Interactive comment on "ALADINA – an unmanned research aircraft for observing vertical and horizontal distributions of ultrafine particles within the atmospheric boundary layer" by B. Altstädter et al.

B. Altstädter (Author): Response Referee #1

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First of all, the authors would like to thank Grant Allen and his valuable contributions. A more precise description of the aerosol inlet and its properties is the major supplement in the new version of the manuscript. In addition, the literature review is extended in the context of a similar UAS application complementary to the authors' system.

In the following, each point is answered directly behind the referee's comment by the authors in blue (remark: p./l. given here, refer to the old version of the manuscript).

Referee #1, G. Allen, full paper review and response by the authors:

Summary:

This paper by Altstadter et al describes a novel measurement platform (drone aircraft) for the measurement of ultrafine aerosol in the Earth's boundary layer. The study describes the technical details of the new platform and its instrumentation (together codenamed ALADINA), and validates the particle measurements against ground-based instrumentation in a small field trial. As this work demonstrates new technology and a clear potential for future atmospheric science, it is very well placed for publication in AMT. It is an excellent resource for those using these type of measurements in the future and for helping to drive this emergent measurement technology forward for wider use. An excellent literature review of ultrafine aerosol science culminates in a well-expressed need for this new type of local-scale sampling to enable pyhsico-chemical process studies for the first time. There follows a rigorous description of the OPC, CPC, and meteorological, instrumentation and its adaptation for use on a UAV platform. Finally, a well-designed, well-executed and nicely-interpreted field trial at a well-equipped GAW site is used for validation and proof of concept. The instrumentation used is reasonably well understood (and expanded on in this work by validation and testing) and so the study is about confirming its utility on a UAV platform. The article is very well written (the best I've read for quite some time - and very few typos - thank you). Plots and structure are appropriate and good quality. I highly recommend this study for plublication and I have just a few recommendations and minor technical comments below.

Specific comments:
1/ It would be useful to add a summary of the quantitative results of the validation to the abstract and conclusions (e.g. "accurate to within X% in total number concentration at typical ambient levels", "1.3 s response time" etc). This is key information.
We agree with the referee's comment. The principal properties of the UAS ALADINA and the main results of this study are not sufficiently represented in the abstract and the conclusions.
Changes/complements in the manuscript:

- p. 12284, l. 11-12: "The CPCs are improved concerning the lower detection threshold and the response time to less than 1.3 s."

- p. 12284, l. 14-15: “The CPCs are operated in this study with two different lower detection threshold diameters of 11 and 18 nm.”
- p. 12284, l. 28- p.12285, l. 2: “In addition, a direct comparison of ALADINA aerosol data and ground-based aerosol data, sampling the air at the same location for more than 1 h, shows comparable values within the range of ±20%.”
- p. 12285, l. 7-8: “Vertical profiles up to 1000 m altitude indicate a high variability with distinct layers of aerosol, especially for the small particles of a few nanometers in diameter on one particular day. The stratification was almost neutral and two significant aerosol layers with total aerosol number concentrations were detected up to 17000±3400 cm^{-3} between 180 and 220 m altitude and 14000±2800 cm^{-3} in the level of 550-650 m. Apart from those layers, the aerosol distribution was well-mixed and reached the total number concentration of less than 8000±1600 cm^{-3}. During another day, the distribution of the small particles in the lowermost ABL was related to the stratification, with continuously decreasing number concentrations from 16000±3200 cm^{-3} to a minimum of 4000±800 cm^{-3} at the top of the inversion in 320 m. Above, the total number concentration was rather constant. In the region of 500 m to 600 m altitude, a significant difference of both CPCs was observed. This event occurred during the boundary layer development in the morning and represents a particle burst within the ABL.”
- p. 12300, l. 6-9: “Two CPCs (condensation particle counters) with different threshold diameters (11 and 18 nm) offer the possibility to measure total particle number concentrations of freshly formed particles with a response time $t_{10\%-90\%}$ of 1.3 s.”
- p. 12300, l. 18-20: “One flight was performed on 8 October 2013 at 13:14 UTC. On this day, new particle formation was observed at the ground by the TSMPS data. A continuous difference of both CPCs, ΔN, represents a low number concentration of freshly formed particles in the prevailing neutrally stratified ABL. In addition, two significant aerosol layers were present with a maximum of 17000±3400 cm^{-3} in 180 and 220 m altitude and 14000±2800 cm^{-3} in the level of 550 m to 650 m in an otherwise well-mixed structure of aerosols in the ABL. During the other flight on 9 October at 08:37 UTC, no particle burst event was detected at the ground, but an internal layer in the atmospheric boundary layer with different aerosol properties was present. From the ground to the inversion at 320 m altitude, the total number concentration was decreasing and reached a minimum above the inversion. At a level between 500 and 600 m altitude, a difference of both CPCs was measured that corresponds to a new particle formation event.”

In addition, the quantitative results (±) of all parameters (meteorology and aerosol instrumentation) are added in the whole text. Therefore, we used the error estimates from our results, because the error deviations, given from the manufacturers, were not realistic for airborne measurements. The CPC1 is in the range of 11 nm and 2 µm with ±20%. The CPC2 detects particles from 18 nm up to 2 µm within a variation of ±20%. The OPC has a variance of ±15%.

2/ As suggeted in the conclusions, ozone is one of the many modulating controls on ultrafine particle bursts and it would be useful to briefly mention that it will be important to measure many atmospheric chemistry parameters simultaneously and coincidentally to enable particle-burst process studies earlier on in the introduction and literature survey. You could reference the following shamelss plug in your literature survey as another promising measurement approach to measure these kind of synergistic properties:

Illingworth, S.M., Allen, G., Percival, C., Hollingsworth, P., Gallagher, M.W., Ricketts, R., Hayes, H., Ładosz, P., Crawley, D., Roberts, G.: Measurement of Boundary Layer Ozone Concentrations On-board a Skywalker Unmanned Aerial Vehicle, Atmos. Sci. Lett., 15(4), 252-258, DOI:10.1002/asl2.496, 2014.

The authors included the suggested literature and emphasized the necessity to measure chemical compounds including precursor gases that are relevant for new particle formation already in the introduction (→ manuscript expansion: please see our answer to referee #2 on

p. 1, l. 40-44). This paper presents a good complement for our measurements and highlights a UAS application for ozone measurements.

3/ Inlet design is often difficult for aerosol particles. Can you confirm (and/or otherwise include in the text) that the inlet is isokinetic for the size range of the particles of interest? Was this tested and/or confirmed? I.e. is the response rate potentially different for different size particles and could there be differentiation in the size distribution due to streamlines around the inlet tip? I suspect these effects will be very small at the slow speeds of the UAV and small aerosol sizes under consideration but it does need to be understood and confirmed. In summary, it would be useful to see more information on the inlet design and characterisation in the text.

We agree with the referee that a more precise description of the aerosol inlet and its properties is helpful. We expanded the information and following details are included in the new version of the manuscript, after p. 12291, l. 7:

"The ALADINA aerosol inlet is a 36 cm long 3/16" straight stainless steel tube. The sampling line downstream the inlet is made of flexible conductive tubings, in total 24 cm long, 1/4" for the OPC and 28 cm long, 1/4" and 3 mm, for the CPCs. Two metal y-pieces sequentially split the flow between the OPC and the CPCs. The ALADINA aerosol inlet system sampling efficiency is dominated by two major particle processes (cf. Baron and Willeke, 2001): diffusional losses for particles with a few nanometer diameter and aspiration enhancement for particles with a few micrometer diameters. Both can be well estimated using empirical equations given in Baron and Willeke (2001). The ALADINA aerosol inlet is neither isokinetic (TAS = 25.0 m s^{-1} and $v_{sampling}$ = 8.8 m s^{-1}) nor isoaxial (mostly in the range of ± 20°). The limited size and weight prohibited a more complex isokinetic flow system. Effects caused by the non-isoaxial sampling are minimized using rounded inlet lips. Due to the non-isokinetic sampling, particles with several micrometer diameters can be enhanced in the total number concentration by a factor of up to three. However, 1 µm particles experience only an enhancement of 7 %. Particle losses due to diffusion were determined in the laboratory as 17% for 10 nm particles and much smaller for larger particles. Thus, the ALADINA aerosol inlet system has a sampling efficiency in the narrow range of 83 % to 106 % for Aitken and accumulation mode particles (10-1000 nm diameters)."

Literature:

Baron, P.A., and Willeke, K.: Aerosol measurements: Principles techniques and applications Wiley, New York, 2001.

Technical comments:

1/ Change "earth's" to "Earth's" on p.12285 line 21 and check for other instances.

We agree with the referee's comment and made this change.

2/ Figure 6: Top panel legends are too small to read. Also, are these taken direct from wetter3.de (they look very similar to those available publicly there)? If so, that site (or the original producer) should be credited. Either way, text needs to be enlarged. I would recommend an easier option of removing these panels if necessary as they don't add too much information that isn't already decribed in the text concerning the synoptic situation. In other words, a plot of GFS data is not needed to illustrate what is already well-expressed in the text for the purposes of this study.

Yes, the top panels are available publicly and the authors agree with the referee that the figures are too small to read and they are not necessary as long as the synoptic situation is described in detail in the text. As the referee has recommended removing Fig. 6, we have made this change.