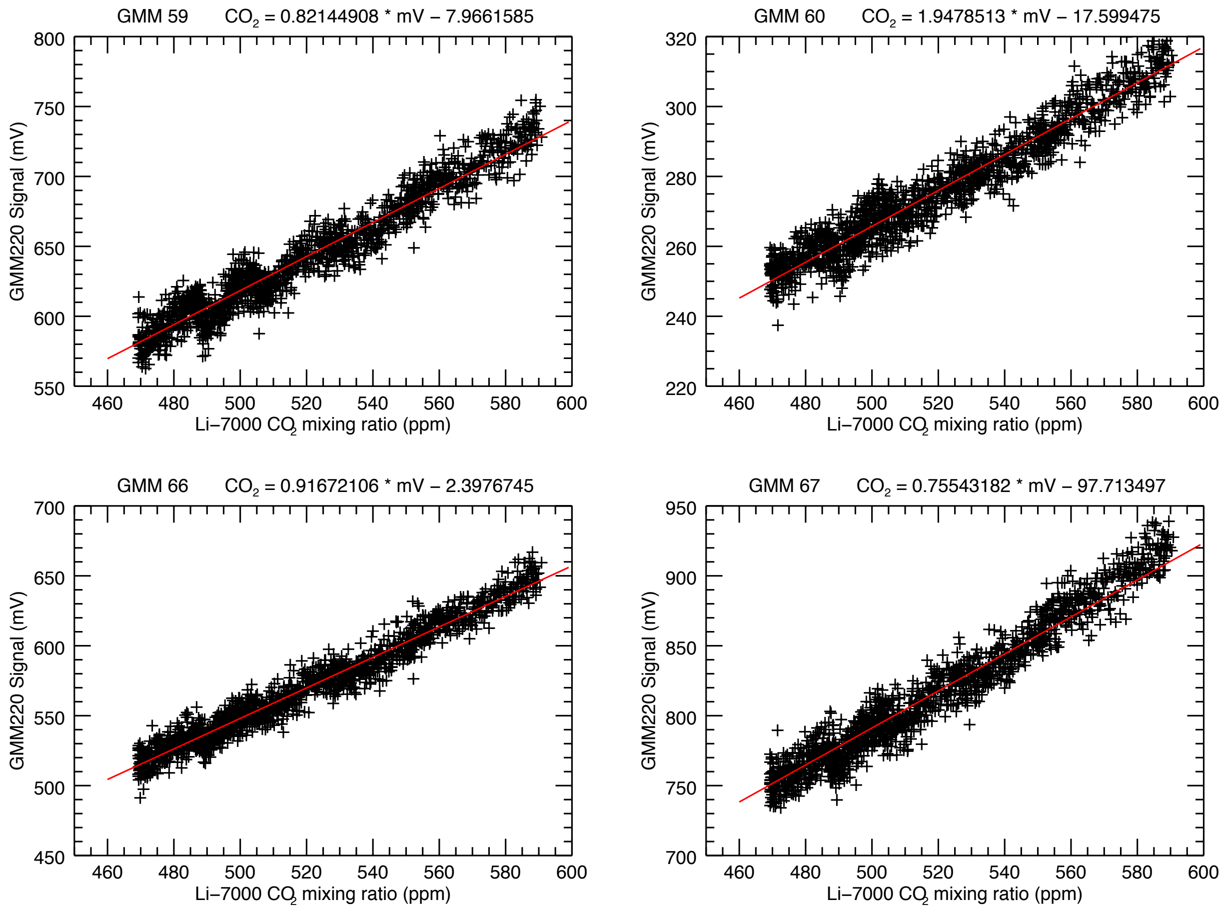

Figure 2 – Regressions between calibrated Li-7000 (*x*-axis) and mV output of GMM Sensors #59, #60, #66 and #67 (*y*-axis). Red shows the linear regression forced through zero.

3. Temperature sensitivity

Temperature dependence was tested over the range of 28-36 °C. The container was filled and sealed at ambient CO_2 (around 430 ppm) and was heated with a heat gun on the outside (Figure 4) to reach an interior temperature of 36°C. Then the sealed container was cooled slowly over a period of 3.5 hours while values were recorded. On average, the sensors respond linearly to temperature changes at -5.44 ppm K^{-1} at 400 ppm (Figure 3), although individual sensors have slightly different dependencies. The manufacturer correction (red in Figure 3) works well.

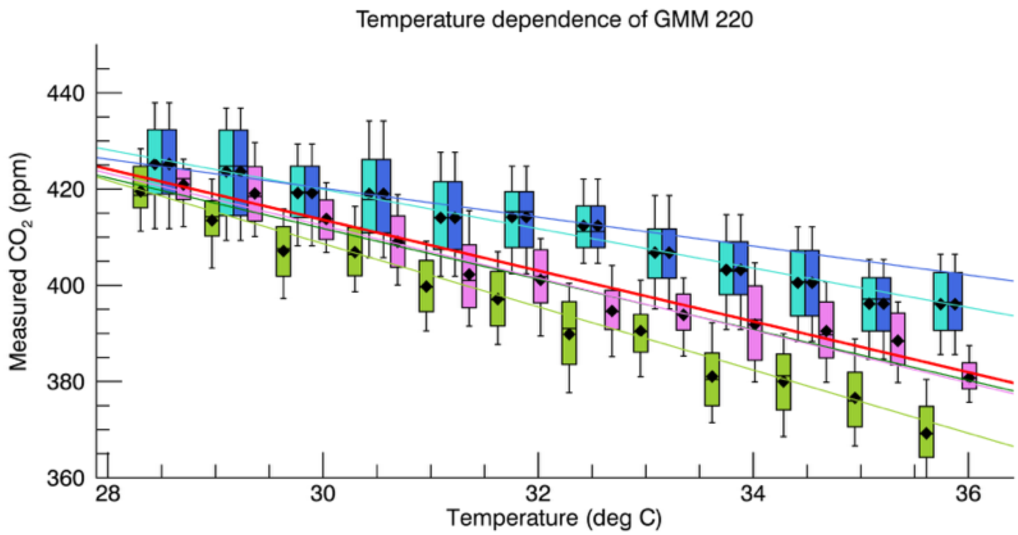

Figure 3 - Temperature dependency of GMM220 instruments in 1 K bins. Each colored box plot represents a different sensor, where green is sensor #59, cyan is #60, blue is #66 and pink is #67. The solid red line is manufacturer supplied correction. The colored boxes show the 25 and 75% percentile, the whiskers indicate the 10% and 90% percentiles. The horizontal lines are the medians and the diamonds are the average in each 1K bin.

Figure 4 - Heating the container;s exterior with a heat gun.

4. Pressure sensitivity

Pressure sensitivity was tested over the range of pfrom 90 - 100 kPa. The container was filled and sealed at ambient CO_2 (around 440 ppm) and then was connected to a vacuum pump. The pressure was slowly lowered to 900 kPa over 20 min while values were recorded. On average, the sensors responded linearly to pressure at a rate of 0.77 ppm hPa^{-1}. The manufacturer correction (Red line in Figure 5) works well.

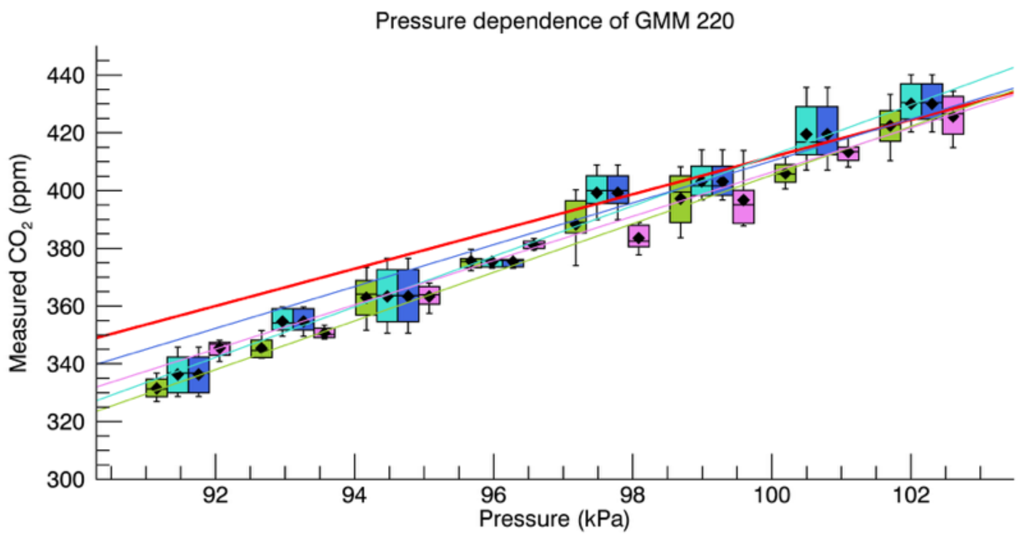

Figure 5 - Pressure dependency of GMM220 instruments. Each colored box plot represents a different instrument. Each colored box plot represents a different sensor, where green is sensor #59, cyan is #60, blue is #66 and pink is #67. The solid red line is manufacturer supplied correction.

Figure 6 - Vacuum pump to evacuate the container.

5. Sensor noise

Sensor precision (defined as standard deviation during an averaging period under constant conditions) was tested by running the sensors for a 24 hour period inside the sealed container. The noise was found to be dependent on the length of averaging period (Figure 7, Table 2).

Table 2 - High frequency noise determined as standard deviation over two hours under controlled conditions (constant T = 26.57 ± 0.078 °C, constant pressure p = 102.981 ± 0.005 kPa).

	Std dev for 5 sec averages (ppm)	Std dev for 10 sec averages (ppm)	Std dev for 20 sec averages (ppm)	Std dev for 40 sec averages (ppm)	Std dev for 80 sec averages (ppm)	Std dev for 200 sec averages (ppm)	Std dev for 400 sec averages (ppm)	Std dev for 800 sec averages (ppm)
Sensor #59	7.76	7.60	7.18	6.25	4.91	3.65	2.98	1.66
Sensor #60	8.50	8.32	7.85	6.80	5.20	3.31	2.07	0.94
Sensor #66	6.96	6.92	6.82	6.54	6.00	4.94	4.14	3.25
Sensor #67	7.53	7.49	7.38	7.14	6.71	4.95	4.32	2.77
Average of all sensors	**7.69**	**7.58**	**7.31**	**6.68**	**5.70**	**4.21**	**3.38**	**2.16**

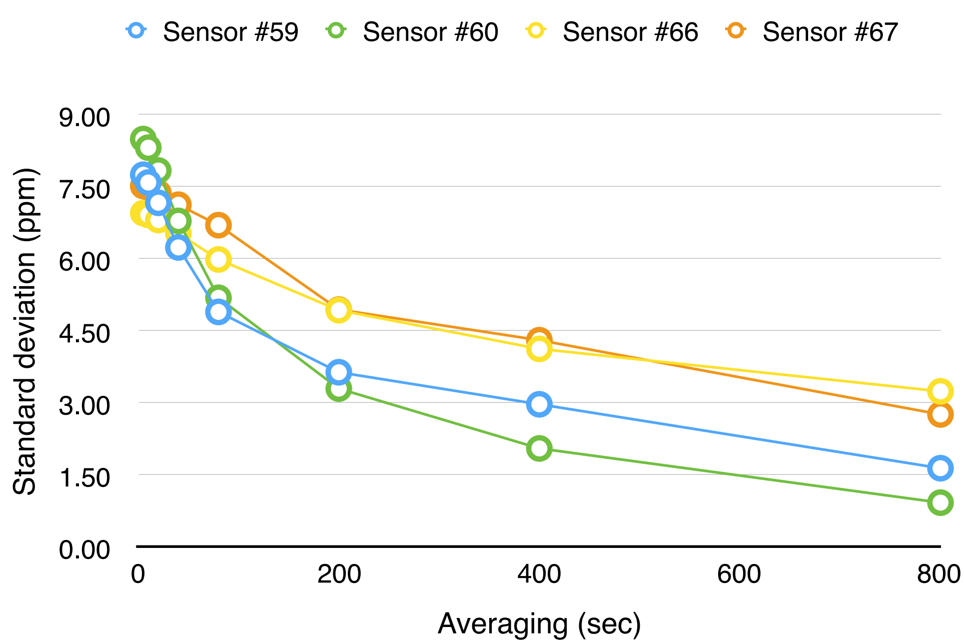

Figure 7 - Graph of noise vs. averaging period for all four sensors.

6. Sensor drift

All sensors were operated in the sealed container for a 24 hour period, while temperature and pressure at beginning and end were recorded for one hour and compared (Table 3). This test quantified the absolute sensor drift over a 24-hour period on average as 0.34 (±0.40) ppm.

Table 3 - Comparison of hourly mean concentrations at start and end of 24 hour run.

	One hour average at t=0..1h (ppm)	One hour average at t=23..24h (ppm)	Drift over 24 hours (ppm)
Sensor #59	430.24	430.611	0.37
Sensor #60	431.138	430.785	-0.35
Sensor #66	428.418	428.711	0.29
Sensor #67	429.182	429.762	0.58
Average absolute drift			0.34
Standard deviation of drift			0.40
Air temperature (ºC)	26.5042	26.7409	0.24
Pressure (kPa)	102.977	102.974	-0.00