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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Characteristics of particle size distributions in the tropical tropopause based on optical particle counter and lidar measurements" *by* S. Iwasaki et al.

S. Iwasaki et al.

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Yellow-marked sentences in our revised paper denote areas we have changed.

We would like to thank the referees for their valuable comments that have greatly improved the quality of this manuscript.

The main aim of this paper was to summarize the findings of field measurements of cirrus clouds in the tropical tropopause layer (TTL), hereafter TTL clouds, by using OPCs and lidar. The reason why this was attempted was because, as reviewer #1 commented, particle number observations of TTL cloud are rare. Our results will contribute to understanding the nucleation mechanism of TTL cloud, particularly the elucidation of the freezing process by comparing aerosol and cloud particle size distributions in

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TTL cloud and those below and above TTL cloud (e.g., Iwasaki et al. 2006 AGU Fall meeting). However, we omitted presenting a hypothesis of the nucleation mechanisms suggested by the observational results as we did not show our model results.

Major changes are as follows:

1. We reanalyzed OPC data after realizing that the detection angle was incorrect, i.e., "Width of collecting area" was not "44ˆo half solid angle" in Table 1, but 39.2ˆo. Consequently, some figures, especially Figure 6 in revised manuscript, were modified in the revised paper. We therefore rewrote the sentences related to the local maximum for particle size distribution dn/dr at 2.0 um in TTL cloud and deleted its implications.

2. We present new reanalyzed figures and have added explanations regarding dn/dr, such as, "TTL clouds exhibit dn/dr enhancement at radii greater than 0.8 um while clouds at 10-15 km do not. Thus, dn/dr enhancement is a unique feature of TTL cloud."

3. We abbreviated "cirrus cloud in the tropical tropopause layer (TTL)" as "TTL cloud." This is because a subvisual cirrus cloud (SVC) is defined as cirrus with an optical thickness of less than 0.03 (Sassen and Cho, 1992) though SVC is usually used for a cloud in the TTL.

4. We added explanations about atmospheric field conditions, such as time-longitude and time-latitude sections of TBB.

5. We added graphs to show the vertical profile of OPC and lidar data to validate our data.

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Comment 1: (i) Mechanism of ice nucleation. Although the characteristic of ice particles in the tropical SVCs was shown well using the data derived from in-situ measurements, there is insufficient explanation about the ice nucleation mechanism. There are mainly four parameters (temperature, water vapor amount, CCN and vertical velocity), which affect the formation of ice particles. Without clearly showing these parameters, the present study has suggested that the deep convections in the vicinity of the observational point are main causes for cirrus formation. Also, the mechanism of cirrus formation by the deep convection has not been indicated clearly. Figures that explain the observational parameters (i.e. temperature profiles of each launch, Horizontal map of GMS or GOES, time-height section of backscatter ratio of lidar and so on) are needed to clearly show the mechanisms of cirrus cloud formation in detail.

Reply: To validate the relationship between the nucleation mechanism of a subvisual cirrus cloud and deep convection is not easy since amount of water vapor and vertical velocity were not measured. In fact, even if these were measured, the proof would still be difficult. We therefore revised the paper to read "TTL clouds are observed frequently in the vicinity of deep convection." and show a figure of the time-longitude and the time-latitude sections TBB (K) in subsection 3.2. We also added, "Fig. 2(a) shows that the deep convection (bluer TBB) of the monsoon extended northward into the Sri Samrong from late in May, and Fig. 2(b) indicates that the horizontal scale in longitude is 1-2x10ˆ3 km."

Comment 2: (ii) Reliability of lidar observational data The manuscript described (in l.11 on p.1601) that the lidar can observe the atmosphere up to 14 km with good accuracy under clear sky. Therefore, are the backscatter ratios (of cirrus clouds probably) at about the altitude of 17 km shown in Table 2 not reliable? From Table 2, it can be seen that the lidar measurements show consistently higher altitudes of cirrus clouds than those of the tropical tropopause (TT) derived from the OPC observation. Does this (i.e. the difference of cirrus altitudes between the OPC and lidar measurements) originate from the bias in lidar measurements? Please show us the plot of backscatter ratio of lidar during the observational period (or the period of the OPC launched) as a function of time and altitude to verify the cirrus cloud height detected by the lidar.

Reply: To clarify our lidar sensitivity, we present general characteristics of the lidar, although most lidar papers do not show this because the determination of lidar sensitivity is difficult.

We consider the backscatter ratios shown in Table 2 to be reliable. This is because clouds were observable at approximately 17 km when there was no cloud below since lidar return from clouds is greater than that from gas. In addition, beta in Table 2 is averaged for 1 hour and 100 m and we add the explanation below the Table 2.

We have added a new figure (Fig. 4) to show that cloud top height measured with the lidar was not always higher than that obtained with OPC in order to validate our observational results in subsection 3.3 in revised manuscript.

Comment 3: First of all, the TT (Tropical tropopause) should refer to a surface; however the data derived from the OPC measurement (May and June) are shown as layers. You need to put a clear definition of TT in the text. The reader may be confused; which (i.e. TT or TTL) is correct for some cases in the text?

Reply: As recommended, we have changed all occurrences of "TT" to "TTL" or "the height at which temperature is less than -75 oC, H_T<-75C"

Further suggestions follow. Comment 4: English usage & Verbiage. As mentioned above, the author should be consistent in their uses of the abbreviations, "TT" and "TTL". There are many erroneous usages of these in this paper. Example in Abstract, l.7 and 20: in the TT -> at the TT

Reply: Since several instances of "TT" and "TTL" were used incorrectly in our first paper, we have introduced "H_T<-75C" (the height at which temperature is less than -75 oC) for clarification.

Comment 5: Please put the clear definition of "TT (Tropical Tropopause)" used in this study in the text (l.14 on p.1602). Is the definition of the tropopause in this study a cold point temperature? Also, please explain the reason that the temperature colder than -75C is assumed as the threshold for the "TT" (l.23 on p.1602).

Reply: We have introduced "H_T<-75C" as the height at which temperature is less than -75 oC and have modified our paper accordingly.

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In our analysis, -75 oC was taken as an empirical value and used to distinguish between TTL clouds and usual cirrus clouds, such as anvil clouds. This is because there appears to be no temperature and height threshold at which TTL cloud appears. For example, Table 12.1 "Guidelines for subvisual cirrus models" in Lynch et al. (2002, Cirrus) shows that SVC appears from -40 oC to -90 oC. However, this temperature cannot be applied to the tropics because it is not possible to distinguish between TTL and anvil clouds. We have therefore added the following text in subsection 3.4:

-75 oC is used as an empirical value with which to distinguish between TTL cloud and usual cirrus clouds, such as anvil clouds. This is because there appears to be no temperature and height threshold at which TTL cloud appears. For example, Table 12.1 in Lynch et al. (2002) shows that TTL cloud appears from -40 oC to -90 oC. However, this temperature is not applicable as it is not possible to distinguish between TTL and anvil clouds in the tropics.

Comment 6: Title, "On the tropical tropopause" should be changed to "in the tropical tropopause layer."

Reply: We have changed the title according to the Reviewer's suggestion.

Comment 7: [Section 2], In expression (1), how should we read "delta Csca" and what does "sca" stand for?

Reply: dCsca/dOmega denotes "the differential scattering cross section (m2/str)" and it is proportional to the detected light power, where "sca" is an abbreviation for "scattering." We have modified the explanation in subsection 2.1.

. [Section 3.1]. Comment 8: A map showing the horizontal convective activity using the data from the GMS and GOES during the observational period will be interesting and helpful in order to more clearly understand the cloud variation. Also please add the description about the characteristics of convective activity during the observational period briefly in the text.

Reply: We have added the following explanation in subsection 3.2: Figure 2 shows (a) time-latitude and (b) time-longitude sections of TBB (K) centered on 17.16 +- 0.5 N, 99.87 +- 0.5 E from 0 N to 30 N and from 70 E to 120 E, respectively. Fig. 2(a) shows that the deep convection (bluer TBB) of the monsoon extended northward into the Sri Samrong from late in May, with Fig. 2(b) indicating the horizontal scale in longitude is 1-2x10ˆ3 km.

Comment 9: Are there any other studies which use the lidar data at Sri Samrong? Please show us the characteristic of cirrus clouds detected by the lidar at Sri Samrong, for example, seasonal cycle of top and bottom heights and vertical profile of occurrence frequency.

Reply: Unfortunately, since no lidar studies have been published or presented on cirrus clouds over Sri Samrong, we are unable to refer or present the Reviewer with such studies.

Comment 10: I recommend that the temperature and mixing ratio of saturated water vapor at the TT are added to Figure 2. Is the onset date of Monsoon at Sri Samrong derived from the precipitation data? If so, please add the precipitation data in Figure 2 as well.

Reply: We have deleted "onset" from the manuscript since our interest is deep convection, not monsoon onset. We show the vertical profile of temperature in Figure 3, but we do not show that of mixing ratio since OPC uses RS80 and can not measure it in TTL.

Comment 11: l.18 on p.1602: Just because the cirrus clouds in the TTL happen to be observed frequently during the rainy season, it cannot be concluded that the occurrence of cirrus increases during the monsoon season in general. Rather, the sentence in the text should be rewritten like as follow. "This study mainly investigated the characteristics of cirrus clouds during the rainy season."

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Reply: We have modified the text at the end of subsection 3.2 as follows:

TTL clouds are observed frequently in the vicinity of deep convection conditions.

Comment 12: As suggested above, the explanation of the TT (tropical tropopause) is required in this section.

Reply: We have changed TT to TTL or "H_T<-75C" (the height at which temperature is less than -75 oC).

Comment 13: How does the interdiurnal variation of the launch time of the OPC influence the results?

Reply: Since the interdiurnal variation in TTL cirrus clouds is unknown, it would be better to launch at different times. Launch times and number were as follows:

Launch time (LT=UT h): Number launched

00-06 LT: 2

06-12 LT: 3

12-18 LT: 4

18-24 LT: 2

However, given the difficulties and lack of available information regarding interdiurnal variation, we have not discussed it in this manuscript.

Comment 14: It makes no sense that the figures 3 (a) and (b) show the different values for the same supposedly profile (e.g 26 March). Did you divide one profile into the data with and without clouds for describing Figures 3 (a) and (c)? It makes sense if Figures 3 (b) and (d) were drawn by the only data associated with the layers where clouds exist. Please show us the all profiles of OPC for validating the cloud layers at each profile.

Reply: We initially divided one vertical OPC profile into data for 10-15 km (Fig. 5(a,c)) and the height at which temperature is lower than -75 oC, H_T<-75C, (Fig. 5(b,d)).

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We then divided the two profiles into data with and without clouds. This meant that 4 profiles could be plotted from one launch on 1 June. That is:

Figure 5a: Particle number concentration without cloud at 10 -15 km,

Figure 5b: Particle number concentration with cloud at 10 - 15 km,

Figure 5c: Particle number concentration without TTL cloud,

Figure 5d: Particle number concentration with TTL cloud.

We have rewritten the text to provide a clearer explanation of how profiles were plotted in subsection 3.4-3.6 in revised manuscript.

OPC data contains a lot of information, i.e., particle number for each channel from the ground to approximately 30 km high; hence, we omitted figures of vertical OPC profiles in our first manuscript. We have added some OPC data graphs in Figure 3 and 4.

Comment 15: l.4 on p.1603: The values of regression line are different from the ones mentioned in the caption of Figure 3.

Reply: We have modified the data based on the Reviewer's comments.

Comment 16: l.6 on p.1603: The profile of 29 May deviates from regression line at 0.3 um. Can you conclude that 0.7 um is a representative value for all profile?

Reply: For easy comparison, we compared the integrated number of the cloud against the regression line. Consequently, "The profile of 29 May deviates from the regression line for 0.3 um." does not change or affect our conclusion. So as not to mislead readers in our conclusion, we have rewritten the relevant sentences in subsection 3.4 in revised manuscript as follows:

$<N>$ with clouds (b,d) also decreases, but it departs from the $<N>$ without clouds (a,c) at radii greater than approximately 0.8 um, respectively; the regression lines are plotted to facilitate comparison in Figs. 5(a,c) and 5(b,d).

Comment 17: [Section 3.5] l.12 on p.1604: Figure 5 is too small to clearly see. The profiles of three days that you mentioned are not found. You should remake figures and describe these three days in the text.

Reply: We have implemented Reviewer's suggestion.

Comment 18: [Section 3.6]. l.21 on p.1604 (probably...): Is it possible that the difference of vertical resolution between OPC and lidar cause the differences of cirrus' altitude? Since the temperature and height variations at the tropopause are most likely small within the synoptic scales, are the differences in height caused by the bias (or noise) of lidar measurement rather than the difference of spatial variations of clouds (or temperature)?

Reply: The difference in the vertical resolution between OPC and lidar is less than approximately 50 m. Therefore, differences exceeding 100 m are considered significant. In subsection 3.3, we have added a new figure (Fig. 4) to show that cloud height measured with the lidar is not always higher than measurements obtained with the OPC. The figure suggests that there is no height bias between OPC and lidar. Therefore, we believe that the horizontal inhomogeneous of cloud height is real.

In addition, we referred to other data in our manuscript. I contacted Dr. Martucci and confirmed that they had corrected for changes cloud height induced by flight attitude. These figures also show horizontal cloud height variations although these authors do not mention about it.

Comment 19: Do the lidar and OPC provide consistent data on cirrus height at the altitude between 10 and 15 km where the precision of a lidar is generally quite good?

Reply: Since the geometrical depth of clouds between 10 and 15 km is not thin, comparisons of cloud heights measured with OPC and lidar is difficult. Therefore, we added figure (Fig. 4), which shows that cloud height at approximately 6.5 km high measured with our lidar is not higher than that measured with the OPC.

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. [Section 4] Discussion. Comment 20: l.17 on p.1606 (... activity frozen.): What causes activity frozen (frozen activity?)? cooling or/and quick vertical movement of humid air?

Reply: We believe that relative humidity and vertical wind speed, Brunt-Vaisala frequency, may be responsible for this process.

Comment 21: l.19 on p.1606 (Only once was...): Table 2 indicates that on 1 June, the temperature and height of the TT is lower than the data of other days. Is the local maximum of size distribution at 10-15 km on 1 June caused by this minimum height of TT?

Reply: We were unable to find a unique temperature profile on 1 June and therefore did not discuss it. We should measure RH, at least, with OPC, and intend to do so in future studies.

Comment 22: l.4 on p.1607 (...therefore indicate that ...): It is not appropriate to conclude that the all profiles of the cirrus result from a single type of mechanism, because each profile most likely has experienced different weather condition. The weather conditions (i.e. the temperature and water vapor distributions) that might alter the characteristics of cirrus in the TTL should be provided to clarify the mechanism of cirrus formation.

Reply: Since no local maximum could be extracted from our reanalysis, we have deleted these sentences.

Comment 23: l.10 on p.1607 (Computer simulations...): To illustrate the mechanism of ice nucleation, you should add the information about the calculation condition of computational simulations in much more details.

Reply: We have deleted this sentence to retain the focus of our paper on OPC and lidar observations.

. [Section 5] Summary. Comment 24: l.16 on p.1607: The authors show no evidence (figure) to support their argument that cirrus was created under the influence of deep convection. It makes readers suspicious of the validity of this argument.

Reply: We believe that "cirrus was created under the influence of deep convection" would be a slight misinterpretation of how we have interpreted the findings of the first manuscript. To clarify, we have rewritten this text as, "TTL clouds were observed frequently in the vicinity of deep convection conditions." Future studies will reveal the relation between TTL cloud and deep convection.

. Appendix A. Comment 25: l.25 on p.1608: You should add the method or condition of how each threshold was derived in this section.

Reply: We have rewritten and redrawn subsection 2.1, Appendix A, and Figure 8 in revised manuscript.

Comment 26: l.6 on p.1609: Model C is not found in Figure 6.

Reply: Model C is the same as the "Hexagon" in Figure 6 in our first manuscript (Figure 8 in revised one) and we have modified the legend accordingly.

. Tables. Comment 27: Table 2: The definition of TT used for this study should be added.

Reply: We have replaced TT with TTL throughout the text as recommended by the Reviewer.

. Figures. Comment 28: You should rewrite the captions so that the readers can understand what you are trying to say with each figure even without reading the main body of text. The figures are too small and not clear.

Reply: We have implemented Reviewer's suggestions.

Comment 29: Figure 2: The upper leftmost mark at top of Figure 2 ("x") is not shown in Table 2.

Reply: Figure 2 was incorrect; we plotted "x" even when OPC did not reach the TTL. We have therefore changed this figure into time-longitude and time-latitude sections to better describe the atmospheric field.

Comment 30: The time scale in Figure 2 (i.e. bottom axis) should be expressed in date rather than Julian day.

Reply: We have implemented Reviewer's suggestion as recommended.

Comment 31: The explanation of the Tbb data source (GMS and GOES) should be clearly indicated in the caption of Figure 2.

Reply: We have implemented Reviewer's suggestion as recommended.

Comment 32: Figure 5: Please add the value of the slope of the regression line to the caption of Figure 5.

Reply: We have implemented Reviewer's suggestion as recommended.

Comment 33: Figure 6: Please add legends to this figure. Which threshold corresponds to which dotted line?

Reply: We have implemented Reviewer's suggestion as recommended.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 1595, 2007.