We sincerely appreciate the reviewer's thoughtful and constructive comments. We have carefully considered each comment and revised the manuscript accordingly. Our point-by-point responses are provided below in bold.

Reviewer 2:

In this paper, a global cloud-type-dependent climatology of mixed-phase clouds is developed using the CloudSat/CALIPSO observations, and the spatial, vertical, seasonal, and regional variations of these clouds is analyzed.

The analysis is useful in understanding the global distribution of mixed-phase clouds, but there are several major technique flaws in the paper. The paper might be accepted after addressing the following comments:

1. In this paper, mixed-phase clouds are grouped into five cloud-type categories: As, Ac, St+Sc, Cu, and Ns+DC, while cirrus clouds are excluded in this study. However, there are a lot of multiple layer clouds in the atmosphere, e. g., a cirrus cloud layer overlapping a cumulus cloud layer. So how are these multiple layer clouds handled in this paper?

   Reply: We thank the reviewer for this question. Multilayer cloud profiles are retained in the CloudSat/CALIPSO analyses, with their treatment depending on the type of analysis. For spatial distributions of mixed-phase cloud occurrence, such as in Figs. 1 and 5, occurrence is calculated at the profile level. Each CloudSat profile is counted at most once for the overall mixed-phase cloud occurrence and at most once for each cloud-type category, regardless of the number of mixed-phase layers of that type within the profile. For example, if a profile contains two mixed-phase Ac layers and one mixed-phase St+Sc layer, it contributes one count to the overall mixed-phase occurrence, one count to Ac, and one count to St+Sc. If a cirrus layer overlaps another mixed-phase cloud layer, as in the reviewer's example, the cirrus layer does not contribute to the five cloud-type categories considered here, while the mixed-phase layer is retained according to its cloud type. Similarly, if ice or liquid layers occur in the same profile as a mixed-phase layer, only the mixed-phase layer contributes to the mixed-phase cloud analyses.

   For the cloud geometry in Fig. 3 column 1 and the vertically resolved mixed-phase occurrence in Figs. 4 and 6, the analysis is performed at the layer level. Individual mixed-phase cloud layers within multilayer profiles are retained; each layer contributes according to its own cloud type and vertical extent. In contrast, for the MODIS LWP statistics in Fig. 3 column 2, only single-layer daytime mixed-phase profiles are retained to reduce ambiguity in interpreting passive MODIS LWP retrievals under multilayer cloud conditions.

   The following texts are added in Sect. 2.3 to clarify this:

“For spatial distributions of mixed-phase cloud occurrence, occurrence is calculated at the profile level as the number of CloudSat profiles containing at least one mixed-phase cloud layer divided by the total number of observed profiles within a given bin. Each profile is counted at most once for the overall mixed-phase cloud occurrence and at most once for each cloud-type category, regardless of the number of mixed-phase layers of that type within the profile. Thus, a profile containing more than one mixed-phase cloud type may contribute to multiple cloud-type categories. For cloud geometry and vertically resolved mixed-phase occurrence, the analysis is performed at the layer level. Individual mixed-phase cloud layers within multilayer profiles are retained according to their cloud type and vertical extent, while non-mixed-phase layers within the same profile do not contribute to the mixed-phase cloud statistics.”

2. The MODIS cloud phase is used in this paper according to Line 137. However, MODIS provides the cloud top phase instead of the total cloud-layer phase, and a lot of mixed-layer convective clouds are identified as ice clouds due to their ice top (for example, Wang et al., doi: 10.1109/TGRS.2023.3317532). How is this issue handled in this paper?

   Reply: We thank the reviewer for raising this issue. In this study, MODIS cloud water path is retained as LWP only when the MODIS optical-properties phase flag classifies the collocated pixel as liquid and the water-path retrieval is valid. Therefore, CloudSat/CALIPSO mixed-phase clouds that are not classified as liquid by MODIS, including mixed-phase clouds with ice-dominated tops as discussed by Wang et al. (2023), are excluded from the MODIS LWP statistics in Fig. 3 column 2. Mixed-phase clouds and their cloud types are identified solely from the 2B-CLDCLASS-LIDAR product. Thus, clouds excluded from the MODIS LWP statistics are still retained as mixed-phase clouds in the CloudSat/CALIPSO-based occurrence and cloud-geometry analyses. Consequently, the MODIS LWP values in Fig. 3 column 2 represent a conditional subset of the CloudSat/CALIPSO mixed-phase cloud population. Among single-layer daytime mixed-phase clouds, the fraction with valid MODIS liquid-phase LWP retrievals ranges from approximately 19.3 % to 50.3 % across the five cloud types and is approximately 19.8 % for Ns+DC. These fractions reflect both the MODIS phase selection and the availability of valid cloud water path retrievals.

   We have clarified this sampling and retrieval limitation in the discussion of Fig. 3 as follows:

   “For the LWP analysis, only single-layer profiles are retained to reduce ambiguity in interpreting MODIS LWP retrievals under multilayer cloud conditions.”

   “In particular, CloudSat/CALIPSO mixed-phase clouds that are not classified as liquid by MODIS, including clouds with ice-dominated tops (Wang et al., 2023), are excluded from the LWP statistics but remain included in the CloudSat/CALIPSO occurrence and

cloud-geometry analyses. Among single-layer daytime mixed-phase clouds, the fraction with valid MODIS liquid-phase LWP retrievals ranges from approximately 19.3% to 50.3% across the five cloud types and is approximately 19.8% for Ns+DC. In addition, because the MODIS cloud optical-property retrieval assumes a single thermodynamic phase for each pixel, the retrieved cloud water path for vertically mixed-phase clouds classified as liquid may not accurately represent the actual liquid water path of the mixed-phase cloud, particularly for clouds with substantial ice content such as Ns+DC."

3. The uncertainty induced by cloud-type classification algorithm should be evaluated or at least discussed. In classic land observations, the cloud type is partially determined based on their spatial distribution pattern, but the CloudSat 2B-CLDCLASS-LIDAR product used in this study (Line 111) does not use the 2-dimensional spatial information of clouds, so the CloudSat 2B-CLDCLASS-LIDAR cloud type product is likely to be different from ground observations and passive satellites.

   Reply: We thank the reviewer for raising this important point. We agree that differences in observational perspective and spatial sampling introduce uncertainty in cloud-type classification. We clarify that the 2B-CLDCLASS-LIDAR algorithm does use spatial information from the vertical and along-track horizontal structure of cloud clusters, although it does not characterize cloud morphology in the cross-track direction. We have clarified this distinction in Sect. 2.1 and added a discussion of the associated classification uncertainty in Sect. 2.4.

   In Sect. 2.1, we revised the description to specify the along-track nature of the horizontal information:

   "Cloud types are classified based on a fuzzy-logic scheme using cloud features such as cloud cluster vertical and along-track horizontal scales, …"

   At the beginning of Sect. 2.4, we added:

   "Cloud type classification is also subject to uncertainty arising from sensor limitations and differences in the observational information used to distinguish cloud categories. Passive-satellite cloud regimes are generally derived from distributions of retrieved cloud-top and optical properties but lack direct information on cloud vertical structure. Previous comparisons found general consistency between CloudSat cloud type distributions and surface-observer and ISCCP climatologies, while also identifying differences for some categories, particularly Cu and Ac, partly associated with CPR sensitivity and near-surface signal contamination (Sassen and Wang, 2008). Comparisons with MODIS cloud regimes likewise showed relatively strong correspondence for some cloud categories but less direct correspondence for middle-level and multilayer clouds, reflecting differences in observational information and classification definitions (Wang et al., 2016). Thus, cloud-type categories derived from

different observing approaches are not necessarily directly equivalent, which should be considered when comparing cloud-type statistics across datasets."

References:

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