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Atmospheric Measurement Techniques Discussions

Interactive comment on "A multi-purpose, multi-rotor drone system for long range and high-altitude volcanic gas plume measurements" *by* Bo Galle et al.

Anonymous Referee #2

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The manuscript presents a multi-rotor aerial drone system equipped with different gas analysing and gas sampling instruments to investigate the composition and flux of volcanic plumes. The drone can reach altitudes of 2.000 m above take-off level, and ranges in the order of 5 km; these are quite remarkable specifications for a vertical take-off and landing drone with a payload mass of up to 2 kg and a take-off weight of max. 6 kg. During a field campaign in May 2019, the plume of Manam volcano in Papua New Guinea has been comprehensively characterized by measuring the in-situ concentrations of SO2, CO2, and H2S in the plume, calculating the total SO2 emission rate by taking into account the determined plume speed data, and by taking gas samples from the volcanic plume with post-flight analysis on the ground for halogens

and carbon isotopes. The data obtained with the drone system have been compared with additional data from ground-based and aerial measurements as well as with atmospheric model calculations and are - as far as such additional data were available - in good agreement. Similar volcanic plume measurements by using multi-rotor drones have already been published, see inter alia the cited references Stix et al. (2018) and de Moor et al. (2019). In the present manuscript, the special aspect is the versatility and modularity of the multi-rotor drone system used. The promising applications of vertical take-off and landing drones in the field of volcano research and monitoring are illustrated.

Page 1, line 22: Instead of "...multi-copter drone..." it seems more appropriate to use the term "...multicopter drone..." or – as in the title of the manuscript – "...multi-rotor drone...".

Page 2, line 56: Instead of "...Mori (2016)..." it should read "...Mori et al. (2016)...". Instead of "...multi-rotor..." it seems more appropriate to use the term "...multi-rotor drone..." consistently – also in several other sections.

Page 4, line 150: At first glance, the presented finding that a balance of "rise and forward motion" is more favourable in terms of energy consumption than "moving only in one direction at a time" seems to be obvious. But possibly a rule for the optimal balance between "rise and forward motion" in terms of minimum energy consumption has been identified. If applicable, this should be specified.

Page 5, line 179: Instead of "longer propellers" it seems more appropriate to use the term "larger propellers" or "propellers with a larger diameter" – also page 24, line 659

Page 7, line 217 – drone drift method: Even if there is no side wind, a multi-rotor drone drifts slightly in one direction when GPS lock mode is deactivated. Has it been investigated how large this offset is and was this taken into account when measuring the plume speed?

Does the drift speed determined from the GPS data also include a vertical speed component? Or does the drone only drift in a lateral direction and maintain the position in the vertical?

Page 7, line 222 – onboard anemometer: According to Appendix A, an FT205EV anemometer has been applied onboard the drone. Please specify whether this anemometer measures only the horizontal or also the vertical component of the wind speed?

Has it been investigated whether - and if so to what extent - the wind measurement using the anemometer mounted on top of the multi-rotor drone was influenced by the air flow created by the propellers?

In addition to the photo in Fig. 1, it would be useful to have a sketch showing the exact location of the onboard anemometer and in particular its horizontal and vertical distances from the propellers.

Page 8, line 245: Please check "...described in section 2.3.1" since this section does not seem to exist.

Page 11, line 307: The wording ". . .using homemade software. . ." is ambiguous, as it could be understood to mean that the software is developed by a software provider with the name "homemade" (which exists); contrary to that it might be intended to indicate that the software is “self-developed”. Please clarify if necessary.

Page 11, line 316: Instead of “. . .a rapidly fluctuation signal is measured. . .” it should read “. . .a rapidly fluctuating signal is measured. . .”.

Page 11, line 325: The wording “. . .a practical solution is to take a sample of a time-varying signal and then expose the sensors to the sampled gas. . .” is possibly inappropriate. Maybe what is meant is that “a sample of gas is taken” and then the sensors are exposed to this sample of gas. Please consider this and amend the wording correspondingly, if necessary.

Page 11, line 326: It is stated that “Our system fulfills these two criteria: the sensors have similar response characteristics. . .” while on page 12, line 345 it is stated that ”Because our sensors operate according to different principles, the sensor response times are usually different;. . .”. Please clarify whether different sensors are meant in each case.

Page 12, line 359: It is stated that “Such dynamic changes (with frequency components of higher than 0.5 Hz) in plume composition are assumed to be improbable for most typical scenarios”. Are there any published studies or own measurement results on this subject?

Page 15, line 444 – small rotary pump: Some of these small rotary pumps have vanes made of graphite, which can cause carbonaceous abrasion. Has it been investigated whether using such a pump influences the gas composition and isotopic analysis?

Page 18, line 530: Please indicate whether the plume speed measured using the anemometer when “the drone is kept in a fixed position” is the horizontal plume speed component only or the sum of horizontal and vertical plume speed components, i.e. including the buoyance of the plume.

Page 19, line 538: Please indicate whether the plume speed measured using the drone drift method is the horizontal plume speed component only or the sum of horizontal and vertical plume speed components, i.e. including the buoyance of the plume.

Page 20, line 556: Please clarify that the altitude is “1000 m AMSL”.

Page 20, line 561: A reference is missing in the caption of Fig. 10.

Page 22, line 590: A reference is missing in the caption of Fig. 12.

Page 24, line 653: Please correct “. . .of of. . .”.

Page 24, line 655: Please correct “. . .the the. . .”.

Page 25, line 677: The trajectories show remarkably long flight distances in both hor-

izontal and vertical directions, especially considering the relatively small drone size. Please indicate whether the drone was manually controlled only during these flight distances and, if so, whether there was any support for the pilot, for example through onboard cameras.

Was the multi-rotor drone also flown occasionally through a volcanic ash cloud? If so, did this have any negative impact on the measuring instruments or the drone, e.g. wear on the rotor blades of the drone?

Page 26, line 718: Has the cited and listed reference “ARELLANO et al. (2016)” already been published or is it otherwise available online?

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