General

The paper contains interesting lidar observations of virga below mixed-phase clouds and a detailed, however often speculative interpretation of the virga observations. My overall impression is that the paper in its present form is not in a good shape. The manuscript is also quite long and should be shortened.

First of all, the lidar setup (zenith pointing, large receiver FOV of 1 mrad) can lead to very low depolarization ratio values introduced by specular reflection (because of zenith pointing). Furthermore, the relatively large FOV can sensitively influence the depolarization ratio observations via multiple scattering by droplets. Nothing is mentioned to these instrumental influences. The interesting finding of a local maximum of the depolarization ratio around 600 m height is in the near-range of the lidar so that systematic instrumental effects cannot be excluded. I mean, the overlap profile (incomplete overlap between laser beam and receiver FOV in the near range) is usually not well known and can vary with time (and diurnal cycle). All this causes artefacts. Nothing is mentioned to this problem.

The observations concentrate on the virga zone below the main altocumulus layers. More precise, the investigation is mainly focusing on the part of the virga from the 0°C level towards the surface. Nothing is said, why the ice crystals can survive such a long time at heights below the 0°C height level. Obviously, the melting crystals cool the surrounding air and keep the temperatures close to 0°C, even up to 1 km below the 0°C height level where the radiosonde (obviously ascending outside of virga) indicated temperatures up to 6°C.

Nothing is mentioned, why raindrops lead to enhanced depolarization ratios! Maybe I overlooked it. Is that because the shapes of the rain drops are no longer spherical during falling, the shape is like the one of pears with the flat side in falling direction…? Please explain!

Nothing is mentioned about the impact of multiple scattering in layers with high droplet concentration. Maybe the raindrop maximum at 600 m is just caused by multiple scattering by numerous small droplets and not by ‘a few big’, nonspherical rain drops. In the paper, there are no profiles of particle backscatter and extinction coefficients. So, there is no opportunity to conclude on the multiple scattering effect. I was puzzled by the fact that the depolarization maximum was always around 600 m height, why not at 800 or 400 or at 1000~m height? I speculate that may have to do with systematic instrumental problems in the near-range of the lidar.

The most important point of concern is the following: I have a severe problem with the ‘theory’ of the authors how ice crystals are nucleated via heterogeneous ice nucleation. The authors believe that large (1mm in size) droplets fall out of an altocumulus layer and then they immediately freeze right below cloud base. I have never heart about such an ice nucleation process. Furthermore, I asked myself: How can 1 mm droplets form in an altocumulus cloud layer where typical droplet sizes are 10-20µm …)

The established, common ‘theory’ of ice nucleation in altocumulus layers is the following:

Ice nucleation (dominated by immersion freezing for temperatures >-25°C) starts at the coldest point of the cloud, i.e., at cloud top. At cloud top the probability of ice nucleation is largest because ice nucleation is a strong function of temperature. The probability increases by an order of magnitude when temperature decreases by 5K. Thus in cases of 500-600m thick cloud layers the ice nucleation probability at cloud top is an order of magnitude higher than at cloud base.

So, most probably first ice crystals nucleate at cloud top via immersion freezing (liquid water droplets freeze), in the liquid-water droplet environment of the altocumulus layer. Then, in the next step, these ice crystals grow fast and immediately start falling. They grow to about 100µm within 60-120s! During falling they continuously grow as long as ice supersaturation is given. When ice subsaturation levels are reached the ice crystals start to shrink and to evaporate. When entering the air mass below the 0°C height level the crystals start to melt but during this process they consume so much energy that they are able to keep the temperatures of the ambient air close to 0°C (in your cases down to almost 1000m below the 0°C height level) although the radiosonde may have measured 6°C.

Finally, the manuscript tells us nothing about the true ice nucleation. There is no information about the altocumulus layer (e.g. cloud top height and temperature), there is no information and discussion about potential seeder/feeder effects (no information about ice cloud layers above the altocumulus), and there is no information about secondary ice formation (triggered by the Hallett Mossop effect) dominating in the height range in which the temperatures are between -5 and -8°C. All this influences the virga properties that are exhaustingly discussed in the paper. It should be clearly said in the introduction that the ice nucleating processes are not covered by the paper. The paper exclusively focus on the virga.

Many aspects mentioned above (but not discussed in the manuscript) triggered many questions! Please do not misunderstand me! I like the approach and want to help to improve the paper. I know that readers appreciate if the authors are critical to their own observations!

Major revisions are needed.

<u>Details:</u>

P1, l18: surface rainfall…..? is not just self-explaining: better use: precipitation that reached the surface. You may define 'surface rain' in the introduction, but I personally do not like such wording.

P1, l19: parent cloud …? Is also not self-explaining: better: …falling out of a shallow mixed-phase cloud layer. Why do we need such a wording? And in the case of seeding from above, then we have grandparent clouds…? I would just call or denote such a clouds … shallow cloud layer or altocumulus layer.

Please change this (surface rain, parent cloud) throughout the article.

P1, l55-56: I think your hypothesis is wrong: …suggesting that most supercooled liquid drops falling out of parent clouds rapidly froze into ice crystals on the tops of virga. See my explanation above.

P3,l83: The lidar is pointing exactly vertically! That means you may have very low depolarization ratios from specular reflection by falling, oriented ice crystals. And layers with specular reflection may be misclassified as liquid-droplet layers.

P3, l84: The receiver field of view is 1 mrad. This means you may have considerable problems with multiple scattering. Multiple scattering in environments with droplets can cause significantly enhanced depolarization ratios. And these high depolarization ratios may be interpreted as ice crystals or as big rain drops. So, there is room for ambiguous interpretation.

That should be commented (zenith pointing, specular reflection, multiple scattering, enhanced depolarization, overlap impact, signal gluing impact).

P4, l93: Please state in which height range gluing of signal profiles is performed (for the cases discussed in Sect. 3.)

P4, l104: What about multiple scattering in water-droplet layers, and corresponding increase in depolarization ratios? Please comment on that!

P4, l111: Below the dark band, enhanced depolarization ratio indicates rain drops. Please explain why? The shape of rain drops during falling deviates from the perfect spherical form? They look like pears? With the flat surface into the falling direction? Please comment on that.

P5, l144: An explanation is need why ice crystals can survive as ice crystals over a distance of 600 m below the height of 0°C level, i.e., for about 1200 s (20 min) when falling speed is high with 50 cm/s. To my opinion, cooling of the surrounding air during evaporation and melting… is the reason.

P6, l 171, 172, 173: parent cloud… I do not like this wording. Furthermore, you do not know whether the crystals were formed in that cloud layer. Maybe ice crystals from above seeded the cloud. So, please be careful with the argumentation. Limit the argumentation to topics and facts that were observed.

P6, Sect 3.3.1: I found this section is too long.

P7, Sect 3.1.2: Check to what extent multiple scattering effects and specular reflection could have influenced the observations.

P8, l218: Why is the volume depol ratio not close to 0.01? Maybe be because of multiple scattering. The paper does not contain any backscatter and extinction coefficients. So, I have no idea whether multiple scattering could be problem or not.

P8, l229-230: How can droplets evaporate and at the same time others grow….?

P8, l235: ..Peaks at 0.1-0.4? …you mean 0.1-0.14? Why is the rain depol peak always at 600 m. Can we have an estimate for the backscatter and the extinction coefficient? Maybe multiple scattering had an influence!

P9, l240-l244: To my opinion, this is speculation. …should be avoided.

P9, l269: Large values of the range - corrected signal coinciding with low depol ratio! That could have been caused by specular reflection by a few falling and oriented ice crystals. One should discuss such influences.

P9, l279-295: What about seeding by clouds higher up. You have no information about all this. There is so much speculation here. Please avoid that. Keep the discussion short.

P10, l297-308: Here you present again the erroneous ice nucleation theory! You should at least also present the established one (in the absence of seeding from above, ice crystals nucleate at cloud top, grow fast and start falling through the cloudoand become large before they leave the main cloud layer and show up in the virga as quite large crystals that may further grow as long a supersaturation over ice is given.

The entire Sect. 3.1.2 is very long and contains many speculative statements. The entire section should be shortened and should be based on what was observed.

P11, Sect 3.2: Another case, again depol peak caused by rain at 600 m! Why always at 600 m height? Should be clarified and discussed.

Speculation about break up processes, occurrence of ensembles of small and large droplets, collision-coalescence effects… all this sounds convincing, but is that the truth? … As long as the role of multiple scattering is not clarified, the discussion is not trustworthy.

Sect. 3.2.1: There is no information about the clouds, the ice nucleation processes, potential secondary ice nucleation processes, seeding effects, nothing. That should be emphasized to keep the entire discussion short. You should concentrate on the virga, because more is not possible. That must be clearly stated in the manuscript.

P12, l369: Ice crystals detected 960m below 0°C height level…. Again, how can they survive? You have to give a reason!

Sect. 3.3.2: ..again, what is the potential impact of multiple scattering?

Figures:

Figure 1: The colored figures should be shown from 27 Dec, 00:00 LT to 28 Dec 16 LT, and probably up to 7 km only to see the necessary details. In the present form, the figure is almost useless.

Figure 3: Is cloud top at 4 km height? We do not know! The decreased depolarization ratio from 3.6 to 4 km could be caused by specular reflection? Who knows! The decrease of the depolarization ratio below the local maximum at 600 m height may be an instrumental effect (bias) because the observations are performed in the near-range of the lidar where nothing is well defined. Please comment on that! So break up of rain droplets is speculation. Also evaporation could have started and the droplets got smaller and spherical again…

Figure 4: Again the overlap problems in the lowest 500 m! Can we trust the depolarization ratio values at heights below 500 m?

Figure 5: Again a layer with low depolarization ratio around 4.5 km height together with large signal! Is that the liquid cloud layer? Or are there falling, oriented crystals producing specular reflection? This time no enhanced depolarization ratio around 600 m height, no big raindrops? This case demonstrates that there is slight decrease of the depolarization ratio from 250 m to 1 km. This is probably the background depol height profile in the absence of any multiple scattering effect.

Figure 6: Bad quality, like Figure 1: What do you want to show. There is almost nothing to see!

Figure 8: Again, one sees the high depolarization ratios indicating ice crystals, one does not see the main cloud layer. One does not know whether the cloud was seeded by higher clouds. One does not see anything. Except the virga of ice crystals, and then the drop in the depolarization ratio, when the crystals melt. Around 600 m again, rain droplets! Always around 600 m! What is the possible reason that the depolarization ratio maximum is always at about 600m. Maybe caused by multiple scattering?

Figure 9 again: Depolarization maximum at 600 m! Why always at 600 m?

Again, please use all of my comments as a constructive contribution to improve the paper. The topic of the article is interesting and deserves publication!