Reply to community commenter

Dear community commenter,

We sincerely thank the commenter for the careful reading of our manuscript and for providing detailed and constructive comments. These comments have helped us to re-examine several aspects of the manuscript. In response, we have carefully revised the manuscript to improve its accuracy, clarity, and completeness. Below, we provide detailed responses to each comment raised in the community comment.

Major comments:

Q1: Why are only the GPM DPR (V07) data from 2018 to 2022 used in the classification study of this paper? Currently, there are more than 10 years of GPM DPR data, and the GPM DPR V07 version algorithm has been applied to the all data before May 2018 (GPM DPR scanning mode changed). The classification algorithm results are closely related to the sample. It is difficult to be convincing if only the GPM DPR data from 2018 to 2022 is used instead of the GPM DPR data of almost all years.

Reply: As the reviewer mentioned, the scanning mode is changed since 2018. This is the key reason why we used the data from 2018 to 2022. During the study period, a total of 8,924,307 precipitation systems occurred, which is a remarkably large number for climatology reanalysis and K-means clustering algorithm. In comparison, the study by Ryu et al. (2021) mentioned by the reviewer only has 328,391 heavy rain events and 6,258,800 heavy rain pixel in their study period 2014 to 2019. In summary, ~ 9 million samples in five years could ensure the statistical robustness of our analysis.

Q2: What is the basis for defining the effective precipitation pixel of the precipitation system in this paper as greater than 0.1mm/h? The minimum sensitivity of GPM DPR for detecting precipitation is 0.2mm/h (KaPR) and 0.5mm/h (KuPR). Moreover, in related literature that also uses the definition of precipitation system, greater than 0.5mm/h is used as the standard. This paper uses 0.1mm/h as the selection standard for effective precipitation pixels, which is very likely to introduce unnecessary noise points.

Reply: About the definition of precipitation, we referred to the widely used Precipitation Feature (PF) dataset developed by Liu (2016). The development of PF dataset is also supported by PMM mission and hence we consider it reasonable to carry out our work with reference to this dataset. According to the document of PF dataset, they used near surface precipitation rate > 0 as the threshold for Ku band PF and GMI precipitation rate > 0.1 mm/h for GMI PF. Moreover, similar as the Precipitation Feature dataset, in the process of identifying precipitation system, we only used PS with at least four precipitation pixels, which could significantly reduce noise points.

Meanwhile, many studied using DPR has shown that the minimum rainfall rate of 0.1 mm/h (Peinó et al., 2024; Seela et al., 2024b) and very low mean rainfall intensities (< 0.1

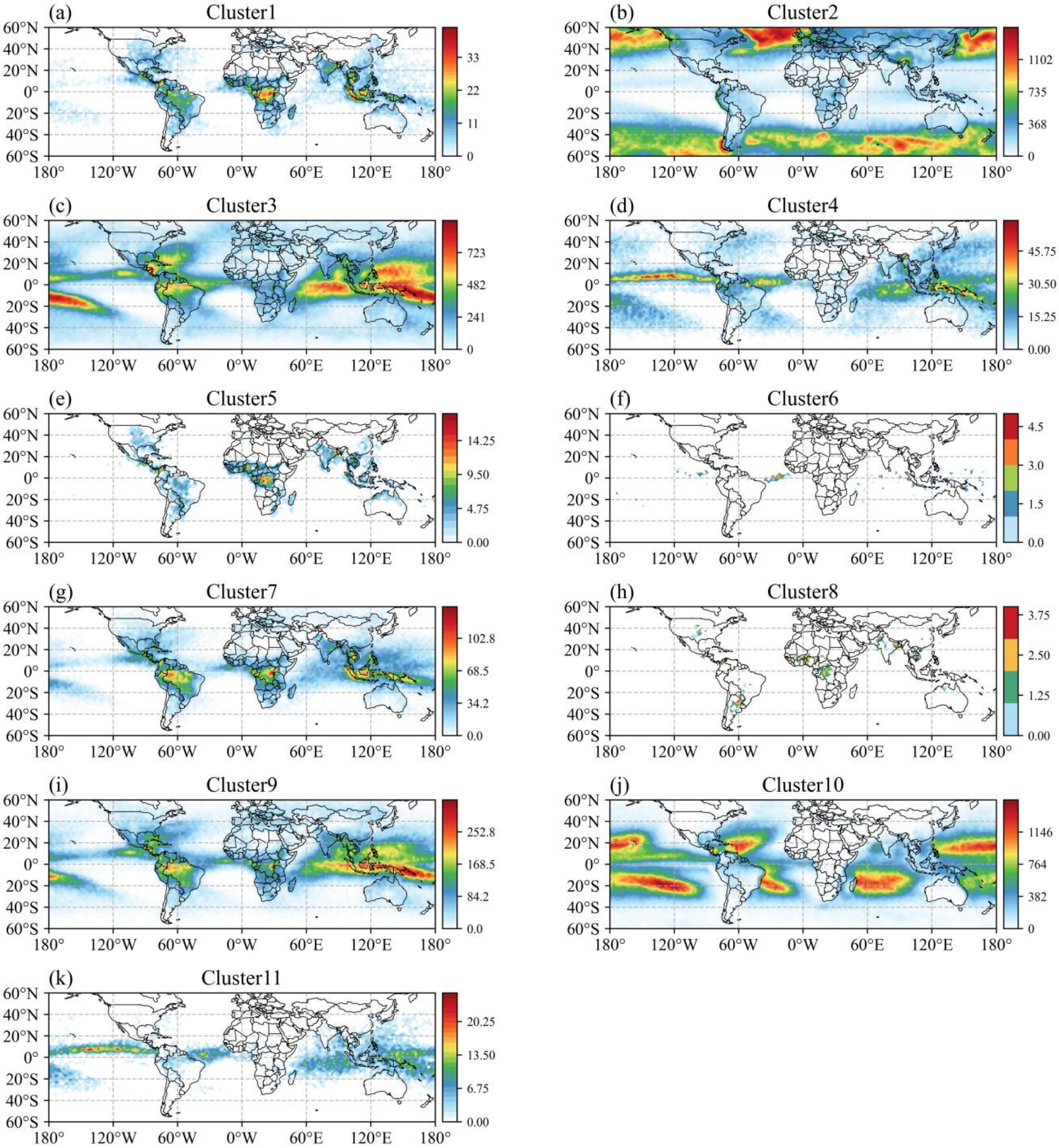
mm/h) are observed (Janapati et al., 2023). Therefore, the threshold 0.1 mm/h is widely used in the applications of DPR. Therefore, we think the threshold 0.1 mm/h is suitable for the study of DPR observation.

Q3: The use of the k-means clustering algorithm as a precipitation system classification algorithm does not solve or overcome the inherent defects of k-means, making the results of this study questionable or unreliable. First, combined with Q1, the results presented in this study may change due to changes in the data set. Secondly, in the process of determining the optimal number of categories presented in this study, I questioned: Why can't "11" be the optimal number of samples? In the supporting materials, I found that "11" and "8" both meet the description of the optimal number of samples mentioned in the article. Unfortunately, however, I did not see the reason for excluding "11" in this article.

Reply: As illustrated in the supplementary figure, the DB index attains its lowest value at K=8, whereas the CH score peaks at K=11. This likely accounts for the reviewer's comment that both 8 and 11 may represent optimal cluster numbers. We think that this line of reasoning may not full capture the features of the two indices. When considering the overall trends and variations of DB and CH, it appears more reasonable to select K=8 as the optimal number. Specifically, the DB value reaches its minimum at K=8 and then rapidly rebounds, showing a consistent increase thereafter. In contrast, at K=8 the CH value also attains a relatively high level, after which it remains elevated with fluctuations.

In addition, to further address the reviewer’s concern, we also performed clustering with K = 11 and analyzed the corresponding results (Reply-Fig. 1 and Reply-Table 1). A direct comparison shows that the 11-cluster solution largely reproduces the same physical regimes identified in the 8-cluster solution. For example, the new Cluster 2 corresponds closely to the high-latitude shallow PS in the 8-cluster classification, with similar spatial distributions and convective characteristics. Likewise, the new Cluster 10 corresponds to the subtropical shallow PS, the new Cluster 3 to the moderate PS, the new Clusters 4, 7, and 9 to the deep PS, the new Clusters 1 and 5 to the strong PS, the new Cluster 8 to the extreme strong PS, and Cluster 6 to the marine extreme PS.

These comparisons indicate that the 11-cluster solution does not introduce fundamentally new precipitation regimes but rather subdivides existing ones, leading to increased redundancy without providing additional physical insight. Therefore, we adopt K = 8 as the optimal number of clusters, as it captures the major precipitation system types in a more concise and interpretable manner while preserving the essential physical information.



Reply-Figure 1 Spatial distributions (2° ×2° resolution) of the PS counts from 2018 to 2022

Reply-Table 1 Precipitation parameters for the different types of PS

	Cluster1	Cluster 2	Cluster 3	Cluster 4	Cluster5	Cluster 6	Cluster 7	Cluster 8	Cluster 9	Cluster 10	Cluster 11
Mean MAXHT20 (km)	14.18	2.99	5.89	10.25	15.46	12.65	12.57	16.45	8.96	2.92	13.78
Mean MAXHT30 (km)	12.87	0.66	3.86	6.97	15.29	9.15	9.71	17.01	6.36	1.32	9.52
Mean MAXHT40 (km)	7.93	0.01	0.7	4.55	10.45	5.7	5.93	13.78	3.25	0.05	6.01
Stratiform percentages (%)	58.06	89.14	54.53	68.49	55.84	66.89	50.47	51.44	52.37	5.57	70.81
Convective percentages (%)	39.29	5.67	41.29	29.28	41.40	31.54	47.24	45.60	45.34	94.28	27.44
Land percentages (%)	60.70%	20.53%	23.98%	19.14%	73.73%	10.13%	49.38%	84.94%	34.80%	6.08%	12.48%
Ocean percentages (%)	39.30%	79.47%	76.02%	80.86%	26.27%	89.87%	50.62%	15.06%	65.20%	93.92%	87.52%
Mean precipitation (mm h^{-1})	129.22	1.48	3.95	87.31	151.91	175.28	32.13	165.33	10.92	8.25	199.57
Number of samples	24156	3846331	1789929	60935	5176	708	105906	710	441863	2635780	12813
Mean precipitation area (km^2)	9,847,674	21,084	130,733	2,653,996	13,098,217	7,645,540	1,574,530	15,019,917	404,531	39,962	8,848,144
>273.15 K frequency (%)	99.98%	85.42%	99.61%	99.82%	100.00%	100.00%	99.99%	99.97%	99.96%	99.19%	100.00%
2.5 km Mean MAX-log10(N_w) [m^{-3} mm^{-1}]	4.67	3.43	3.9	5.09	4.83	6.13	4.25	4.89	4.16	3.68	5.3
2.5 km Mean MAX-D_m [mm]	3.02	0.97	1.99	2.55	3.08	2.6	2.9	3.15	2.58	1.05	2.77
2.5 km Mean	3.36	3.23	3.36	3.78	3.37	4.47	3.29	3.34	3.33	3.45	3.91

log10(N_w) [m^{-3} mm^{-1}]											
2.5 km Mean D_m [mm]	1. 58	0. 82	1. 29	1. 26	1. 65	1. 32	1. 56	1. 74	1. 44	0. 83	1. 31

Q4: Unfamiliarity with the relevant important literature of this study:

Overall Reply to Q4: We thank the reviewer for the suggestions regarding these papers. We acknowledge that we did not cite all of references mentioned. However, one of them has been cited in our manuscript (Ryu et al., 2021), one was published after our submission (Shi et al., 2025), and one focuses on the impacts of aerosol, which is not directly related to our topic (Xi et al., 2024). Our study aims to reveal the microphysical characteristics of precipitation systems on a global scale, which, to our knowledge, remains insufficiently addressed in the current literature. The majority of previous studies have focused on specific regions. Nevertheless, as the reviewer noted, more and more studies have been emerging recently, such as (Choi et al., 2025; Ryu et al., 2021; Shi et al., 2025). This also indicates that the global microphysics of precipitation is receiving increasing attentions from researchers.

(a) There are important studies that have used GPM DPR data to conduct similar clustering studies; (Such as Global DSD investigation: Ryu, J., Song, H.-J., Sohn, B.-J., & Liu, C. (2021). Global distribution of three types of drop size distribution representing heavy rainfall from GPM/DPR measurements. Geophysical Research Letters, 48, e2020GL090871. https://doi.org/10.1029/2020GL090871)

Reply: This paper has been cited and discussed in the original manuscript.

(b) Yan Zhang's relevant important papers on the global precipitation system is not mentioned; (Such as: Global precipitation system size, Yan Zhang and Kaicun Wang 2021 Environ. Res. Lett. 16 054005)

Reply: We read this paper during the writing. Nevertheless, we did not cite firstly it because it used the IMERG dataset, but not DPR observation directly. The two kinds of datasets were different. Simply speaking, the IMERG shows the horizontal distribution and the evolution of a storm, while the DPR observation reveal three-dimensional structure and instantaneous observation of a storm. Nevertheless, we cited this pater in the revised manuscript in section 3.1.

(c) One paper, although with a different research purpose, uses both the precipitation system as the basic research object and a similar clustering method. (Aerosol effects on the three-dimensional structure of organized precipitation systems over Beijing-Tianjin-Hebei region in summer)

Reply: We do not aim to relate this paper to aerosol as the relationship between aerosol and precipitation is a complex topic. Meanwhile, our paper aims to reveal the precipitation on a global scale. There are too much regional papers about precipitation microphysics, it is neither practical nor advisable to cite all these references.

(d) This paper does not mention a crucial paper in its investigation of extreme precipitation research. It also uses GPM DPR data and provides valuable conclusions for extreme precipitation research. (A global view on microphysical discriminations between heavier and lighter convective rainfall)

Reply: This paper was published on July, 2025 and we have submitted our manuscript before that. We thank the reviewer's suggestion and have cited this paper in the revised paper.

Q5: This study's research method for microphysical processes is relatively simple, considering only the warm rain process, without exploring the contribution of ice phase processes to precipitation and its structure formation.

Reply: To be honest, unlike the numerical model and ground-based observation, previous methods using DPR in the study of microphysical processes is still limited. The method using ΔZ_e and ΔD_m was widely used in the literature, such as the study by Shi et al. (2025) mentioned by the reviewer in Q4d . Meanwhile, the retrieval process of the dual-frequency radar does not separate the liquid and solid precipitation in its DSD products.

Q6: The visualization of this study is relatively simple and not aesthetically pleasing. It does not meet the standards of ACP.

Reply: We have revised the figures according to editors' suggestions in the submission process. If you have any specific suggestions, please let us know and we are pleasure to make revisions. Thanks.

Detailed comments:

Q1: Some language details are confusing.

(a) In lines 67 and 68, what does PR mean? The PR mentioned above is the abbreviation for precipitation radar. The PR here is obviously not the same, which is confusing.

Reply: We apologize for any confusion. In lines 67 and 68, 'PR' denotes Precipitation Rate, not Precipitation Radar as defined in line 46. This have been revised accordingly in the updated manuscript.

(b) In line 94, what does "if PSs" mean? It is confusing.

Reply: Revised to "of PSs".

(c) There is a duplication of the description of DB index in lines 173 and 175, which is confusing.

Reply: We reworded the context related the introduction of DB index.

Q2: There is a lack of common knowledge about GPM DPR radar. The manuscript is very unprofessional in this regard.

(a) The description of the operating band of DPR KuPR in lines 47 and 52 is obviously inconsistent, and the performance parameter values of the operating band should be described to one decimal place.

Reply: The line 47 states that the PR onboard TRMM operated at Ku-band (13.8 GHz). The line 52 indicates that the DPR operate at Ku and Ka band (13.6 GHz and 35.5 GHz). We have revised the values in 52 line from 13 and 35 to 13.6 and 35.5.

(b) The description of lines 53-54 is incomplete. The differential scattering between the two bands caused by rainfall is not only related to the size of the particles, but also to the particle number concentration.

Reply: This sentence was deleted.

(c) In line 54, what do Dm and Nw mean when they appear for the first time? The full text does not provide a detailed definition, and this is the first time its abbreviation appears.

Reply: The full text of D_m and N_w were added here.

(d) Similarly, on line 105, "FS" is not fully described.

Reply: The FS is Full scan. We revised the context.

(e) On line 106, 125 m refers to the vertical range resolution, which is not clearly described here.

Reply: We revised the term to vertical range resolution in the context.

Reference

Choi, S., Ryu, J., Lee, S.-M., and Sohn, B.-J.: Characteristics of Global Light Rain System From GPM/DPR Measurements, Journal of Geophysical Research: Atmospheres, 130, e2024JD042434, https://doi.org/10.1029/2024JD042434, 2025.

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Liu, C.: GPM precipitation feature database (1.0), 2016.

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Seela, B. K., Janapati, J., Lin, P.-L., Lan, C.-H., and Huang, M.-Q.: Evaluation of GPM DPR Rain Parameters with North Taiwan Disdrometers, Journal of Hydrometeorology, 25, 47–64, https://doi.org/10.1175/JHM-D-23-0027.1, 2024.

Shi, R., Lu, C., Xu, W., and Luo, Y.: A global view on microphysical discriminations between heavier and lighter convective rainfall, Commun Earth Environ, 6, 511, https://doi.org/10.1038/s43247-025-02473-0, 2025.

Xi, J., Li, R., Fan, X., and Wang, Y.: Aerosol effects on the three-dimensional structure of organized precipitation systems over Beijing-Tianjin-Hebei region in summer, Atmospheric Research, 298, 107146, https://doi.org/10.1016/j.atmosres.2023.107146, 2024.