Review comments by Dr. Witschas

The revised paper manuscript by Gasch et al. impressively demonstrates how respective scan patterns (or fixed beam configurations) impact the accuracy of retrieved wind speeds from airborne wind lidar instruments. The research is well presented, and hence, it is recommended to publish the paper after minor technical corrections.
In section scanning-beam setup it is stated that Witschas et al., 2023 using three LOS directions, however, only two are used, namely the fore and back propagating beams with an off-nadir angle of 20°. This should be corrected.
Furthermore, in Table A1, Schäfler et al. is cited for a scan pattern different from the VAD scan and the nadir pointing. I am not aware of which scan pattern was applied. It would be useful to cite Witschas et al. 2023 here, as the fore and aft scan was applied to the mentioned 2-µm DWL.
Apart from that, I have no further comments and I am looking forward to seeing the paper published in AMT.

Answer:
With we would like to thank Dr. Witschas for the detailed reading of the revised manuscript and the helpful corrections, which we have included in the manuscript.

Comments from a second review of:
Advancing airborne Doppler lidar wind profiling in turbulent boundary layer flow-an LES-based optimization of traditional scanning-beam versus novel fixed-beam measurement systems
Gasch, et al. 2023

We would like to thank the reviewer for the remarks on the revised manuscript and the detailed information. Addressing the points raised below has certainly improved the quality of our manuscript.

The authors responded to my comments and have made a better case for a FIX5 ADWL being added to our airborne options for remote sensing of the atmospheric PBL. As with any reading of a manuscript multiple times there still remain a few questions. Since this paper is, in large part, lidar technology neutral and is primarily a sampling sensitivity study, the issues of PRF, EAP and backscatter weighting in sample integration required (or desired) are set aside (Line 235). In practice, it may be neither desirable nor necessary to fly within the PBL or even just above the PBL. The trapezoidal "truth volume" is defined by the flight altitude and scanning geometry. In practice, a much more capable (EAP) lidar is required to deal with the R*R losses by flying higher and thus requiring significant hardware and optical resources to have multiple perspectives illuminated with individual lasers. This reality is further in force when considering going to space. I only mention this since I do not think these simulation results should be mistaken for a general conclusion regarding scanning a high EAP lidar vs using multiple lower EAP lidars in a fixed configuration.

Answer: We agree that real-world measurements are subject to a number of additional challenges not addressed in our simulation study which we mention repeatedly. The focus of the study on airborne wind profiling in the turbulent boundary layer is stated in the title, therefore we think that confusion with other Doppler lidar applications is unlikely. We do not suggest direct transfer of the results to other applications (e.g. ADL systems on fast jet aircraft above the PBL or in space) in our study.

In order to provide more clarification and context to the reader we have now included a section addressing the scope of the lidar simulation in the lidar simulation section (see also our answers below). Further, we have extended the list of points relevant for ADL performance in real-world measurements in the conclusions.

As a side note, we think that flying within the boundary layer or just above is frequently applied and beneficial for boundary layer studies. With such a flight pattern below cloud base sampling using high-resolution in-situ measurements can be achieved, which has been conducted frequently in the past.

That aside, I have 2 points that the authors may want to address in their final submission:

1. What was the assumed PRF for the SNS13 scan type? 10Hz as appears to be the case for the FIX5 in Table 2? If so, then the spacing between samples in the along track direction during each of the 12 stares would be ~10m flying at 100m/s. Right?

Answer to 1: Good point, for the lidar simulation we referred to G20 and hence did not make this sufficiently clear. In line with G20, we do not specify a PRF in our study since the lidar signal processing is not simulated. Hence, we only specify a frequency at which radial wind data is available. We now give a more extensive explanation in the 'Lidar simulation' section and renamed this frequency to 'data rate' in order to avoid confusion with the PRF (see also our answer above). The data rate is 10 Hz for both the SNS13 and the FIX5 system. A 10 Hz data rate corresponds to 10 m sampling distance for each individual radial velocity measurement, since the aircraft is flying at 100 m/s. For the SNS13 pattern the stare duration for each stare direction is 1 s, e.g. averaging 10 radial velocity measurements per viewing direction (see the revised Fig. 2).

2. The quality metric discussion (lines 289 – 305) still contains several possibly confusing concepts in spite of the authors' efforts to explain the difference between MAE, MAErep and MAEturb.

Answer to 2: Thank you for bringing our attention to this, we now clarify that the calculations are conducted exemplarily for the u component but equal for the wind components. Further we now specify the meaning of the index i, which refers to the individual wind profile points.

a. As I understand it, it takes the SNS13 13 seconds to complete a scan with 1 second dwells that will then be processed into a vector wind profile with 30m vertical resolution. The difference between the two computed horizontal wind components (w assumed zero and thus an error source) at each vertical level and the trapezoidal "beam truth" at those same levels contributes to the MAE expression (Eq 1). "N" is the number of complete profiles achieved while "flying" the 8 transects shown in Figure 1 which would yield N ~ 144.

Answer to 2a: We now clarify the meaning of the formulas and explain the used variable in more detail. We also have corrected N to read N^R. N^R refers to the overall number of wind profile points available for each system setup and retrieval strategy, e.g. 67200 for the standard case (see Fig. 3). As written above, we now clarify that the MAE calculation is exemplarily conducted for the u component but valid for the other wind components as well. We hope that this avoids the confusion which occurred previously.

It is important to note that we do not assume zero vertical wind in the retrieval but instead retrieve w as well (see Fig. B3 where the retrieval quality for the w component is shown). We did not explain the retrieval procedure clearly enough in the retrieval section and did not include the reference to G20. We have now corrected this omission in the 'Retrieval strategy' section and Table 2.

b. It appears that the 1 second dwell used by SNS13 in practice is replaced (Line 245) with distance integrations between 60 and 1800m. Is this integration per LOS perspective? Or is it the distance the plane flies before generating another vector wind profile? If so, then the number and location of SNS13 radials used to represent the LES domain samples will vary while only the along track length of the FIX5 integration lines will vary.
c. I can see how the FIX5 system can be programmed to generate a complete profile every so many meters since all 5 lidars are in constant operation.

Answer to 2b and 2c: Based on the changes to your point 2a have now included the correct variable names in Sec. 5 to provide more clarity for the reader.
The retrieval procedure is equivalent for both the SNS13 and the FIX5 system. The along-track sampling distance specifies the distance over which radial velocity measurements are

considered. It is defined as a ground-relative volume (see Fig. 1 and Fig. 2), e.g. all lidar stares that fall into a retrieval volume are considered, irrespective of the aircraft position from which they were conducted. For example, measurements by forward and backward stares occur before and after the aircraft passes over a given ground-based retrieval volume, respectively. As stated by the reviewer, for shorter averaging distances less radial velocity measurements fall into the retrieval volume both for the SNS13 and the FIX5 system (both system always provide 10 Hz data rate in the simulation). For the SNS13 system at short averaging distances, a sufficient number of radial velocity measurements from different azimuth positions is rarely available in the retrieval volumes. Hence, the number of retrievable profiles N^R is severely degraded compared to N^T (CN filtering removes unreliable wind profile values, e.g. when the azimuthal spread of the lidar measurements is too small, leading to a collinear retrieval matrix, see Appendix B). To avoid the issue of non-retrievable retrieval volumes the along-track averaging distance is usually set to correspond to the distance covered by the aircraft during one scan revolution (thus covering all azimuthal positions) in real-world measurements.
As you write, the FIX5 system allows wind profile retrieval even at short along-track averaging distances, since all retrieval volumes contain measurements from 5 different azimuth positions.
Based on our answers and corrections provided above we hope that the retrieval strategy and quality metrics calculation are clear now.

d. With the frozen turbulence assumption, how is it that a system that makes 12 one second (100m sampling lines) plus 1 sec nadir dwell, has a larger representativeness error than a system with (5)13 second lines....unless there are few to no organized circulations(e.g. OLEs or plumes) on scales of order 1km in the LES simulation. In that case, the advantage seems to be all in having 5 lidars operating simultaneously (5*13 = 65 vs. 12) or a factor of 5 used to beat down the MAE due to random turbulence on the scales of 100m and less.

Answer to 2d: We agree, the reason for the reduced representativeness error is because the five lidars are operating simultaneously. Thereby, different parts of the retrieval volume are constantly explored, whereas the scanning system can only measure at one location at a time. The results are independent of whether a frozen turbulence assumption is used or not. One can also view it from a perspective as mentioned by the reviewer: With five beams, five times the measuring distance is available inside each retrieval volume, compared to a single beam system. However, the reduction in retrieval error is not a full factor of five since the sampling error scales approximately with the root of the number of measurements conducted. Further, the simultaneous measurements from the multiple beams are not fully independent due to the spatial correlation of turbulence and the sampling of coherent eddy structures.