Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2019-1013-AC1, 2020

Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Roll vortices induce new particle formation bursts in the planetary boundary layer" *by* Janne Lampilahti et al.

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Received and published: 30 May 2020

We thank the referee for the constructive comments on our manuscript, please find our responses below.

Major comments

1. Measurement average : All measurements are performed at different frequency and the authors choose to average all the data over different periods (4 min, 12 min, 30min). They did not justify why they choose these periods. Why not using the same periods for all instruments ? The DMPS SD are not averaged what was the frequency for this instrument?

Answer: The time resolutions used were those of the processed data, we did not re-

average the processed data afterwards. We changed the text to better reflect this. The DMPS processed data had time resolution of 10 min, we also added this information to the text.

"The NAIS measured the particle number-size distribution in the mobility diameter range 2-42 nm and ion number-size distribution in the mobility diameter range 0.8-42 nm at 4 min time resolution. We used data from the positive polarity of the instrument."

"The time resolutions of the DMPS and the NAIS were 10 min and 4 min respectively, from the NAIS we again used particle data from the positive polarity. The PSM measured particle number-size distribution between 1-2 nm and the time resolution was 12 min."

2. Measurement location : Could you please justify that inlet height differences are unnoticeable on aerosol measurements ? Especially, when you used the synergy between anemometer at 125m above the ground with a CPC at 23m.

Answer: The vertical particle flux was calculated from a CPC and a 3d anemometer positioned at 23 m above ground. The anemometer at 125 m above ground was only used in wind data analysis. We removed the mention of the 125 m anemometer from the text since the results of this analysis are not shown in the text.

3. In general the figure labels are really long because you explained most of the time the way you used to process the data. I found it odd, especially because you are limited in word numbers. For example, I have many questions about Figure 9. From what I understood, figure 9 shows size distribution and formation rate calculations based on observations of geometric mean diameter.

Answer: We made the captions in Figures 2-9 shorter by moving some of the interpretation of the figure to the main text instead of keeping it in the caption. Figure 8 caption we kept the same since it describes a supporting case study and explaining it in detail in the main text would break the flow where it is mentioned as part of the GR estimation.

- First of all, geometric mean diameter given in table 3 is observed at the end of the event, an hour after the beginning ? This is not clearly stated when the Dp values refer to.

Answer: At the measurement station the roll vortex induced new particle formation (RI-NPF) is observed as an intermittent, concentrated mode of sub-20 nm particles, with sudden beginning and end. One might describe it as a particle stripe in the sub-20 nm sizes. To obtain the geometric mean diameter for each RI-NPF reported in Table 3 we fitted a log-normal curve to the particle number-size distributions present in the RI-NPF and chose the peak value at the beginning of the RI-NPF observation as the geometric mean diameter that we report in Table 3.

In Table 3 caption we added that the geometric mean diameter is reported at the beginning of the RI-NPF:

"Dp = geometric mean particle diameter of roll-induced NPF event, determined at the beginning of the roll induced NPF observation"

- Then you use a constant GR of 1.9nm/h. Why ? You have measured the GR for each case. Then why using this value corresponding to GR from days that showed multiple subsequent roll-induced NPF events ? According to Table 3, the GR ranges from 0.8 to 4.3 nm/h. The use of GR value 2 times lower or larger might causes a lot of difference in the diameter growth and the formation rate.

- Moreover, I don't understand the last sentence : Âń We then used random sampling (1000 samples), also varying the GR, to estimate 25th, 50th and 75th percentile values for the formation rates of 3- and 10-nm-sized particles ÂÅij . From this sentence, one can understand that the GR is not fixed anymore. What are the values used then ??? Also, you used 1000 random samples from what you calculated. Do you have 1000 samples from what you calculated ? You have 3 (GR variations ?) * One SD/hour *nb

of events (46) or did I miss something ?

- How do you control this random factor ? Could the 1000 samples belongs to one or 2 specific events ? If the GR is two times larger, what will be the error on the formation rate.

- And so you did all that to get formation rates that you measured directly ???

Answer: In order to clearly observe particle growth we had to see more than one RI-NPF event go over the station. We estimated the GR from the change in the geometric mean diameters in the subsequent RI-NPF events. This happened on 13/29 days in Table 3. In addition on 8 May 2013 the zeppelin flew through the same RI-NPF multiple times throughout the day for several hours, which also allowed us to observe the particle growth and calculate GR.

We changed the text to read:

"Multiple roll-induced NPF events during a single day were observed on 13/29 days. In these cases by looking at the change in particle diameter between subsequent roll-induced NPF events we were able to estimate the GR. In addition, on May 8, 2013 we could calculate the GR from a single roll-induced NPF event by following it with the zeppelin aircraft (Figure 8)."

From the 14 GR values we calculated the median, 25th and 75th percentile GRs. These represent the average GR for the RI-NPF particles in Table 3. We assumed that the underlying distribution of the GRs is a normal distribution with mean equal to the median GR and the standard deviation equal to the inter quartile range (IQR) of the GRs. From this normal distribution we then randomly sampled a GR.

Assuming that in Table 3 the particles in each RI-NPF case were formed at time t = 0 hours and that the GR remained constant, we estimated the time dt since the RI-NPF particles in Table 3 were formed using dt = Dp/GR, where Dp is the geometric mean diameter of the particles at the beginning of the RI-NPF observation.

This way we were able to put all the RI-NPF observations in Table 3 on a common time axis where the time is the time since particle formation. We then divided this time axis into 1-hour bins and in each bin calculated the median, 25th and 75th percentile particle number-size distribution. Again we assumed that the particle number-size distributions in each bin were normally distributed with mean equal to the median and standard deviation equal to the IQR. Then we randomly sampled a distribution from each bin and used the randomly sampled values to calculate the formation rate time series for 3 nm and 10 nm particles.

The particle size distribution displayed in Figure 9 consists of medians in each bin and the median GR was used to calculate the time since start of NPF.

We repeated the above random sampling 1000 times in order to obtain 1000 formation rate time series. From these formation rates we calculated the median, 25th and 75th percentile values. These are then our estimates for the average J3 and J10 plus their uncertainties, which are displayed in Figure 9.

In principle we could calculate formation rate for some individual cases. This means the case needs to have at least two subsequent RI-NPF events during the same day in order to estimate the GR, and also there needs to be particles for long enough time in the interesting size-range. Being this specific discards most of the data and we are left with just a couple of case studies. Instead we wanted to use a method that uses all the available observations. This allows us to get a formation rate that better represents the average and allows us to estimate the uncertainty.

We added a more explicit description to the text regarding the above procedure.

“We aggregated all the roll-induced NPF observations in Table 3 into 1-hour-averaged bins using the median GR and the geometric mean diameters of the particles, assuming that the particles were formed at t=0 hours (Figure 9).

Then we calculated the formation rates and their uncertainties. We assumed that the

roll-induced NPF GRs were normally distributed with mean equal to the median GR and standard deviation given by the magnitude of the IQR. Given the sampled GR we distributed the roll-induced NPF observations into 1-hour bins. For each 1-hour bin we assumed that the number-size distributions again followed a normal distribution with mean equal to the median and standard deviation given by the IQR. We randomly sampled a number-size distribution from each bin and calculated the formation rates based on that. We repeated this procedure 1000 times in order to estimate the J3 and J10 and their uncertainties shown in Figure 9.”

4. Fraction of area : So you use a ratio of two periods and that give you a fraction area covered by the roll-induced NPF. Could you please explain the idea behind it ? I guess that this is related to the wind speed of the air mass over the site vs over the region. So, assuming both wind speeds are similar this is just a ratio of the horizontal extend of the NPF event when passing over the site and the horizontal extend of the NPF observed by the airborne instruments. What is the time shift between the aboard and grounded measurements ? Is the wind speed really constant during the whole period ?

Answer: First we assume that the RI-NPF extends a long distance along the length of the rolls, which is supported by the aircraft data. So then to estimate the area fraction we want to know what the spacing of RI-NPF is perpendicular to the rolls.

We needed more than one RI-NPF observation at the station during the same day in order to estimate this. Figure 1 shows how the rolls and by extension the RI-NPF move over the station if there is a difference in the direction of the roll axis and the mean wind direction.

If the wind conditions stay the same during the period when the multiple RI-NPF events move over the measurement station, then we can assume that the rolls move over the site at a steady pace. This means that the spatial extent across the RI-NPF events is directly proportional to the time interval we observe the RI-NPF events at the field station. This means that the time that subsequent RI-NPF events spent on top of the measurement station divided by the total time it took for these RI-NPF events to move over the station is equal to the fraction of area covered by the RI-NPF events.

We can check the wind measurements from the mast at 33.6 m height above ground and see how constant they are (the 125 m measurement was not available for the whole time). For this we prepared Figure 2. Of course this does not tell us how the wind behaves in the rest of the boundary layer.

On most of the days the wind conditions do not fluctuate significantly during the multiple RI-NPF observations. On 2007-06-10 and 2017-04-24 the wind direction changes more than 100 degrees, and this could introduce some uncertainty, but would not have much effect on the final result.

The above analysis only requires ground-based observations. Since the flights covered a relatively small area we found them to be inadequate at estimating the spatial extent of RI-NPF in the direction perpendicular to rolls. One might argue that along the flight tracks in Figure 5 the concentrated particle areas took roughly half of the area on the track, which is in line with our findings from the above analysis.

We changed the text to better explain the method:

"In addition, we estimated the fraction of area covered by the roll-induced NPF. We assumed that the roll-induced NPF events extend much longer along the rolls, which is supported by the aircraft data. This means that for the area fraction we need to estimate what the spacing of the roll-induced NPF events is perpendicular to the direction of the rolls.

If the wind conditions stay the same during the period when the multiple RI-NPF events move over the station, then we can assume that the rolls move over the station at a steady pace. This means that dividing the time that subsequent roll-induced NPF events observed during the same day spent on top of the measurement station by the total time it took for the roll-induced NPF events to move over the site can be used as

an area fraction estimate. According to measurements from the mast, on average the wind conditions during the observations did not change significantly."

Minor remarks L161 – 171 : You could probably use figure 10 to ease the understanding. It would be useful !

Answer: We prepared Figure 1 to illustrate how rolls move over the measurement station perpendicular to the mean wind direction and added it to the text.

L176 : "Organized convection causes the insects to congregate due to the lower BL convergence related to the updraft zones. The number density of insects in the updraft zone is probably further increased by the insects' tendency to resist upward motion to lower temperatures, adiabatic cooling of the rising air." Please rephrase these two sentences. I think there are many ideas in there but need to be further explained. Personally, I don't know anything about insects and this is hard to link it to the dynamics you seemed to describe.

Answer: We made this part more concise.

"Insects tend to congregate at the updraft zones of rolls and they can be seen as clear air echoes by weather radars."

The point is that the weather radar can be used as an effective tool in detecting rolls, since insects are usually present in the air during the summer season.

L 225 : induced not induced

Answer: Fixed.

Figure 8 : These two figures are pretty interesting but I think that you need the reader to understand what you show. So here there are apparently 2 event types : One regional and one induced by roll vortices. Looking at Figure 5b, I see several zones associated with high N3-20. One in the 4 first km north to SMEAR II mast and the second one is further north (12km). According to wind speed direction the one located further north

did not cross the site measurement. So my question is how could you separate the Roll vortices induced NPF from the regional one given the fact that both are located in the same zone ? If you used only the mean geometrical diameter, could you please justify why this is relevant ???

Answer: We know that the high N3-20 zone 4 km north of SMEAR II moved over the station and over the zeppelin's measurement area from south-west to north-east, which is perpendicular to the mean wind direction. This is illustrated in Figure 3 where the location of each concentrated particle stripe observation is put onto a map. The dot size for the zeppelin measurements is proportional to the altitude.

In addition, analysis of wind components measured from the top of the 125 m mast confirms that the rolls were moving in the same direction and at a rate consistent with the RI-NPF observation in Figure 8 B (Figure 4). The rolls were also observed in the weather radar image as parallel lines of higher reflectance (Figure 5).

In Figure 4, vz, vâĹě and vâŁě refer to the vertical wind component, the wind component along the rolls (direction checked from weather radar) and the wind component perpendicular to rolls (positive direction to the left side of the parallel wind component). All components have a low-frequency peak at 4e-4 Hz and the phase differences are consistent with rolls moving to the north-east of the station (see the methods section on detection of roll vortices). 4e-4 Hz is consistent with one roll moving over the station in about 20 minutes.

From the airplane the high N3-20 zone 4 km north of SMEAR II was observed around 10:00 AM, just when it had moved over the field station. The particle region 12 km north of Hyytiälä was observed at the end of the flight (around 11:30 AM). Probably the RI-NPF event moved further north-east with the rolls during the measurement, or it could be that this is a new RI-NPF occurring in an adjacent roll or rolls that previously did not extend all the way to the measurement area. The roll vortices are not perfectly straight continuous structures and undergo change over time.

In Figure 8 the mean geometric diameters were fitted over the growing particle mode and then we chose the time periods when we were measuring the concentrated particle stripes (that is we were measuring the RI-NPF, where the regional NPF was enhanced) and when we were not measuring them (we were only measuring the regional NPF).

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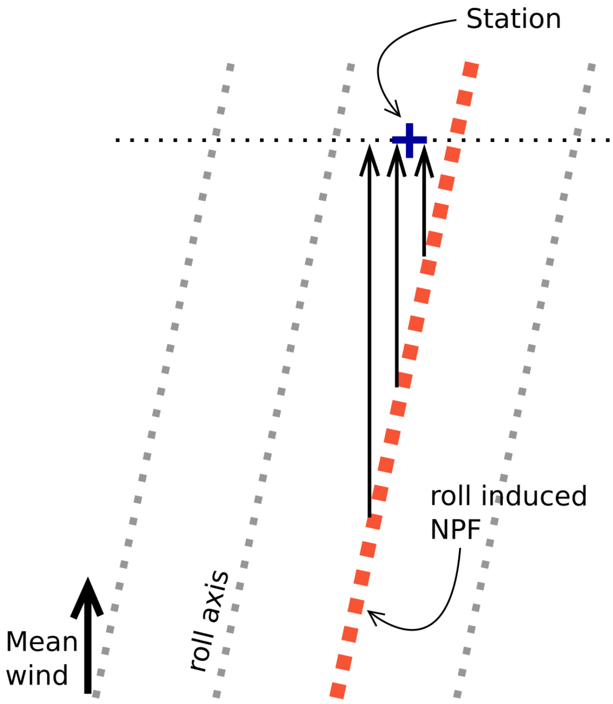


Fig. 1. An illustration of how a difference in the direction of the mean wind and the roll axis causes the rolls (and roll-induced NPF) to move over a stationary point perpendicular to the mean wind.

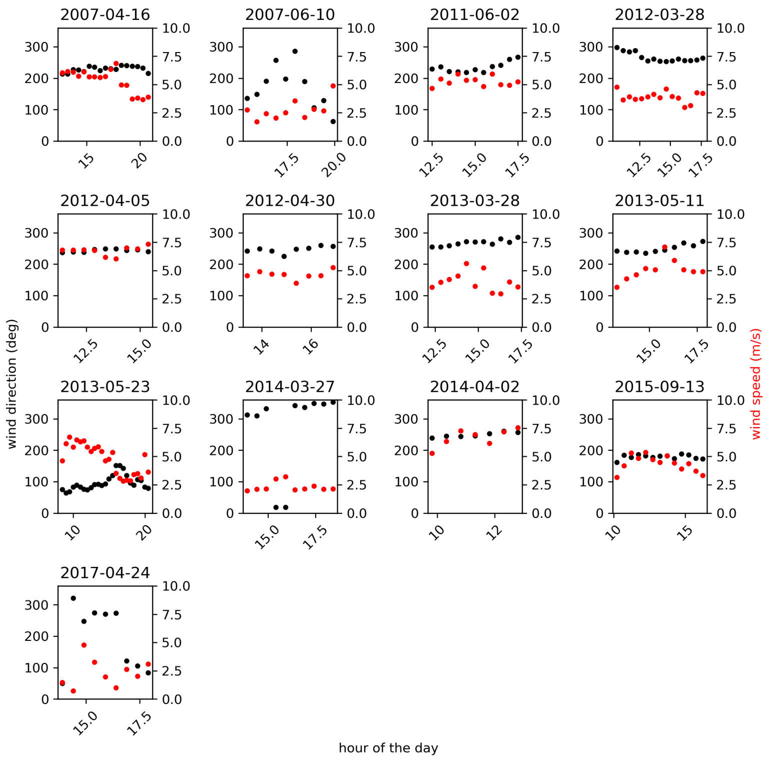
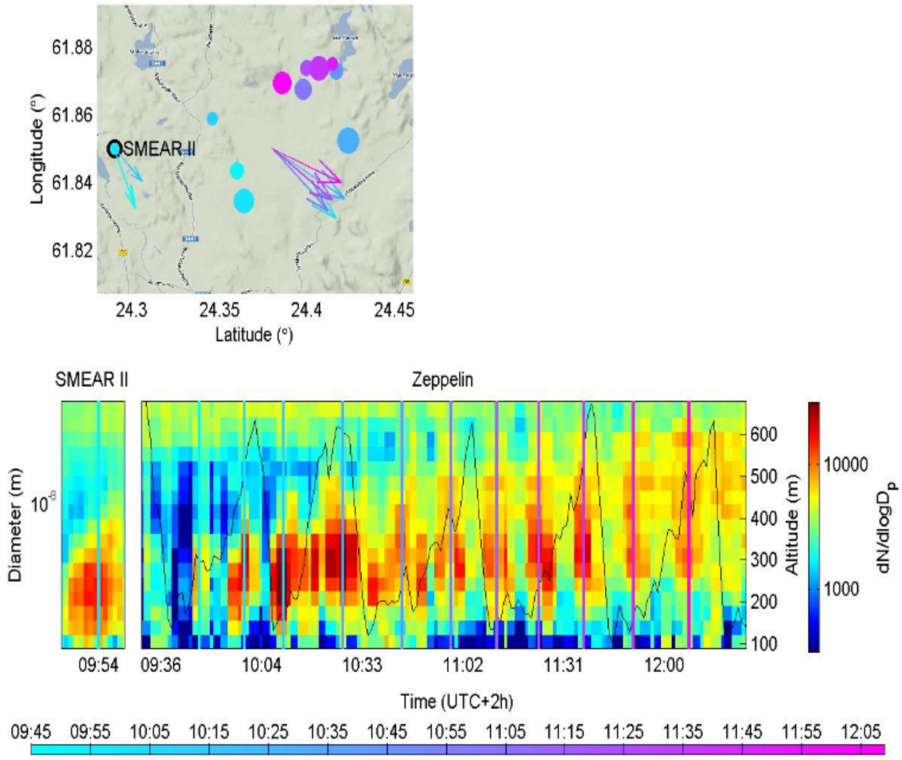
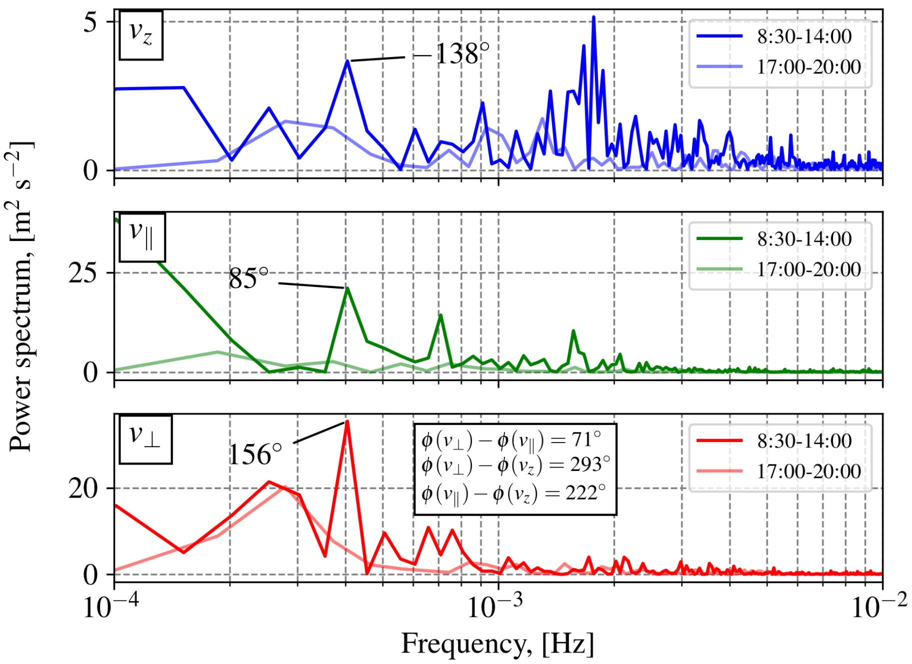


Fig. 2.



61.88
61.86
61.84
61.82
Longitude (°)
SMEAR II
24.3
24.35
24.4
24.45
Latitude (°)
SMEAR II
Zeppelin
Diameter (m)
Altitude (m)
dN/dlogD_p
10000
1000
600
500
400
300
200
100
09:54
09:36
10:04
10:33
11:02
11:31
12:00
Time (UTC+2h)
09:45 09:55 10:05 10:15 10:25 10:35 10:45 10:55 11:05 11:15 11:25 11:35 11:45 11:55 12:05

Fig. 3.



v_z
138°
8:30-14:00
17:00-20:00
$v_{||}$
85°
$v_{\perp}$
156°
$\phi(v_{\perp}) - \phi(v_{||}) = 71°$
$\phi(v_{\perp}) - \phi(v_z) = 293°$
$\phi(v_{||}) - \phi(v_z) = 222°$
Power spectrum, [m^2 s^{-2}]
Frequency, [Hz]

Fig. 4.

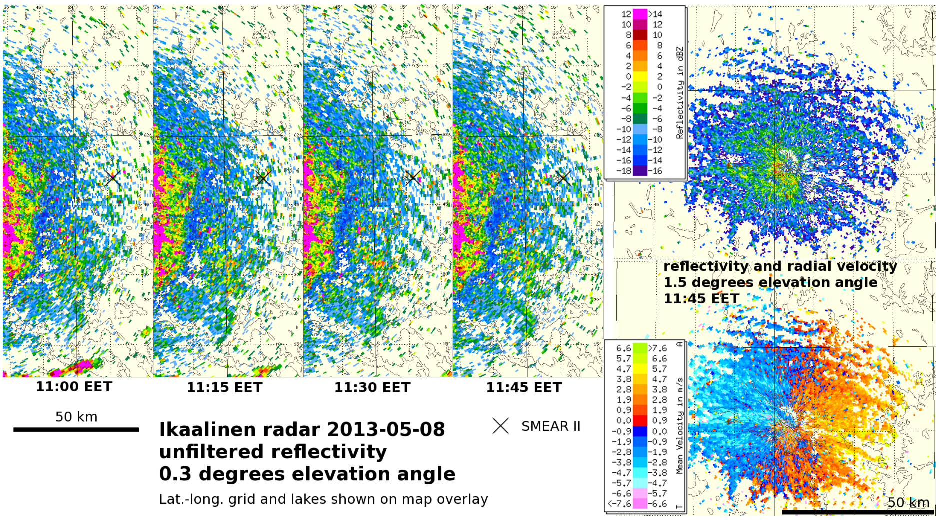

11:00 EET
11:15 EET
11:30 EET
11:45 EET
50 km
Ikaalinen radar 2013-05-08
unfiltered reflectivity
0.3 degrees elevation angle
Lat.-long. grid and lakes shown on map overlay
SMEAR II
Reflectivity in dBZ
reflectivity and radial velocity
1.5 degrees elevation angle
11:45 EET
Mean Velocity in m/s
50 km

Fig. 5.