Reviewer#1

This paper presents a valuable and comprehensive study on the climatology, variability, and trends of Mesoscale Convective Systems (MCSs) over the Asian Monsoon Region (AMR) from 2001 to 2023. The manuscript is well-written and concise, making it a pleasure to read. There remain a few points that require further clarification and polish.

We thank the reviewer for the thoughtful and constructive comments on our manuscript. The suggestions have helped us clarify several aspects of the methodology and improve the presentation of our results. Our detailed responses are provided below. For clarity, our responses are highlighted in blue.

Major comments:

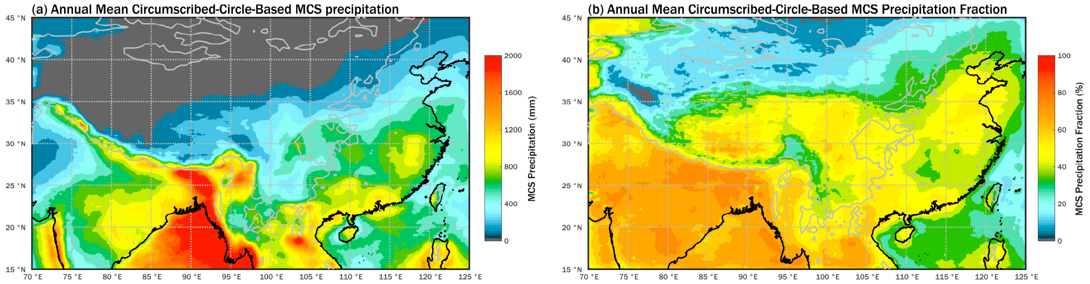
1. The authors use a simplified spatial-temporal overlap method to associate hazards with MCSs: if a hazard event occurs within the "impact area" of an MCS on the same day, it is considered MCS-associated. While operationally straightforward, this approach introduces significant uncertainties and potential overestimation of MCS contributions, particularly for hazards with different spatial and temporal scales.

1.1 The MCS impact area is defined via a circumscribed circle of the MCS's bounding rectangle (Fig. 2), which may not accurately represent the true spatial extent of convective hazards.

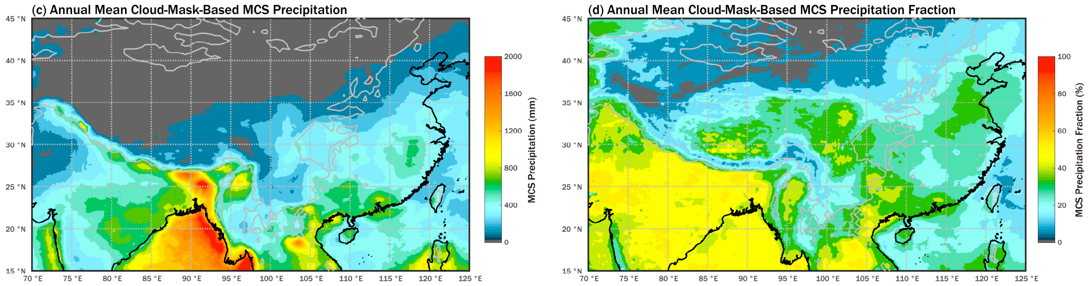
Thank you for this comment. We agree that representing the MCS impact area using the circumscribed circle of the bounding rectangle is a simplified geometric approximation and may not fully capture the real spatial extent of a convective hazard. This approach was adopted to provide a consistent and operational definition of the MCS influence area for large-scale, long-term statistical analyses involving systems with diverse morphologies and movement characteristics. Because the brightness temperature data used to identify and track MCSs in this study have a temporal resolution of 30 min, the systems may move substantially between successive observation times. As a result, weather impacts such as precipitation may occur slightly outside the instantaneous cloud boundary defined at the 30-min temporal resolution. The cloud-mask-based definition could therefore underestimate the spatial extent associated with the MCS.

It should also be noted that the primary objective of this study is to examine the regional-scale statistical relationships between MCS activity and convective hazards rather than to establish precise event-level attribution. In addition, the available hazard datasets are generally reported at daily temporal resolution and aggregated at administrative-unit scales, which limits the possibility of establishing precise event-to-event correspondence at finer spatial and temporal scales. Therefore, this method is used as a practical approximation for regional climatological analyses. In the revised manuscript, we will further clarify these methodological limitations and emphasize that the results should be interpreted as regional and climatological statistical associations rather than precise event-scale attribution.

We also conducted a supplementary comparison using a more conservative cloud-mask-based definition of the MCS impact area. The comparison shows that the choice of impact-area definition mainly affects the absolute magnitude of MCS-related precipitation, whereas the overall spatial distribution pattern remains broadly similar between the two definitions. In general, the circumscribed-circle-based definition yields larger precipitation amounts than the cloud-mask-based definition, which is consistent with its broader spatial coverage. These results suggest that, although the exact magnitude of MCS-related precipitation is sensitive to the definition of the impact area, the overall spatial pattern of MCS-related precipitation remains broadly similar between the two definitions. In the revised manuscript, we will clarify the influence of this methodological choice on the precipitation statistics and explicitly acknowledge its limitations.


(a) Annual Mean Circumscribed-Circle-Based MCS precipitation

(b) Annual Mean Circumscribed-Circle-Based MCS Precipitation Fraction


(c) Annual Mean Cloud-Mask-Based MCS Precipitation

(d) Annual Mean Cloud-Mask-Based MCS Precipitation Fraction

Figure 1: Annual mean spatial distributions of (a) circumscribed-circle-based MCS precipitation, (b) circumscribed-circle-based MCS precipitation fraction, (c) cloud-mask-based MCS precipitation, (d) cloud-mask-based MCS precipitation fraction. The black solid line represents the coastline, and the gray solid line represents the 1000 m elevation contour. Color shading indicates: annual mean (a) cumulative MCS precipitation (mm) and (b) MCS precipitation fraction (%).

1.2 The analysis uses daily resolution for all hazards. MCSs evolve rapidly (lifetimes of hours), and associating a daily-aggregated hazard with an MCS that may have occurred only briefly within that day can lead to false positives. This is especially problematic for short-lived events like tornadoes.

Thank you for this important comment. We agree that the daily temporal resolution used to associate hazards with MCS occurrences may introduce some uncertainty, particularly for short-lived events such as tornadoes. In this study, we used daily-scale hazard records mainly because the wind, hail, and tornado datasets employed are only available, or most consistently available, at daily resolution. Under this constraint, our objective is to investigate the statistical relationship between MCS activity and hazardous weather occurrence at regional and climatological scales, rather than to establish strict event-scale attribution. We acknowledge that this temporal mismatch is a limitation of the analysis. In the revised manuscript, we will explicitly note that the reported relationships should be interpreted as statistical associations, and that the results for short-lived hazards, especially tornadoes, require more cautious interpretation.

2. The identification of MCSs relies heavily on Tb thresholds (233 K for CCAs, 225 K for cold cores) and an area threshold of 3000 km². While the authors justify these thresholds based on precipitation efficiency and computational trade-offs (Fig. 3), the sensitivity of the results to these choices is not thoroughly tested. The authors are not advised to pick “the best” set of thresholds, but at least they need to provide the error bars of their results.

Thank you for this valuable suggestion. In response to this comment, we conducted additional threshold sensitivity tests to assess the robustness of the main results to parameter selection. Considering the computational cost of MCS identification and tracking over a large domain and long time period, we limited this analysis to the ECAS region for 2001–2023.

Specifically, we performed MCS identification and tracking over the region 110°–127°E, 25°–42°N, which is slightly larger than the ECAS domain (112°–125°E, 27°–40°N). We then carried out a one-at-a-time sensitivity analysis, in which only one threshold was varied in each test while the other thresholds were fixed at their reference values. The reference thresholds were set to a CCS threshold of 225 K, a duration threshold of 3 h, an overlap ratio threshold of 0.15, and an area threshold of 3000 km², consistent with those used in the manuscript. We separately tested CCS thresholds of 220 and 230 K, duration thresholds of 2 and 4 h, overlap ratio thresholds of 0.10 and 0.20, and area thresholds of

2000 and 4000 km². For each threshold setting, we calculated the interannual trends of the metrics such as MCSD and MCSH over the ECAS region to evaluate the sensitivity of the results to threshold selection.

For the cold-cloud threshold (233 K), we did not conduct an additional sensitivity analysis of the same type, primarily because the identification of cold-cloud systems is relatively insensitive to changes in this threshold. As shown in Fig. 3b of the manuscript, the number of identified cold-cloud systems remains nearly unchanged across the 230–245 K threshold range.

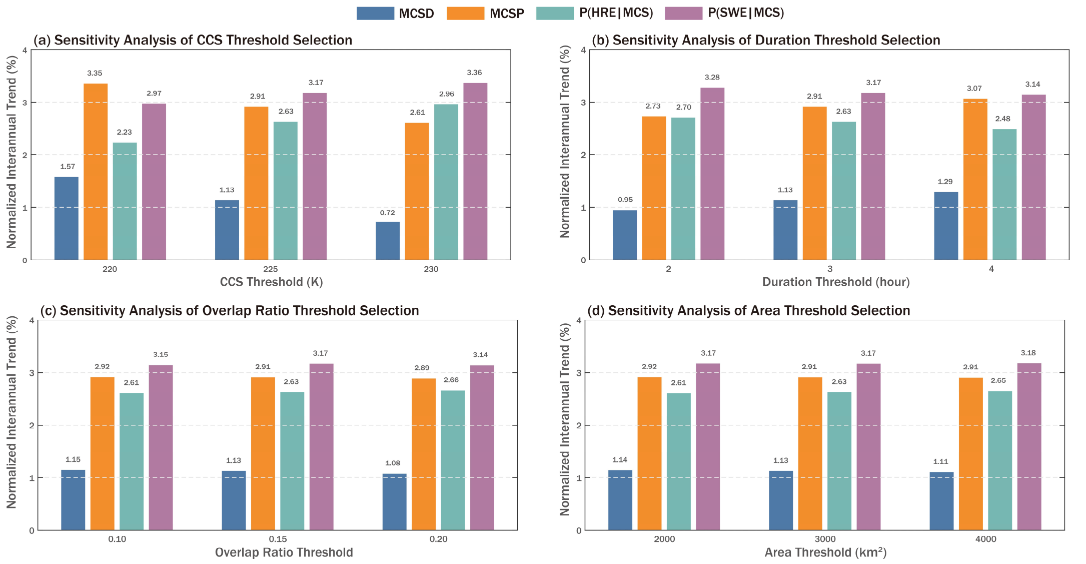


Figure 2: Sensitivity of the normalized interannual trends of MCSD, MCSP, $P(HRE|MCS)$ and $P(SWE|MCS)$ to (a) CCS threshold, (b) Duration threshold, (c) Overlap-ratio threshold, (d) Area threshold. All displayed trends are significant at the 5% level according to a two-tailed Student's t-test.

Fig. 2 compares the normalized interannual trends of four representative metrics under different threshold perturbations, where the normalized trend is defined as the ratio of the interannual trend to the corresponding multi-year mean over 2001–2023. The results show that the CCS threshold and the duration threshold have relatively larger impacts on the results, particularly on the normalized interannual trends of MCSD and MCSP. Moreover, these results appear to suggest that MCSs with more active convective characteristics (i.e., lower cloud-top temperatures) and longer durations tend to exhibit larger upward trends in their precipitation impacts, as illustrated in Fig. 2a, b. Fig. 3 further summarizes the sensitivity of the normalized interannual trends of all key metrics to threshold selection. Although the trend values differ across threshold settings, all metrics retain upward trends, supporting the robustness of the main conclusions of this study to threshold selection.

Tables 1 and 2 further list the trend values and normalized trends of the key metrics in the manuscript under different threshold settings. The main differences arise in a few specific threshold settings, under which the interannual trends of some metrics do not reach statistical significance at the 5% level based on a two-tailed Student's t-test. For example, under the threshold combination of a CCS threshold of 230 K, an overlap ratio threshold of 0.15, a duration threshold of 3 h, and an area threshold of 3000 km^2, the interannual trend of MCSH is not significant at the 5% level.

Table 1: Interannual trends of MCSD, MCSH, MCSP, and MCSPF under different threshold settings. Values in parentheses denote the ratio of the trend to the corresponding multi-year mean. Underlined values indicate trends that are not statistically significant at the 5% level according to a two-tailed Student's t-test.

CCS threshold (K)	Overlap ratio threshold	Duration threshold (hour)	Area threshold (km^2)	MCSD (day • yr^{-1})	MCSH (hour • yr^{-1})	MCSP (mm • yr^{-1})	MCSPF (pp • yr^{-1})
225	0.15	3	3000	1.20(1.13%)	2.54(1.57%)	15.27(2.91%)	0.83(1.91%)
220	0.15	3	3000	1.36(1.57%)	2.83(2.10%)	15.18(3.35%)	0.88(2.39%)
230	0.15	3	3000	0.83(0.72%)	2.08(1.22%)	14.31(2.61%)	0.73(1.59%)
225	0.15	2	3000	1.05(0.95%)	2.45(1.45%)	14.86(2.73%)	0.78(1.72%)
225	0.15	4	3000	1.30(1.29%)	2.59(1.68%)	15.42(3.07%)	0.85(2.05%)
225	0.10	3	3000	1.22(1.15%)	2.56(1.58%)	15.31(2.92%)	0.83(1.91%)
225	0.20	3	3000	1.12(1.08%)	2.43(1.53%)	14.99(2.89%)	0.80(1.87%)
225	0.15	3	2000	1.22(1.14%)	2.58(1.59%)	15.40(2.92%)	0.83(1.91%)
225	0.15	3	4000	1.17(1.11%)	2.49(1.56%)	15.11(2.91%)	0.82(1.90%)

It should be noted that, to ensure comparability among the threshold sensitivity experiments, the supplementary analysis was conducted using the same identification domain and statistical window settings across all tests. Therefore, even though the reference-threshold experiment used the same threshold parameters as the main analysis in the manuscript, the corresponding results from the present sensitivity analysis differ slightly from those reported in the manuscript. This difference mainly arises from the adjustment of the identification domain rather than from changes in the thresholds themselves, and therefore does not affect the overall conclusions of the threshold sensitivity assessment. We will include the above sensitivity analysis results in the supplementary material and add the corresponding description in the Methods section of the revised manuscript.

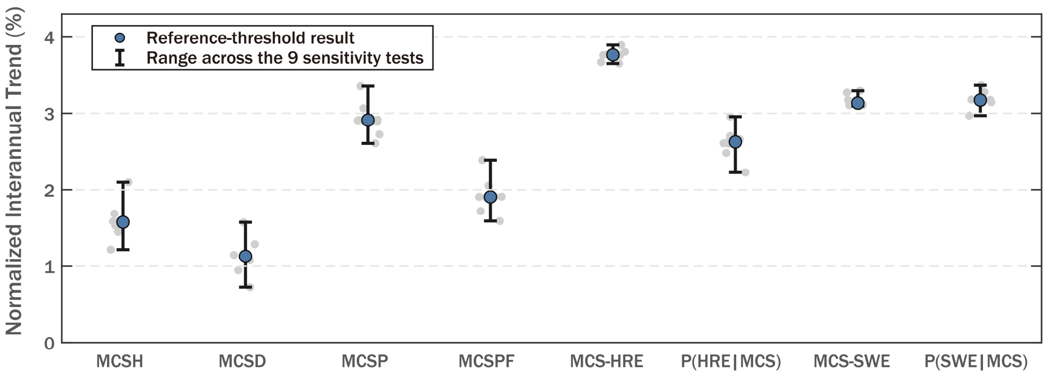


Figure 3: Sensitivity of key metrics to threshold perturbations. Gray dots represent the individual values obtained from the 9 tests. The reference-threshold results are obtained using a CCS threshold of 225 K, an overlap ratio threshold of 0.15, a duration threshold of 3 h, and an area threshold of 3000 km^2. Error bars indicate the minimum-to-maximum range across the 9 sensitivity tests.

Table 2: Interannual trends of MCS-HRE, $P(HRE|MCS)$, MCS-SWE, and $P(SWE|MCS)$ under different threshold settings. Values in parentheses denote the ratio of the trend to the corresponding multi-year mean. Underlined values indicate trends that are not statistically significant at the 5% level according to a two-tailed Student's t-test.

CCS threshold (K)	Overlap ratio threshold	Duration threshold (hour)	Area threshold (km^2)	MCS-HRE (day • yr^{-1})	$P(HRE\|MCS)$ (pp • yr^{-1})	MCS-SWE (mm • yr^{-1})	$P(SWE\|MCS)$ (pp • yr^{-1})
225	0.15	3	3000	0.097(3.77%)	0.063(2.63%)	0.071(3.13%)	0.062(3.17%)
220	0.15	3	3000	0.096(3.90%)	0.062(2.23%)	0.066(3.27%)	0.061(2.97%)
230	0.15	3	3000	0.096(3.67%)	0.067(2.96%)	0.074(3.09%)	0.065(3.36%)
225	0.15	2	3000	0.096(3.65%)	0.063(2.70%)	0.073(3.11%)	0.063(3.28%)
225	0.15	4	3000	0.097(3.81%)	0.061(2.48%)	0.072(3.29%)	0.062(3.14%)
225	0.10	3	3000	0.097(3.77%)	0.062(2.61%)	0.071(3.11%)	0.061(3.15%)
225	0.20	3	3000	0.097(3.77%)	0.065(2.66%)	0.071(3.17%)	0.061(3.14%)
225	0.15	3	2000	0.097(3.76%)	0.062(2.61%)	0.072(3.17%)	0.062(3.17%)
225	0.15	3	4000	0.097(3.76%)	0.064(2.65%)	0.070(3.12%)	0.062(3.18%)

Minor comments:

1. The delineation of the "AMR" domain warrants clarification. As currently defined (Line 185), it encompasses South Asia while omitting Japan and the Korean Peninsula in East AMR. To avoid confusion and improve geographical precision, refining the terminology for this study region would be beneficial.

Thank you for the suggestion. We agree that referring to the analysis domain simply as “AMR” may be imprecise. In the revised manuscript, we will describe it more precisely as a selected study domain within the Asian monsoon region.

2. Line 21. Change “upward” to “increasing”.

Thank you for the suggestion. We will replace “upward” with “increasing” in line 21 in the revised manuscript.

3. Line 62. This statement is true maybe only for China.

Thank you for pointing this out. We agree that this statement is too broad. In the revised manuscript, we will revise the wording to make it more precise and avoid overgeneralization.

4. Figures 1 and 2. The two figures can be merged.

Thank you for this suggestion. We will merge Figures 1 and 2 in the revised manuscript.

5. Line 83. The precipitation attribution does not make sense. Assuming a squall line passing through, the diameter of influence would be the length of the linear system.

Thank you for this comment. We agree that for elongated systems such as squall lines, a diameter-based definition may overestimate the effective influence area and thus lead to over-attribution of precipitation to MCSs. We have addressed this issue in more detail in our response to Major Comment 1.1 and will clarify this limitation in the revised manuscript.

6. Line 107. Please keep consistent in putting space between number and unit.

Thank you for pointing this out. We will systematically check and correct the spacing between numbers and units throughout the revised manuscript.

7. Line 107. Just say “CCAs with cold cores”.

Thank you for this suggestion. We will revise the text to “CCAs with cold cores” in the revised manuscript.

8. Line 111. Any sensitivity tests on varying overlapping thresholds?

Thank you for this suggestion. We have conducted sensitivity tests using different overlapping thresholds, as detailed in our response to Major Comment 2. We will incorporate a clearer description of this sensitivity analysis in the revised manuscript.

9. Line 112. Same, any sensitivity in duration thresholds?

Thank you for this suggestion. We have conducted sensitivity tests using different duration thresholds, as detailed in our response to Major Comment 2. We will incorporate a clearer description of this sensitivity analysis in the revised manuscript.

10. Line 155. The authors may list the possible data sources of the reports.

Thank you for this suggestion. The possible data sources of these reports are described in Section 2.1 and summarized in the Data Availability section. In the revised manuscript, we will also add a brief description of these sources at Line 155 for clarity.

11. Line 188. How are TCs removed, both spatially and temporally?

Thank you for this comment. In removing TCs that were mistakenly identified as MCSs, we considered both temporal coincidence and spatial overlap. Specifically, for each identified MCS, we examined its spatial extent at each time step throughout its lifetime. If, at any time, the MCS overlapped with a 500-km-radius circle centered on the contemporaneous TC center, it was classified as a TC mistakenly identified as an MCS and removed from the analysis.

12. Line 191. Then how is this product matched to the hourly IMERG rainfall data?

Thank you for this comment. The IMERG rainfall product used in this study has a half-hourly temporal resolution. Therefore, no additional temporal aggregation was required when matching it with the MCS product. Spatially, precipitation pixels within the circumscribed circle of the bounding rectangle of the MCS region were classified as MCS-related precipitation.

13. Line 196. The accumulated MCS-hour would be interesting too.

Thank you for this helpful suggestion. We agree that accumulated MCS-hour could also be an informative metric for characterizing local MCS activity. In this study, however, we used MCSD because the wind, hail, and tornado datasets employed are mostly available at daily resolution, making MCSD more directly comparable to the hazard records used in the analysis. In addition, daily-based metrics provide a more straightforward basis for examining the statistical relationships between MCS occurrence and hazardous weather. We will emphasize the potential value of accumulated MCS-hour in the revised manuscript.

14. Lines 189-214. The authors may summarize all the MCS metrics into a table.

Thank you for the suggestion. In the revised manuscript, we will add a summary table of all MCS metrics to improve clarity.

15. Line 232. Where are the “some areas” located?

Thank you for this comment. The “some areas” here refer to the region between 32°N and 34°N and between 87°E and 102°E, corresponding to the eastern Tibetan Plateau. We will specify this more clearly in the revised manuscript.

16. Line 296. How about “fraction” instead of “proportion” to be consistent with MCSPF.

Thank you for this suggestion. We will replace “proportion” with “fraction” in the revised manuscript for consistency with MCSPF.

17. Line 328. There is an inherent misalignment in the temporal resolution of the two key datasets: daily hazard reports versus half-hourly MCS tracks. This leads to an approximation where any hazard on the same day is linked to an MCS, even if it preceded the MCS initiation (e.g., hail before MCS onset). It is suggested that the authors more clearly articulate this as a methodological limitation, discussing its potential to dilute the specificity of the association between MCSs and convective hazards.

Thank you for pointing out this issue. We agree that linking hazard events to MCSs at daily resolution may introduce temporal matching errors and may cause some hazard events to be misattributed to MCSs. The main purpose of this study is to examine the overall relationship between MCS activity and convective weather processes such as precipitation and strong winds at regional and climatological scales, rather than to make precise event-based attribution. In the revised manuscript, we will make this methodological limitation more explicit and note that this temporal matching approach may cause some hazard events to be incorrectly attributed to MCSs, thereby leading to potential overestimation of the statistical association between MCS activity and convective hazards.

18. Line 362. What about the seasonality?

Thank you for this comment. We separately analyzed the trends for the warm and cold seasons. The results show that the overall trend patterns are broadly similar between the two seasons, with the main difference being the spatial extent of the areas that pass the significance test. Following the reviewer’s suggestion, we will add a brief discussion of these seasonal differences in the revised manuscript and provide the corresponding figures for the warm and cold seasons in the Supplementary Material for reference.

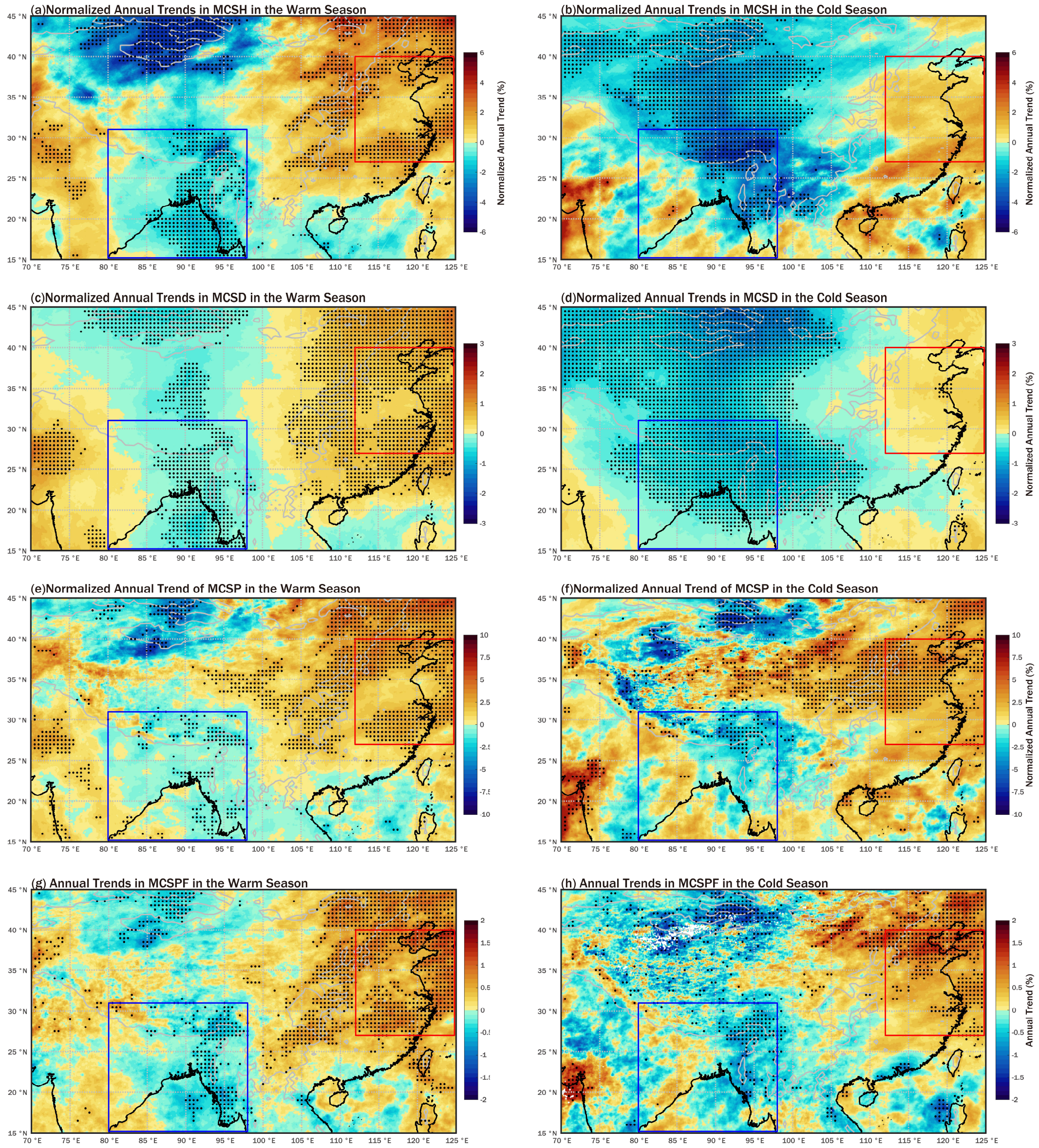


Figure 4: Spatial distribution of the interannual variations of (a, b) MCSH, (c, d) MCSD, (e, f) MCSP, and (g, h) MCSPF, with warm-season results shown in the left column and cold-season results in the right column. The black solid line represents the coastline, and the gray solid line represents the 1000 m elevation contour. The color shading in (a - f) denotes the normalized annual trend, which is the ratio of the interannual trend of each grid to its annual mean value (unit: % yr-1); color shading in (g, h) denotes the annual trend (unit: % yr-1). The black dots indicate regions with statistical significance at 5% level, as determined by a two-tailed Student's t-test. The blue box indicates the range of BoBCR in this study, and the red box indicates the range of ECAS in this study.