



Supplement of

Low-complexity methods to mitigate the impact of environmental variables on low-cost UAS-based atmospheric carbon dioxide measurements

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Sensor Selection

Table S1. Examples of low-cost NDIR CO₂ sensors

Manufacturer	Vaisala	Senseair	ELT Co.	Korea Digital Co.	GE Sensing	Amphenol Adv. Sensors	Cozir
Model	GMM222C	K30	S100	AN100	T6615	T6613	Cozir-A
Measurement range [ppm]	0–2,000	0–5,000	0–10,000	0–5,000	0–10,000	0–2,000	0–10,000
Accuracy [ppm]	±30	±30	±50	±200	±75	±30	±50
Weight [g]	220	17	10	29	17	-	20
Cost [USD]	-	95.00	-	-	104.81	99.72	109.00

Sources: senseair.com, eltsensor.co.kr, farnell.com/datasheets/484016.pdf, amphenol-sensors.com, co2meter.com, Al-Hajjaji et al. (2017), and Yasuda et al. (2012).

Table S2. Literature search arguments and their results.

Search string	Results
+CO2 +unmanned +aerial	11,300
+CO2 +unmanned +aerial +(K30 OR K-30 OR “K 30”)	67
+CO2 +unmanned +aerial... +(GMM222C OR S100 OR AN100 OR T6615) -(K30 OR K-30 OR “K 30”)	6
+Carbon +dioxide +unmanned +aerial	10,500
+Carbon +dioxide +unmanned +aerial +(K30 OR K-30 OR “K 30”)	62
+Carbon +dioxide +unmanned +aerial... +(GMM222C OR S100 OR AN100 OR T6615) -(K30 OR K-30 OR “K 30”)	3
+Carbon +dioxide +remotely +piloted +aircraft	1520
+Carbon +dioxide +remotely +piloted +aircraft +(K30 OR K-30 OR “K 30”)	7
+Carbon +dioxide +remotely +piloted +aircraft... +(GMM222C OR S100 OR AN100 OR T6615) -(K30 OR K-30 OR “K 30”)	1

Experiments

Table S3. List all the experiments performed and their sensors. The sensor intercomparison experiments are not listed in this table.

Type	Name	Duration [min]	Reference Sensors	Test Sensor
Chamber	Pressure	90	LI-840A	K30_11, K30_12
	Temperature 1	300	LI-840A, LI-820	K30_13, K30_14 K30_21, K30_22 K30_31, K30_32
	Temperature 2	300	LI-840A, LI-820	K30_21, K30_22 K30_31, K30_32
	Rel. humidity 1	90	LI-840A, LI-820	K30_13, K30_14 K30_21, K30_22 K30_31, K30_32
	Rel. humidity 2	90	LI-840A, LI-820	K30_21, K30_22 K30_31, K30_32
	Bench	Pressure Correction (Learn 1)		LI-840A
Pressure Correction (Learn 2)			LI-840A	K30_21, K30_22
Pressure Correction (Test 1)			LI-840A	K30_21, K30_22
Pressure Correction (Test 1)			LI-840A	K30_21, K30_22
Pressure Time-response (Learn 1)			LI-840A	K30_21, K30_22
Pressure Time-response Learn 2			LI-840A	K30_21, K30_22
Pressure Time-response Test 1			LI-840A	K30_21, K30_22
Pressure Time-response Test 2			LI-840A	K30_21, K30_22
Temp. and RH 1			LI-840A	K30_21, K30_22
Temp. and RH 2			LI-840A	K30_13, K30_14 K30_21, K30_22 K30_31, K30_32
Temp. and RH 3			LI-840A	K30_13, K30_14 K30_31, K30_32
Temp. and RH 4			LI-840A	K30_13, K30_14 K30_21, K30_22

Sensor Intercomparison

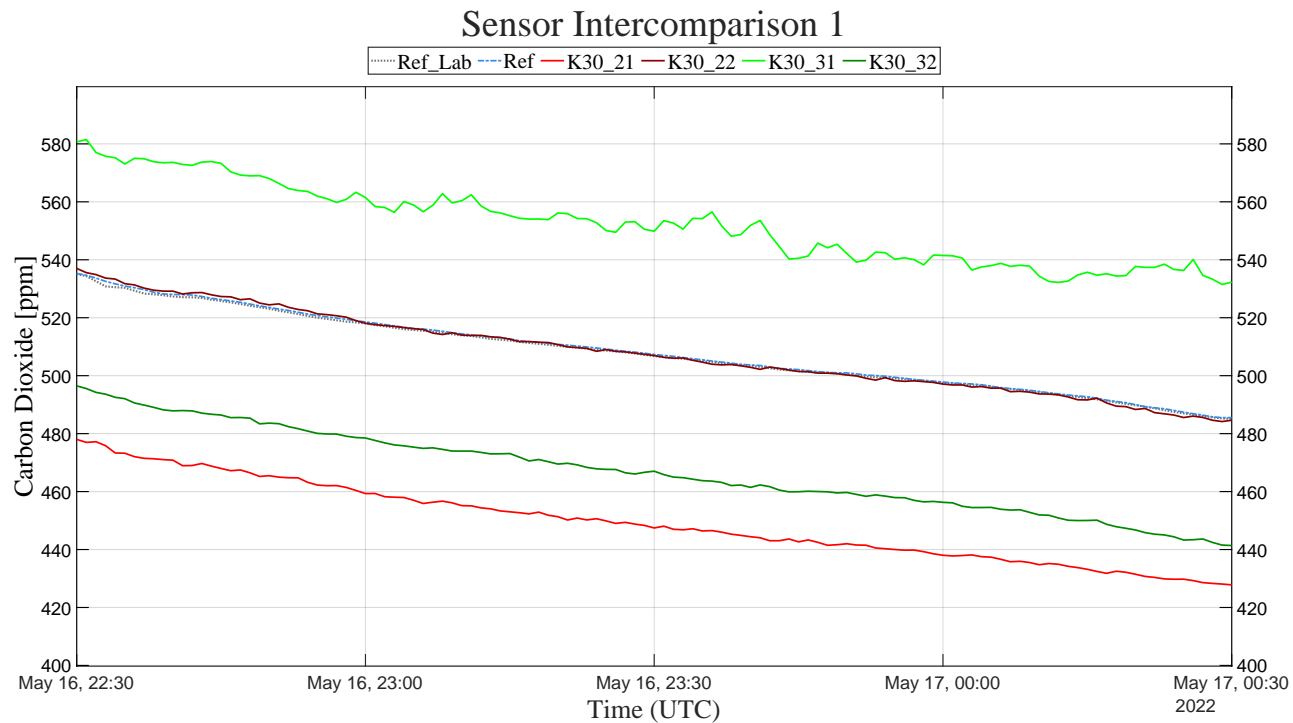


Figure S4. Time series for the sensor intercomparison. Reference and test sensors were left running inside an empty laboratory for 2 hours.

Variables During Sensor Intercomparison 1

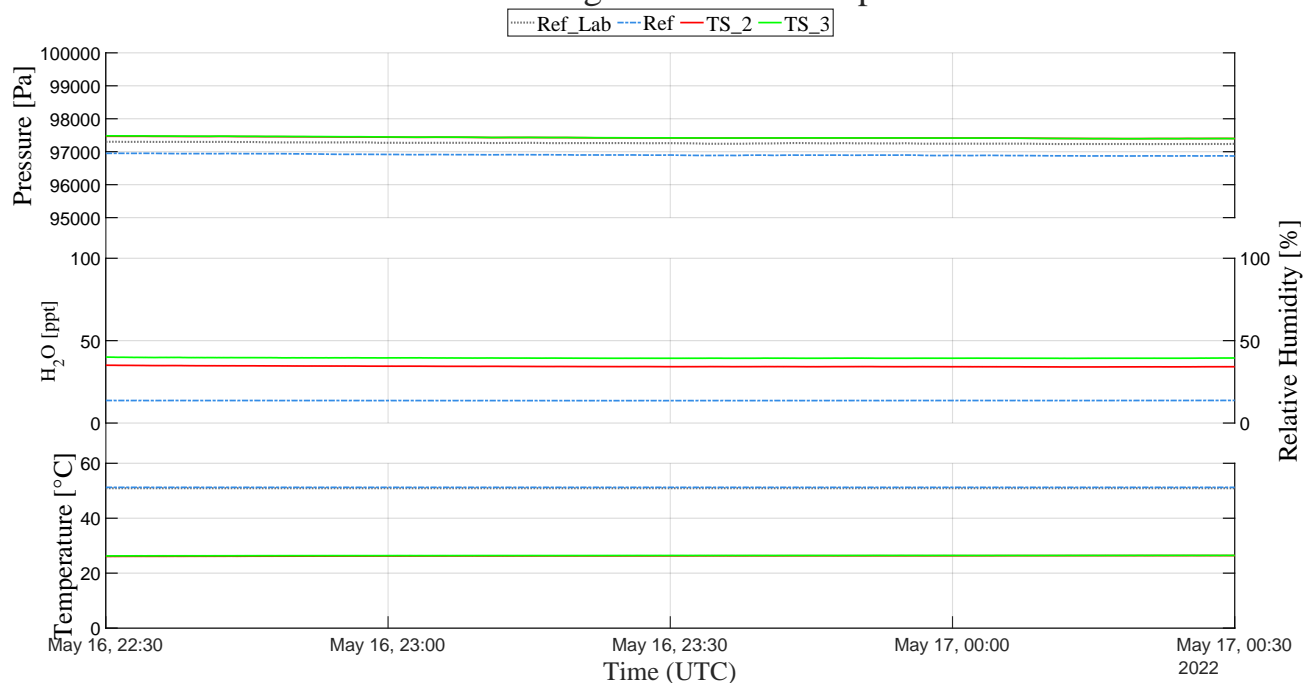


Figure S5. Environmental conditions during the 2-hour sensor intercomparison.

Table S6. Metrics for the experimental conditions for the 2-hour sensor intercomparison.

Variable	Sensor	Minimum	Maximum	Average	Standard deviation
Pressure [Pa]	Ref_Lab	97231	97303.17	97261.5	20.98
	Ref	96870	96952.17	96903.78	23.91
	TS_2	97397.18	97468.89	97427.32	20.84
	TS_3	97394.98	97481.88	97430.21	25.17
Temperature [°C]	Ref_Lab	50.91	50.91	50.91	0
	Ref	51.2	51.28	51.23	0.01
	TS_2	26.09	26.39	26.28	0.08
	TS_3	26.27	26.47	26.41	0.05
H ₂ O [ppt]	Ref	13.57	13.75	13.65	0.03
Relative Humidity [%]	TS_2	34.05	35.07	34.35	0.26
	TS_3	39.27	40	39.45	0.16

Sensor Intercomparison 2

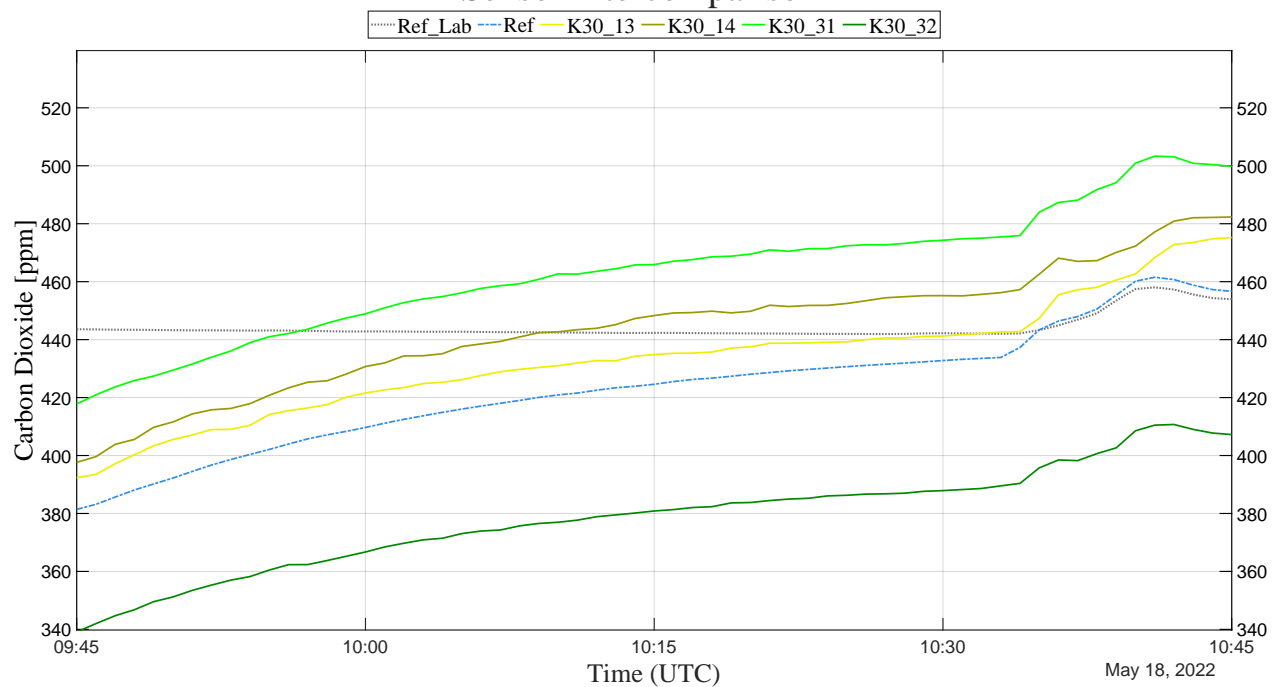


Figure S7. Time series for sensor intercomparison. Reference and test sensors were left running inside an empty laboratory for 30 minutes after the second run of the chambered relative humidity experiments.

Variables During Sensor Intercomparison 2

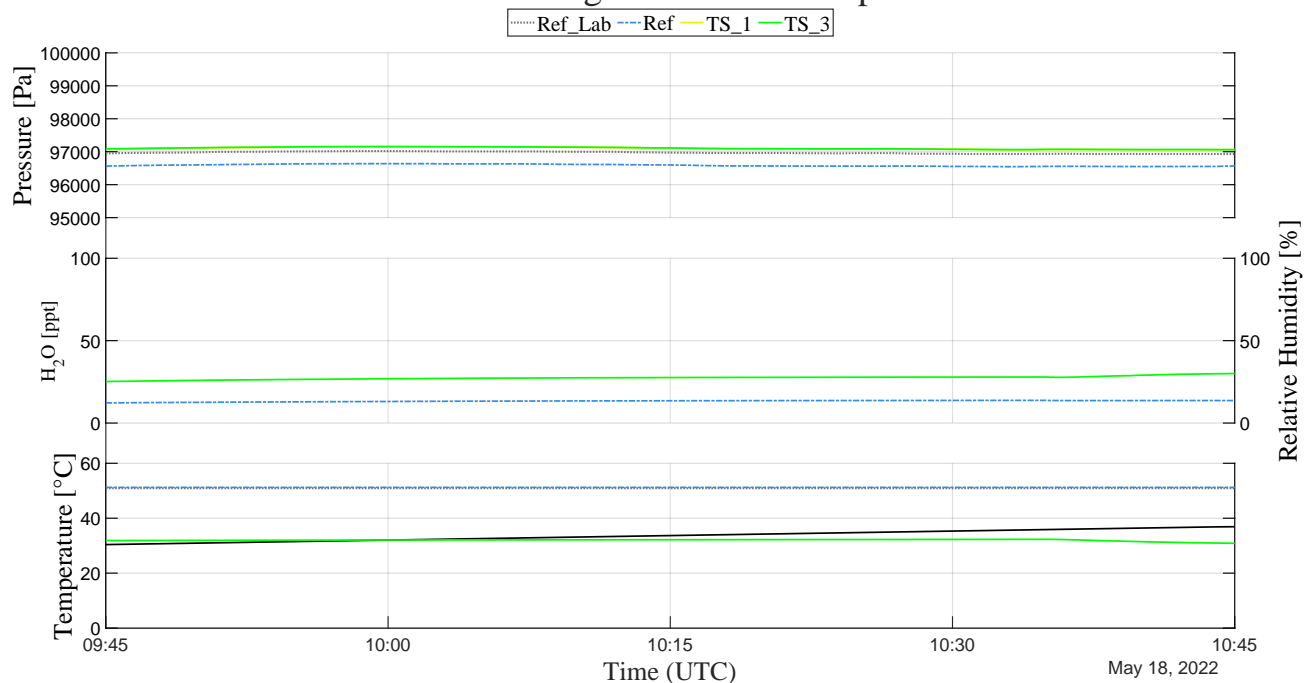


Figure S8. Environmental conditions during the 30-minute sensor intercomparison.

Table S9. Metrics for the experimental conditions for the 30-minute sensor intercomparison.

Variable	Sensor	Minimum	Maximum	Average	Standard deviation
Pressure [Pa]	Ref_Lab	96928.33	97019.33	96970.4	32.21
	Ref	96545.5	96637.83	96588.75	32.51
	TS_1	97059.56	97151.18	97102.62	32.37
	TS_3	97061.45	97157.06	97107.03	33.65
Temperature [°C]	Ref_Lab	50.91	50.91	50.91	0
	Ref	51.23	51.23	51.23	0
	TS_3	30.86	32.31	32	0.34
H ₂ O [ppt]	Ref	12.22	13.81	13.34	0.42
Relative Humidity [%]	TS_3	25.27	30.09	27.5	1.06

Chamber: Pressure

Table S10. Metrics for the experimental conditions for the chambered pressure experiment, where Ref stands for Reference sensor and TS_1 for Test System 1 (one HYT-271 and two K-30 sensors).

Variable	Sensor	Minimum	Maximum	Average	Standard deviation
Pressure [Pa]	Chamber	60,165.59	105,001.76	-	-
	Ref	98,512.17	98,561.50	98,539.36	12.78
Temperature [°C]	Chamber	25.17	25.41	25.36	0.08
	TS_1	26.78	26.95	26.87	0.03
H ₂ O [ppt]	Ref	2.81	3.13	2.96	0.06
Relative Humidity [%]	TS_1	43.00	47.09	45.64	0.98
CO ₂ [ppm]	Ref	453.04	468.00	461.68	2.55

Chamber: Temperature

Table S11. Metrics for the experimental conditions during the chambered temperature experiment.

Variable	Sensor	Minimum	Maximum	Average	Standard deviation
Pressure [Pa]	Ref_Lab	96,749.67	97,170	96,886.62	133.11
	Ref	96,373.33	96,800	96,517.16	131
	TS_1	96,896.69	97,323.5	97,033.84	136
	TS_2	96,911.51	97,341.7	97,050.26	135.05
	TS_3	96,898.3	97,324.74	97,033.77	134.65
Temperature [°C]	Chamber	10.47	40.98	-	-
	TS_2	12.1	44.21	-	-
	TS_3	13.07	45.19	-	-
Relative Humidity [%]	Chamber	43.78	49.27	45.56	1.05
	TS_2	31.38	37.21	33.76	1.3
	TS_3	34.4	41.01	36.91	1.51
CO ₂ [ppm]	Ref_Lab	454.17	483.68	467.22	8.39
	Ref	469.12	485.66	474.65	4.02
	K30_13	471.93	503.9	-	-
	K30_14	470.69	502.78	-	-
	K30_21	471.01	517.61	-	-
	K30_22	464.32	510.3	-	-
	K30_31	464.91	487.22	-	-
K30_32	471.12	510.14	-	-	

Chamber Temperature Experiment

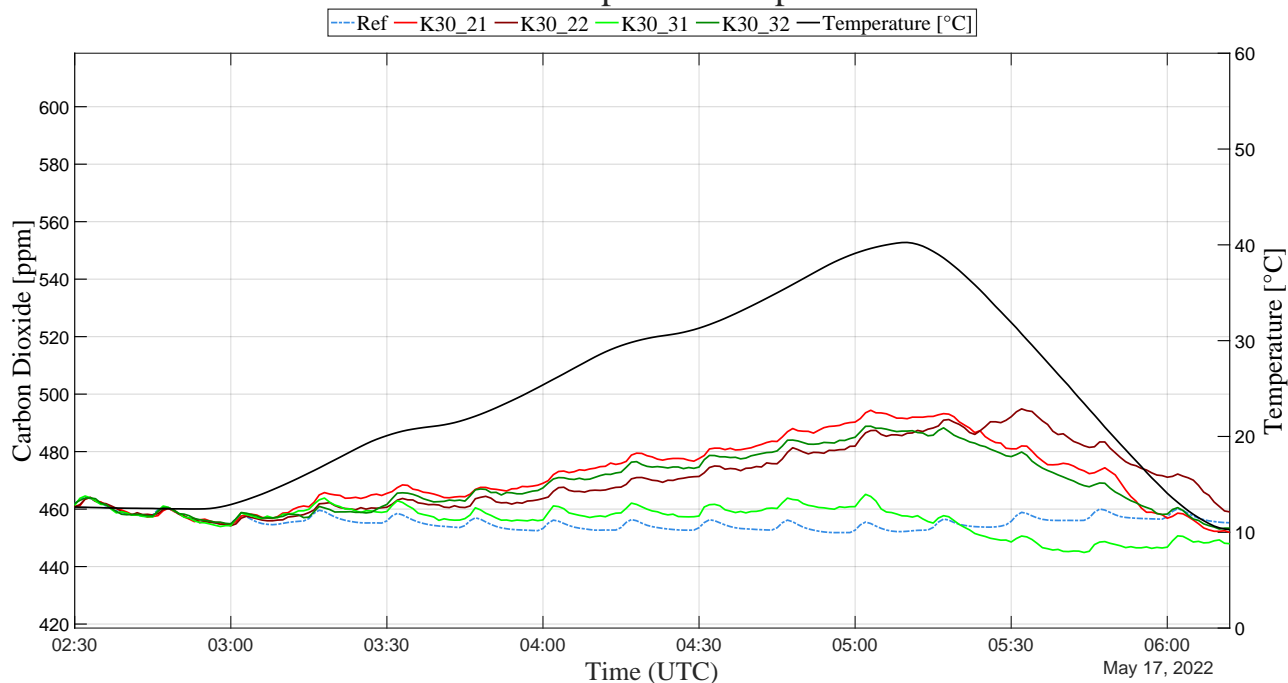


Figure S12. Original data for the test run of the temperature correction coefficients. CO₂ values after corrections with coefficients from the “Learn” run.

Table S13. Metrics for the experimental conditions during the test run of the temperature correction coefficients.

Variable	Sensor	Minimum	Maximum	Average	Standard deviation
Pressure [Pa]	Ref_Lab	97223.67	97393.17	97304.15	46.87
	Ref	96862	97029	96944.27	43.98
	TS_2	97386.73	97563.75	97470.78	48.25
	TS_3	97386.54	97562.07	97468.35	47.65
Temperature [°C]	Chamber	10.28	40.25	-	-
	TS_2	15.26	41.88	-	-
	TS_3	15.74	42.54	-	-
Relative Humidity [%]	Chamber	43.48	47.81	45.17	1.23
	TS_2	25.87	38.39	34.16	4.01
	TS_3	30.68	42.32	38.3	3.65
CO ₂ [ppm]	Ref_Lab	448.14	462.11	452.29	3.69
	Ref	451.82	464.22	455.54	2.46
	K30_21	451.87	494.38	-	-
	K30_22	454.2	494.87	-	-
	K30_31	444.91	465.14	-	-
	K30_32	453.06	488.83	-	-

Chamber Temperature Experiment (Corrected)

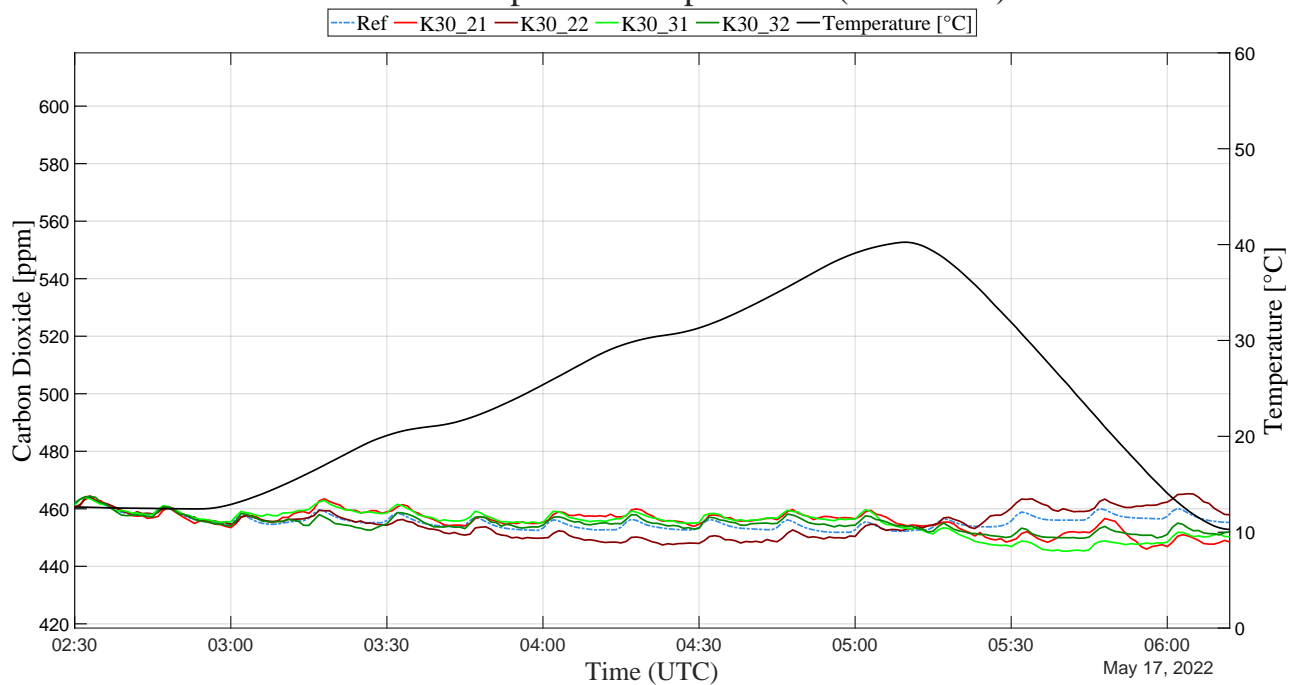


Figure S14. Results for the test run of the temperature correction coefficients. CO₂ values after corrections with coefficients from “Learn” run.

Chamber: Relative Humidity

Table S15. Metrics for the experimental conditions during the chambered relative humidity experiment.

Variable	Sensor	Minimum	Maximum	Average	Standard deviation
Pressure [Pa]	Ref_Lab	96,665.17	97,010	96,782.7	97.64
	Ref	96,288.08	96,640	96,408.73	98.57
	TS_1	96,810.75	97,145.8	96,919.33	93.65
	TS_2	96,828.37	96,949.96	96,901.46	40.26
	TS_3	96,809.64	97,152.3	96,927.45	96.1
Temperature [°C]	Chamber	25.88	27.45	27.07	0.33
	TS_2	28.66	30.29	29.97	0.43
	TS_3	29.78	31.18	30.94	0.33
Relative Humidity [%]	Chamber	15.1	85.4	-	-
	TS_2	11.67	61.75	-	-
	TS_3	12.15	68.8	-	-
CO ₂ [ppm]	Ref_Lab	444.38	449.42	446.5	1.43
	Ref	443.8	452.83	447.85	2.33
	K30_13	449	461.25	-	-
	K30_14	448.3	466.06	-	-
	K30_21	449.03	460.13	-	-
	K30_22	448.9	462.86	-	-
	K30_31	448.2	461.68	-	-
	K30_32	448.94	459.06	-	-

Variables During Chamber Rel. Humidity Experiment

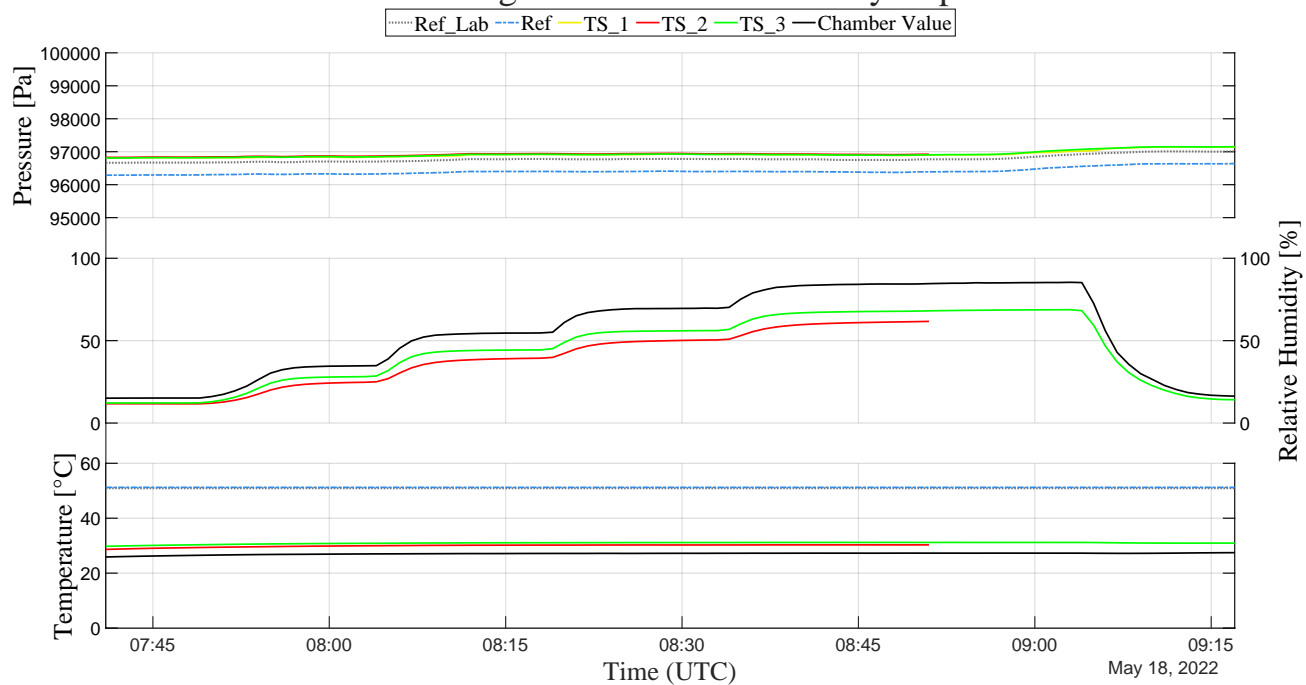


Figure S16. Time-series data for the experimental conditions during the test run of the relative humidity correction coefficients. The solid black curve represents the relative humidity inside the chamber. The yellow, green, and red curves represent the variables for test systems 1, 2, and 3. The dashed blue curve represents the variables for the reference sensor.

Chamber Rel. Humidity Experiment (Corrected)

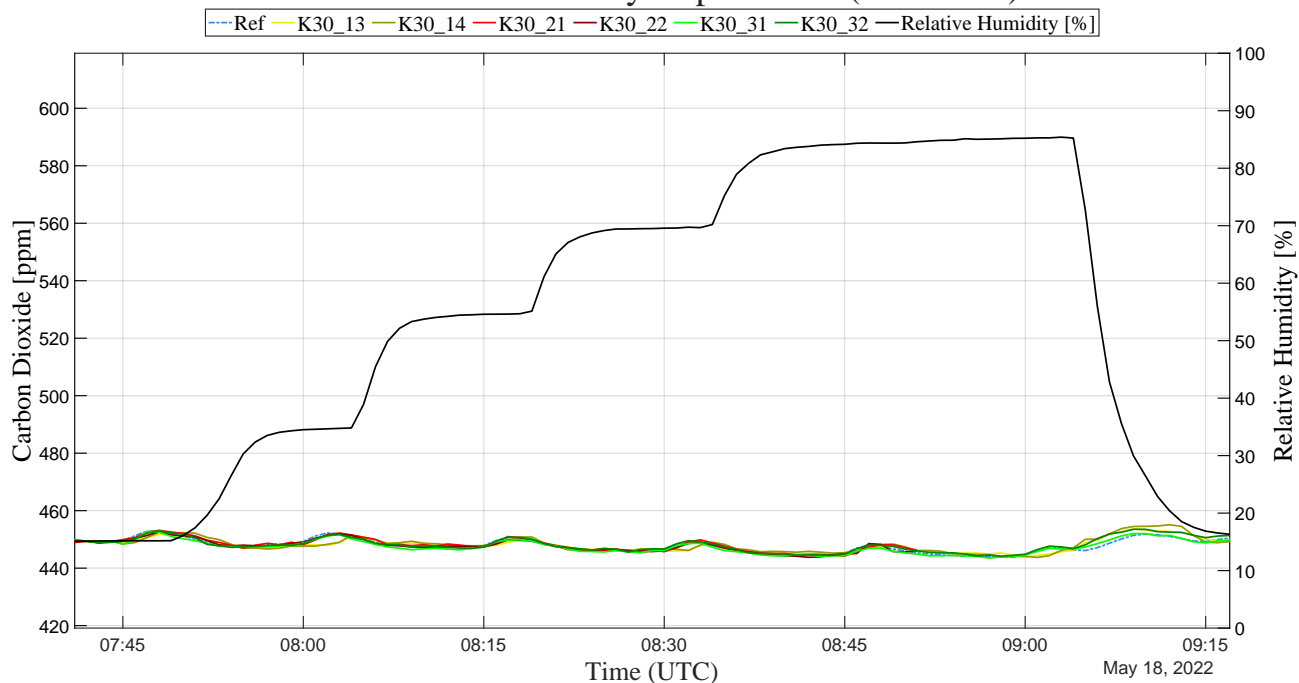


Figure S17. Results for the test run of the relative humidity correction coefficients. CO₂ values after corrections with coefficients from the “Learn” run.

Chamber: Joint Correction

Table S18. Coefficients from the joint correction method for temperature and relative humidity.

Sensor	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	R^2
K30_21	-0.0008	-0.0026	0.0381	-0.0050	0.0027	0.8186	-0.0035	-0.0585	-0.3789	-44.635	0.9869
K30_22	-0.0012	-0.0107	0.0027	-0.0067	0.1319	1.8161	-0.0062	-0.0901	0.2411	4.6896	0.9855

Pressure Time Response Correction Test Case 2

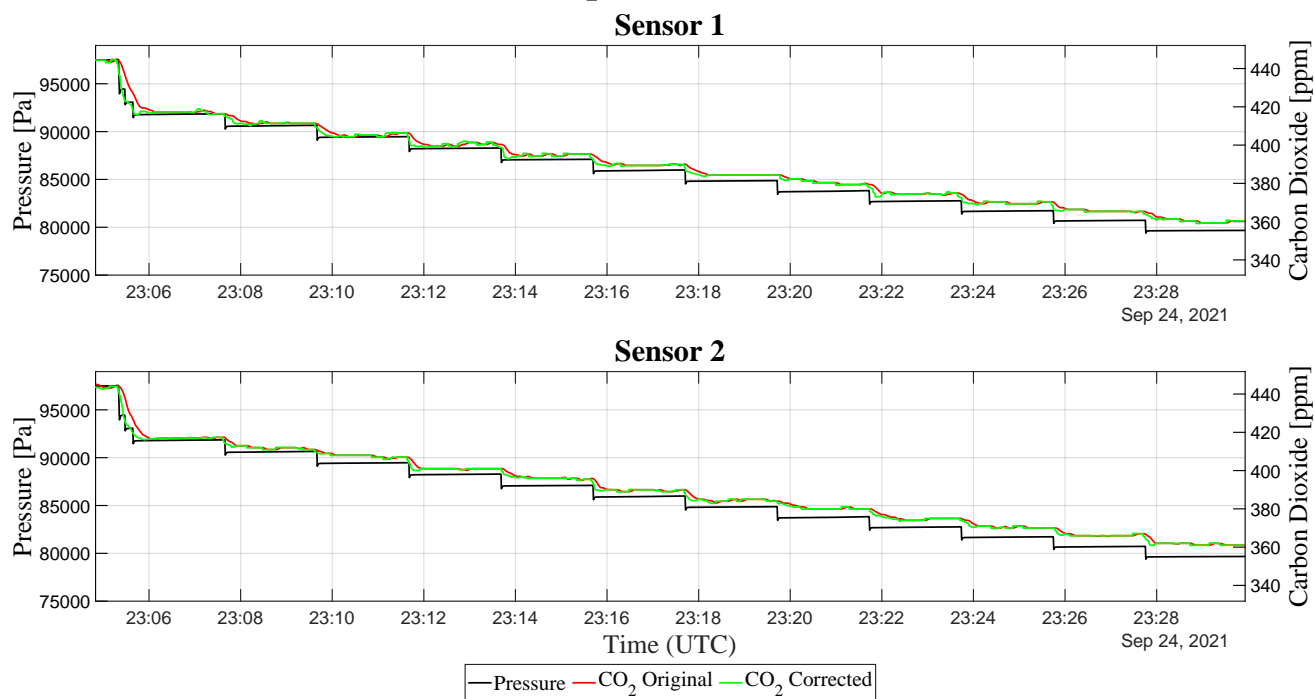


Figure S19. Second test case for the pressure time response correction.

Workbench Experiment 1

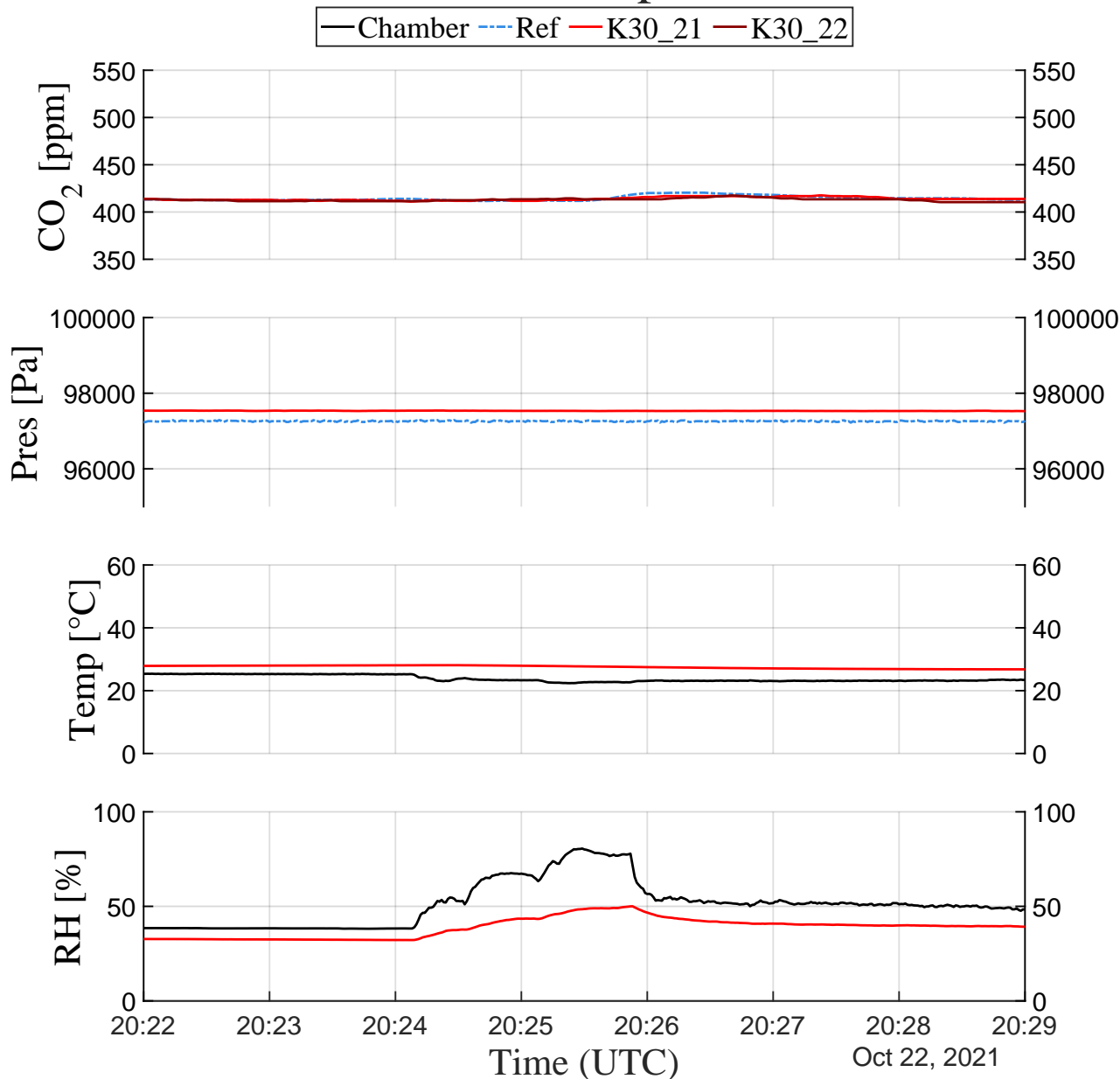


Figure S20. Results for the first Benchtop experimental setup (a.k.a. large plastic container). In this case, the water spray was used to increase the humidity of the container.

Workbench Experiment 2

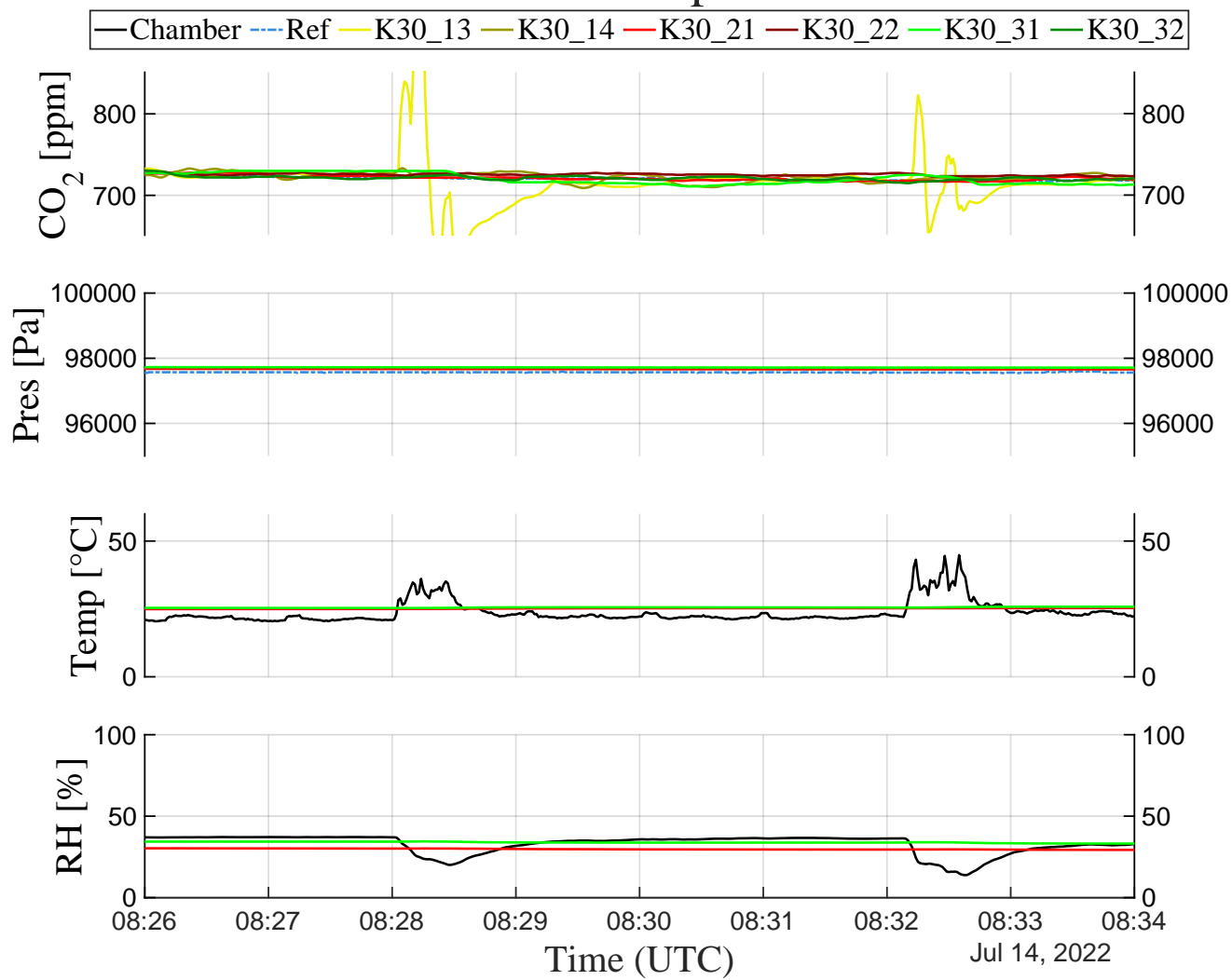


Figure S21. Results for the second Benchtop experimental setup (a.k.a. directly exposed to electric heater).