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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Analysis of cirrus cloud over the Tibetan Plateau from CALIPSO data: an altitude perspective" *by* Feng Zhang et al.

Feng Zhang et al.

oxeye75@163.com

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1. Sect. 2.1: The cirrus occurrence number from CALIPSO is used to investigate the geographical distribution of cirrus in the study. How about the geographical distribution of the effective sampling number of CALIPSO over the TP? Are there much more default values in some regions than others? Will the inhomogeneous distribution of effective sampling data result in large biases in the calculated distributions of cirrus occurrence numbers? Response: Fig. 1 shows the geographical distribution of the effectively sampled cirrus number by CALIPSO over the TP during the summertime from 2012 to 2016. The spatial resolution is $1^{\circ}\times2^{\circ}$ and the sampling criteria are the same as that in the manuscript. We can tell that only two regions failed to have values. Both of them are on the outer edges of Tibet Plateau so the default values there won't affect

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our study. Despite these regions, the rest of the study areas have abundant sampling numbers to allow us to gain a solid knowledge of the cirrus characteristics. The effective sampling data results are indeed inhomogeneous; however, this does not mean a large bias of the CALIPSO data. All the numbers counted in our study are quality assured. The inhomogeneity can be influenced by the CALIPSO orbit and how we set our domain resolution, but considering the large sampling numbers, this geographical inhomogeneity can reveal the reality of cirrus distribution and this is also the inspiration of our study. We want to explore what kind of mechanism trigged this geographical inhomogeneity of cirrus and the characteristic of cirrus on the Tibetan Plateau.

Figure 1. Geographical distribution of cirrus numbers effectively sampled by CALIPSO during the June-August period from 2012-2016.

Figure 2. Topographic maps over Tibetan Plateau 2. P7, L12 – P8, L12 and Fig. 1: I would like to see a plot showing the geographic distribution of terrain height in the region. Several variables (e.g., surface diabatic heating, radiation cooling, latent heat, sensible heat, and water vapor evaporation) are mentioned in the discussion, but none of them are displayed. Are there any signals at higher altitudes to see the influence of topographic height on cirrus? In which study and by what model is the cirrus formation simulated (stated in P8, L4-5)? Response: Fig. 2 shows the geographic distribution of terrain height in the region. Fig.3 shows the monthly mean surface net thermal radiation, water vapor evaporation, latent heat flux and sensible heat flux from ERA5 data, respectively. Radiative cooling is the net outgoing radiative energy flux(Sun, Sun, Zhou, Alam, & Bermel, 2017), it can be given as

Where is the thermal emission of the radiative cooler with temperature , and is the atmospheric radiation with air temperature . Here we assume the atmospheric radiation is the same in our study region, the radiative cooling is determined by the surface thermal emission , which is the upper left plot in Fig. 3. Essentially, the maximum radiative cooling region lies in the southwest of the Plateau where the terrain height exceeds 4500 m. The top right and bottom left figures show the evaporation and surface latent

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heat flux, respectively. Their patterns are identical. The regions with higher altitude tend to be drier than lower altitude regions, so evaporation and surface latent heat flux is not the main contributor to the formation of cirrus below 9 km. The bottom right figure shows the surface sensible heat flux. Higher altitude region also shows strong sensible heat flux. However, the magnitude is around 70 Wm-2, which is smaller than the magnitude of surface radiative cooling (130 Wm-2). Therefore, the surface radiative cooling caused by terrain height triggered cirrus below 9 km and the surface sensible heat flux is the second contributor. Figure 3. Geographical distribution of monthly mean (a) surface radiation cooling, (b) evaporation (c) latent heat flux, and (d) sensible heat flux over Tibetan Plateau. The study period is June, July, and August from 2012 to 2016. 3. P8, L13 – P10, L9 and Fig. 2: It seems that the negative gravity wave acceleration cannot fully explain the distribution pattern of cirrus occurrence number shown in the figure. Could the geographical distributions of other relevant variables, such as gravity wave induced fluctuations of water vapor and temperature, be investigated? Is it possible that shallow or mid-level convection in this region play a role in the formation of cirrus? Response: We agree with the reviewer. The negative gravity wave acceleration cannot fully explain the distribution pattern of cirrus occurrence number. Following the classical circulation decomposition [Lorenz, 1967], the perturbation is decomposed into stationary part and transient part. The stationary part is mainly caused by geographical factors, while the transient part is mainly caused by the fluctuations in the atmosphere such as gravity waves. Here is the Lorenz decomposition formula:

where overbar () and prime (âĂš) represent the temporal mean and anomaly. Similarly, bracket (< >) and star (*) represent the spatial mean and anomaly. Thus, and are the stationary part and the transient part, respectively. Figure 4 shows the geographical distribution of (a) transient temperature fluctuation and (b) 5-year averaged specific humidity at 250 hPa (about 11 to 12 km). There is significant temperature fluctuation at the north side of the Tibet Plateau, with a peak near 79 ° E and 41 ° N. However, the water vapor condition at 250 hPa over the western TP is too poor to form more cirrus clouds, so the cirrus clouds are concentrated in the northeast. Tempera-

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ture fluctuation includes convections, gravity waves, and other atmospheric activities at different scales. Besides, the convections, the eastward subtropical upper-level jet stream passes over the TP and its adjacent orography are all likely to trigger gravity waves and intensify temperature fluctuation [Cohen and Boos, 2016]. Therefore, the fluctuations in temperature contribute to the formation of cirrus between 9-12 km.

Figure 4. Geographical distribution of (a) temperature fluctuation and (b) 5-year averaged specific humidity at 250 hPa (about 11 to 12km). 4. P10, L10 – L12, L2 and Fig. 3: Here it might not be fully appropriate to state that deep convection is another cirrus formation mechanism (P10, L12) since atmospheric dynamics and microphysical processes in the formation of cirrus should be distinguished and described clearly. Can the difference between the timing of the CALIPSO overpasses and the period of daily OLR data fully explain the difference between the location of maximum cirrus number and the center of low OLR shown in the figure? From the geographical distribution of OLR, one can see strong convection activity in most areas of eastern TP, where the cirrus occurrence number is very small. Does this indicate that the cirrus formation (occurrence number) cannot be well explained by the convection activity (OLR) at this altitude range? Response: Yes, our conclusion can be affected by the timing of the CALIPSO overpasses. CALIPSO passes our interested regions twice a day while the OLR data is daily. Moreover, OLR is reanalyzed grid data while the CALIPSO sampling number is the mean of each $1^{\circ}\times2^{\circ}$ box. These two reasons can cause a mismatch between strong OLR value and small cirrus occurrence number. However, OLR is just an indicator of the deep convection. Deep convection alone cannot guarantee the formation of cirrus, and other factors such as condensation nuclei and water vapor are also needed. Therefore, the convective outflow level and OLR only offer a necessary condition for the uplift of cirrus, but it is not sufficient enough to ensure the occurrence of cirrus. As we can see from Figure 7, the convective overflow height is around 12 km in most areas of eastern TP and the OLR is below 210 Wm-2, indicating strong convection activities there. From Fig.5a and Fig. 6a, we can see water vapor is more abundant when latitude is smaller than 30N at 200 hPa. The atmospheric vertical mo-

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tion and favorable water vapor condition helps the formation of cirrus above 12km.

Figure 5. Geographical distribution of (a) specific humidity anomaly and (b) temperature anomaly from monthly ERA5 data.

Figure 6. Geographical distribution of (a) specific humidity absolute anomaly and (b) temperature absolute anomaly from monthly ERA5 data.

Figure 7. Distribution of convective overflow height and OLR. 5. P12, L3-11 and Table 1: What does the symbol "-" stand for in Table 1? Can the scatter plots be shown with figures? Response: Symbol "-" stands for failing to pass the significant test. Scatter plots are less intuitive than direct correlation coefficient. Therefore, they are ignored here. Technical issues: P1, L19-21: The sentence needs to be rephrased. Response: Thank you for the suggestion. Then sentence has been rephrased as "The geographical distributions of summertime cirrus with different cloud-top heights above the Tibetan Plateau are investigated by using the 2012 - 2016 Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data.". P1, L21: "exhibits". Response: Corrected. P9, L16: What does "along with smaller particle size" mean? Smaller aerosol particles, or smaller cirrus particles? Response: Sorry for the misleading information. The increase of ice crystals numbers will bring the shrink of their size, so the smaller particle size means the smaller ice particle size. This sentence has been changed correspondingly. P9, L19: What do you mean by saying the wave accelerations are on the order of +/- 1 m s-1? The values are too high or too low? Response: These values are relatively low. Therefore the wave acceleration is not the only contributor. Fluctuations both in velocities and temperature-induced by gravity wave contribute to the formation of cirrus between 9-12 km. P10, L5: The concept of the Froude number needs to be described or explained. Response: Thank you. This part has been added. We have added related information into the text. P10, L12: "triggered"? Response: corrected. We appreciate Reviewer 1 very much for his constructive comments.

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Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2019-1000/acp-2019-1000-AC2-supplement.pdf

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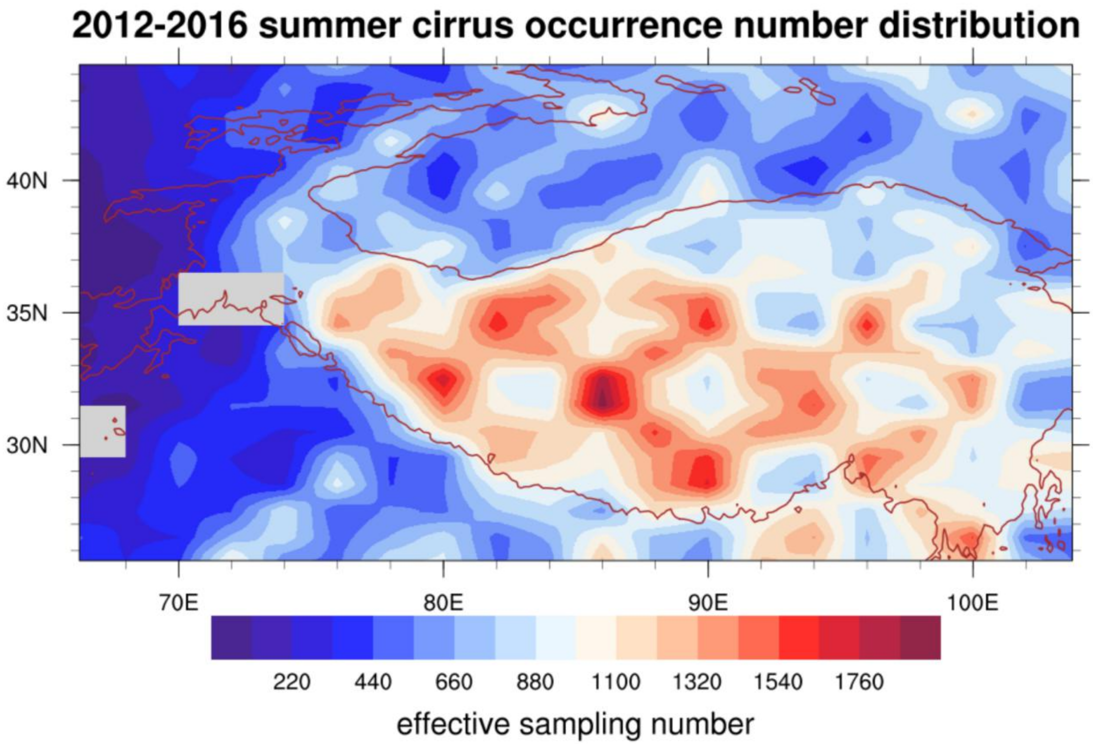

Fig. 1. Geographical distribution of cirrus numbers effectively sampled by CALIPSO during the June-August period from 2012-2016.

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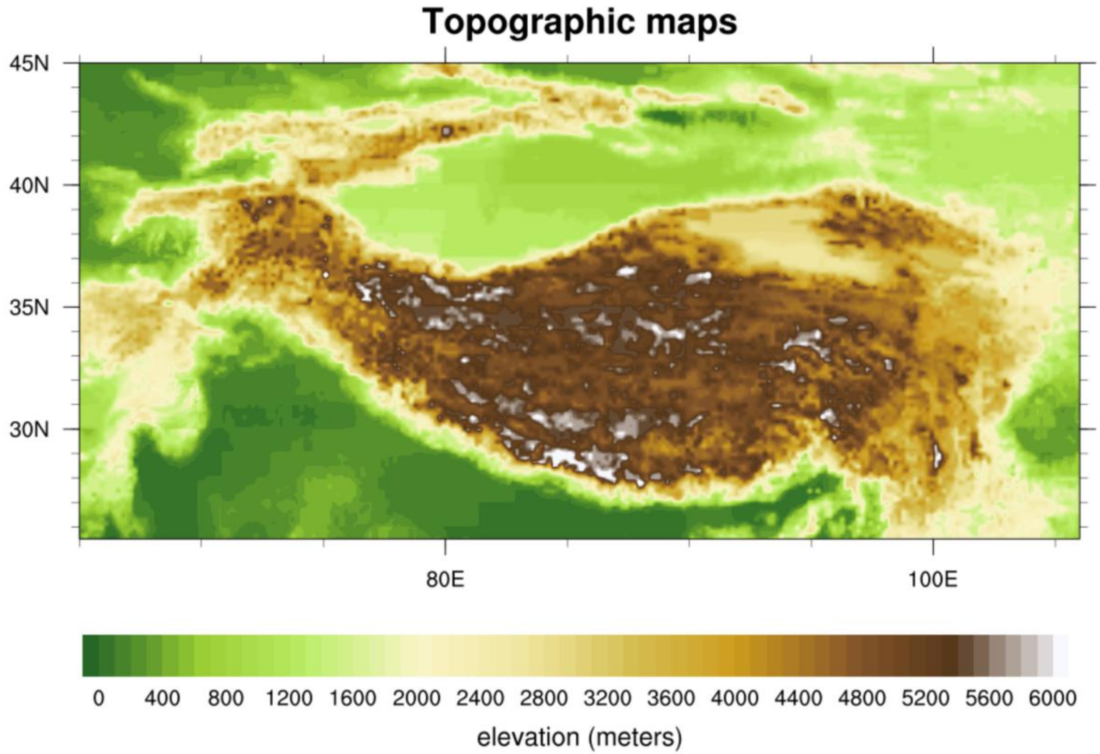

Fig. 2. Topographic maps over Tibetan Plateau

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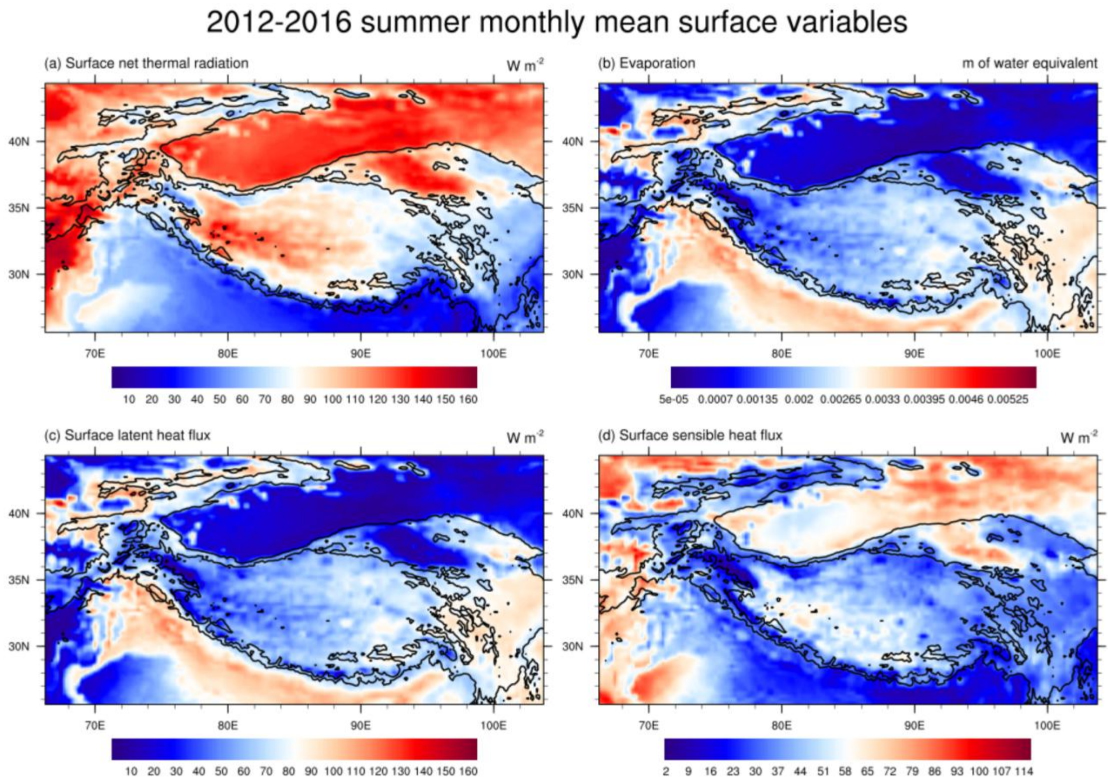

Fig. 3. Geographical distribution of monthly mean (a) surface radiation cooling, (b) evaporation (c) latent heat flux, and (d) sensible heat flux over Tibetan Plateau. The study period is June, July, and Augu

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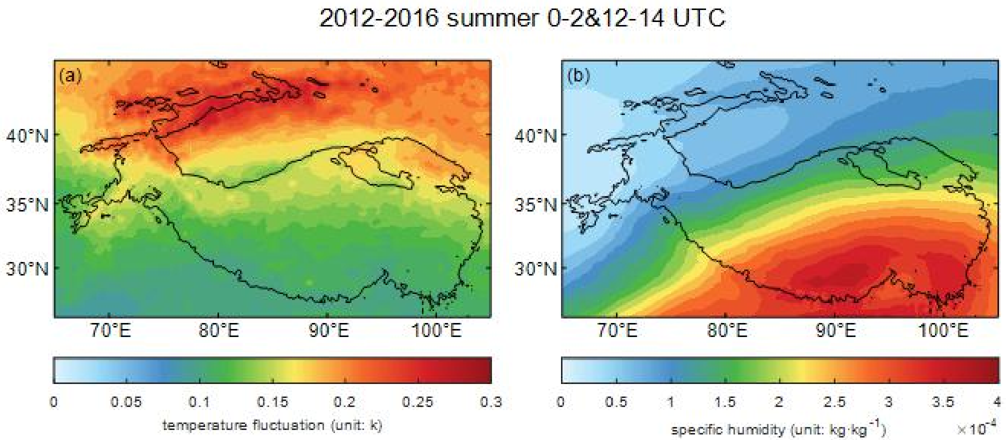

Fig. 4. Geographical distribution of (a) temperature fluctuation and (b) 5-year averaged specific humidity at 250 hPa (about 11 to 12km).

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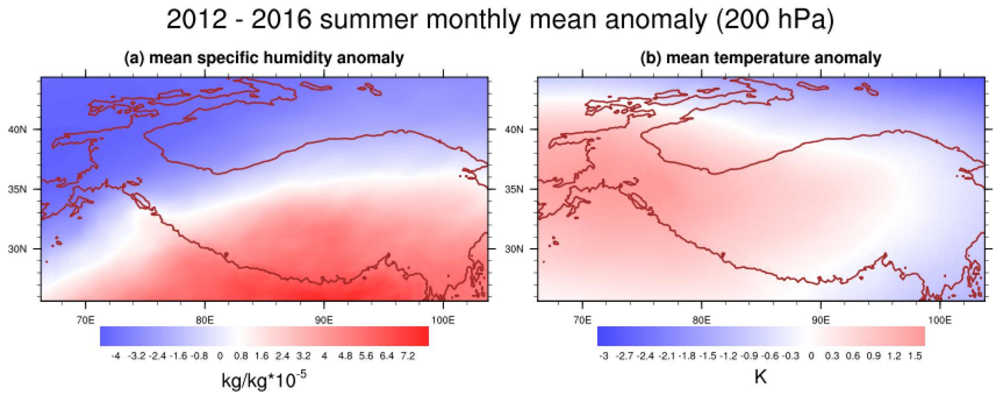

Fig. 5. Geographical distribution of (a) specific humidity anomaly and (b) temperature anomaly from monthly ERA5 data.

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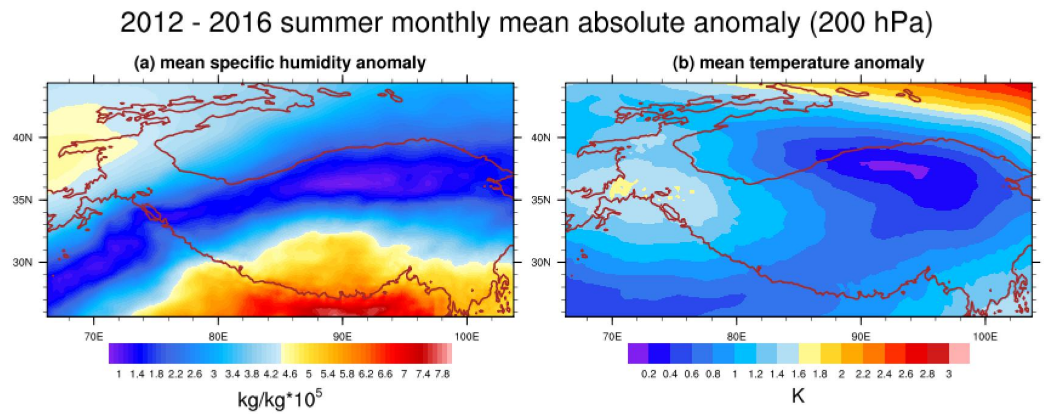

Fig. 6. Geographical distribution of (a) specific humidity absolute anomaly and (b) temperature absolute anomaly from monthly ERA5 data.

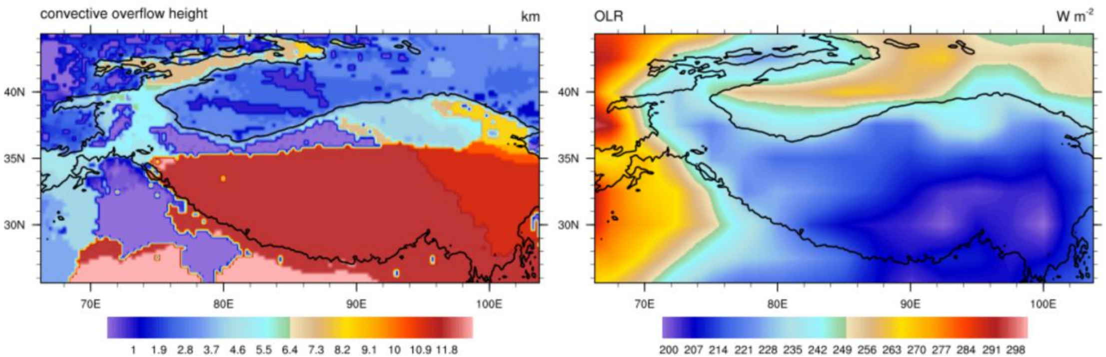

Fig. 7. Distribution of convective overflow height and OLR.

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