Review of

Changes of cirrus cloud properties and occurrence over Europe during the COVID-19 caused air traffic reduction

Qiang Li and Silke Groß

General: Based on CALIPSO satellite lidar measurements, changes of cirrus cloud properties and occurrence caused by the air traffic reduction in March-April 2020 are investigated in this study. For this purpose, the meteorological situations of March-April of previous years were first analyzed in order to find years that are comparable to 2020, so that differences found between these years and 2020 can be clearly atrributed to the reduced air traffic. The findings presented are reduced cirrus cloud occurrences and thicknesses and also smaller mean values of cirrus linear depolarization ratio, especially at temperatures colder than T < -50◦ C.

The study fits well into the scope of ACP, is very interesting and of high relevance, especially from the perspective of ongoing anthropogenic impact on climate. The manuscript is clearly structured and fluently written, though unfortunately the phrasing is confusing at times, to my feeling due to language difficulties. Therefore, I recommend a language check.

Regarding the methods used in the study, I regret to say that I do not consider them to be scientifically mature. First, the physical understanding of cirrus and contrail formation seems to need some improvement (see comments in the introduction). Next, the analysis of the similarity of the years: it is performed for March to April, but in the following analysis March and April are treated seperately. I would recommend an analysis as in Figure 1 for both months and then a separate choice of years similar to 2020.
Here are some more examples of what I mean by a not mature analysis (more explanations are given in the specific comments): the years similar to 2020 are defined, but in the analysis one other year is used; Table 2 is not very informative; the estimate of the overall reduction in OR (cirrus occurrence rate) is too high, etc.
However, my major problem with the paper are the further analyzes and interpretations. First, the OR for all cirrus are considered. But when analyzing the PLDR (particle linear depolarization ratio), two temperature ranges are introduced, namely the one in which contrails can develop (at temperatures below about -50◦ C where the Schmidt- Appleman criterion is fulfilled) and the other at warmer temperatures, i.e. where the influence of aviation is at the most very small, but most likely not existing. I would say that if the reduction in cirrus is caused by air traffic, then this should only be seen in the cold temperatures, for both OR and PLDR. If the reduction is to be found at all altitudes (which seems to be the case from what I see in the presented material), this points to another reason. I can imagine that using years to compare with 2020 for March and April seperately would give clearer results. I also suggest to perform the analysis of both OR and PLDR for the two temperature ranges.

In summary, I would strongly encourage the authors to repeat the analysis by taking into account the recommendations outlined above and in the specific comments to present robust and important results on the aviation influence on cirrus occurrence and properties. After that, the article should be published in ACP.

The specific comments are organized as follows: Text from the manuscript ist shown in quotation marks, the comments are without.

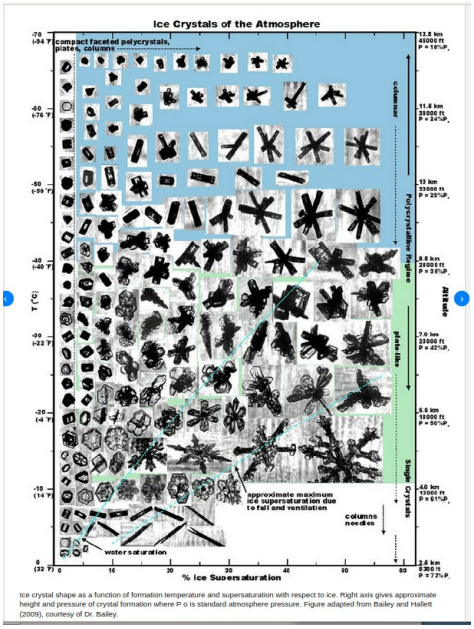
Specifc comments:

1) Page 1, lines 20-21:
‚... ice crystals in air form and grow as a function of temperature and ice supersaturation ...'

The major driver is the vertical velocity.

2) Page 1, lines 20-21: ‚… there is a general trend toward larger morphological complexity as the supersaturation increases as well as the temperature drops...'

The morphological complexity decreases when the temperature drops. The colder it is, the more the ice particles tend towards spherical shapes, as there is not enough water available to form more complex shapes (see e.g. Lawson et al., 2019, JGR, Figure 22) or https://www.researchgate.net/figure/Ice-crystal-shape-as-a-function-of-formation-temperature-and-supersaturation-with-respect_fig11_221917565



Ice crystal shape as a function of formation temperature and supersaturation with respect to ice. Right axis gives approximate height and pressure of crystal formation where P o is standard atmosphere pressure. Figure adapted from Bailey and Hallett (2009), courtesy of Dr. Bailey.

3) Page 2, lines 5-6: ‚According to theoretical ray-tracing simulations of laser backscatter depolarization (e.g. Takano and Liou, 1989), the geometric properties (shape and composition) of aerosols and ice crystals...'

Composition is not a geometric property.

4) Page 2, lines 16-18: '… to study the characteristics of ice clouds (e.g. Schotland et al., 1971; Sassen, 1991; Ansmann et al., 2003; Groß et al., 2012; Urbanek et al., 2018).

Please add here: Rolf et al. (2012) and Kienast-Sjögren et al. (2016).

Rolf, C., Krämer, M., Schiller, C., Hildebrandt, M., and Riese, M.: Lidar observation and model simulation of a volcanic-ash-induced cirrus cloud during the Eyjafjallajökull eruption, Atmos. Chem. Phys., 12, 10281–10294, https://doi.org/10.5194/acp-12-10281-2012, 2012.

Kienast-Sjögren, E., Rolf, C., Seifert, P., Krieger, U. K., Luo, B. P., Krämer, M., and Peter, T.: Climatological and radiative properties of midlatitude cirrus clouds derived by automatic evaluation of lidar measurements, Atmos. Chem. Phys., 16, 7605–7621, https://doi.org/10.5194/acp-16-7605-2016, 2016.

5) Page 2, lines 31-32: 'This region was also used in a recent study by Schumann et al. (2021) to investigate air traffic and contrail changes during COVID-19.'

Better (because regions cannot be used ...):
Recently, Schumann et al. (2021) investigated air traffic and contrail changes during COVID-19 in the same region.

6) Page 2, lines 33-34: 'To largely exclude the effect of meteorological conditions on cirrus occurrence and cirrus properties in our study, we extended this study to a larger ...'

At this point, it is not clear to the reader what your study is about …. this would have to be explained beforehand. I suggest to move the next paragraph ('During the COVID-19 pandemic aviation ...') before the sentence mentioned above ('This region was also used ...').
Also, briefly explain which methods are applied by Schumann et al. (2021) to clearly show the differences/similarities of the two studies.

7) Page 3, lines 4-5: '~~Since~~ In May/June 2020 aviation shows ...'

8) Page 5, lines 11-12: 'Cirrus ice crystals generally form ~~in the outflow frontal of the deep convections and~~ in ~~the~~ regions of ascending motions (producing the necessary supersaturation ~~of~~ over ice)~~, or they form~~ by ice nucleation on aerosol particles in the upper troposphere (in-situ origin cirrus), or they appear in the cold outflow of frontal systems or convection as frozen cloud droplets that had formed at lower altitudes and warmer temperatures (liquid origin cirrus).'

The sentence was confusing, see the changes.

9) Page 5, lines 12-13: 'Aircraft emission of aerosols can lead to the formation of contrails depending on the surrounding meteorological conditions (including temperature, pressure, and humidity) ~~of~~ at the flight track.'

The contrails form on the aerosols emitted by aircraft, but not these aerosols lead to the formation, but the water vapor from the aircraft together with the surrounding meteorological conditions.

10) Page 5, lines 15-16: 'In addition, the aerosols might also change the optical properties of naturally occurring cirrus clouds.'

Not the aerosols, but the appearing contrail or contrail-cirrus ice crystals might change the optical properties of naturally occurring cirrus clouds.

11) Page 6, lines 1-2: 'However, looking at the year to year variability for the time period May-August ...'
It would be good to show this, if not in the main article, then in an appendix or supplementary material.

12) Page 6, lines 3-5: **'**For the relative humidity we found that the relative humidity for those ranges ...'
(a) Avoid repetition of 'relative humidity'
(b) What ranges do you mean here ?
(c) Is this sentence at the right place here? The text continues with the
'The largest agreement of the general situation in March/April 2020 ...',
Which general situation do you mean? The relative humidity is not shown … or do you refer to Figure 1?
(d) You continue with
'Looking at the median and mean values of the general distribution ...'
Which 'general distribution' do you mean here ? Relative humidity ?
Please clearly indicate what you describe here and, if it is relative humidity, it would be also good to show a figure comparable to Figure 1, if not in the main article, then in an appendix or supplementary material.

13) Page 6, lines 10-11: Only now you mention Figure 2, containing information on relative humidity, which would be needed already above (see last comment):
'The derived temperature and humidity along with their median and mean values in April are shown in Figure 2.'
But, why only April and not March-April is shown here ?
In lines 20-21 you mention again that 'So, we use CALIPSO data of March and April ...'
Or, better, show both months. And also, analyze both month seperately in Fig. 1 (see general comments).

Same question for Table 2 (note also that 'Medain' should be 'Median' in the temperature column). And, Table 2 is redundant to Figure 2.

It would be much more infomative (and in the following for the reader easier to follow the discussion) to list the deviation of the years with respect to 2020 and then highlight the choice of the years for comparison with 2020. This choice can also be noted in the Table caption.

2014	***2015***	2016	2017	2018	***2019***	
0.542	***-0.264***	1.827	-1.100	0.895	***0.197***	median T (C), difference to 2020

14) Page 6, line 16: '… a larger spread as found for the relative humidity. ~~However, t~~ The values differ ...'

15) Page 6, line 20: ' … we mainly focus our analysis to the years 2014, 2017, 2019 and 2020.'
I think you mean 2014, **2015** (not 2017), 2019 and 2020, yes (see line 17)?

2017 is quite different to 2020 in median T (see Table above), however, in Figures 3 (and following Figures) also 2017 is mentioned, though from Table 2 and line 17 2015 is closer to 2020 ? Is this a typo or did you analyze 2017 ? If this is the case, I recommend to redo the analyzes for the year 2015.

16) Page 7, lines 7-8: 'Even if we extend our examination (not shown) to the year~~s~~ 2015 … '

?? See previous comment – 2015 is quite close to 2020.

17) Page 7, line 9: ‘And even for 2018 ….’

The largest difference of median T (and mean relative humidity) to 2020 is in 2016.

18) Page 7, lines 16-17: ‘The cirrus OR for a geometrical thickness of 2.0 km shows only minor reduction of overall about 4% compared to more than 5% of the reference years.’

Calculating the percentage reduction of the geometrical thickness categories results in ~ 20 – 25 % for all categories; I do not see a minor reduction for geometrical thickness of 2.0 km.

> 0.1 km 19.4 % (from 31% to 25%)
> 0.3 km 21.4 % (from 28% to 22%)
> 1.0 km 25.0 % (from 16% to 12%)
> 2.0 km 20.0 % (from 5% to 4%)

19) Page 7, lines 18-19: ‘From the current analysis, it is striking to note that the cirrus OR in April 2020 are smaller by a factor of 30% ...’

From the numbers in Table 3 it would be smaller than ~ 20 – 30% (see also previous comment). I recommend to also cahnge that in the abstract and other places in the manuscript.

20) Page 7, lines 18-19: ‘The average thickness of cirrus clouds in April 2020, however, is significantly smaller and reduced to only 1.18 km.’

Do you have an explanation as to why that is ?

21) Page 8, line 12: 3.2 Cirrus ~~P~~particle linear depolarization ratio

22) Page 8, line 24: ‘T = -50◦ C is one of the threshold conditions for contrail formation ...’

If there is no contrail formation at warmer tempratures, then these clouds are most likely not influenced by aviation. I would think that then it would make sense to do the previous analyzes (Section 3.1) in addition also for T < -50◦ C, as you do it now for the PLDR, yes ? Otherwise possible effects from the warmer natural cirrus are mixed in the those of contrail cirrus.

I also recommend to show the temperature (maybe median temperature at altitude intervals) on the right y-axis in Figure 3, left panel, to see the region of aviation influence.

23) Page 9, line 2: condistions = conditions

24) Page 9, line 2: ‘We also compare the vertical profiles of the PLDR median (Figure 7 - solid lines) along with the corresponding 20% and 80% percentiles (dashed lines) for the height range between 8 and 12.3 km. These are the typical cruising altitudes for passenger and cargo aircrafts. ‘

In Figure 7, I also recommend to introduce the median temperature at the right y-axis. In addition, the lower altitides should also be shown to see the PDLR below the cruising altitude.

From Figure 6, it is seen that the median PDLR at warmer temperatures is also lower in 2020 than in the other years. Since this is below the main cruising altitudes, does that not indicate that the natural cirrus clouds will also be reduced in 2020, perhaps due to the meteorology? That should be discussed here. (see also next comment)

25) Page 9, line 24 ff: Test of the significance of differences between the cirrus PLDR in different years: I guess that you apply the test to the whole temperature range, yes ? Given the differences of the PLDR in the two ranges (<> -50◦ C) discussed in the previous section, I recommend to carry out the tests for the two regions seperately, especially because the influence of aviation should be visible in particular at the colder temperatures as this is the place where contrail / cotrail cirrus can form.
In case you would find a difference at warmer temperatures, that would be an indication of a reason other than aviation. (see also last comment)

Tables 4 and 5: Extend the captions, for example explain which parameter the test was applied to and what the meaning of p and h is.

26) Page 11, line 6 ff: '... the occurrence rates (OR) of cirrus clouds over these three regions show that on average the cirrus clouds occurred more frequently over Europe and USA than over China. ...'

The OR of cirrus clouds over these three regions are discussed, but not shown. I recommend to present plots in an Appendix or Supplementary material.

27) Page 11- 12: PLDR in different regions: Are the meteorological conditions in the compared years also comparable over USA and China ?

28) Page 12, lines 19-20: 'Due to the westerly jet stream, aerosol source is dominated by clean marine for the north Atlantic and European region and for the north American region, whereas by continental and dust for the Chinese region.'

I don't see a connection between this sentence and the previous conclusions ? … I would delete it.

29) Figure 1: Please indicate the unit in the color bar.

30) Figure 5: Please include a color bar.
Caption: '… more red area indicating larger number densities.' Please check the language.