Distributed wind measurements with multiple quadrotor UAVs in the atmospheric boundary layer

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1 Review response

We want to thank the two anonymous reviewers for their valuable feedback and valid points of criticism to our manuscript.

1.1 Review Comment 2

1.2 RC2, General Comments

1. *The paper describes the procedure to use multiple drones for free field measurements. It is well written and includes many details on the drones itself as well as on the methodology for calibrating the drones. Measurements for different flight patterns for the drones are compared to measurements from a met mast with cup and ultrasonic anemometers as well as lidar systems. Even though the analysis is not at its limit, the results are already very promising. Nevertheless I do have a few questions and comments.*

   Thank you for the positive feedback. Indeed, we are developing our method further and we hopefully produce some more promising results this year.

1.3 RC2, Specific Comments

1. *The term „swarm“ suggests that the drones are somehow communicating and that one drone-path depends on the path and reaction of the other drone, which is not the case. I would suggest to use another term (unfortunately I do not have a better idea).*

   For clarification we add a definition of the system to the manuscript. Further, we changed the word from "swarm" to "fleet" of quadrotor. In this particular case a "fleet" only defines two or more drones flying simultaneously without any communication in between the drones.

2. *Would it be possible to use perform the calibration in the a wind tunnel und laminar wind flow? Even though the presented calibration function seem to be linear I can imagine that the ambient turbulence and gusts in the wind field*

might result in an overshoot in the control system which can bias the parameters. In the paper the authors used the 10 minutes averaged data right away — what happens if they use lets say 2 minutes averaged data or 5 minute averaged data for their calibration? Will that increase the error? By looking at shorter time windows the amount of calibration data will automatically increase and maybe will give additional insight in the dynamic response of the drones.

In general, it should be possible to perform the calibration in wind tunnels, it could even be more accurate concerning the mean wind speed due to the possibility to set a specific wind speed and being independent from changes in the turbulent atmospheric boundary layer. Nevertheless, some adjustments for the hovering mode need to be performed in order to guarantee a specific hover position of the UAV in the wind tunnel, due to GPS failure indoors. The calibration was performed using 10 min averaged data in order to obtain a robust method for calculating the wind speed. Decreasing the time average could increase the accuracy of dynamic behavior. However, besides the advantage of decreasing the average time window, it will also cause new issues concerning the synchronicity of the tower and the UAV data, for example how to handle the time delay of the wind measurements due to the horizontal distance between the compared measurement systems. At least a new evaluation of 2 min time averaged wind data using the parameter of the calibration with 10 min averaged data is provided in appendix C of the manuscript.

3. *The authors mention that they are interested in capturing small-scale structures with an array of drones, which is a very nice idea. Doing that, they should say something about the smallest scale they can resolve with the drones, which is about 0.25m for a single drone, but what about the arrangement of multiple drones? What is the minimum spacing between the drones in horizontal and vertical direction so that the drones do not „feel“ the effect of the neighbouring drone? I can imagine that this could be an issue in the vertical direction due to the downwash of the drones. Can the authors comment on that?*

   A detail study about the minimal possible distance between the drones before they influence their measurements themselves is not performed yet. Nevertheless, during the flight campaign we performed a pattern with approx. 6 m horizontal distance between the UAVs and we could not observe significant changes in the measurements. The minimal possible horizontal spacing before influencing the neighboring drones also strongly depends on the relative wind direction and the considered flight pattern. Obviously, if the drones are distributed perpendicular or parallel to the wind direction the minimal distance before influencing the neighboring drone will change significantly. The minimal vertical distance also depends on the wind conditions. If the flight is performed in strong winds, the downwash of the drone will drift fast downstream of the mean wind direction. Thus, the drone allocate at lower altitude will not be affect by the downwash as it would be influenced in lower wind conditions. In the present study at the flight pattern “drone tower”, what has been used for the calibration, the minimal vertical distance between neighboring drones was 10 m and we have not detected any abnormalities in the data. More detailed studies regarding this topic are out of the scope of this study and will be targeted in more specific studies.

4. *figure 7, b) and c): the vertical positions of the cup and the quadrotors should be marked and maybe separated. It is hard to identify e.g. seven time series in figure 7 c) and it is hard to see which measurement represents which range in vertical*

direction.

The vertical positions of the anemometers and the quadrotors are additionally marked in figure 7 b) and c).

2 Relevant changes to the manuscript

We list here the relevant changes to the manuscript:

1. Introduction:
   - Text modifications in response to referee comments.
2. Section 2:
   - Text modifications in response to referee comments.
3. Section 3:
   - Text modifications in response to referee comments.
4. Section 4:
   - Text modifications in response to referee comments.
5. Section 5:
   - Text modifications in response to referee comments.
6. Section 6:
   - Text modifications in response to referee comments.
   - Figure 7 was modified in response to referee comments.
7. Section 7:
   - Text modifications in response to referee comments.
8. Section 8:
   - Text modifications in response to referee comments.
9. Appendix:
   - Table was added about sensor specification in response to referee comments.
   - Figures and tables were added for an additional evaluation of the 2 min time averaged data in response to referee comments.