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Atmospheric Chemistry and Physics Discussions
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Interactive comment on "Aerosol particle formation in the upper residual layer" *by* Janne Lampilahti et al.

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We thank the Referee for the comments. Our responses are below:

Comment: Roughly isokinetic sampling : Could you please be more precise. The inlet is either isokinetic with a control of the flow within the inlet or not isokinetic. It seems that you are controlling it with a valve and with a constant speed of the Cessna. Therefore most of the time the sampling should be isokinetic. However, roughly is too vague. What are the deviation from the isokinetic conditions ? This condition has a large impact on the measurement quality and therefore on their validity. Please correct and add more information about that.

Answer: From Schobesberger et al (2013) (reference in the manuscript): "The aerosol inlet's design was adopted from the University of Hawai'i shrouded solid diffuser inlet design originally presented in McNaughton et al. (2007) for use aboard a DC-8 aircraft. Our inlet is a downsized version of it, suiting the lower cruising speed of the Cessna."

Detailed characterization of the inlet can be found in McNaughton et al. (2007). In our measurement range (<400 nm) the inlet losses should be negligible.

Inside the main sampling line the velocity of sample air was ∼2 m/s (∼47 lpm controlled by a manual valve), while the instruments (UCPC: 1.5 lpm, PSM: 2.5 lpm, SMPS: 1 or 4 lpm) drew the air at the core sampling inlets between ∼0.5-2 m/s. Under these conditions considerations of isokinetic sampling are not necessary. So we removed this part from the text.

Comment: Figure 3 analysis : "The layer had increased number concentrations of sub-20nm and sub-3nm particles." in comparison to what ? The descent profile ? I think you should clearly name the reference you are comparing these results to. Moreover, you should definitely show the profiles from the early morning flight on Figure 3. That would raise no doubts that the aerosol layer was not present before the sun rise and that could give the reader a clear reference. "at this point there were no signs of the particle layer" This is misleading. The layer didn't disappear spread into lower layers, in this case the ML. Is there a threshold for the RL height ? I believe the highest is the better due to lower temperature and cleaner air. But is there any RL height range for those events ? Could you also add the ML height in this figure ?

Answer: We added the particle number concentrations in the different size ranges at altitudes below/above and in the layer to the text.

We also added the particle number concentration vertical profiles from the early morning ascend/descend to the figure (Fig. 1).

We removed the misleading sentence and instead wrote: "The airplane entered back into the ML at 12:56 and the particle number concentration was increased throughout the ML, suggesting that the particles in the elevated layer were mixed into the ML"

We added an estimate of the ML height based on the Doppler lidar data as dashed line to the figure.

In Figure 1C the temperature soundings from Jokioinen show how a temperature inversion at the top of the previous day's ML remains at roughly the same altitude (2000-2500 m asl.) during the night and height of this inversion indicates the height of the residual layer.

Comment: L 168-171 : The NPF starts at 12:36 but the vertical particle flux show minimum values at 10:30 et 13:00. If aerosols are coming from the residual layer (around 1700m), the process is not instantaneous right ? So the NPF should be related to the minimums of Vertical particle flux occurring at 10:30 and 11:30. Can you estimate the vertical speed of the aerosols ? Is the aerosol speed playing a role in the NPF occurrence ? I would think that yes due to the fact that slow motion aerosol would have grown to much larger sizes ? Could you run the analysis also for non event days ? Is there a vertical wind speed threshold that need to be exceeded ? Also for other NPF cases linked to RL NPF events, Can you tell us more about the vertical particle flux patterns observed before the occurrence of NPF ? Is it different for each case ?

Answer: If the particles are formed at the top of the RL, disconnected from the ML, then the intensity of mixing in the ML would have no effect on the particle formation. If the particles are entrained into the ML then more intense mixing would transport the particles to the surface quicker and vice versa. Also if the ML remains quite shallow due to weak mixing it may be that the particle layer is not mixed down and remains aloft.

Buzorius et al. (2001) observed that the vertical particle flux was mostly negative during NPF events and the authors argued that the particles were probably formed aloft and mixed down.

In RL NPF we were looking for negative peak in particle flux when the nucleation mode particles were first observed. In other words the particle flux is most negative when the particles are observed for the first time since all the particles would be above the flux measurement setup and none below. As the particles are further mixed into the ML the number concentration difference above and below the flux measurement setup decreases and the particle flux becomes less negative.

Comment: Figure 6: I'm not sure what you plotted on this figure. The color code correspond to dN/dlogDp (cm-3). So is it a total concentration or is it from a specific bin ? It must be a specific bin and most probably within the fine diameter range due to the conclusions drowned. Could you please provide the percent of NPF event linked to aerosol formation in the upper layer ? Then you could used this result to justify the 75th percentile use.

Answer: The figure shows the median and the 75th percentile aerosol particle number size distribution as a function of altitude calculated from 2011-2018 flight data. We did not inspect all flight profiles during 2011-2018 for layers. However Väänänen et al. (2014) (reference in the manuscript) reported that for 2013-2014 campaigns 16/36 ($\sim$44%) profiles had a sub-25 nm particle layer. We added this number to the Introduction.

Comment: L52 : need to define ML

Answer: we added the following definition to the Introduction when we first mention the ML:

"Type of atmospheric boundary layer where turbulence tends to uniformly mix quantities such as aerosol particle concentrations."

Comment: L147 : In the aircraft data : not well said

Answer: We replaced it with "In the airborne measurements"

Comment: Figure 7 : Need to be more precise : - early morning of June 5th : 0 – 4h ?

Is there a reason why you choose that time to determine the Residual layer ? could you provide some stat for each cases of the delay between the moment when the Inversion layer reach the Residual layer and the moment when the NPF occurs at the ground ? That could be great to have as well the RL height, and the estimated speed of the aerosol.

Answer: We chose this sounding on Jun 5 because in the next sounding the RL was already mixed into the ML. In general we used the latest temperature profile where the top of the RL was visible. We added Table 1 that shows all this information (Fig. 2). We find this analysis is not accurate enough to estimate mixing speeds for the aerosol particles though.

Comment: L220 : So you found 8 cases out of ? That would be nice to see a table showing the number of days of observations, the number of events at the ground, the number of event linked to roll vortices, the number of event linked to the RL, and the number of event that are not yet related to anything. And precise the type of events (classic banana or burst of particles at higher diameter than 3nm ? Again here you said these cases were not observed at the same time : Could you provide a table with their main characteristic : Start time, duration, GR, diameter at time start ?

Answer: The campaign was 8 months Feb-Sep in 2014. We provide Table 1 (Fig. 2) for information on the specific cases. Since this particular analysis was to study the relationship between the mixing time of the RL top into ML and the appearance time of the nucleation mode particles. We did not think that classifying other types of NPF events would add much information.

Comment: L236 : please replace transported event by "transported event"

Answer: Fixed

Comment: L 246- 252 : could you provide the number and the percentage ?

Answer: We added these to the text

Comment: Reference that might be added to your manuscript : A lot of work have been done by the French group of the LaMP to study NPF events on the ground at an alti- tude site but also using aircraft measurements. You should cite some of them in your paper. Aircraft observations for links between altitude and NPF: Crumeyrolle et al 2010, Altitude site: Boulon, et al.: Investigation of nucleation events vertical extent: a long term study at two different altitude sites, Atmos. Chem. Phys., 11, 5625–5639, https://doi.org/10.5194/acp-11-5625-2011, 2011. C. Rose, et al., Frequent nucleation events at the high altitude station of Chacaltaya (5240 m a.s.l.), Bolivia,https://doi.org/10.1016/j.atmosenv.2014.11.015. H Venzac, et al - 2007 - Aerosol and ion number size distributions were measured at the top of the Puy de Dôme (1465 m above the sea level) for a three-month period. The goals were to investigate the vertical extent of nucleation in the atmosphere and the effect of clouds on nucleation. J. Boulon, et al. New particle formation and ultra- fine charged aerosol climatology at a high altitude site in the Alps (Jungfraujoch, 3580 m a.s.l., Switzer- land). Atmospheric Chemistry and Physics, European Geosciences Union, 2010, 10 (19), pp.9333-9349.

Also maybe look at that one : https://www.mdpi.com/2072-4292/12/4/648. It does also look at the impact of the dynamics on the nucleation events with a clear focus on the dynamics. You can actually see that the perturbation induced by flows at different altitude might also enhanced the possibility to observed NPF events. The turbulent fluxes occurring at each layer top is inducing favourable conditions to generate NPF events.

Answer: We thank the Referee for these references. We added more information to the Introduction regarding previous studies (see our answer to Referee #1). We added some of these studies there.

References

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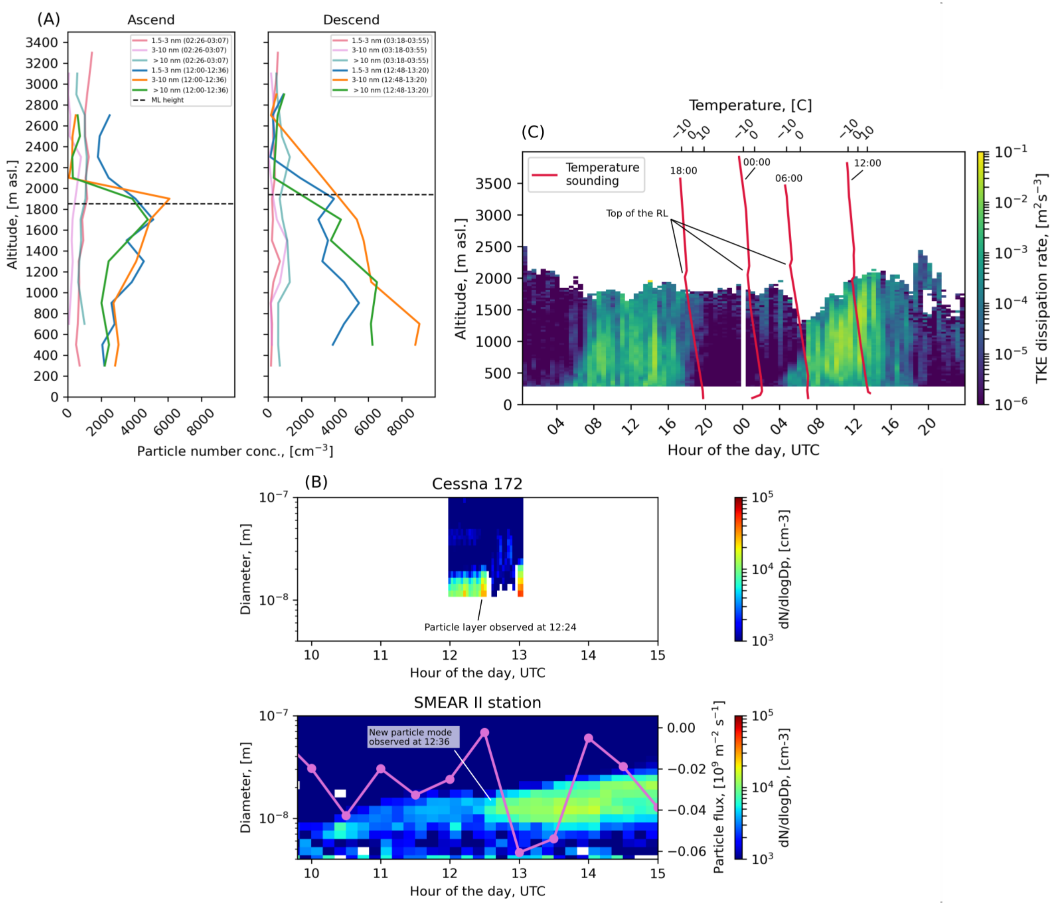
(A)
Ascend
Descend
1.5-3 nm (02:26-03:07)
3-10 nm (02:26-03:07)
>10 nm (02:26-03:07)
1.5-3 nm (12:00-12:36)
3-10 nm (12:00-12:36)
>10 nm (12:00-12:36)
ML height
1.5-3 nm (03:18-03:55)
3-10 nm (03:18-03:55)
>10 nm (03:18-03:55)
1.5-3 nm (12:48-13:20)
3-10 nm (12:48-13:20)
>10 nm (12:48-13:20)
Altitude, [m asl.]
Particle number conc., [cm−3]
(C)
Temperature, [C]
Temperature sounding
Top of the RL
18:00
00:00
06:00
12:00
Hour of the day, UTC
TKE dissipation rate, [m2s−3]
(B)
Cessna 172
Diameter, [m]
Particle layer observed at 12:24
dN/dlogDp, [cm-3]
SMEAR II station
New particle mode observed at 12:36
Particle flux, [109 m−2 s−1]

Fig. 1.

Table 1: rl_h = residual layer height during night or early morning (m asl), rl_ht = time when the rl_h was observed (time when the sounding was released, hour of the day, UTC), mode_t = nucleation mode particle mode first appears (hour of the day, UTC), mode_t1/mode_t2 = nucleation mode particle mode appearance confidence interval (hour of the day, UTC), rl_t = new mixed layer reaches the top of the residual layer (hour of the day, UTC), rl_t1/rl_t2 = new mixed layer reaches the top of the residual layer confidence interval (hour of the day, UTC), bl_h = observed maximum height of the previous day's boundary layer (m asl.), dp = mean mode diameter for the newly appeared particle mode, when they first appear (nm), gr = growth rate calculated for the newly appeared partice mode (nm h^{-1}), pf = the value of the negative particle flux peak (10^9 m^{-2} s^{-1}).

date	rl_ht	rl_h	mode_t1	mode_t	mode_t2	rl_t1	rl_t	rl_t2	dp	bl_h	pf	gr
20140328	5.3	1100	8.5	9	9.5	5.5	7	8	20	1300	-0.25	2.28
20140331	7.6	2400	14	14.5	15	12	13.5	14	10	2200	-0.06	2.1
20140404	8.5	2200	10.5	11	11.5	10.5	11	11.5	8	2800	-0.04	1.39
20140409	5.5	1500	9	9.25	9.5	6	6.5	7	8	1800	-0.13	1.18
20140415	5.3	1600	14.5	14.25	15	12	13	14	11	1700	-0.18	1.94
20140422	0.0	1800	12	12.5	13	10.5	11	11.5	17	1900	-0.17	1.0
20140518	0.0	1500	9.5	10	10.5	8	8.5	9	13	1900	-0.11	2.91
20140705	5.3	1500	11	11.5	12	8.5	9	10	12	1700	-0.1	4.83

Fig. 2.

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Discussion paper