Response to Reviewers' Comments

First of all, we thank the reviewers for their comprehensive evaluations and thoughtful comments, which help tremendously to improve the quality of our work. We have tried our best to address the reviewers' concerns one by one. For clarity purpose, here we have listed the reviewers' comments in black, followed by our responses in blue, and the modifications to the manuscript are in italics. We sincerely hope that the reply and the revisions can meet the expectations of editor and reviewers.

Reviewer #1:

Comments on "Characterizing the near-global cloud vertical structures over land using high-resolution radiosonde measurements" by Xu et al.

General Comments

My comments and questions have been adequately addressed in the revision and I found the manuscript in good shape. I recommend this manuscript to be accepted for publication in its current form.
Response: We deeply appreciate the reviewer's approval of our last revised manuscript. Thanks again for the thoughtful comments, which help tremendously to improve the quality of our manuscript.

Reviewer #2:

Comments on "Characterizing the near-global cloud vertical structures over land using high-resolution radiosonde measurements" by Xu et al.

General Comments

The current version of the manuscript, pending a couple of extremely minor and quick technical/grammar corrections, is ready for full publication in EGUsphere.
Response: We deeply appreciate the reviewer's approval of our last revised manuscript. According to EGUsphere's requirements, we have tried our best to carefully review the technical/grammatical corrections of the manuscript in the revised version (Manuscript_tracked.docx).

Reviewer #3:

Comments on "Characterizing the near-global cloud vertical structures over land using high-resolution radiosonde measurements" by Xu et al.

General Comments

This study explores the cloud vertical structure using twice daily radiosonde observations. The main focused cloud properties are on the number of cloud layers, cloud base height, cloud top height, and cloud thickness. Radiosonde measurements are compared with a Ka-band cloud radar at one site and ERA5 reanalysis data. The most interesting finding to me is Figure 7a which shows the global statistics of CBH, CTH, and CT for multi-layer clouds. But, as one of the reviews said, there are several uncertainties associated with the radiosonde measurements and their retrieval method. I have a few minor comments listed below.

Response: We thank the reviewer for his/her comprehensive evaluation and thoughtful comments, which help tremendously to improve the quality of our work. We have tried our best to address the reviewer's concerns one by one. For clarity purpose, here we have listed the reviewer's comments in black, followed by our responses in blue, and the modifications to the manuscript are in italics. We sincerely hope that the reply and the revisions can meet the expectations of editor and reviewer.

Specific Comments

1. What is the vertical resolution of ERA5 reanalysis data? "137 levels from the surface to a height of 80 km ASL". For example, what is the resolution at 2 km, 5km, and 10 km. I think ERA5 reanalysis data takes account of the local sounding data. I'm a little surprised to see the large differences between radiosonde and ERA5. Is it because the resolution of ERA5 is too coarse?

Response: The ERA5 reanalysis can provides single level variables (e.g., cloud base height (CBH) and total cloud cover) on one level or near surface, pressure level variables (e.g., temperature and relative humidity) on 37 levels from 1000 to 1 hPa, and model level variables on 137 levels from the surface to a height of 80 km ASL (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-complete?tab=overview). We changed the sentence "The product consists of hourly analysis fields on 137 levels, from the surface to a height of 80 km ASL." to "The product consists of *single level variables (e.g., CBH and total cloud fraction) on one level or near surface or one level, pressure level variabl*es (e.g., temperature and relative humidity) on *37 levels from 1000 to 1 hPa, and model level variables on 137 levels from the surface to a height of 80 km ASL (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-complete?tab=overview)*." in the revised version (Manuscript_tracked.docx).

Unfortunately, the vertical resolution of CBH does not seem to be documented in ERA5. The CBH in ERA5 is detected using the cloud cover or cloud water mixing ratio threshold. When cloud cover is greater than 1 %, the height from ground to the base is defined as CBH (Wang et al., 2022), which may lead to the underestimation of CBH in ERA5. In addition, the coarse resolution of RH and T profiles from ERA5 reanalysis may be one of the reasons causing the large differences in CBH between radiosonde measurement and ERA5 measurements, as you suggested. Previous studies pointed out that the CBHs of both high-level clouds and relatively low-level clouds were underestimated in ERA5 (e.g., Miao et al., 2019; Wang et al., 2022; Li et al., 2022). The underestimation for high-level clouds in the ERA5 results were caused by the poor specification or parameterization of critical RH from model (Miao et al., 2019). The underestimation of relatively low clouds may be associated with issues of cloud parameterization schemes used for ERA5.

References:

Li, D., Liu, Y. Z., Shao, T. B., Luo, R., and Tan, Z. Y.: Assessment of cloud base height product from ERA5 reanalysis using ground-based observations, Chinese J. Atmospheric Sci., https://doi.org/10.3878/j.issn.1006-9895.2208.22109, 2022. (In press).

Miao, H., Wang, X. C., Liu, Y. M., and Wu, G. X.: An evaluation of cloud vertical structure in three reanalyses against CloudSat/cloud-aerosol lidar and infrared pathfinder satellite observations, Atmos Sci Lett., 20, e906, https://doi.org/10.1002/asl.906, 2019.

Wang, R. J., Zhou, R. J., Yang, S. P., Li, R., Pu, I. P., Liu, K. Y., and Deng, Y.: A new algorithm for estimating low cloud-base height in southwest China, J. Appl. Meteorol. Clim., 61, 1179–1197, https://doi.org/10.1175/JAMC-D-21-0221.1, 2022.

2. Eq.5: I understand the authors want to have an RH profile to determine the cloud layer. RH_liquid and RH_ice both have a physical meaning, that is the relative humidity respect to water and ice, respectively. However, RH_mixed is just a combination of RH_liquid and RH_ice. It is not correct to say "RH_mixed is the RH with respect to liquid-ice mixed".

Response: Thank you very much for pointing out the mistake. We changed the sentence "To obtain the RH profile with respect to liquid-ice mixed ($RH_{mixed}(z)$), …" to "In this case, the RH is termed as RH_{mixed}, which is a combination of RH_{liquid} and RH_{ice}. To obtain the RH_{mixed} profile, the solutions of ice phase and liquid phase are scaled linearly with T(z) (Austin et al., 2009). …" in the revised version (Manuscript_tracked.docx).

Reference:

Austin, R. T., Heymsfield, A. J., and Stephens, G. L.: Retrieval of ice cloud microphysical parameters using the CloudSat millimeter-wave radar and temperature, J. Geophys. Res.-Atmos., 114, D00A23, https://doi.org/10.1029/2008JD010049, 2009.

3. Eq.7-9: I think it is smart to use the first and second derivatives to find the cloud layers. Is it possible that Eq. 7 is satisfied due to some fluctuations of T and RH in nature? For example, when Eq. 7 is satisfied it might be a false signal, not the true cloud layer.

Response: Thanks for your recognition. Yes, Eq. 7 is satisfied when there are some fluctuations in air temperature (T) and relative humidity (RH) in nature. Thus, only using the vertical gradients of T and RH to detect cloud layers may cause error. To obtain the accurate cloud vertical structures, we combine both the vertical gradients of T and RH and the altitude-dependent thresholds of RH to detect cloud layers. After detecting moist layers by using the first and second derivatives of T and RH, we identified cloud layers by using height-resolving RH thresholds defined in Table 2.

4. Figure 5: Because radiosonde observations are compared with radar at one site, I would recommend the author to plot the same figure but only using data from MMCR. The figure can be in the supplementary. I guess the agreement would be better.

Response: If I understand correctly, you suggest comparing the CBHs and cloud top heights (CTHs) from radiosonde measurements with those from MMCR at 374 radiosonde stations, which is similar to Fig. 5. We also guess the agreement would be better. Unfortunately, we only obtained the cloud vertical structure (CVS) from MMCR at one site (Beijing Nanjiao weather observatory). When MMCR data are available at a mass of sites in the future, we will compare the radiosonde-derived CVS with those from MMCR on a global scale.