RESPONSE LETTER MANUSCRIPT # JOC-18-0879

We would like to thank the reviewers for thoroughly reading this manuscript and for giving valuable and constructive suggestions which help to improve the quality of the paper. The point-by-point response follows below, whereby the reviewer's comments are written in italic.

COMMENTS FROM REVIEWER #1

General comments R1:
In this manuscript, the seasonal and diurnal variations of cloud characteristics in three subregions of the Tibetan Plateau were analyzed based on recent satellite observations. The revealed vertical structures of clouds at different regions and different time are impressive. And the implications that changes in large-scale circulations might result in distinct cloud patterns have the potential to inspire further studies on understanding the climate changes over the Tibetan Plateau. Some minor points are listed below.

Response:
We appreciate the positive feedback for our study and we have been able to incorporate changes to reflect most of the minor comments by the reviewer.

Comment 1, R1:
The boundary of the three regions should be reconsidered. The authors have mentioned that "the boundary of the westerly-dominated zone of the TP can be more south". The TP region is characterized by strong influences of complex topography at different spatial scales. On both Fig. 3 and Fig. 10, there is no signals corresponding to the division of the current three regions. So regimes taking into account both the cloud features and the circluation patterns should be defined instead of the simple boxes in Fig. 2.

Response
Thank you for this comment! We understand that the suggestion of choosing different domains is highly standing to reason, which is also why both reviewers point this out. It would have been interesting to explore this aspect. However, there are a few reasons, why we think that this is beyond the scope of this particular study:

1. The focus of this study was to identify different cloud regimes based on the different impact of large-scale circulation patterns and atmospheric moisture transport. For this, the applied framework seems to be the best available framework, we could found, even though it might be fairly simplified, since it takes into account different moisture sources tracked by water isotopes (Yao et al., 2013). Both precipitation regimes and regimes of different moisture sources are hence needed, in order to fulfill our aim.
2. You suggest to instead divide the region into our cloud regimes. In our opinion, this is both difficult and contradicting to the aim of the study, because we wanted to construct a climatology where the regional differences can be directly compared to seasonal differences, since the regions reflect the seasons of the two dominant large-scale systems. Creating first cloud regimes and then a regional framework based on that, would rather follow the aim to create a new framework based on cloud structure instead of investigating cloud structures in a pre-defined framework. Furthermore, it would be difficult to define horizontal boundaries for new regions based on the cloud regimes, since the different cloud micro-physical and macro-physical properties partly show different regimes (e.g.) and because the regimes mainly can be distinguished through the vertical and profile-based properties. This is also the reason why Fig. 3 and 10, which are based on the column-integrated values in a 1 x 1 grid, do not show any distinct regional signals whereas the vertical properties, such as radar reflectivity (Fig. 5) and vertical cloud fraction (Fig. 6), show significant differences between the chosen regions. The reason why we don't see any clear signal here, is probably the coarse temporal and spatial resolution of CloudSat. So instead of using the identified cloud

regimes as boundaries, we suggest that it could be used together with more detailed studies about precipitation regimes and moisture sources, in order to create a new regional framework.

3. Finally, our results show also that we see a more clear signal of seasonal differences than regional differences in the cloud regimes, which means that choosing different boundaries would probably not influence the most important conclusions of this paper. In contrast, it enables a discussion why for some parameters there is a mismatch between seasonal and regional differences (e.g. Fig. 7). If we would just investigate regional differences based on regions which show the most distinct cloud patterns, the discussion of linking the regional differences to large-scale circulation impact would not be possible to the same extent.

Instead of experimenting with new regional frameworks, we clarified in our discussion, why the applied framework was chosen and why it would be difficult to use the identified cloud regimes, in order to define new horizontal boundaries (line xx). We added a discussion point on which other large-scale systems exist (line xx), in order to clarify that the framework we used is simplified and cannot explain the impact of all large-scale circulation patterns over the TP, but instead focuses on the two most important systems (see for example “Recent changes in the moisture source of precipitation over the Tibetan Plateau”, Zhang et al., 2017).

Finally, we are away of the strong influence of topography, which is why we added this point in our discussion (line xx). Even though the effects of topography can have different scale, we really focus on large-scale here, again due to the coarse spatial resolution of CloudSat. We therefore think that it is beyond the scope of this study to choose a regionalization framework based on topography. What we, however, tested was the relationship between elevation and cloud properties by looking at joint PDF and zonal vertical cloud fractions. As can be seen in the figures below, no clear relationship between elevation and cloud top height or cloud thickness (Fig. 1) could be identified and no obvious latitudinal boundary can be derived from the vertical cloud fractions (Fig. 2).

(a) (b)

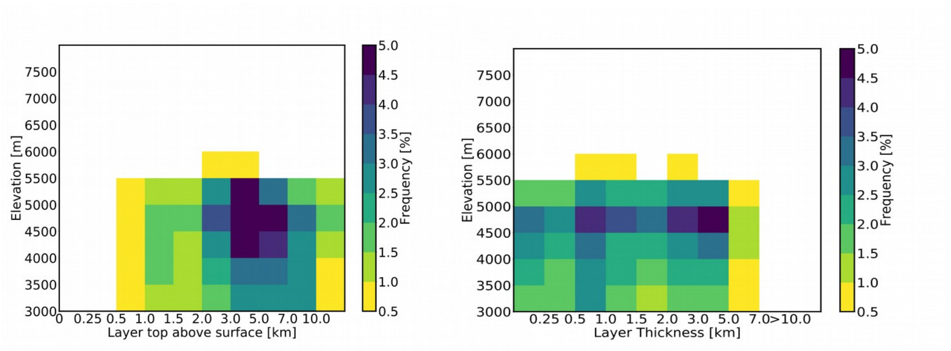

Figure 1: Joint PDF of cloud layer top heights (a) and cloud layer thicknesses (b) over the Tibetan Plateau.

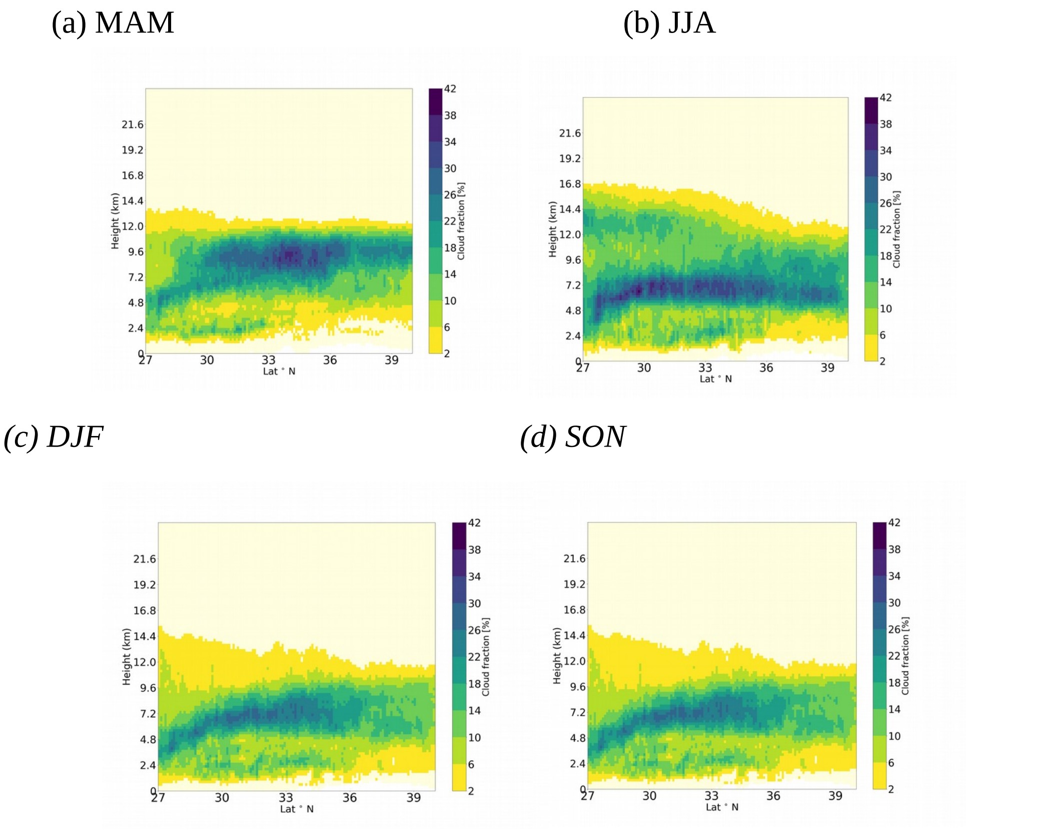

Figure 2: Zonal vertical cloud fraction for different seasons averaged over the Tibetan Plateau between 27 N and 45 N for elevations over 3000 m ASL.

Comment 2, R1

The validity of Fig. 3b should be checked, since there are large regions with value between 50-60% both to the north and to the south of the TP.

Response

Thank you for the careful reading and for pointing this out. We agree with this comment and understood that our Fig. 3b is slightly misleading here. In order to directly compare the monsoon and westerly season, we chose the same range in the color bar in Fig. 2a and Fig. 2b. The minimum value of “50 %” means also that all grid cell values with the cloud frequencies below 50 % are colored in yellow. Hence, the large regions, which you are referring to, are not as homogenous as they seem in the figure, but show rather that cloudiness in these regions is below 60 or 50 %.

We changed the colorbar accordingly (by exteniding the displayed color range) and hope we could clarify that the grid cells outside of the plateau do not look as homogenous. We also added the token "<" to the labels of the colorbar to clarify which grid cells refer to 40 % and values below 40 %. We also tried to choose other minimum values of the displayed color range (e.g. 10 %), but since regions which such small values are rare and mainly outside of the plateau, the chosen colorbar as it is now seemed to be the best choice.

The validity of Fig. 3B was also double-checked, but as specified above, we proceed on the assumption that your doubts about the validity only arised from our unclear labeling of the colorbar. If you are more interested about the details of the calculation, the respective scripts can be found at *https://github.com/JuliaKukulies/cloudsat_climatology*.

Comment 3, R1:
The current results on clouds can be further discussed according to the hourly rainfall features over the TP. A recent reference is "Hourly station-based precipitation characteristics over the Tibetan Plateau, IJOC, 2018". Also, as discussed in the manuscript, the mismatch between rainfall and cloud features related to the sampling time of satellite data can be further explained by refering to the diurnal cycle of different types of rainfall.

Response
Thank you for this comment and for pointing out the interesting paper on hourly precipitation over the TP. We think, you have raised an important point here. Therefore, we added a few aspects (including the conclusions from Li, 2018) concerning hourly precipitation in section 5 (the two paragraphs from line xx). We also expanded the discussion on the mismatch between rainfall and cloud features due to different sampling times of the satellites by referring to the diurnal cycle of different types of rainfall. We added, for example a discussion on precipitation phase, duration and intensity and tried to link the identified cloud features more closely to hourly precipitation features (with focus on day-night differences).

Since we think that the linkage between cloud and precipitation characteristics is an important aspect of the constructed climatology (especially for the identification of underlying mechanisms), we elaborate on precipitation features in the second paper of this paper sequence. There, we examine the diurnal cycle based on hourly precipitation from the Global Precipitation Measurement Mission and set it into the context of the temporal structure of cloud characteristics.

COMMENTS OF REVIEWER #2

General comments, R2:
This study provides a detailed statistic feature of cloud properties over Tibetan Plateau by using CloudSat and CALIPSO satellite datasets, including cloud vertical structures, cloud occurrence frequency, cloud layer amount and characters of ice clouds. Compared with former studies, which mainly paid attentions on summer and cumulus, this study provides a seasonal and diurnal views of cloud variation over TP. Also, the manuscript is well written and could be published on IJOC after addressing the follow several minor concerns.

Response
We appreciate both the time and effort the reviewer has dedicated to provide valuable feedback on this manuscript and we appreciate the positive feedback on our study. We have addressed the minor concerns and incorporated changes to reflect most of the minor comments by the reviewer.

Comment 1, R2:
The authors give a discussion the linkages between cloud and large scale circulation, but I guess that the reader would require more, especially for the cloud dynamic and micro physics. Any attempt to add more physical explanations would be welcome.

Response
Thank you for this suggestion. We agree with this comment and have therefore added more details about the physical mechanisms which link the cloud properties to large-scale dynamics. The changes can be found both as explanations in the result section and in the discussion section.

More specifically, we added ...

- an elaborated explanation of how the radar reflectivity profiles are linked to stratiform vs. convective cloud systems (line xx)

- more details about the differences of ice clouds in the monsoon-dominated and westerly-dominated region and what these properties implicate about the formation process, e.g. cirrus clouds as residues from older convective cloud cells (line xx)
- an elaborated explanation of how the microphysical properties cloud phase and optical depth reflect the impact of large-scale circulation, by referring to more organized convection and meso-scale convective systems in the monsoon-dominated region (line xx)
- a more detailed physical explanation of how ice clouds affect the heat budget and why an increased westerly circulation could lead to an enhancement of this effect (line xx)
- a discussion point on other large-scale circulation features which affect the northern regions: Tibetan Plateau vortices and Western Disturbances (line xx)
- an important reference, where the linkage between large-scale circulation and cloud structures has been studied over the TP: Lau et al., 2002 (line xx)
- a discussion point on the fact that large-scale circulation and mean flow affects storm formation and tracks and thereby cloud micro- and macrophysical properties (line xx)
- a discussion point on how microphysics also can feedback on large-scale circulation through radiative-dynamic interaction, with autoconversion as an example mechanisms (line xx)

We hope that the added physical explanations could add value to the discussion on linkages between cloud structure and large-scale circulation patterns. Furthermore, we would like to mention that large-scale circulation is not only linked to cloud features, but in first hand to precipitation features, which are not included in this part of the paper sequence. Due to comment #3 of reviewer #1, we also expanded our discussion on physical explanations for the observed day-night differences in cloud features by referring among other things to the formation and maturing of meso-scale convective systems during nighttime (cf. section 5).

Comment 2, R2:
For the regionalization of Tibetan Plateau in section 3, would it be better that if the authors try to use the cloud regimes? Can it influence the main conclusions of this study?

Response
Thank you for this suggestion, which we understand is highly standing to reason. It would have been interesting to explore this aspect. However, there are a few reasons, why we think that this is beyond the scope of this particular study:

1. The focus of this study was to identify different cloud regimes based on the different impact of large-scale circulation patterns and atmospheric moisture transport. For this, the applied framework seems to be the best available framework, we could found, even though it might be faily simplified, since it takes into account different moisture sources tracked by water isotopes (Yao et al., 2013). Both precipitation regimes and regimes of different moisture sources are hence needed, in order to fulfill our aim.
2. You suggest to instead divide the region into our cloud regimes. In our opinion, this is both difficult and contradicting to the aim of the study, because we wanted to construct a climatology where the regional differences can be directly compared to seasonal differences, since the regions reflect the seasons of the two dominant large-scale systems. Creating first cloud regimes and then a regional framework based on that, would rather follow the aim to create a new framework based on cloud structure instead of investigating cloud structures in a pre-defined framework. Furthermore, it would be difficult to define horizontal boundaries for new regions based on the cloud regimes, since the different cloud micro-physical and macro-physical properties partly show different regimes (e.g.) and because the regimes mainly can be distinguished through the vertical and profile-based properties. This can also be seen in the figures based on the 1 x 1 grid, which do not show as distinct regional and seasonal structures of the column-integrated values in comparison to vertical properties, such as radar reflectivity () and vertical cloud fraction (), which show significant differences between the chosen regions. The reason for this is probably the coarse resolution of CloudSat. So instead of using the identified cloud regimes as

boundaries, we suggest that it could be used together with more detailed studies about precipitation regimes and moisture sources, in order to create a new regional framework.

3. Finally, our results show also that we see a more clear signal of seasonal differences than regional differences in the cloud regimes, which means that choosing different boundaries would probably not influence the most important conclusions of this paper. In contrast, it enables a discussion why for some parameters there is a mismatch between seasonal and regional differences (e.g.). If we would just investigate regional differences based on regions which show the most distinct cloud patterns, the discussion of linking the regional differences to large-scale circulation impact would not be possible to the same extent.

Instead of experimenting with new regional frameworks, we clarified in our discussion, why the applied framework was chosen and why it would be difficult to use the identified cloud regimes, in order to define new horizontal boundaries (line xx). We added a discussion point on which other large-scale systems exist (line xx), in order to clarify that the framework we used is simplified and cannot explain the impact of all large-scale circulation patterns over the TP, but instead focuses on the two most important systems (see for example “Recent changes in the moisture source of precipitation over the Tibetan Plateau”, Zhang et al., 2017).

Comment 3, R2:
Please revise the Figure 10’s caption.

Response
Thank you for pointing this out. We have revised the caption of Figure 10, where (a) and (b) refer to the seasonal mean optical depth values of the atmosphere over the TP, (c) and (d) to the seasonal optical depth of detected cloud layers, (e) and (f) to the relative occurrence frequency of liquid cloud layers and (g) and (h) to the the seasonal median cloud layer base. We also changed the respective references to the subfigures in the text which describes Figure 10.