<u>**Response to the Editor**</u>

It seems to me that you have responded thoroughly to the referees and I have decided that it is not necessary to ask them to provide further reports on the paper prior to publication. However, there are some small further points of clarification that I recommend before publication:

Reply: Thank you very much for your positive response. We have carefully gone through your suggestions and incorporated the changes into the revised manuscript.

1) Generally in the responses I found it difficult to identify where you had made changes to the paper and where you had simply provided a response to the referee. Since your responses will be part of the material available with the paper, please can you make it explicit, particularly with regard to substantial points, when you have changed the paper. I also encourage you to think again about whether a very modest change to the paper (in addition to the response to the referee) would be useful to the reader. This is particular the case for Figures -- some figures provided as part of the responses are included in the revised paper -- some (I think) are not.

Reply: Thank you for your kind suggestions. We have mentioned now the changes made in the revised manuscript. There are six figures (R1-R6) shown in the Response to the Reviewers. Figure R6 is kept as Figure 9 in the main manuscript. Figures R1-R4 are kept in the supplementary Figures S5, S3, S2, S1, respectively. Figure R4 is just shown to explain the Reviewer's Comment.

2) A particular example is with respect to 'persistence' -- one of the points raised by Referee 1. You have given some concrete information on that in your response but I cannot see any mention of that in the revised paper. Please consider briefly mentioning it.

Reply: We have added this information in the revised manuscript.

3) Re Figure 4 -- Referee 2 asked for a colour code -- your reply is that the colours are to allow individual lines to be distinguished -- the colour of a particular line has no meaning. It took me a while to work that out. I recommend that you say something a bit more explicit in the caption -- e.g.'The colours have no specific meaning but are simply used to make it easier to distinguish between different days.' -- that will avoid reader confusion.

Reply: Thank you for the suggestion. We have corrected it in the revised manuscript.

4) Referee 2 commented on lines 347-348 --in your response you say 'We mean here that the cirrus clouds occurrence presented from 15:00 IST on day one to 11:00 IST on day two.' -- but I can't see any mention of 15:00/11:00 in the text. The Referee also refers to 347-348 in their comment on 623-624 -- i.e. 'Though MPL detection is limited to nocturnal cirrus clouds, it has captured the diurnal pattern in the occurrence of the single and multiple layered cirrus clouds that show the augmentation during the evening and morning hours. ' You have not made any change in that sentence -- I suppose that is because you feel that you have argued

earlier that while your technique has limitations the information that it provides it genuinely useful. You may want to reiterate that point, giving brief justification.

Reply: Thank you for your careful crosschecking which allowed us to rectify it. In the revised manuscript, we have incorporated the changes. We have modified the sentence in the revised manuscript.

Please provide with your revised paper a brief summary of the changes that you have made and those that you have not made -- I then expect to accept the paper without further delay.

Reply: We thank the handling Editor for going through the manuscript and responses carefully and providing a suggestion for the missing corrections. We have now carefully incorporated the changes made in the manuscript in the responses of the Reviewers. The changes made in the revised manuscript are explicitly mentioned with corresponding line numbers.

Response to the Reviewer #1

Manuscript Titled "Temporal and vertical distributions of the occurrence of the cirrus clouds over the coastal station in the Indian monsoon region" by Ali et al.,

General Comment

This paper discusses on the vertical distribution of tropical cirrus based on Micro-Pulsed Lidar observations carried out at a tropical station, Kattankulathur (12.82° N, 80.04°E), near Chennai, during 2016, 2017 and 2018. The highlight of the study is on the diurnal variation of the tropical cirrus, which is rarely reported elsewhere. Though the general characteristics of the tropical cirrus over the study/near-by region (e.g., lidar observations from Gadanki) are well known, the study on the diurnal variation of tropical cirrus is being reported for the first time. The authors have showed the diurnal variation of cirrus for different seasons, based on extensive MPL observations carried out in each month during 2016, 2017 and 2018 and delineated the occurrence of single-layer and multi-layer cirrus and their inter-annual variations. The authors also tried to correlate the cirrus occurrence with the convection and tropopause temperature.

Reply: We thank the Reviewer for going through the manuscript and providing positive comments and valuable suggestions to improve it further. We have incorporated all the necessary corrections suggested in the revised manuscript.

Major comments:

1. Occurrence of cirrus is frequent in the altitude region 12-16 km. The POC shown in Figure 6 shows cirrus occurrence very close to CPT and even above CPT-altitude. During July and August, cirrus (cirrus-top) is observed at CPT and also above the CPT-altitude. Mean altitude separation of cirrus-top from CPT-altitude also shows significant seasonal variation. Cirrus/ice particles at the vicinity of CPT and above have large implications. The authors may quantify the occurrence of cirrus above CPT (and the altitude separation from CPT-altitude) for different seasons (from hourly/high resolution data on different days in a month/season) and highlight the implications of cirrus near/above the CPT in the revised version.

Reply Thanks for the Reviewer's suggestion. Cirrus clouds frequently occur above the CPT during May (~7%), July (~10%), and August (~9%) above the CPT as shown in Figure R1. During the rest of the months, cirrus occurrence above the CPT is less than 2-3%. We have calculated the altitude separation between CPT and cirrus cloud top occurring above the CPT in May, July, and August, which are ~ 0.35±0.22 km, 0.28±0.20 km, 0.43±0.35 km, respectively. The occurrence of the cirrus top above the CPT indicates the transport of the water vapor into the lower stratosphere. Such water vapor transport by means of the formation of the cirrus clouds can radiatively affect the stratospheric chemistry. Our observations indicate that the cirrus top occurring above the CPT varies between ~0.1 km to 0.7 km. It is to be noted that the occurrence of the cirrus top above the CPT is calculated relative to the mean CPT altitude at 5:30 IST and 17:30 IST. However, CPT shows significant diurnal variation with amplitude ranging between 0.2–0.5 km (Mushin et al., 2017). This information has been

incorporated into the revised manuscript. Figure R1 is also provided as Figure S5 in the Revised Supplementary material.

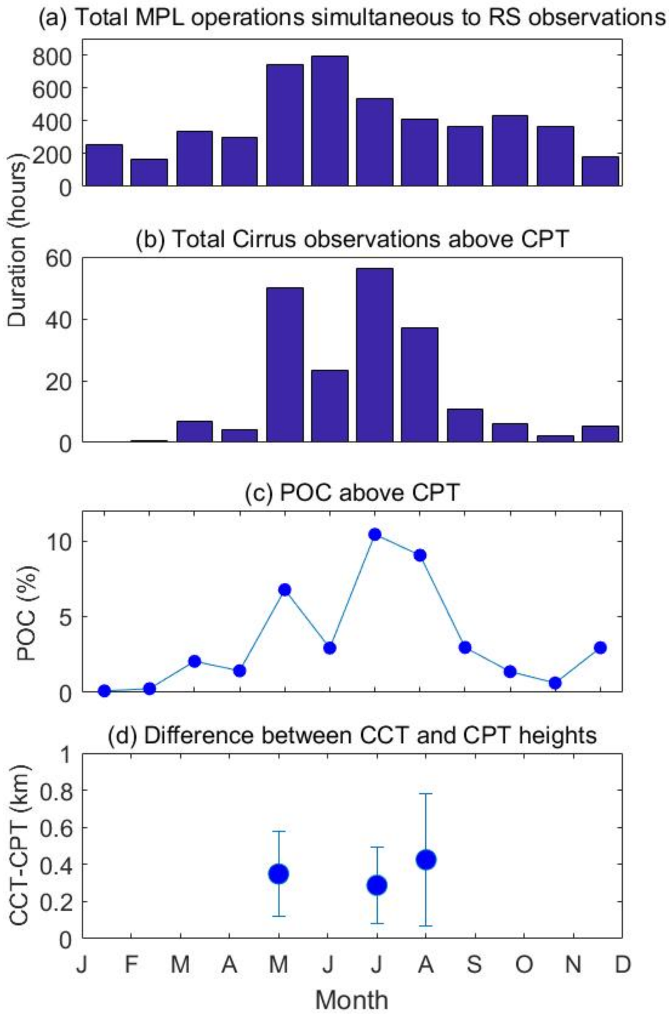

Figure R1: (a) The total MPL operations simultaneous to radiosonde observations during 2016-2018. (b) The total cirrus observations and (c) percentage occurrence of the cirrus clouds occurring above the CPT.(d) the difference between the altitudes of cirrus clouds top and CPT.

2. Authors can check, if the same cirrus persists more than a day from the consecutive days of MPL observations. Persistence of cirrus for longer time has large implications in the upper troposphere/near tropopause region.

Reply: Thanks for the suggestions. We have checked the occurrence of the cirrus clouds persisting for more than a day. In total 665 days, cirrus clouds were observed during 2016-2018. Out of which, for 93 days (i.e., 14%), cirrus clouds persist more than a day. The persistence of the cirrus clouds longer than a day frequently occurs from May to August (covering SW monsoon) and during October-November (covering NE monsoon). It is to be noted that cirrus persistence for a longer duration may large implications on the TTL region

which we would like to carry out in a future study. This information has been added to the revised manuscript.

3. The manuscript requires some more tightening, by editing unnecessary discussion/presentation, removing the repetitions in the text and highlighting the essence of the results. Results should be presented in clear and effective way, without losing the crisp. Figure 8 can be avoided, as the details shown in this figure are already seen in figure 7.

Reply: Thanking you for your suggestions. We have edited the manuscript carefully wherever required. As suggested, figure 8 is removed from the main manuscript and kept as supplementary Figure S2 in the revised manuscript.

4. Authors should carefully modify the text in the manuscript correcting the grammar errors.

Reply: We corrected the grammatical errors with the help of a native English speaker and using Grammarly software.

<u>Specific/Minor comments</u>

Minor comments are commented as notes at the required places of the text in PDF version of the manuscript.

Reply: Responses of the minor comments annotated to the PDF version of the manuscripts are as follows

Line 131: Delete was

Reply: Deleted

Line 154: what are those high frequency variations?

Reply: These high-frequency variations are generally known due to short-scale waves such as long-lived gravity waves and turbulence mainly detected using the doppler weather lidar (Liu et al., 2014). Such signals are also present in the MPL, however, they are not characterized yet and are generally referred to as random variations arising due to background noise. The content is suitably incorporated in the revised manuscript.

Line 159: Background NRB signal of ambient air? Do you mean background NRB noise?
Please clarify.

Reply: Yes, we mean here the background noise that is the signals from ambient air or cloud-free air.

Line 182: source of data?

Reply: We have used the same source of the data, i.e., MPL observations during 2016-2018, for the seasonal mean altitude profiles of the extinction coefficients. The details of deriving the extinction coefficients are provided in Ananthavel et al., (2021a); Ananthavel et al., (2021b). This content is incorporated in the revised manuscript (Line 189).

Line 258: what is threshold value fixed? is this threshold value fixed/same for all the time and/or all the seasons?

Reply: We have already mentioned the threshold criteria in the first version of the manuscript. The threshold value is taken as the mean plus two standard deviations of the background NRB signal from ambient air. This threshold value is calculated for each profile, so it is not a fixed value but rather a fixed criterion. Changes are incorporated in the revised manuscript.

Line 315: Correct this sentence

Reply: The sentence is suitably corrected in the revised manuscript.

Line 339: This information needs to be included in the figure caption.

Reply: We have included it in the figure caption of Figure 4 of the revised manuscript.

Line 386: Incomplete sentence. Combine the previous sentence with this sentence. Above three sentences can be combined

Reply: As suggested, we have combined and modified the sentences.

Line 390: Cirrus is closely associated with turbulence. Strong turbulence occurs in the afternoon /evening hours. This sentence requires modification.

Reply: Thank you for the nice suggestions. We agree with the Reviewer that the cirrus clouds occurrence is closely associated with the turbulence and it generally becomes stronger during afternoon and evening hours (Parameswaran et al., 2004; Mushin et al., 2016) consistent with our findings of the higher occurrence of the cirrus clouds during afternoon and evening hours. This information is added in the revised manuscript.

Line 407: Rapid fall in cirrus occurrence observed after sunrise and before sunset, in all seasons. Is it due to the dominance of noise before sunset and after sunrise, limiting the detection of cirrus signal at higher heights?

Reply: In the first version of the manuscript, we have already mentioned the content related to less occurrence or rapid decrease in the cirrus clouds occurrence after sunrise and before sunset. It could be due to the limited detection capability of MPL under solar noise. Additionally, dissipation of the subvisible and thin cirrus clouds just after sunrise may cause a rapid decrease in the POC.

Line 413: This is a casual sentence... correction required

Reply: This sentence is corrected in the revised manuscript.

Line 415: How do you confirm that cirrus near COT during night hours is due to turbulence. In other time also, turbulence can exist.

Reply: We agree with the Reviewer that turbulence is closely associated with cirrus clouds, and it can occur anytime. However, studies on the turbulence at Gadanki (13.45, 79.2) close to this station over the Indian monsoon region reveal more frequent turbulence during the nighttime than during daytime (Mushin et al., 2016). Thus, cirrus clouds occurring during the evening and early night could be related to turbulence. It is incorporated in the revised manuscript.

Line 419: is the second peak due to remnants of deep convective outflows?

Reply: Yes, the second peak in the occurrence of the cirrus clouds could be remnants of the cumulonimbus outflow anvils. We have carefully checked the LDR value to ascertain the cirrus clouds in the cases of cumulonimbus clouds present at a higher altitude. This content has been added to the revised manuscript.

Line 423: Is it the limitation of MPL in detecting cirrus at higher heights due to solar noise?

Reply: It can be noticed that the daytime cirrus clouds at higher altitudes are significantly less when compared to night-time. At higher altitudes, cirrus clouds are generally thin or subvisible that may remain undetected by the MPL due to high solar noise. It is incorporated in the revised manuscript.

Line 429: If cumulonimbus exits, the lidar signal will not penetrate beyond a certain height above the cloud base.

Reply: We agree with the Reviewer that the MPL signal will not penetrate cumulonimbus clouds. In our study, we checked the LDR value for each profile to ascertain the cirrus clouds. **This information is suitably incorporated into the revised manuscript.**

Line 431: It will be interesting to quantify the amount cirrus (in %) crossing above CPT and the altitude extend up to which it can occur above CPT. This can be examined for all seasons. The contour figure shows the frequency of cirrus above CPT is observed from May-Sep, with maxim during July and August. Another interesting feature is the occurrence of cirrus top aligning with the CPT, particularly during Aug. and Sep. Hence, it will good to discuss the separation of cirrus top/altitude with the CPT altitude, for deference season.

Reply: Thank you for your valuable suggestions. Please see the response to your major comments 1.

Line 432: Cirrus layer close to CPT could be in situ generated due to cold temperatures and abundance of moisture transported from deep convection.
Cirrus close to COT could be due to remnants of clouds from deep convective outflows

Reply: We agree with the Reviewer and added the information in the revised manuscript.

Line 436: cannot confirm. It could also be due to limitation of cirrus detection by MPL.

Reply: We have modified the sentence in the revised manuscript.

Line 477: Does Double peak / multilayer cirrus have any association with generation mechanism of cirrus.

Reply: Yes, peak occurrence of the upper layer cirrus clouds close to CPT could be in-situ generated due to cold temperatures and the abundance of moisture transported from deep convection. At the same time, the peak occurrence of the lower layer cirrus clouds close to COT could be due to remnants of clouds from deep convective outflows. This information is added in the revised manuscript.

Line 483: this figure can be avoided, as that information are seen in figure 7. addition information is the interannual variations, which can be discussed in text

Reply: This figure is removed from the main article and kept as a supplementary figure.

Line 502: need to correct the sentence

Reply: The sentence is corrected in the revised manuscript.

Line 522: this is not correct

Reply: The sentence is corrected in the revised manuscript.

Line 564: how it is connected to cirrus occurrence/formation?

Reply: We have described the connection between the circus occurrence and the ENSO and QBO in the revised manuscript.

Line 820 (pp 25): Are these profiles smoothed one?

Reply: The NRB gradient and potential temperature gradient profiles are smoothed by 10 points running mean filter. Other profiles are not smoothed. This point is also indicated in the caption of Figure 2 of the revised manuscript.

References:

Ananthavel, A., Mehta, S. K., Ali, S., Reddy, T. R., Annamalai, V., & Rao, D. N. (2021a). Micro Pulse Lidar measurements in coincidence with CALIPSO overpasses: Comparison of tropospheric aerosols over Kattankulathur (12.82 oN, 80.04 oE). Atmospheric Pollution Research, 12(6), 101082.

Ananthavel, A., Mehta, S. K., Reddy, T. R., Ali, S., & Rao, D. N. (2021b). Vertical distributions and columnar properties of the aerosols during different seasons over Kattankulathur (12.82 oN, 80.04 oE): A semi-urban tropical coastal station. Atmospheric Environment, 256, 118457.

Liu, X., Xu, J., & Yuan, W. (2014). Diurnal variations of turbulence parameters over the tropical oceanic upper troposphere during SCSMEX. *Science China Technological Sciences*, *57*(2), 351-359.

Muhsin, M., Sunilkumar, S. V., Ratnam, M. V., Parameswaran, K., Murthy, B. K., Ramkumar, G., & Rajeev, K. (2016). Diurnal variation of atmospheric stability and turbulence during different seasons in the troposphere and lower stratosphere derived from simultaneous radiosonde observations at two tropical stations, in the Indian Peninsula. *Atmospheric Research*, *180*, 12-23.

Muhsin, M., Sunilkumar, S.V., Venkat Ratnam, M., Krishna Murthy, B.V. and Parameswaran, K., 2017. Seasonal and diurnal variations of tropical tropopause layer (TTL) over the Indian Peninsula. *Journal of Geophysical Research: Atmospheres*, *122*(23), pp.12-672.

Parameswaran, K., Sunil Kumar, S. V., Krishna Murthy, B. V., Satheesan, K., Bhavani Kumar, Y., Krishnaiah, M. and Nair, P. R.: Lidar observations of cirrus cloud near the tropical tropopause: Temporal variations and association with tropospheric turbulence, Atmos. Res., 69(1–2), 29–49, doi:10.1016/j.atmosres.2003.08.002, 2003.

<u>Response to the Reviewer #2</u>

The authors state (line 353) that "the diurnal structure of the cirrus occurrence is of its first in kind". However, I can name at least two studies that yielded the diurnal cycle of cirrus clouds on a global scale. The first one (Noel et al, 2015) used space-borne lidar CATS operating between February 2015 to October 2017. This period overlaps with the period analyzed in the manuscript, and I believe it makes sense to compare the results with those of (Noel et al., 2015). An extensive analysis is not required, but at least some general comparisons should be made and discussed.

Reply: We thank the Reviewer for going through the manuscript and providing positive comments and valuable suggestions to improve the manuscript further. We have incorporated all the necessary corrections suggested in the revised manuscript.

We have revised the statement as "the diurnal structure of the single, and multi-layer cirrus occurrence is of its first in kind."

We thank the Reviewer for providing the important information to compare our results with CATS data, this we have planned to explore data in a separate study. However, as suggested, the comparison of the total cirrus occurrence using MPL with high-level clouds using CATS is carried out as shown in Figure R2.

It can be seen that the diurnal features of the cirrus clouds occurrence during DJF and JJA calculated over the NH tropics (0-30 N) from CATS observations compared well with the MPL observations over Kattankulathur. The occurrence of the cirrus clouds over the altitude ~ 8-17 km is consistent in both ground-based and space-borne observations. Also, the occurrence is higher during the NH summer than NH winter. However, the total POC does not show pronounced diurnal variation. This information is added in the revised supplementary material.

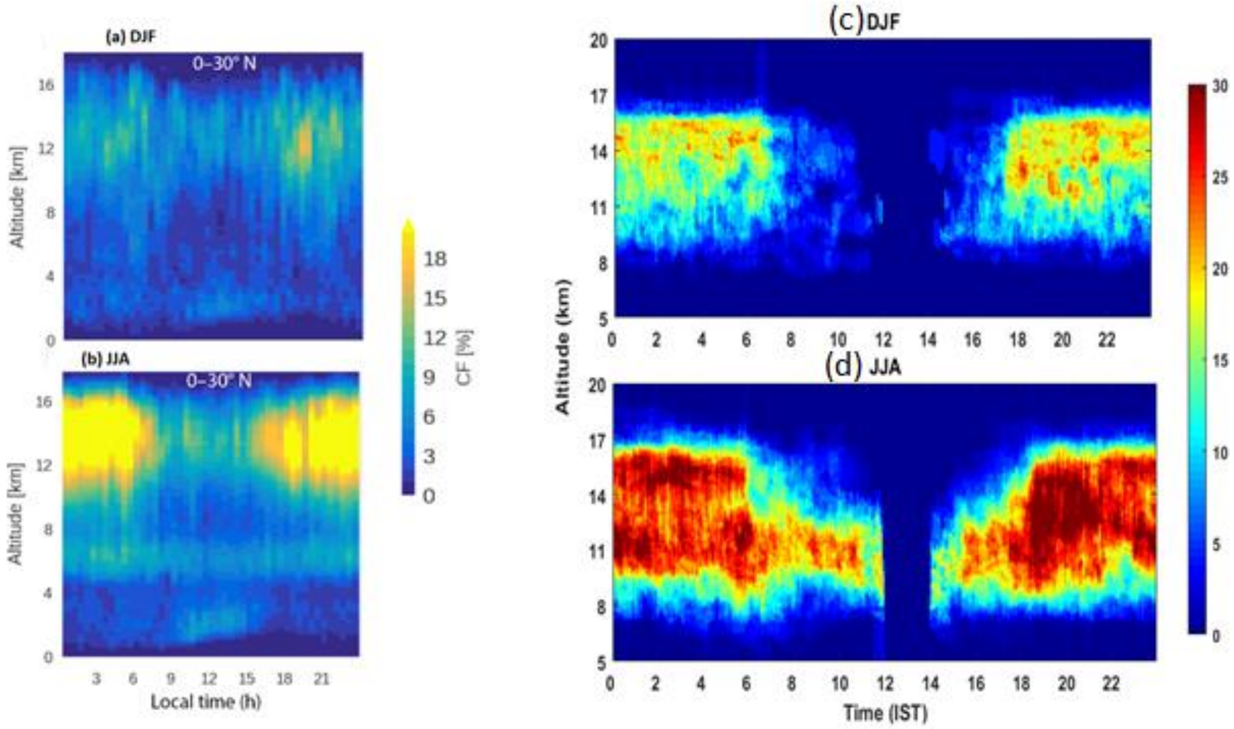

Figure R2. The vertical profile of cloud fraction as a function of local time of observation over the land in the Northern Hemisphere tropics during (a) DJF and (b) JJA from 2015 to 2017 (Reproduced from Noel et al., 2018). The occurrence of cirrus clouds as a function of time and altitude observed over Kattankulathur (India) during (c) DJF and (d) JJA from 2016 to 2018.

In the second work (Feofilov and Stubenrauch, 2019), high clouds have been retrieved from two space-borne infrared sounders, AIRS and IASI, which observe the atmosphere both day and night and their daytime SNRs are the same as the nighttime ones. Even though Fig. 5 and 6 of this work show that the diurnal cycle is not that pronounced at the considered location, I tried to compare its properties to those reported by the authors of the reviewed manuscript. For this, I retrieved the amplitude and peak time values for the point closest to (12.82N, 80.04E) from the publicly available dataset (doi:10.13140/RG.2.2.13038.15681) and analyzed the data. The direct comparison is hindered by differences in the cirrus cloud definitions between the reviewed manuscript and in (Feofilov and Stubenrauch, 2019), differences in sensitivities, wavelengths, and observation geometry. Still, one can see a correlation between the monthly occurrence of cirrus clouds (Fig. 6 of the reviewed manuscript) and the diurnal cycle amplitude (Fig. 1a) and between the peak times occurrence frequency for DJF, MAM, JJA, and SON (Fig. 1b). The latter plot is a combination of single- and multi-layer clouds because the infrared sounders use to retrieve the upper cloud in the case of a multi-layer cloud. Therefore, it should be compared to a weighted average of Fig. 5a and 5b of the manuscript. One can note that JJA peak of Fig. 1b corresponds to JJA peak in Fig. 5a of the manuscript, MAM peak of Fig. 1b corresponds to MAM peak of Fig. 5b, whereas DJF and SON peaks correspond to a superposition of Fig. 5a and 5b. Further analysis is beyond the scope of this review. The main purpose of this exercise was to put the results obtained by the authors in a more general context. The authors are encouraged to develop this further themselves

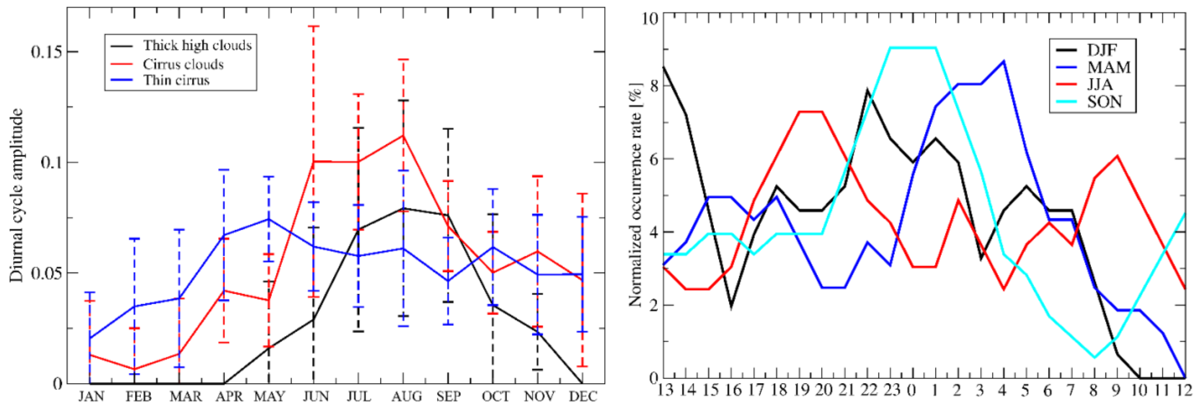

Figure 1. Diurnal cycle of high clouds (P <440 hPa) retrieved from a combination of AIRS and IASI space-borne infrared sounders (Feofilov and Stubenrauch, 2019) in 1ºx1º bin containing the point (12.82N, 80.04E), to be compared with Fig. 5 and 6 of the manuscript under review. (a) diurnal cycle amplitude; (b) occurrence rate of peak time values for DJF, MAM, JJA, and SON for thin cirrus clouds

Reply: We appreciate the Reviewer's effort in comparing the results and agree with the Reviewer that cirrus occurrence using space-borne observations (IASI and AIRS) shows a nearly similar diurnal pattern with a single layer cirrus occurrence using observation (MPL) during JJA. Similarly, multi-layer occurrence using MPL during MAM also agrees with space-borne observations. This indicates that both ground and space-borne observations are consistent. However, the space-borne observation usually detects the cloud top layer, so the distinction between single and multi-layer cirrus is difficult from the AIRS and IASI observation. As suggested by the Reviewer, we have compared the results by combining the single and multiple layer cirrus clouds occurrence from the MPL observations, as shown in Figure R3. As mentioned by the Reviewer, the total occurrence of the cirrus clouds does not reveal any pronounced diurnal cycle. The result was kept aside from the original manuscript and single and multi-layer clouds that show the pronounced diurnal cycle are analyzed. This information is added to the revised manuscript.

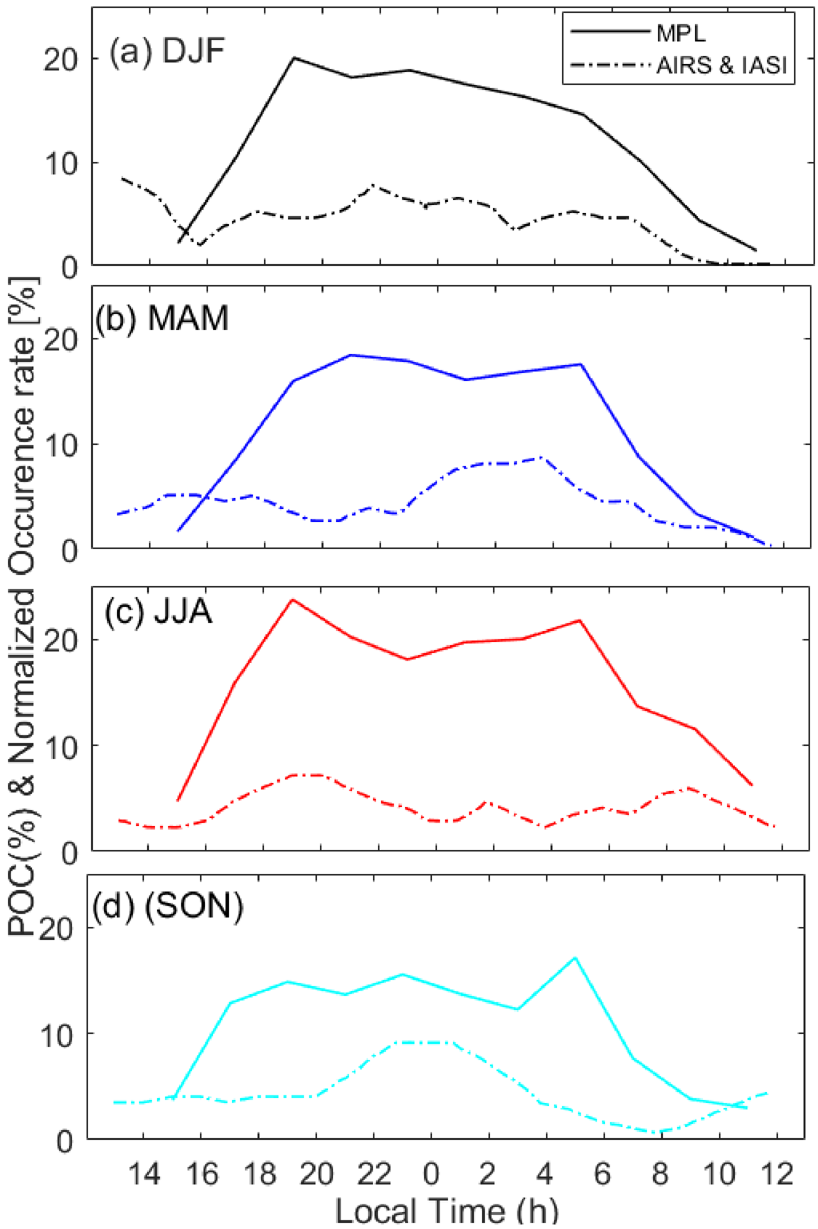

Figure R3. Comparison of the diurnal variation of the total percentage occurrence of the cirrus clouds using the ground-based (MPL) and space-borne (AIRS and IASI) observations over Kattankulathur.

Comment:
Line 30: Please, specify the heights and/or state that the effect applies to the whole column.

Reply: The cirrus clouds affect the whole column (Fleming and Cox, 1974); however, its effect is most pronounced in the TTL region. Yang et al (2010) quantified the radiative impacts of the cirrus clouds on the TTL and observed the net cloud radiative heating below ~16 km and mostly cooling above ~17 km. This information is added in the revised manuscript (Lines 30-35).

Line 56: To my knowledge, the probability of inhomogeneous nucleation is much higher than that of homogeneous one. The way the phrase is formulated makes one think that their probability is comparable and homogeneous one might be even more preferable.

Reply: We agree with the Reviewer that the formation of cirrus clouds due to inhomogeneous nucleation is higher than that of homogeneous nucleation. This sentence is rephrased in the revised manuscript.

Line 110, Eq. 1: I would expand alpha and beta coefficients and add the coefficient of multiple scattering here. By the way, what is the value of this coefficient for the MPL lidar? Does it affect the analysis?

Reply: We thank the Reviewer for the important point to consider for the retrieval of the cloud signal from the MPL observations. This study detects the cirrus clouds using the normalized backscatter (NRB) signal after correcting the system-dependent parameters such as deadtime, after pulse, and the overlap corrections. However, the multiple scattering effects were not considered as it is negligible for our MPL due to its narrow field of view (FOV) (Comstock 2002; Campbell et al., 2002; Bissonnette 2005; Lewis et al., 2022).

Moreover, NRB signals above 8 km are mainly from the clouds and the background molecules, as the signals from the aerosol are almost negligible. Thus, for the study the cirrus clouds, especially their occurrence, NRB data is utilized.

Line 154: Indeed, the vertical smoothing increases SNR. But, wouldn't it be better to average in time and keep the original vertical resolution? What is the rational for vertical averaging?

Reply: We agree with the Reviewer, and we would like to mention that we have applied the time averaging of the data. The MPL observations are obtained at 1 min. Time interval and 30 m vertical interval which has been averaged to 5 min interval profiles without doing any vertical averaging. The 5-min averaged NRB gradient profiles have several small-scale fluctuations besides the stronger fluctuations due to the cirrus cloud layer. Thus, we have applied the running mean averaging to the NRB gradient profile only to detect the cirrus cloud base and top as well as to reduce the computation timings. It is to be noted that, the signal also fluctuates within the cloud layer which is not important while computing its base and top that gets smoothed out by the running mean filter. The running mean filter does not affect the cloud signal and its base and top.

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Line 164 and elsewhere (e.g. line 284): the authors mention the difference between daytime and nighttime SNR. Indeed, the sensitivity of cloud detection is not the same for daytime and nighttime, and clouds of certain type cannot be detected during the day. Normally, this should reduce the diurnal cycle retrieval only to optically thicker clouds, but I do not see a clear threshold defined for the analysis. Another methodological issue I see here is the attenuation of the backscattered radiation. This does not affect the lower cloud boundary detection, but it might affect the upper boundary and if the photons are absorbed then there's no information coming from the upper layers. This makes these layers indistinguishable from clear sky. I did not get whether the methodology described in lines 155- 164 manages to tell the attenuated signal from clear sky one. I would say that the reference molecular backscatter profile could be estimated from the atmospheric pressure/temperature profile and added to the analysis, but I do not see this in this section. Could you, please, clarify?

Reply: We agree with the Reviewer that estimation of the diurnal cycle of the cirrus clouds occurrence normally will be limited to the optically thicker clouds. In our study, we have mange to operate the Lidar during day time except 11:00-14:00 IST in clear sky conditions. Before detecting the cirrus clouds using the NRB signal, we have checked for the presence of the signals above the threshold value taken as the mean plus two standard deviations of the background NRB signal from ambient air (over the altitude ~ 25-30 km).

We again agree with the Reviewer that cloud top detection depends upon its optical thickness. In the cases of optically thick clouds, the photon (lidar signal) may get absorbed by the clouds, and hence detection of the cloud top may not be accurate. Hence, the cloud top detected is considered an apparent cloud top. As mentioned earlier, the cloud base or top is detected only when the signal is more than two standard deviations from the molecular and attenuated backscatter from the background /ambient air.

It is to be noted that the backscatter signal in the cloud-free condition is the combination of the molecular and attenuated backscatter. Thus, the signal from the molecular backscatter (obtained from the temperature and pressure profiles) is removed before obtaining the aerosol backscatter.

However, as the signal from the molecular backscatter is very low, the backscatter signals above the threshold value (mean plus two standard deviations of the background NRB signal from ambient air over the altitude 25-30 km) will be much higher than the molecular backscatter. It will not affect the detection of the cloud base and top heights.

To illustrate the threshold value for identifying the cirrus cloud, we have considered the typical case of the multiple cirrus clouds observations as shown in Figure R4. The details of these cirrus cloud observations have been described in the main manuscript (Figure 2d). We have taken the vertical profiles of the NRB signals from surface to 30 km at 16:30 IST, 20:30 IST, 03:40 IST, and 06:00 IST, as shown in Figures R4b-e, respectively. As mentioned earlier, the background mean plus one and two standard deviations are obtained from the NRB signal between 25 km and 30 km. During daytime (16:30 IST), the NRB signal up to the attitude of ~ 6 km is much higher than the background signals shown as dashed lines (cyan and red for one and two standard deviations, respectively). Above it, the NRB signals again go below the threshold value. However, the NRB signal again started to increase and become higher than the threshold value at ~ 9 km due to the cirrus clouds. During night times (20:30 IST and 3:40 IST), the NRB signals are higher than the threshold value up to altitude ~16-17 km. However, during the morning hours, the NRB signals are higher than the threshold value up to the altitude of ~ 10 km. The cirrus clouds were ~ 12 km and ~ 16 km.

Thus, we see that, though the NRB signal is poor during the daytime, it provides the detection of the cirrus clouds. However, detection is limited to the optically thicker clouds. This information is added to the supplementary material.

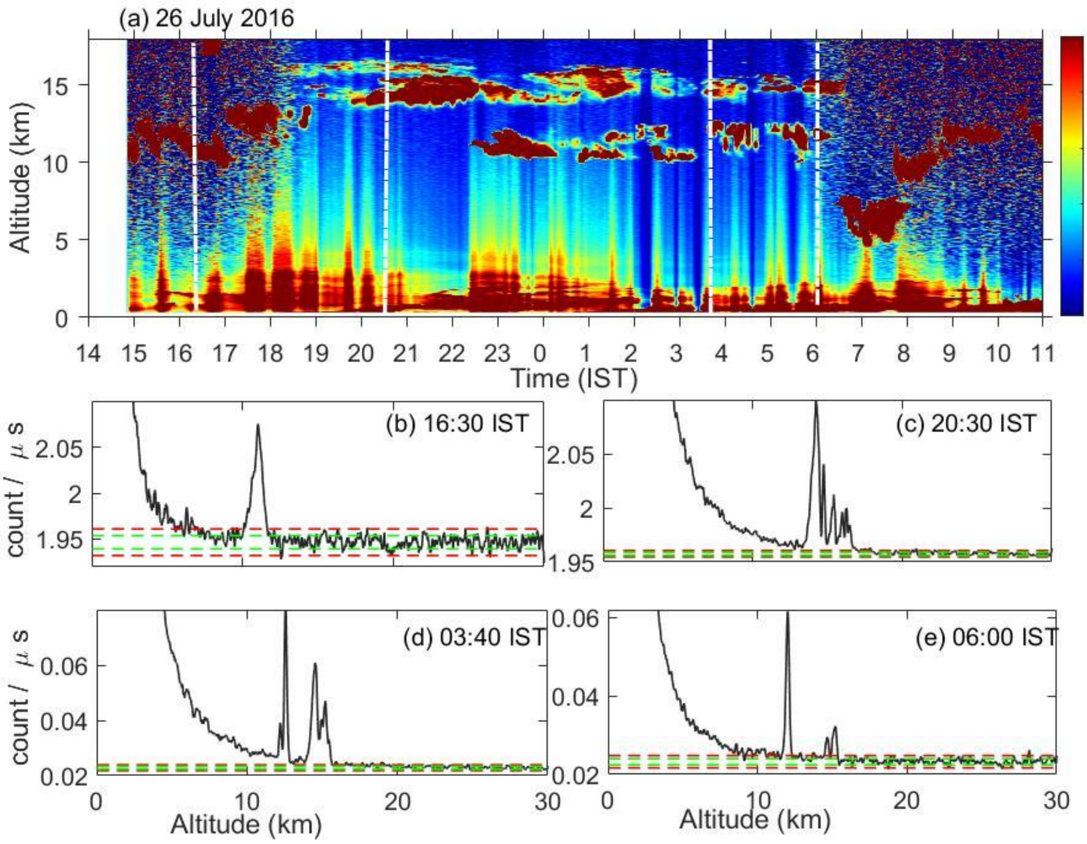

Figure R4: (a) Time height section of the normalized backscattered (NRB) signals over the altitude 0.3 -20 km observed on 15:00 IST on the first day (26-07-2016) to 11:00 IST on the second day (27-07-2016) displaying the multi-layered cirrus clouds. The vertical dashed lines indicate the timings that are taken for SNR analysis. (b)-(e) display the NRB signals from surface to 30 km at 16:30 IST, 20:30 IST, 03:40 IST, and 06:00 IST with the background mean plus one and two standard deviations are obtained from the NRB signal between 25 km and 30 km.

Line 336: color scale is missing for Fig. 4

Reply: The colors have no specific meaning but are simply used to make it easier to distinguish between different days. It is corrected in the revised manuscript.

Lines 347-348: how does this statement match the main purpose of the manuscript, which is the diurnal cycle retrieval?

Reply: Thank you for pointing out this mistake. We have modified it in the revised manuscript. We mean here that the cirrus clouds occurrence presented from 15:00 IST on day one to 11:00 IST on day two. However, it is noted that many times cirrus clouds especially very thin and subvisible types remain undetected due to high solar noise. Such thin cirrus clouds may not be detected during the daytime due to the limitation of the instrument. It is corrected in the revised manuscript.

Lines 410-411: how to tell the increase in sedimentation load from other reasons for the descending? What is the proof of this statement?

Reply: Thanks to the Reviewer for the clarification. Generally, the cirrus clouds during the winter season are either thin or subvisible (Sivakumar et al., 2003) as this season is

free from any deep convection. Sedimentation occurs due to a decrease in the temperature close to the tropopause. Our observation indicates that the cirrus clouds are not always laminar and descend even in winter. Such descending cirrus during the winter season could be due to increases in sedimentation (Nair et al., 2012). However, the optically thicker clouds while descending, as shown in Figure R5 appears related to gravity settlement due to increased load by sedimentation. A detailed analysis of the descending type of the cirrus clouds is being carried out, which we are planning to report in a separate study. This information is incorporated in the revised manuscript.

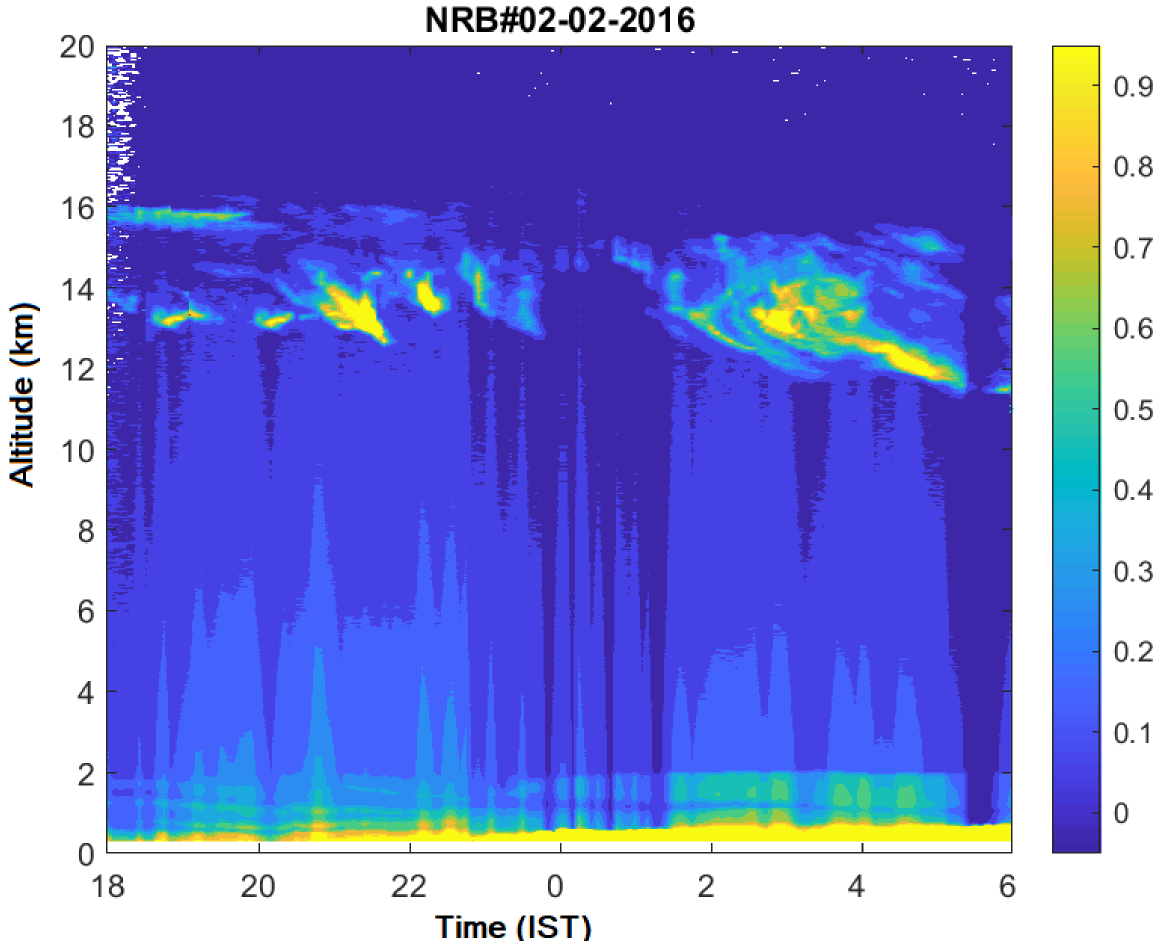

Figure R5: Time height section of the NRB signal observed during a typical winter season (02 February 2016)

Lines 434-439 and elsewhere: sometimes, the term POC (percentage of occurrence of cirrus) is used as some cloud type: "the lower layer of POC", "the POC has a limited vertical extent", and so on. Strictly speaking, the POC has no vertical extent, it's just a percentage. This misusage is misleading. Please, fix it throughout the whole manuscript.

Reply: Thanks to the Reviewer for pointing out this mistake. We have fixed this issue in the revised manuscript.

Lines 562-564: where is the proof of this relation? What are the values of Pearson's correlation coefficients for the interannual variation and ENSO or QBO strength?

Reply: We have added the information on the relationship between the POC and convection (OLR), POC anomalies, and ENSO and QBO indices in the revised manuscript. The POC is negatively correlated with OLR. That is, the deeper the convection, the higher the occurrence of the cirrus clouds. To understand the interannual variations of the POC, we have obtained the POC anomalies by subtracting the annual cycle calculated over the period 2016-2018. We have taken a four-month lag in POC anomalies for ENSO (POC anomalies lagging ENSO) (Mehta et al., 2015). It is observed that the POC anomalies lagged at four-month is positively correlated with the ENSO index significant at a 95% confidence level. It indicates that occurrence enhances during the El Nino years and decreases during the La Nina years. The POC anomalies positively correlated with the QBO index significant at a 95% confidence level. It indicates the POC enhancement during the westerly phase and decrement during the Easterly phases. Though POC shows a strong interannual variation in connection with the ENSO and QBO, it needs a thorough investigation with longer-term datasets. This information has been suitably incorporated into the revised manuscript.

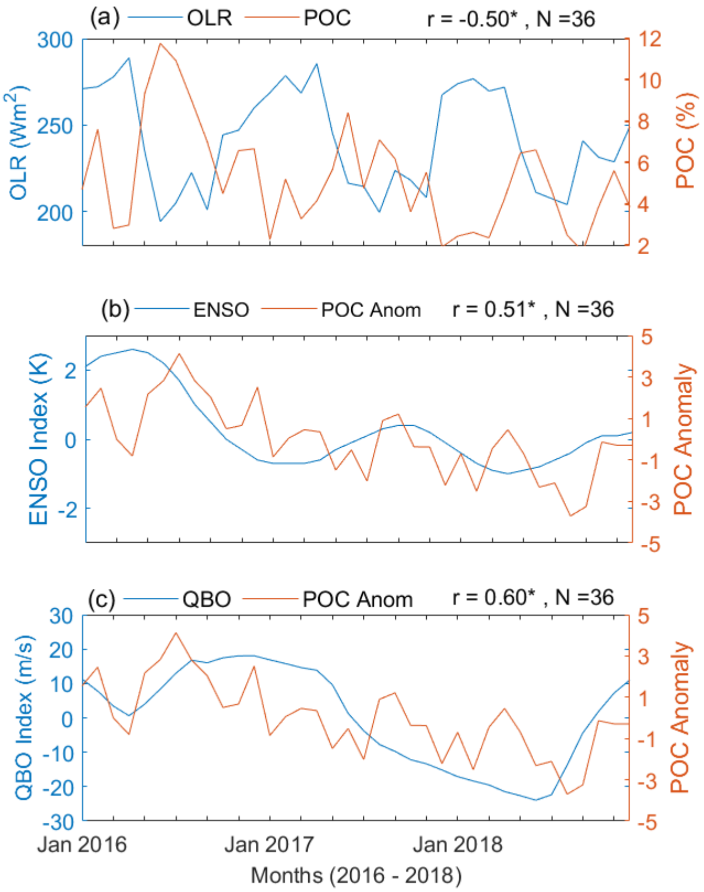

Figure R6: The time series of (a) the POC and OLR (b) a four-month lagged ENSO index (the Niño 3.4 SST anomalies) and POC anomalies (c) the QBO indices (the zonal wind at 50 hPa) and POC anomalies. The correlation coefficient (r) and the number of months (N) are also shown. The asterisk indicates that the correlation coefficient is significant at a 95% confidence level.

Line 618: please, add the uncertainty values to each occurrence rate value here and elsewhere.
Reply: We have calculated the overall percentage of the occurrence by taking the ratio of the total number of cirrus clouds observed to the total number of observations for every 5 min and 30 m altitude intervals over the period 2016-2018. The monthly (seasonal, annual) percentage occurrences are thus calculated by counting the total hours of the cirrus occurrence divided by the total hours of the observations during a given month (season or year). As the percentage of the occurrence is calculated by dividing the total hours of the cirrus observations divided by the total hours of the MPL observations, there is no uncertainty in the measurement. Note that the cirrus occurrence here and in the rest of the manuscript is not the averaged one.

Lines 623-624: please, see the comment to lines 347-348 above
Reply: We have modified the sentence in the revised manuscript.

Other comments:

Line 30: "have net warming" –please, reformulate
Reply: We have modified this sentence in the revised manuscript.

Line 353: "is of its first in kind"–language issues
Reply: Corrected the sentence in the revised manuscript.

Line 299: "shaper and colder" –I didn't get what is meant here
Reply: Sorry for the typo. It is sharper and colder. We mean that, in this case, the tropopause is sharper and colder compared to the previous case.

Line 498: "at" is missing in "POC is higher altitude"
Reply: Corrected

Line 506: please, change "May month" to "month of May" or just to "May"
Reply: Thank you for the excellent suggestion. We have corrected it in the revised manuscript.

Line 525: "11778 hours lidar was operated", please rephrase
Reply: We have rephrased the sentence as "lidar was operated for11778 hours" in the revised manuscript

Line 599: "at relatively higher altitudes": please, change either to "at relatively high altitudes" or to "at higher altitudes" depending on what you want to say here

Reply: We have changed the sentence as suggested in the revised manuscript.

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