

Response to Referee's (Referee #2) Comments

The authors present a study case of the formation and characteristics of a cirrus cloud using the combination of multiple observational tools. For the method, they show how the combination of COBALD and Boulder Counter can be used for the estimation of lidar ratio for optically thin cirrus. Their results highlight the role of gravity waves and crystals injection from the typhoon Hato to explain the formation of the cloud. It describes a new method and an observational study case of the observed impacts of the gravity waves which is significant for the understanding of the interplay between small scale dynamics and microphysics. Finally, it thus also highlights the impacts of typhoons on cirrus clouds.

Although the method is interesting and new to my knowledge, the paper is long and would be improved by a more concise writing to improve the understanding of the methods and key findings of the authors. Therefore I recommend a major revision.

Reply: We thank the referee for going through the manuscript thoroughly and providing constructive suggestions/ideas for its further improvement. Our response to each comment or suggestion (in black text) is shown below in blue text.

Specific comments :

- 1) The paper is quite long and modifications to shorten it a bit might be useful for a better understanding of the study. Here are a few suggestions/ideas to do so :

In the data method part, the authors wrote a short summary of the history/functioning of the instruments COBALD, SOLAIR, CALIOP, CATS, Himawari-8, added to cited literature relative to each one of the instruments (which should be enough). This might be adding details that are not crucial for the understanding of the author's method.

Reply: We appreciate the ideas/suggestions provided by the referee to shorten the data and method section. As suggested, we have tried to shorten the description of data and method section by moving some details of COBALD to Appendix A, presented at the end in the revised manuscript. For better understanding, we have divided Section 2.2.2 into two subsections (2.2.2.1 and 2.2.2.2) to separate the description of SOLAIR Boulder Counter from the methods used for the estimation of cloud microphysical properties in the revised manuscript. However, we have retained the description of CALIOP, CATS and Himawari-8 observations as they were, because their description is short compared to COBALD and Solair Boulder Counter.

Same comment for the description of ERA5, the justification to use this dataset could be shortened to lines 6,7, and added details such as number of levels available might be added information confusing for the reader (do we need these 37 levels here?)

Reply: There are different types of ERA5 data products available to the users. In the current manuscript, we have used ERA5 data products available at 37 pressure levels which is different

from ERA5 data products available at 137 model levels that provide better resolution in the TTL as compared to those available at few pressure levels. We have deleted this information on 37 levels in the revised manuscript.

Overall, this all method section from p4 to p12 would gain to be summed up to improve the understanding of the discussion regarding each result. Maybe a table, with each key variable and the corresponding instrument? This is just a suggestion.

Reply: We highly appreciate referee's idea of summarizing method section in the form of a table. We have included a table in the revised manuscript.

The lidar ratio part (starting p.17) first describes a discussion about different methods to retrieve this variable, when the key message of the paragraph, which is the authors methods and their demonstration of the use of COBALD and Boulder Counter to retrieve it, appears at the end. This paragraph might gain to be restructured/ shortened to guide the reader to its key points.

Reply: We have moved the discussion on different methods to retrieve lidar ratio to the Appendix in the revised manuscript.

p30, the paragraph from line 12 to line 19 : As it is, it might be added to the introduction. It doesn't comment on the results, but introduces knowledge about literature regarding gravity waves, not directly connected to the author's findings that are described afterwards. Maybe rephrase/shorten it ? The introduction on the other hand is missing some references to existing literature about gravity wave impacts on cirrus clouds, as the authors are demonstrating it in this study.

Reply: We thank the referee for this suggestion. We have moved the paragraph from line 12 to line 19 of p30 to the introduction.

- 2) The authors present different formulas to calculate the ice water content and efficient coefficient, describe the differences/ similarities then recap all their results in a table page 19. Is there a conclusion regarding the differences between the effective diameters ?

Reply: We thank the referee for pointing this out. We have added a conclusion regarding the differences between the effective diameters.

- 3) figure 2 doesn't fit exactly the description in the text :

CL4 is said to have crystals smaller than 40 microns when I don't see the 20 or 25 microns curve (so the crystals are in fact smaller than 20 microns?). Same comment for CL5.

Reply: We thank the referee for pointing this out. This discrepancy is caused because Fig. 2c shows profiles of particle concentration at six different size channels expressed in radius (please see the figure caption) while the text describes the particle size in diameter. We have revised Fig. 2c and expressed particle size in diameter to be consistent through the manuscript.

- 4) figure 12 : the symbols for COBALD, CALIOP, CATS are almost indistinguishable on the figure.

Reply: We have increased the size of the symbols and changed their colours in the revised Fig. 12 to make them distinguishable.

- 5) figure 13 and comments from line 14-28 p.31 : The test of MERRA-2 accuracy could be just mentioned, more details would belong to an appendix. I am not sure what figure 13 is adding to the work already presented in the previous parts ? Maybe I am missing something here.

Reply: This figure is used to show the location of cold-point tropopause, unresolved by GEOS-5 temperature profiles, and the presence of tropopause cirrus clouds as observed by CATS, CALIOP, and COBALD shown in Figs. 11 and 12. It was difficult to locate the cold-point tropopause from Fig.12, so we have used near-co-located observations (within 400 km and 6 hours) with respect to CATS and CALIPSO profiles as shown in Figs. 11 and 12. Each panel in Fig. 13 clearly shows the location of cold-point tropopause and presence of thin tropopause cirrus cloud layers.

- 6) Figure 14 is in section 3.4.3 which is highlighting the role of gravity waves in the formation of CL5. It describes that temperature anomalies are inferred by subtracting a monthly mean profile to the 23 August profile. I am not sure to understand why choosing a monthly time scale here when gravity waves usually have periods no longer than a few days ?

Reply: Thanks for this comment. The wind or temperature profile at any given instant is a combination of the background mean plus wave perturbation. To extract the wave perturbation, the background mean variation needs to be removed. There are various methods to achieve this, and it is quite common to remove the monthly mean, seasonal mean, or climatological mean profile to obtain the perturbation profile. Sometimes, individuals also apply a linear or polynomial fit to the instantly measured individual profile to remove the background. In our case, since we have sufficient data, we opted to remove the monthly mean profile. The perturbation profile, obtained after removing the mean, consists of waves with contributions from a broad spectrum, ranging from high frequency to internal period. There are several observational studies (e.g., Reinares Martínez et al., 2021; Kim et al., 2016; Kim and Alexander, 2015) which used monthly mean profile to estimate perturbation for studying the gravity waves.

- typos/formulations

p.13, l17 : extra space between 100 and unit

Reply: We have removed the extra space between 100 and unit in the revised manuscript.

p.13, l 19, p34 l22 : 'extremely cold temperature'. The 'extremely' is confusing, compared to what ?

Reply: We have deleted the words “an extremely cold” in the revised manuscript.

References

Kim, J.-E. and Alexander, M. J.: Direct impacts of waves on tropical cold point tropopause temperature, *Geophysical Research Letters*, 42, 1584–1592, <https://doi.org/10.1002/2014GL062737>, 2015.

Kim, J.-E., Alexander, M. J., Bui, T. P., Dean-Day, J. M., Lawson, R. P., Woods, S., Hlavka, D., Pfister, L., and Jensen, E. J.: Ubiquitous influence of waves on tropical high cirrus clouds, *Geophysical Research Letters*, 43, 5895–5901, <https://doi.org/10.1002/2016GL069293>, 2016.

Reinares Martínez, I., Evan, S., Wienhold, F. G., Brioude, J., Jensen, E. J., Thornberry, T. D., Héron, D., Verreyken, B., Körner, S., Vömel, H., Metzger, J.-M., and Posny, F.: Unprecedented Observations of a Nascent In Situ Cirrus in the Tropical Tropopause Layer, *Geophysical Research Letters*, 48, e2020GL090936, <https://doi.org/10.1029/2020GL090936>, 2021.