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 #2

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The authors thank the anonymous referee for his/her comments. His//her constructive criticism helped to improve the manuscript. In addition, the literature review is extended in connection with similar UAV applications and the results are deeper interpreted, especially due to the more detailed description of Figs. 15 and 16.

Here again, 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 #2, full paper review and response by the authors:

Summary

This paper is clear in its aims of introducing the ALADINA UAS platform and justifying the measurement need regarding small-scale vertical and horizontal ultrafine particle variability. It is a welcome addition to the growing uses of UAVs in atmospheric science and is within the remit of this journal. A good attempt is made to describe the platform and instruments and interpret of the measurements from the field study. I think the manuscript could benefit from more detail to highlight the changes made to the instruments when integrating them into the UAV, and to discuss considerations given to possible inlet and flow path effects one might expect when airborne. More explanation of the observed new particles, particularly on the 8th, will help embed the results more firmly into the measurements made concurrently by more established techniques.

Specific Comments

Aerosol and turbulence measurements from UASs are described in [Corrigan et al, Atmos. Chem. Phys., 8, 737–747, 2008], using a TSI 3007 CPC and Met One OPC, given the system similarities, this paper should be highlighted more in the literature review.

We thank the referee for his/her comment and expanded the following sentences in the manuscript in order to provide a more detailed description of similar/additional UAS applications, p. 12287, l. 21-22: "Some applications, with regard to sample atmospheric aerosol by a UAS, can be seen e.g. in Clarke et al., (2002) who have tested among other instruments, a "mini OPC" (Met One 237A) for in-situ aircraft measurements. Bates et al. (2013) investigated the vertical distribution of atmospheric aerosols in the Arctic (Svalbard, Norway) by means of the UAS Manta. The aerosol package contained in particular a three-wavelength absorption photometer for detecting the optical properties of black carbon (BC). Tropospheric ozone, which is besides its role as greenhouse gas, an important precursor for new particle formation, was investigated by Illingworth et al. (2014). In this study, the variability of ozone concentrations within the ABL was measured by an electrochemical concentration cell (ECC) ozonesonde, equipped on a Skywalker UAS. Corrigan et al. (2008) presented, as part of the extensive MAC (Maldives Autonomous Unmanned Aerial Vehicle Campaign) campaign, vertical profiles of aerosols and BC, measured with the payload installed in the UAS Manta. The aerosol payload contained a total particle counter (TSI Model 3007) with a threshold diameter of 10 nm, an optical particle counter (Met One Model 9722) and a three-wavelength absorption photometer (adapted from Magee Scientific AE-31). The system is similar to ALADINA, but the authors of this presented P360 “ALADINA” study, have a clear focus on the formation of ultrafine particles relating to atmospheric processes.”

Similarly, the AMT paper [Thomas et al. Atmos. Meas. Tech., 5, 243-257, 2012] should be included on page 12287, line 27 after ‘fluxes’.
We thank the referee for his/her literature note and added the following reference (p. 12887, l. 27, after “fluxes”).

Literature:
Thomas, R. M., Lehmann, K., Nguyen, H., Jackson, D. L., Wolfe, D., and Ramanathan, V.: Measurement of turbulent water vapor fluxes using a lightweight unmanned aerial vehicle system, Atmos. Meas. Tech., 5, 243–257, doi:10.5194/amt-5-243-2012, 2012.

The newest concept for this paper is the integration of a dual CPC system with modified size responses into a UAS,a description or diagram with details of the modified flow paths, any isokinetic inlet considerations, and thoughts regarding of the airflow around the UAS to allow the reader to fully understand the integration of the two CPCs and OPC into the UAS.
Please see our answer to the first referee that describes a detailed analyse of the aerosol inlet (here: interactive comment p. 3, l. 12-28).

The authors give a clear, concise description of the aircraft. More information about or referencing the make and model of basic sensors used where appropriate: platinum wire probe, P14 rapid, data acquisition system, telemetry radio, also which data is sent via telemetry.
The meteorological sensors, data acquisition and data transfer are well described by Wildmann et al. (2013, 2014a, 2014c) - numbering referring to the manuscript. With the telemetry down-link it is possible to observe the data of all meteorological sensors, IMU, GPS, CPCs and OPC directly on a ground-station with a transmission rate of 1 Hz (AMOC). Similarly, the flight data from the autopilot is transmitted to another ground-station (ROCS).

Repeated several times in this paper is the assertion that the difference between N18 and N11 is an indicator of new particle formation. In addition, modifying and integrating the CPCs to measure N18-N11 whilst flying is a difficult challenge. With these points in mind, the manuscript would benefit from more insight and analysis on Figs 15c (particularly) and 16c.
Really to expand on Page 12298 line 14: “A continuous difference between CPC1 and CPC2...meaning there is a significant number of particles with a diameter of particles in the size range between 11 and 18nm.” Without more explanation some readers may dismiss Fig 15c as a systematic offset between CPCs.
We agree with the referee that sentence above might cause confusion. We have changed the following sentences in order to give a more precise description of the aerosol data obtained by the vertical profiles of ALADINA. Yes, there is a continuous difference between CPC1 and CPC2 that indicates a weak amount of freshly formed particles in the atmospheric boundary layer. The number concentration is rather small, except for the level in 180 and 220 m. A second layer was measured in the region of 500 to 620 m.
In order to give a clearer picture of our results, we have revised the following lines: “At the ground the mean total aerosol number concentration of the small particles is 10000±2000 cm^{-3} and constant to a height around 180 m (Fig. 15.c). Between 180 and 240 m altitude, a layer of significantly enhanced aerosol is observed. The maximum of the CPC1 is

N_{11}=17000±3400 cm^{-3} and the CPC2 detects a maximum of N_{18}=14500±2900 cm^{-3}. A second layer of enhanced aerosol load is detected in 550 to 620 m altitude. Above, the total aerosol number concentration is decreasing to the same amount as measured at the ground. All in all, a continuous difference between CPC1 and CPC2 is observed by the vertical distribution of *ΔN*, meaning there is a certain number of particles in the size range between 11 nm and 18 nm. Nevertheless, the most dominant differences are in the two distinct aerosol layers. […]

The number concentration of the small particles is increasing (compared with the previous day) at the ground to a maximum of 12500±2500 cm^{-3} and identically measured by both airborne CPCs (Fig. 16.c). Up to a height of 100 m, the total aerosol number concentration is increasing to a maximum of 16500±3300 cm^{-3} and afterwards decreasing until reaching the inversion in 320 m with a minimum of 4000±800 cm^{-3} Above the inversion and up to a level of around 480 m altitude, the aerosol distribution is rather constant. But in the height of 480 to 620 m, the total aerosol number concentration is rapidly increasing to N_{18}=8000±1600 cm^{-3} and N_{11}=11000±2200 cm^{-3}. This difference corresponds to *ΔN*=3000±600 cm^{-3}, thus to a particle burst and here without any obvious connection to the stratification of the ABL. In the altitude between 620 and 1000 m, the total aerosol number concentration is decreasing again and both CPCs detect the same amount. All in all, a high dependency of atmospheric aerosols on the atmospheric stratification is observed, apart from the particle burst events."

I think some discussion of formation mechanisms and transport through the column, to tie in with the theta stratifications, general meteorology and supporting aerosol measurements is warrented. It would be clearer to add a N18-N11 trace to Figs. 15c and 16c to help this analysis.

The authors thank the referee for his/her suggestion and made this change. Now the difference of CPC1 and CPC2 is mentioned as ΔN and the trace is included in the Figs. 15c and 16c (please see the plots in the new version of the manuscript → supplement).

In addition, can a comparison be made with the SMPS data and the CPCs by integrating the TSMPS over the size range of each CPC and OPC channel and at the time of low altitude/surface sampling (above 800nm should add little in the way of number conc)?

This value could be added to Figs 15 and 16 at the appropriate altitude level to provide a visual quantitative assessment of system performance relative to surface instruments. Building such linkages described above between the UAV and ground data will build confidence in the system's abilities to make real-world measurements.

The authors thank the referee for his/her remark. We totally agree with the referee that it would be clearer if we compare our results with the aerosol data gained by the GAW station. We have recently published other results that contain a direct comparison of aerosol data, measured with ALADINA and the ground data from the GAW station. E.g. the NAIS data is integrated and compared to the integrated total number concentration of the CPC during a new particle formation event. The main goal of the ALADINA paper by Altstädter et al. (2014) is to present the technical issues and first results, gained from the test campaign in October. The other publication by Platis et al. (2015) goes more into detail in order to investigate NPF in connection with the ABL. The authors reference to the following literature:

Platis, A., Altstädter, B., Wehner, B., Wildmann, N., Lampert, A., Hermann, M., Birmili, W., and Bange, J.: Case study of an airborne measured new particle formation event in the atmospheric boundary layer, submitted to Bound.-Lay. Meteorol., 2015.

Technical comments

12287 line 28. A minor point, but low cost with respect to manned aircraft isn't always the case. For example, if you wanted a sub 25kg UAV that could go all the places a light manned

aircraft could (airspace permitting), it might costs considerably more. Perhaps acknowledging this by changing ‘low’ to ‘potentially lower’ would suffice.
We agree with the referee and made this change: low to potentially lower.

P12288, line 24 – I think “Save” should read “Safe”
We have made this change.

P12289, line 28 ‘is’ should be ‘are’.
The authors changed it.

P12295 line 6, ‘weaken’ should be ‘weakened’
The authors have done this change.

P12297 line 1 – presumably ‘mixing ratio’ refers to ‘water vapour mixing ratio’, this should be specified here, line 9, and figure 11 caption (consider using ‘q’ to save repetition).
We agree with the referee and specified “*q*” for water vapour mixing ratio in the whole manuscript.

P12297 line 18 ‘extend’ should be ‘extents’
We have done this change.

Figure 7: Top four panel’s x-axis tick marks need aligning with those of lower panel.
We agree with the referee and have improved the Figs. 7 and 8 (see supplement).