Author's Response

We sincerely thank the Editor and two referees for their careful assessment of our work and for the constructive suggestions. We have revised the manuscript to improve its clarity, organization, and scientific presentation, and have rechecked the figures, tables, and language where necessary. All modifications are shown in the tracked-changes file. Please note that the Supplement remains unchanged. Below, we address the referees' comments point by point and indicate the corresponding changes. For clarity, our responses are highlighted in blue.

Reviewer#1

This study presents a comprehensive climatology of MCS-related hazards over the Asian Monsoon Region based on a 23-year database. The paper is well-structured, clearly written, and methodologically rigorous. I recommend publication after minor revision.

1. The manuscript frequently uses language implying causality (e.g., "MCSs drive," "MCSs contribute," "MCSs trigger"). While the statistical associations are strong and physically plausible, the observational framework cannot definitively establish causality. The authors do acknowledge this in the discussion, but the abstract and key conclusions still use causal language. Instead, "MCS-related" is more appropriate.

Thank you for this comment, we have carefully checked the revised manuscript and corrected similar expressions throughout the text.

2. The authors note that the Tibetan Plateau shows high MCSH and MCSD but low MCSP, attributing this to high elevation making weak convection more easily detected by Tb thresholds. This explanation makes sense, but it raises a broader question: if MCS identification is elevation-biased, how might this affect the spatial patterns and trend analyses across the AMR, given the substantial topographic variation in the region?

Thank you for this valuable comment. We agree that the potential bias in MCS identification over the Tibetan Plateau may not only affect the absolute level of MCS activity in this region, but also raises a broader question of whether such a bias could further influence the spatial distribution and trend

analysis of MCSs across the entire study domain.

As described in the manuscript, the high elevation of the Tibetan Plateau enables convective clouds to more readily reach high cloud-top altitudes, making them more likely to be identified as MCSs by Tb thresholds—even when the convective activity is weak (Kukulies, 2023; Kurosaki and Kimura, 2002). Consistent with this potential identification bias, MCSH and MCSD are relatively high over the Tibetan Plateau during the cold season, whereas MCSP remains low, suggesting that the identified MCSs may include a fraction of cloud systems associated with little precipitation. Therefore, we added a precipitation constraint to the original Tb-based MCS definition to mitigate this potential elevation-related identification bias, and conducted a sensitivity analysis by comparing the results before and after applying the constraint. Specifically， Based on the original Tb-based MCS database (hereafter referred to as the baseline MCS database), we constructed a precipitation-constrained MCS database, in which an additional criterion was imposed requiring the area with precipitation rates exceeding 2 mm h^{-1} within each MCS to be greater than 300 km^2 at each time step.

First, we compared the spatial distributions of annual mean MCSH derived from the two datasets (Fig. R1). The results show that the differences are mainly concentrated over the central and western Tibetan Plateau, where the baseline MCS database reveals higher MCSH than the precipitation-constrained MCS database. In contrast, the two datasets exhibit generally consistent spatial patterns of MCSH across the rest of the study region, which indicates that introducing the precipitation constraint mainly affects the estimated MCS activity over parts of the Tibetan Plateau, while having only a limited influence on the spatial distribution of MCS activity in the other major MCS-active regions.

We then examined the trends in MCS activity. Comparison of the trends in MCS occurrence shows that the differences between the two datasets are likewise characterized by clear regional variations. The baseline MCS database tends to overestimate the statistical significance of decreasing trends in MCS occurrence over the Tibetan Plateau and the regions to its north, while underestimating the statistical significance of increasing trends over northeastern China. In contrast, the major spatial patterns of MCS occurrence trends over the Indian Peninsula, the Bay of Bengal, the Indochina Peninsula, and eastern China remain largely unaffected by the precipitation constraint. Furthermore, the trends in MCSP derived from the two datasets are generally consistent (Fig. R3). These results suggest that the potential identification bias can affect local trend estimates to some extent, but does not alter the overall conclusions of this study regarding trends in MCS activity across the major regions of the

AMR.

We further compared these results with previous studies about trends of MCS activity. Different studies are generally consistent regarding the major trend characteristics over regions such as Northern India, the Indochina Peninsula, and Eastern China (Guo et al., 2023; Nekkali and Osuri, 2026), whereas substantial differences exist for the Tibetan Plateau. For example, some studies found no statistically significant changes (Mai et al., 2020), while others reported increasing trends (Guo et al., 2023). Previous studies have also shown that differences in MCS identification can lead to discrepancies in trend estimates over local regions such as the Tibetan Plateau and northeastern China (Guo et al., 2023), which further suggests that the trends of MCS activity in these regions are relatively sensitive to the identification method and statistical definition.

Overall, these results suggest that the Tb-based identification bias over high-elevation regions is indeed an important source of uncertainty in the MCS climatology over the Tibetan Plateau. However, its influence is largely confined to specific areas and does not substantially alter the major spatial patterns or trend characteristics identified across the AMR study region. At the same time, imposing an additional precipitation constraint would introduce new threshold dependence and could exclude MCSs associated with relatively weak precipitation. We therefore retain a consistent Tb-based MCS definition as the basis for the primary analyses. In the revised manuscript, we have explicitly noted that the estimated level of MCS activity and its interannual trends over the Tibetan Plateau sensitive to the identification method should be interpreted with caution in Lines 437–441.

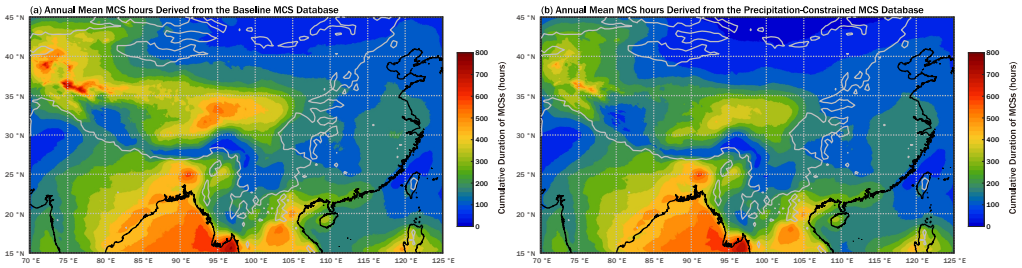


Figure R1: Annual mean spatial distributions of MCSH. (a) Baseline MCS database, (b) Precipitation-constrained MCS database. The black solid line represents the coastline, and the gray solid line represents the 1000 m elevation contour. Color shading indicates: annual mean cumulative MCS duration (hours).

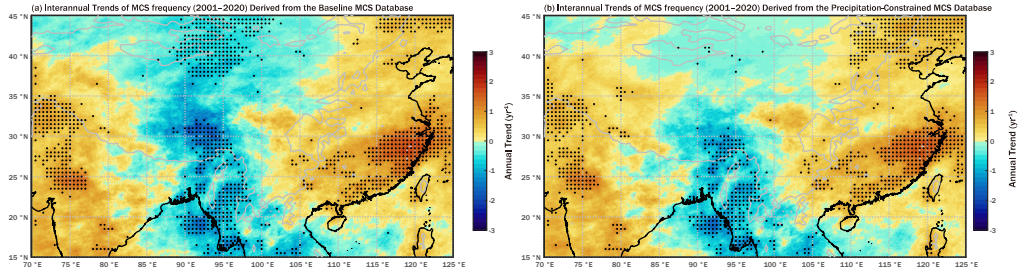


Figure R2: Spatial distribution of interannual trends of MCS frequency (2001-2020). (a) Baseline MCS database, (b) Precipitation-constrained MCS database. The black solid line represents the coastline, and the gray solid line represents the 1000 m elevation contour. The color shading in (a) denotes the annual trend. The 2001–2020 period was selected for the trend analysis to facilitate comparison with Guo et al. (2023).

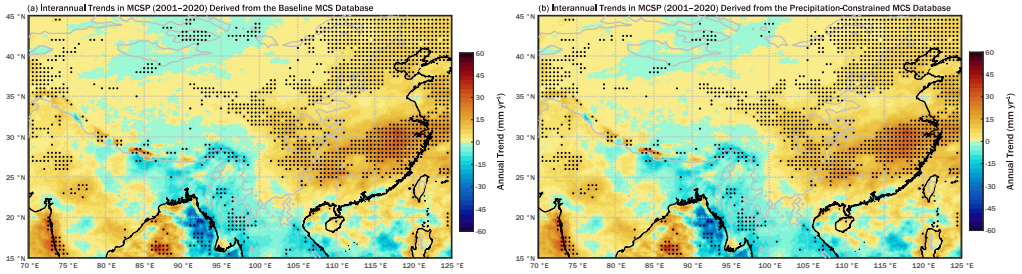


Figure R3: Spatial distribution of interannual trends of MCSP (2001-2020). (a) Baseline MCS database, (b) Precipitation-constrained MCS database. The black solid line represents the coastline, and the gray solid line represents the 1000 m elevation contour. The color shading in (a) denotes the annual trend. The 2001–2020 period was selected for the trend analysis to facilitate comparison with Guo et al. (2023).

3. Hail and tornado reports are deemed to be biased. The authors should highlight that.

Thank you for this comment. We have highlighted this potential bias in Lines 402–404 and 515–517 in the revised manuscript.

References

Guo, Y., Fu, Q., Leung, L. R., Na, Y., and Lu, R.: Trends in warm season mesoscale convective systems over Asia in 2001–2020, J. Geophys. Res.-Atmos., 128, e2023JD038969, https://doi.org/10.1029/2023JD038969, 2023.

Mai, Z., Fu, S., Sun, J., Hu, L., and Wang, X.: Key statistical characteristics of the mesoscale convective systems generated over the Tibetan Plateau and their relationship to precipitation and southwest vortices, Int. J. Climatol., 41, E875–E896, https://doi.org/10.1002/joc.6735, 2021.

Nekkali, Y. S. and Osuri, K. K.: Changes in the characteristics of mesoscale convective systems over the Indian monsoon region: Recent decadal variability, Theor. Appl. Climatol., 157, 463, https://doi.org/10.1007/s00704-026-06360-2, 2026.

Kukulies, J.: Observing and modeling precipitation in the Tibetan Plateau region-from large-scale processes to convective storms, University of Gothenburg, Sweden, 2023.

Kurosaki, Y. and Kimura, F.: Relationship between topography and daytime cloud activity around Tibetan Plateau, J. Meteorol. Soc. Jpn., 80, 1339-1355, https://doi.org/10.2151/jmsj.80.1339, 2002.

Reviewer#2

General comments:

As detailed in the comments below, there are some concerns about the presentation and interpretation of the results the authors obtained in the revised manuscript. Thus, the submitted manuscript, in its current form, requires revisions for publication in ACP.

Thank you for your careful review and constructive comments. We have made further revisions to the manuscript based on your comments. Detailed responses to each comment and the corresponding revisions are provided below.

Specific comments:

1. The way the paper is written suggests that the approach varies depending on how AMR is defined. The target area is first defined in the "Data" section, but this leaves the ambiguity in the introduction unresolved. Since the authors seem to be interested only in the defined target area to begin with, they should have emphasised from the outset why it is necessary to conduct this research within that specific area. If the authors intend to address AMR in a broad sense, they should include a review of regions at the same latitude as China — such as India, the Philippines, South Korea, Taiwan, and Japan. There should be no reason to exclude these regions. In particular, trends in northeastern India and Bangladesh shown in Fig. 9 and 10 require discussion. Furthermore, it is necessary to clarify how the authors' study fits into the broader context of AMR.

Thank you for this valuable suggestion. We agree that the use of the term Asian monsoon region (AMR) in the original manuscript may cause ambiguity regarding the spatial scope of the study. In the original manuscript, the specific study area was not defined until the Data section, whereas the preceding use of "AMR" in the Introduction may have led readers to interpret the study as covering the entire Asian monsoon region. To address this issue, we have clarified the definition of the study area and revised the related terminology throughout the manuscript.

First, we have clarified the spatial scope of the study in the Introduction of the revised manuscript in Lines 71–73. Specifically, this study focuses on a selected domain (15°N–45°N, 70°E–125°E) within the broader AMR, which mainly covers a major subtropical-to-midlatitude continental sector of the Asian monsoon region and its adjacent seas. To distinguish this study area from the broader Asian monsoon region, the term "AMR study domain" is used consistently throughout the revised manuscript

to refer specifically to the selected study domain. On this basis, we further added a brief explanation of why this region was selected as the study area in Lines 73–75. The AMR study domain covers regions with distinct monsoon characteristics and MCS activity patterns, allowing the spatial differences and long-term changes in MCSs and MCS-related hazards to be examined across different regional settings.

Second, to broaden the regional coverage of the literature review, we have expanded the Introduction (Lines 61–65) to include relevant studies on the climatological characteristics and long-term changes of MCSs over regions such as India, the Philippines, and Taiwan, thereby providing a more complete background on MCS activity within the broader AMR and further clarifying the position of the present study within this broader context.

In addition, we have added a discussion (Lines 427–431) of the trends over Bangladesh and northeastern India shown in Figs. 9 and 10. MCS activity over these regions exhibits a spatially coherent and statistically significant decreasing trend, whereas the decreases in MCSP and MCSPF are more spatially scattered, indicating that the reduction in MCS activity is not accompanied by proportional changes in MCS-related precipitation impacts. Such differences may reflect regional differences in precipitation efficiency.

Finally, we further clarified in the Conclusion how the present study relates to the broader AMR in Lines 507–513. This study focuses on the AMR study domain, with particular emphasis on the spatial distributions and long-term changes in MCSs and MCS-related hazards over a major subtropical-to-midlatitude continental sector of the AMR and its adjacent seas. The results primarily apply to the AMR study domain, while providing regional evidence for understanding the spatiotemporal variability of both MCS activity and MCS-related weather hazards across the broader AMR.

2. Although the study appears to address multi-hazards, heavy rain and tornado events may sometimes occur simultaneously; this is likely not the case in most instances. Are there any events that should be treated as a single category? If so, please clearly state the rationale. If not, please narrow the scope of the study to scrutinise the results more closely and use those findings to articulate the differences from previous research clearly.

Thank you for this valuable comment. We agree that the original manuscript did not clearly explain how different types of hazards were addressed, which may have caused ambiguity regarding the

analytical scope of this study.

In this study, heavy rainfall events, strong wind events, hail days, and tornado days represent different types of severe weather hazards that may accompany MCSs. Because the datasets for these hazards differ in observational units and recording methods, we apply corresponding identification criteria according to the characteristics of each dataset and analyze their relationships with MCSs separately, rather than combining them into a single hazard category. If the same MCS event is associated with two or more hazard types, each hazard is counted separately within its respective category rather than being treated as a distinct compound-hazard event. Given the differences among these datasets, we also do not further quantify the co-occurrence frequency of different hazard types.

Accordingly, we have clarified the scope of this study of the revised manuscript. Specifically, we focus on the relationships between MCSs and different hazard types separately, rather than on the co-occurrence frequency of different MCS-related hazards. Within this clarified scope, we further discussed differences in the characteristics of the relationships between MCSs and different hazard types based on the independent analysis of each hazard. The results show that these relationships exhibit distinct characteristics: most heavy rainfall events are closely related to MCSs; severe wind events show a relatively weaker relationship with MCSs and more pronounced spatial variability; hail and tornadoes also occur relatively frequently on days affected by MCSs, although the corresponding results are subject to greater uncertainty due to reporting biases and the spatial aggregation scale.

In summary, we have made the following revisions to the manuscript:

(1) In the Methods section (Lines 219–221), we have clarified how different hazard types are treated in the analysis;

(2) In both the Introduction (Lines 68–72) and the Conclusions and Discussion section (Lines 509–513), we have added further clarification on how our study differs from previous research;

(3) In the Conclusions and Discussion section (Lines 514–517), we have added a comparison of the relationships between MCSs and different hazard types.

3. The methodology is mixed and unclear. The authors should describe logically and coherently what tools were used, what steps were taken, and what results were obtained.

Thank you for this important comment. We have reorganized the Data and methods section in the revised manuscript and streamlined the methodological descriptions in other sections. Specifically, a

new subsection (now Sect. 2.2.3) was inserted between the original Sects. 2.2.2 and 2.2.3, with the original Sect. 2.2.3 consequently renumbered as Sect. 2.2.4. The content on the definitions of MCS metrics, originally presented in Sect. 3.2, was moved to the new Sect. 2.2.3 so that these metrics are introduced before the description of the statistical methods used to examine the relationships between MCSs and weather hazards (Sect. 2.2.4). In Sect. 2.2.4, we further clarified the procedures used to associate MCSs with different weather hazards and moved the method for determining the MCS impact area from the former Sect. 2.1 to this subsection, bringing together the criteria for defining MCS–hazard associations and the corresponding statistical procedures. Finally, repetitive methodological descriptions in other parts of the manuscript were streamlined to avoid redundancy.