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A measurement system for CO_2 and CH_4 emissions quantification of industrial sites using a new in situ concentration sensor operated on board uncrewed aircraft vehicles

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Test ID	Real flow (g/s)	All tests average		By test					
		Quantified flow		Quantified flow		$\overline{WS}_{1.5m}$ ± $\sigma_{WS_{1.5m}}$ (m/s)	$\sigma_{WD_{1.5m}}$ (°)	Median $\sigma_{CH_4,1s}$ (ppb)	CH_4 signal/ noise
		Flow (g/s)	Relative error (%)	Flow (g/s)	Relative error (%)				
2019W40-01	**9.5**	**10.6**	**12%**	11.6	22%	**1.8** ± 0.9	18.74	61.40	4767
				9.7	2%	**1.6** ± 0.5	15.58	55.87	5321
2019W40-05	**30.0**	**21.4**	-29%	24.7	-18%	3.0 ± 0.6	12.44	68.99	4278
				18.2	-39%	3.5 ± 1.1	11.55	61.71	4694
2019W40-02	**1.0**	**0.9**	**-6%**	0.9	-6%	3.1 ± 1.0	23.32	84.89	298
2019W40-06BIS	**3.0**	**5.5**	85%	5.5	85%	**0.8** ± 0.2	28.32	38.57	5983
2019W40-08	**5.0**	**2.6**	-48%	*1.9*	-61%	**0.6** ± 0.3	**40.25**	74.45	1104
				3.3	-35%	2.3 ± 0.5	12.36	48.57	1277
2019W40-16B	**1.5**	**0.7**	-54%	0.7	-54%	**1.2** ± 0.5	**39.65**	72.30	1321
2019W40-07	**0.5**	**0.4**	**-14%**	0.4	-14%	**1.7** ± 0.5	18.77	54.99	271
2019W40-13	**0.2**	**0.1**	-21%	0.1	-21%	2.6 ± 1.1	25.33	84.71	162
2019W40-14	**1.0**	**2.2**	125%	2.2	125%	**0.7** ± 0.4	27.46	46.67	4043
2019W40-16AB	**1.5**	**0.9**	-38%	0.9	-38%	**0.5** ± 0.1	9.34	295.97	125
2019W40-17	**2.0**	**1.2**	-40%	1.2	-40%	2.3 ± 0.5	17.91	150.61	139
2019W41-01	**2.0**	**1.5**	-24%	1.5	-24%	**2.0** ± 0.5	12.38	123.09	1206
2019W41-02	**4.0**	**1.7**	-58%	1.7	-58%	**1.2** ± 0.4	17.73	82.60	3521
2019W41-05AB	**6.0**	**1.9**	-69%	*1.5*	-75%	**1.7** ± 0.6	**40.44**	112.78	386
				2.3	-62%	**0.6** ± 0.2	**93.52**	85.76	3400
2019W41-06	**1.0**	**0.7**	-30%	0.7	-30%	**0.7** ± 0.4	**61.36**	92.08	1916
2019W41-07	**1.0**	**0.7**	-32%	*0.6*	-38%	**0.7** ± 0.4	**41.23**	78.75	3314
				0.8	-24%	**0.7** ± 0.4	**41.44**	76.62	1704
				0.7	-35%	**0.5** ± 0.2	**62.19**	80.41	1811
2019W41-08	**2.0**	**1.1**	-45%	1.5	-24%	**1.3** ± 0.2	12.50	130.63	868
				0.7	-67%	**1.3** ± 0.3	9.72	70.89	559
2019W41-SAT	**150.0**	**68.4**	-54%	*66.4*	-56%	**0.5** ± 0.2	28.00	223.15	1353
				70.4	-53%	**0.6** ± 0.2	**51.74**	176.45	1711
2019W41-11AB	**1.0**	**0.9**	**-5%**	0.8	-16%	2.6 ± 0.8	22.75	189.66	270
				1.1	6%	2.5 ± 0.7	21.35	200.13	510
2019W41-13	**5.0**	**8.3**	66%	10.3	107%	2.9 ± 0.8	16.02	204.12	1178
				6.3	25%	3.0 ± 0.8	13.91	183.51	1086
2019W41-12	**0.4**	**0.3**	-29%	0.3	-29%	2.8 ± 0.7	21.42	159.50	50
2019W41-09	**0.5**	**0.8**	54%	*0.7*	48%	2.9 ± 0.8	15.74	156.14	355
				0.8	60%	2.9 ± 0.7	19.34	182.26	318
2019W41-16	**0.6**	**0.6**	**4%**	*0.4*	-34%	**0.4** ± 0.1	**72.95**	191.83	193
				0.8	41%	**0.9** ± 0.4	**68.96**	174.91	284
2019W41-17	**1.0**	**1.6**	60%	*1.4*	36%	**1.0** ± 0.6	**69.14**	241.00	358
				1.8	83%	**0.8** ± 0.4	**58.80**	163.19	489
2019W41-18	**2.0**	**3.9**	93%	3.9	93%	**1.2** ± 0.6	27.64	216.54	1281
2019W41-23AB	**3.0**	**4.5**	48%	*2.9*	-2%	**2.0** ± 0.7	12.16	260.45	678
				6.0	99%	**1.1** ± 0.4	23.08	256.14	1110

Table S1. Known true values and estimates by our quantification method of CH_4 emissions flow rates for all successful quantification flights, for the TADI 2019 campaign, mean wind speed at 1.5m altitude, relative standard deviation of the wind at 1.5m, median value of the 1s rolling standard deviation of CH_4 (ppb) and ratio of the 1s rolling standard deviation and of the amplitude of variation of CH_4 (%). For the averaged values of all tests, relative errors between estimates and known true values are presented in (%), with values between -20 % and +20 % in bold characters, values between -50 % and +100 % in italics and values outside these ranges underlined. Mean wind speed at 1.5m values below 2.3 m/s and standard deviations of wind direction above 33.1° are presented in bold characters.

Test ID	Real flow (g/s)	All tests average		By test					
		Quantified flow		Quantified flow		$\overline{WS}_{1.5m}$ ± $\sigma_{WS_{1.5m}}$ (m/s)	$\sigma_{WD_{1.5m}}$ (°)	Median $\sigma_{CH_4,1s}$ (ppb)	CH_4 signal/ noise
		Flow (g/s)	Relative error (%)	Flow (g/s)	Relative error (%)				
2021W36/07-4	**0.1**	**0.10**	**-3%**	*0.088*	-12%	**1.9** ± 0.4	27.42	23.47	239
				0.115	15%	**2.2** ± 0.4	21.61	22.34	147
				0.088	-12%	2.4 ± 0.4	11.13	18.40	488
2021W36/08-5	**0.2**	**0.31**	57%	0.473	137%	**0.9** ± 0.4	**54.87**	32.45	605
				0.251	25%	**1.0** ± 0.4	23.02	29.76	618
				0.218	9%	**0.6** ± 0.2	**67.75**	26.35	561
2021W36/08-6	**0.1**	**0.13**	28%	*0.106*	6%	**0.8** ± 0.4	**42.78**	27.01	242
				0.151	51%	**1.0** ± 0.4	**60.55**	39.12	206
2021W36/08-7	**0.3**	**0.22**	-28%	0.216	-28%	**1.0** ± 0.3	**41.06**	35.99	121
2021W36/08-8	**2.4**	**3.04**	27%	*1.794*	-25%	**1.5** ± 0.6	24.29	29.49	8017
				4.279	78%	**1.5** ± 0.5	**34.62**	28.78	5862
2021W36/08-9	**0.6**	**0.26**	-57%	0.258	-57%	**1.4** ± 0.4	**41.72**	31.52	259
2021W36/08-10	**1.7**	**3.63**	114%	*3.161*	86%	**1.1** ± 0.6	**63.01**	28.73	1937
				4.107	142%	**2.2** ± 0.5	16.09	20.33	2878
2021W36/08-11	**0.25**	**0.30**	21%	0.302	21%	**1.9** ± 0.3	9.97	16.77	550
2021W36/09-12	**0.4**	**0.22**	-46%	0.217	-46%	**0.8** ± 0.1	2.10	33.12	971
2021W36/09-13	**3**	**2.11**	-30%	2.112	-30%	**0.58** ± 0.02	**44.26**	33.29	5851
2021W36/09-14	**0.2**	**0.24**	**19%**	*0.148*	-26%	**1.2** ± 0.2	8.23	41.50	116
				0.263	31%	**1.7** ± 0.1	6.24	24.41	766
				0.285	43%	**1.5** ± 0.2	0.85	21.14	666
				0.260	30%	**1.5** ± 0.1	4.73	31.17	331
2021W36/09-15	**0.08**	**0.20**	149%	0.226	182%	2.6 ± 0.4	3.48	33.22	132
				0.173	117%	2.99 ± 0.02	0.64	16.73	252
2021W36/09-16	**0.075**	**0.09**	**19%**	*0.079*	6%	3.6 ± 0.3	8.93	35.87	132
				0.099	32%	2.71 ± 0.04	5.21	21.22	98
2021W36/09-17	**0.375**	**0.35**	**-8%**	0.372	-1%	3.7 ± 0.2	2.60	40.84	246
				0.322	-14%	3.6 ± 0.1	1.32	20.86	401
2021W36/09-18	**2**	**2.37**	**19%**	*1.367*	-32%	3.0 ± 0.1	3.05	37.37	1387
				2.800	40%	2.9 ± 0.1	0.31	38.02	874
				3.266	63%	3.5 ± 0.2	1.87	35.99	1444
				2.052	3%	3.0 ± 0.1	1.27	18.30	1214
2021W36/09-19	**0.01**	**0.017**	70%	0.021	111%	2.5 ± 0.1	3.82	38.03	148
				0.007	-30%	2.71 ± 0.02	1.18	20.31	38
				0.023	130%	2.8 ± 0.1	1.79	28.33	64
2021W36/09-20	**5**	**4.75**	**-5%**	4.755	-5%	2.1 ± 0.1	6.99	46.36	5360
2021W36/10-21	**0.3**	**0.38**	26%	*0.138*	-54%	**0.8** ± 0.3	23.42	40.76	1022
				0.289	-4%	**0.7** ± 0.3	26.06	30.07	589
				0.569	90%	**0.6** ± 0.3	**35.03**	31.53	999
				0.514	71%	**0.6** ± 0.2	**37.34**	53.24	265
2021W36/10-22	**0.6**	**0.57**	**-5%**	*0.461*	-23%	**1.3** ± 0.3	9.53	25.12	884
				0.677	13%	**2.1** ± 0.4	9.31	28.69	479

Table S2. Same as Table S2 for the results of the 2021 TADI campaign

Platform	Run ID	Duration (min)	Distance to platform (m)	Quantification (Y/N)		WS at drone elevation ($m.s^{-1}$)		WD at drone elevation (°)	Signal/noise	
				CH_4	CO_2	Mean	Stdev.	Stdev.	CH_4	CO_2
P1	**1_P1**	11	450	N	N	9.3	3.1	8.5	697	86
P1	**2_P1**	10	450	Y	Y	9.3	2.8	7.9	**103**	**66**
P1	**3_P1**	19	450	Y	Y	10.1	2.2	6.7	**78**	**92**
P1	**4_P1**	17	130	Y	Y	10.4	1.7	5.2	**2468**	**523**
P1	**5_P1**	11	160	Y	Y	9.2	1.5	4.2	**1625**	**398**
P1	**6_P1**	11	150	Y	Y	8.6	1.4	4.3	**1970**	**454**
P1	**7_P1**	12	160	Y	Y	7.4	3.0	10.0	**1413**	**328**
P1	**8_P1**	10	160	Y	Y	8.4	1.7	6.9	**1204**	**303**
P2	**1_P2**	10	420	N	N	9.2	2.7	9.2	186	132
P2	**2_P2**	16	420	Y	N	9.9	1.9	4.9	**265**	165
P2	**3_P2**	18	420	Y	N	9.1	2.6	7.2	**1049**	83
P2	**4_P2**	16	420	Y	Y	10.4	2.3	9.0	**4337**	**93**
P2	**5_P2**	10	260	Y	Y	10.5	2.7	10.0	**437**	**84**
P2	**6_P2**	11	350	Y	Y	9.7	4.0	14.4	**1047**	**106**
P2	**7_P2**	10	350	y	Y	10.6	2.9	10.0	**336**	**117**

Table S3. List of all flights operated during on 19 April 2019 for the monitoring of the P1 and P2 platforms emissions, with duration of the flight. approximate distance between the flight plane and the platform, validity for the CH_4 or CO_2 emissions quantification (Y if valid. N if not valid), average and standard deviation of the wind speed at UAV elevation ($m.s^{-1}$), standard deviation of the wind direction at UAV elevation (°), signal to noise ratio of the CH_4 and CO_2 concentrations (bold characters for the flights were the emissions quantification have been used calculated for each species).

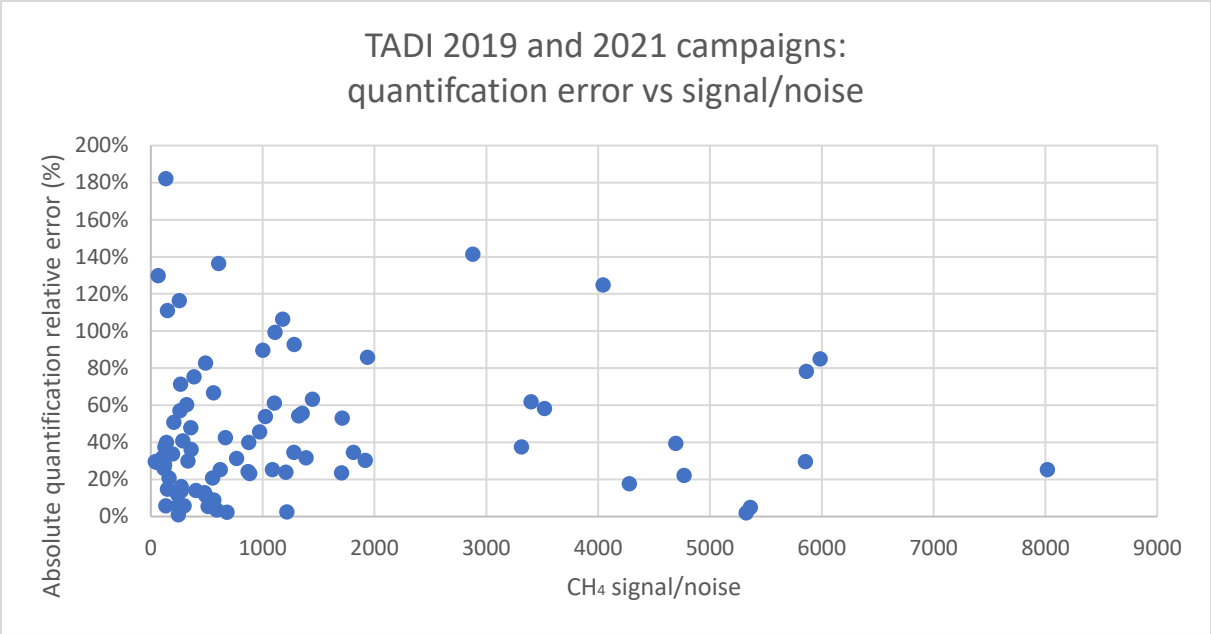

Figure S1. Absolute values of the relative errors of quantification (%) as a function of the CH4 signal to noise ratio, for all individual flight of the TADI 2019 and TADI 2021 campaigns.

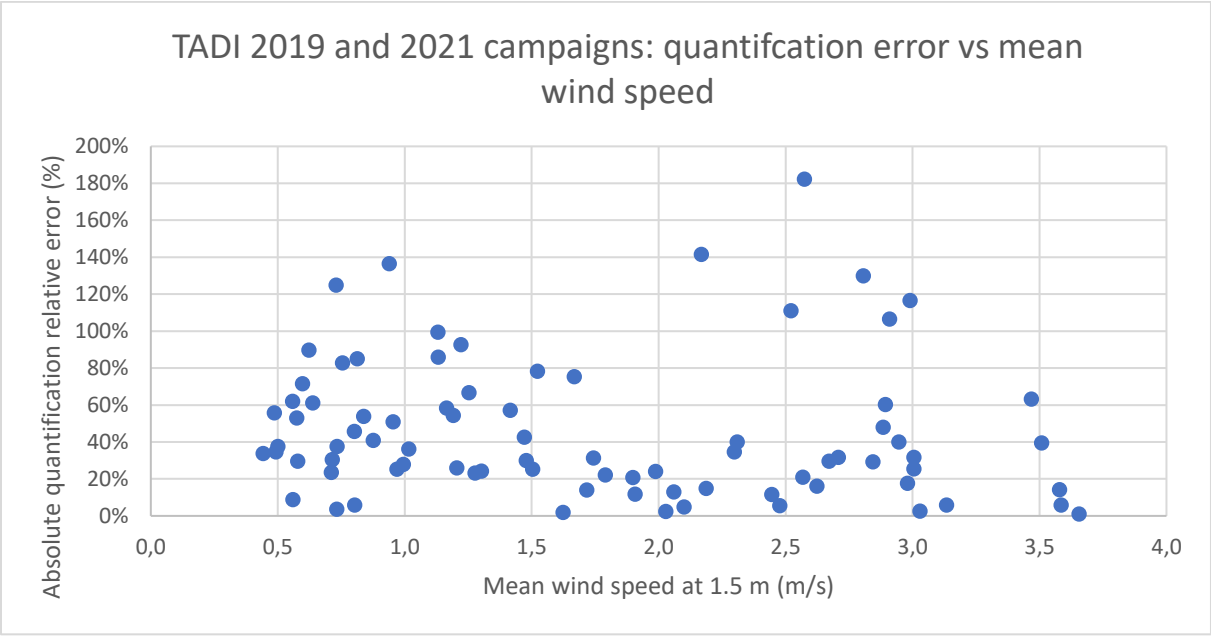

Figure S2. Same as Figure S1 but for absolute values of the relative errors of quantification (%) as a function of the mean wind speed ($m.s^{-1}$).

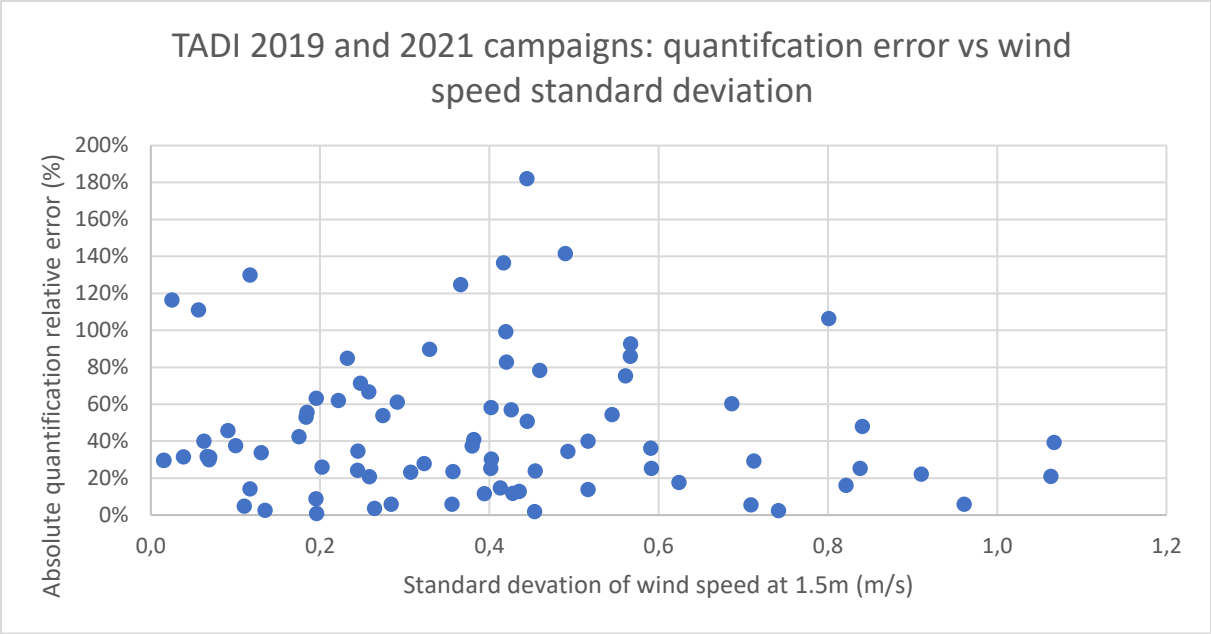

Figure S3. Same as Figure S1 but for absolute values of the relative errors of quantification (%) as a function of the standard deviation of the wind speed ($m.s^{-1}$).

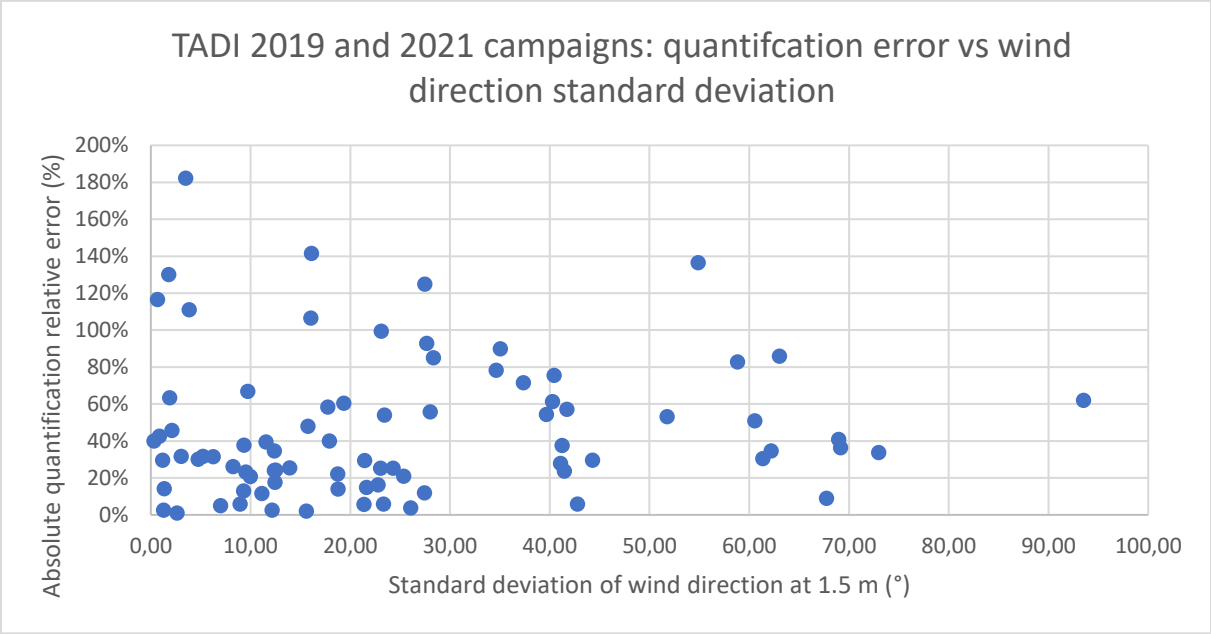

Figure S4. Same as Figure S1 but for absolute values of the relative errors of quantification (%) as a function of the standard deviation of the wind direction (°).