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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.

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Response to questions and suggestions from Reviewer 2

Reviewer: 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. . .".

Response: Done! Multi-rotor drone is consistently used.

Reviewer: 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.

Response: Done!

Reviewer: 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.

Response: More details on this are given and are illustrated by a graph showing flight-logs for a typical flight (Fig.1.). "When ascending and moving horizontally, it was found that energy consumption could be reduced if the rise and forward motion was balanced in an optimal way, as compared to moving only in one direction at a time. This is because a considerable horizontal component in the movement gives a lift that reduces the energy consumption for maintaining the vertical position. An additional advantage is that the drone then fly in undisturbed air with less turbulence compared to a clean vertical movement."

Reviewer: 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.

Response: Done!

Reviewer: 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 ?

Response: We have not noticed this effect when hoovering at calm conditions and thus has not specifically studied this effect. We only use horizontal wind speed taken from the drone, as wind direction is taken from the MobileDOAS traverse intersection of the

plume, assuming a straight line between the source and the point of maximum gas column.

Reviewer: Does the drift speed determined from the GPS data also include a vertical speed com- ponent? Or does the drone only drift in a lateral direction and maintain the position in the vertical?

Response: The drone keep its altitude and we only use the horizontal component of the wind.

Reviewer: 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 ?

Response: The anemometer only measures horizontal wind.

Reviewer: 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 ?

Response: We have not investigated this, except checking that there is no influence when hoovering at ground.

Reviewer: 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.

Response: We have not included a specific figure for this but instead improved Fig 1 (now Fig 2) to include the location of the anemometer. This new figure is attached here as Fig.2.

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

Response: Changed to section 2.2

Reviewer: 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 .

Response: Changed to “self-developed”

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

Response: Changed to “fluctuating”

Reviewer: 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 inappro- priate. 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 corre- spondingly, if necessary.

Response: Changed as suggested

Reviewer: 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.

Response: The text referred to on page 12 have been changed to “Because sensors often operate. . .” to clarify that this is a general statement as compared to the text on page 11 that refers to our system in specific.

Reviewer: 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 ?

Response: No specific study has been made on this. This sentence is based on personal experiences only.

Reviewer: 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 ?

Response: No, this has not been investigated by us. We have not recognized that this may be an issue. . . ' Reviewer: 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 .

Response: The anemometer measures horizontal wind only, as also the other methods and model. This has been clarified in text and Fig 9 (new Fig 10)

Reviewer: 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.

Response: Only the horizontal components are evaluated in the drift method. In principle it would be possible to also measure the vertical component, but only the horizontal component is used in the emission rate measurements.

Reviewer: 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 . . .".

Response: All these remarks are recognized and corrected.

Reviewer: Page 25, line 677: The trajectories show remarkably long flight distances in both horizontal 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.

Response: Yes, we agree that the long flight distances are remarkable. This, and the operability demonstrated, are some of the main justifications of this paper. All flights were manually operated and about one third of the flights were assisted by an on-board camera. The camera was mainly used to make it possible to avoid clouds and helped the pilot to keep track of the flight parameters (goggles). More on this is included on page 7. " Camera: During the later part of the campaign at Manam it was found to be useful to include a camera running in FPV (First Person View) mode. The main reason for this was that it facilitated the avoidance of clouds and thereby reduced energy consumption. It also improved the maneauverability as it gave the pilot access to critical parameters in real time within his view (goggles)."

Reviewer: 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 ?

Response: The drone was flown through volcanic clouds. Its unclear how much ash they contained. No wear on the hardware was noticed at site. However, a couple of months after return home, severe wear on the motors due to acidity, was noticed. To play safe the motors were replaced.

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

Response: The reference is a report from a field campaign in 2016, which is free to access through this link: https://research.chalmers.se/publication/254380. However, there is probably not enough detail in this report to fully implement the method. To simplify this, we have shared the essential steps of the code in the Appendix.

Please also note the supplement to this comment:
https://amt.copernicus.org/preprints/amt-2020-452/amt-2020-452-AC2-supplement.pdf

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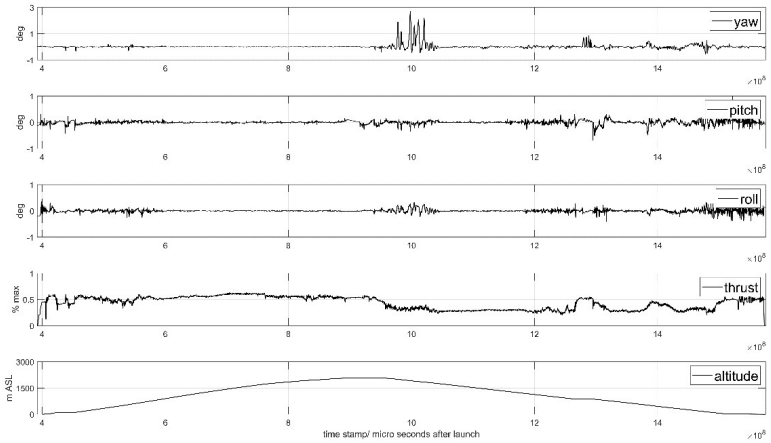

Fig. 1. New Fig.1 showing an example of drone flight log

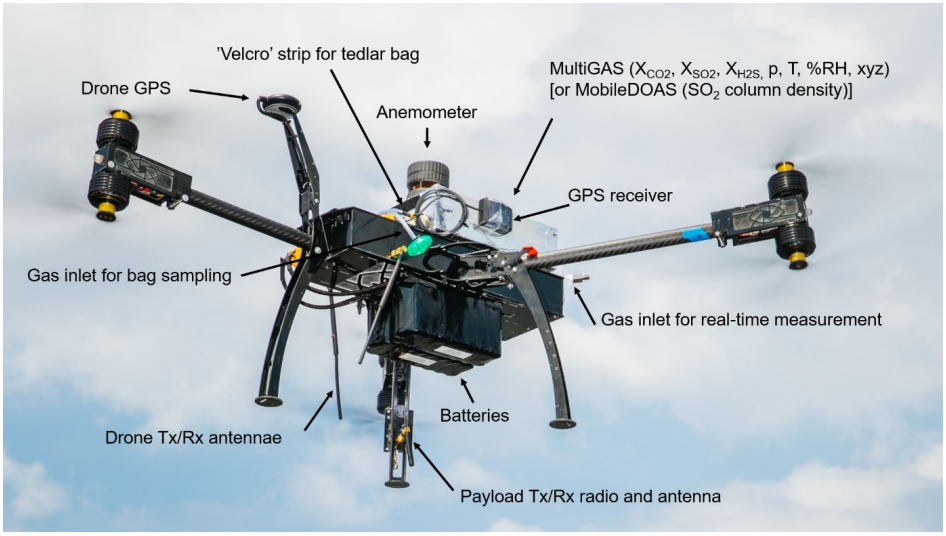

Fig. 2. This is the new Fig.2., replacing the earlier Fig.1.

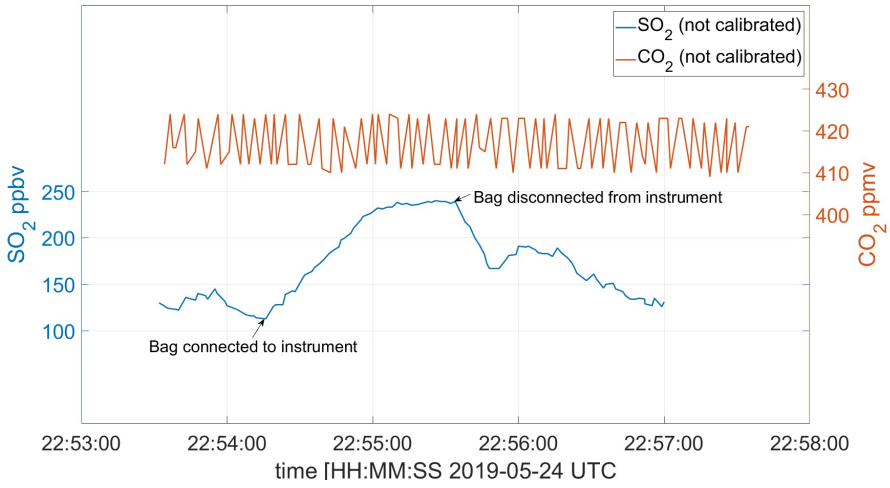

Fig. 3. Figure illustrating closed loop gas-bag measurements, Fig S.1. in Supplement