Review of

How frequent is natural cloud seeding over Switzerland?

by Proske et al.

General comment:
This study develops a method to investigate occurrence frequencies of natural cloud seeding based on DARDAR satellite products. The region of Switzerland is used here as an example, but it is emphasized that the method can be applied to other areas as well. Two seeding cases are separated in the study, the first represent cirrus above other clouds with the -35◦C isotherm in between, while in the second the cirrus are part of thicker clouds with the -35◦C isotherm inside. Topographical, day/night and seasonal variations of the frequencies of seeding situations are analyzed. Further, sublimation calculations for the seeder ice crystals are performed showing the part that do not sublimate before reaching the lower feeder cloud. In addition, a method to identify in-situ and liquid origin cirrus clouds based on the DARDAR mean effective ice particle size is presented.
The topic of the paper is well suited for ACP and also is of high scientific interest. The methods used are scientifically sound and the results are robust and provide new insights into the field. Thus I recommend the paper for publication in ACP with minor changes. Below you find a number of comments/recommendations to consider for the final version of the paper.

Specific comments:

1) Figure 1 (and elsewhere in the text): I guess that the indices ‚i‘ and ‚l‘ in Δzil mean ‚ice‘ and ‚liquid‘. To my opinion it would be more consistent to change the ‚l‘ to ‚m‘, because the corresponding clouds are termed mixed-phase clouds and could be ice, liquid or mixed.

2) Page 2, line 50 ff: You might take into account to add Wolf et al. (2018), ACP, to the listed references (here and later). They sorted ice particle shapes and size distributions according to liquid and in-situ origin cirrus clouds.

Wolf, V., Kuhn, T., Milz, M., Voelger, P., Krämer, M., and Rolf, C.: Arctic ice clouds over northern Sweden: microphysical properties studied with the Balloon-borne Ice Cloud particle Imager B-ICI, Atmos. Chem. Phys., 18, 17371–17386, https://doi.org/10.5194/acp-18-17371-2018, 2018.

3) Page 2, lines 54: ‚ *… ice can only be formed via heterogeneous nucleation on ice nucleating particles (Kanji et al., 2017).‘*

I suggest to change this to ‚ *… ice can only be formed via heterogeneous nucleation on ice nucleating particles (e.g. Kanji et al., 2017, and references therein).‘* because this has been known for a long time and Kanji et al. is a recent overview paper.

4) Page 2, line 56 ff: ‚ *… the Wegener-Bergeron-Findeisen process, where ice crystals grow at the expense of liquid droplets, when the saturation ratio is between saturation with respect to water and ice ...‘*

The WBF process is where the water vapor saturation ratio is between subsaturation with respect to water and supersaturation with respect to ice ($S_w < 1$ and $S_i > 1$).

5) Page 3, line 58 ff: You might consider to add the recent article of Korolev and Leisner (2020), ACP, to the references of secondary ice production:

Korolev, A. and Leisner, T.: Review of experimental studies of secondary ice production, Atmos. Chem. Phys., 20, 11767–11797, https://doi.org/10.5194/acp-20-11767-2020, 2020.

6) Page 5, line 101 ff: *‚The two satellites are designed for their data to be combined: the lidar on CALIPSO is able to identify the thin upper layers of cirrus clouds that the radar on CloudSat misses (Winker et al., 2010), while the latter is able to look through thick clouds where the lidar beam is attenuated.‘*

You mention the lidar (thin) and radar (thick) clouds, but where/what kind are the clouds from the visible camera and a three-channel infrared radiometer noted before? If all instruments are combined, does the DARDAR product cover the whole range of clouds or are the thinnest/thickest missed ? Can you give an estimate here on the percentag eof missed clouds ? This might be important in the especially for thin cirrus, yes ?

7) Page 5, line 119-120: *‚… DARDAR categories 1, 2, 3 and 4 (ice, ice + supercooled, liquid> −35◦C and supercooled) ...‘* These are only 3 categories, liquid > −35 ◦ C and supercooled are the same.

8) Page 6, line 124-126: *‚… liquid cloud droplets have been found to supercool to −35 ◦ C before freezing homogeneously (Murray et al., 2010; Herbert et al., 2015). The temperature for homogeneous freezing of water droplets is also often given as −38 ◦C (Kanji et al., 2017).‘*

There are earlier references for the existence of supercooled drops and also for the temperature of homogeneous drop freezing … e.g. Pruppacher & Klett ?

9) Page 7, line 130: *‚… air density, air temperature and the relative humidity determine the ice crystal sublimation rate and fall velocity.‘*

Aren‘t the the ice crystal size and the vertical velocity of the air also important for the fall velocity? In line 143 you metion that you use reff...

10) Page 7, line 141-142: *‚Relative humidity and temperature were therefore taken from ERA5 reanalysis data...‘*

What about the quality of ERA5 RH in the cirrus temperature range? Isn‘t there a dry bias ?

11) Page 9, a) line 190-196: The percentages stated here, the numbers in the caption of Figure 3 and the graphs shown in Figure 3 b seems not to be consistent. Maybe I misunderstand something, but then it would be good to better explain.

b) line 197: *‚In 56 % of these cases (18 % in total), Δz_{il} is smaller than 100 m.‘*

Shouldn‘t these numbers be visible in Figure 3 b (see also previous comment) ? I see the 18 % for cloud free conditions, but the percentage of cirrus clouds with Δz_{il} smaller than 100 m is ~41 %, not 56 % ?

12) Page 11, line 219: ‚*Our results for multi-layer cloud occurrence frequency are similar to but smaller than the ones given in the literature.*‘

‚Similar to but smaller than‘ is hardly possible …
Also, for convenience for the reader, please repeat the number of ‚our results for multi-layer cloud occurrence frequency‘ so that there is a directly comparison of the numbers in the text.

13) Table 3: The sum of the first two numbers in the first row (18 + 13 = 31 %, all seasons, all day, whole domain) should be the same as stated on page 9, line 194, yes ?
‚*32 % of the measurements contain both a cirrus and a mixed-phase cloud simultaneously.*‘

This number could be repeated for the convenice of the readers.

14) Page 11, line 248: ‚*Table 3 also contains the results of a climatological analysis of* Δ*zil.*‘

I recommend to say ‚seasonal‘ instaed of ‚climatological‘.

15) Page 11, line 249: ‚*The relative increase is similar …*‘

More clear is: The relative increase of the fractions of Δzil is similar …

16) Page 12, line 250-252: ‚*There is no noticeable difference in frequencies during day and night.*‘

There are noticeable differences between day and night (winter), and also differences between the summer and winter days and nights. Please clarify.

17) Page 12, line 266: You might cite here also Krämer et al. (2000), ACP.

Krämer, M., Rolf, C., Spelten, N., Afchine, A., Fahey, D., Jensen, E., Khaykin, S., Kuhn, T., Lawson, P., Lykov, A., Pan, L. L., Riese, M., Rollins, A., Stroh, F., Thornberry, T., Wolf, V., Woods, S., Spichtinger, P., Quaas, J., and Sourdeval, O.: A microphysics guide to cirrus – Part 2: Climatologies of clouds and humidity from observations, Atmos. Chem. Phys., 20, 12569–12608, https://doi.org/10.5194/acp-20-12569-2020, 2020.

18) Page 13, line 276-277: ‚ … *freeze … predominantly homogeneously at temperatures below−35◦C.*‘

More correct: ‚… at temperatures around −35 ◦ C.‘

19) Page 13, line 296 ff: ‚*This suggests that the influence of the liquid origin on the microphysical properties of the cirrus clouds is lost once the clouds are lifted, for example because the large ice crystals sediment out, or that lifting of entire clouds above the −35 ◦C isotherm hardly ever occurs. Wernli et al. (2016), who investigated the frequency of the formation pathways in a trajectory-based analysis, already noted that ice crystal sedimentation and cloud turbulence could “potentially alter the local cirrus characteristics and ‘confuse’ the simple categorization”. This seems to be the case with the data presented here, or otherwise the data suggests that liquid origin clouds are hardly ever lifted entirely above the −35 ◦ C isotherm.*‘

This is a very good and sound discussion and Figure 4 provides new insights in the characteristics of liquid and in-situ origin cirrus. I like to add here that I think that the latter suggestion ‚*liquid origin clouds are hardly ever lifted entirely above the −35 ◦ C isotherm.*‘ is more likely. It is true that especially ice crystal sedimentation alter the characteristics of liquid origin clouds, but not to such an extent that it completely disappears, but the influence decreases with increasing altitude, because the altitude the ice crystals reach depends on their size and the updraft, i.e. the higher the altitude the smaller the largest ice crystals (see also Luebke et al. 2016 and Krämer et al., 2020). But such an effect is nearly not visible in Figure 4c. Another argument that liquid origin clouds are hardly ever lifted entirely above the $-35{\circ}$C isotherm is that they appear mostly in meteorological systems with large vertical extents, namely in warm conveyor belts or convection.

20) Page 16, line 325: ‚*Figure 5c shows that ice crystals do not survive the fall from cirrus cloud base heights above 11 km.‘*

… which correpsonds to the temperature limit of $-65{\circ}$C from Figure 5a.

21) Page 18, line 377-378: *‚... where they act as seeds for the glaciation of clouds.‘* … in case they fall in an environment that is subsaturated with respect to water – otherwise (supersaturated) they would grow.
By the way: did you consider the updraft in the sublimation calculations? Maybe a point to mention at the appropriate place in the paper.

22) Page 18, line 390: ‚*In sublimations calculations ...‘* Remove the latter ‚s‘ in sublimations.