Author Comment to Referee #3

Egusphere-2025-1670, 'Interannual variability of the Asian summer monsoon anticyclone' by O. Kachula et al.

We thank Referee #3 for the positive review and for further guidance on how to revise our manuscript. Our reply to the reviewer comments is listed in detail below. Questions and comments of the referee are shown in bold face.

1. **What is the purpose of defining the ASMA on a day-to-day basis? The main emphasis of the recent work is the interannual variability and long-term trend in the ASMA boundaries, which can be simply obtained by the monthly representation of the ASMA boundaries using the existing methods.**

   A: Our motivation to find a method that can define the ASMA on any time scale, not only on a day-to-day basis, is to provide a tool that does not depend on averaging the data. The proposed method can be useful for measurement campaigns with a typical duration of several weeks and provides a finer temporal resolution of days or even hours.

2. **The title of the paper can be modified as "Temporal variability of the Asian summer monsoon anticyclone" as it covers variation from day to day to long-term trends.**

   A: We thank reviewer #3 for this proposal and revised the title accordingly. The new title is "An optimization-based approach to track the Asian summer monsoon anticyclone across daily and interannual variability"

3. **The present study states that the importance of defining the ASMA boundaries; however, they did not discuss the recent work by Musaid et al. (2024) providing the definition for ASMA boundaries based on the Jet stream cores. Provide the citations sentence in the L42-43: "Different ways to define the boundary of the ASMA exist"**

   A: We thank reviewer #3 for pointing out to different studies to define ASMA boundaries. Musaid et al. (2024) is cited in the revised version of the manuscript.

4. **L 60-64: The Authors proposed a method to identify MSF background values for an individual point in time per isentropic surface, which is an optimised MSF value to describe the ASMA boundaries, which can capture its day-to-day variability. This is one important aspect of Musaid et al. (2024) to study to day variation of the ASMA to understand its variation during active and break phases of the monsoon. They also proposed a new GPH method to define the ASMA for the active and break phases of the monsoon based on the GPH values at the tropical easterly jet (TEJ) and subtropical westerly jet (STJ) locations. Their main conclusion is that other methods are not suitable to capture the ASMA boundaries on a shorter scale, especially on the day-to-day scale. This aspect needs to be discussed here.**

   A: It is beyond the scope of our work to compare our methodology with all existing methods that can define the ASMA boundaries. We did a comparison for a few selected methods in particular Santee et al. (2017) and Manney et al. (2021) that also use MSF to demonstrate the advantages of our method. Our intention was to develop a tool, which is simple to use that can encircle the ASMA on any time scale. And our method requires for this only the Montgomery streamfunction that incorporates geopotential, temperature and the specific heat capacity at constant pressure.

5. **L83-90: The title of this paper emphasises on Interannual variability of the ASMA; however, the authors fail to provide novelty, rather they end up highlighting the meridional transport of the tracers and pollutants to the global stratosphere. Authors need to focus and provide the main objectives carried out in this paper.**

   A: L83-90 (preprint version), as well as description of the StratoClim and ACCLIP campaigns above, provide the motivation for developing the method that can be suitable for short time scale measurement campaigns and doesn't require averaging in time. The paper provides the intra-seasonal and interannual analysis based on the suggested methodology and shows that the spatio-temporal evolution of the ASMA aligns with previous studies. Moreover our work supports recent evidence of a bimodality of the ASMA and discusses new results concerning the interannual ASMA area decrease supporting another recent paper of Qie et al. (2025) who show the weakening some trends of ASMA quantities.

6. **L104: Why specific time 12:00 UTC, considered for the analysis instead of the daily average?**

   A: Please see answers 1 and 4 that explain why we avoid data averaging.

7. **L230: Figure 4 describes climatological mean residual MSF; however, the description provided is very brief.**

   A: Figure 4 used as an example of residual MSF values and as an introduction to possible bimodality of the ASMA which is discussed in more details in section 3.2.

8. **L245: Traditionally, researchers use the withdrawal phase instead of the break-up phase of the monsoon. So, the sentence can be revised as "During the withdrawal phase in September, the shape of the mean residual MSF is elongated and shrunk along the latitude axis, indicating the break-up of the anticyclonic circulation. It is suggested to use the withdrawal phase instead of the breakup phase throughout the manuscript.**

   A: Thank you for this suggestion, however both terms can be found in literature. The withdrawal phase related to the monsoon rainfall so we prefer to keep the break-up phase terminology to emphasize the relation to the Asian summer monsoon anticyclone.

9. **L248: The authors mentioned that residual MSF (L232) is not used to obtain the ASMA boundaries. How are ASMA boundaries obtained?**

   A: It seems there is a misunderstanding here. The sentence in L232 is:

   The mean residual MSF does not represent the optimized boundaries of the ASMA at any specific time-point and are used here only for a qualitative description of the ASMA development from pre-monsoon to post-monsoon.

Note that the sentence (l. 232, submitted version) is on the *mean* residual MSF value. The sentence clearly states that if we average multiple days of the residual MSF values the result won't represent the ASMA boundary of any specific point in time.

10. **Descriptions about Figures 5-7 are very short, they can be kept as subplots in one figure. Figure 8 can also be included. Why not comparisons with existing methods discussed here?**

    We prefer not to merge Figures 5-7 due to figures scalability issues and potential loss of clarity. Figures 8 and C2 show the comparison with existing methods (e.g. Ploeger et al., 2015) and L254-262 contain the discussion.

11. **L250: change 15.07.2017 as 15 July 2017 and elsewhere in the manuscript.**

    A: We agree, the correct format for dates in ACP publications is '15 July 2017'. We revised the manuscript accordingly.

12. **L255: Replace "our boundary" with "ASMA boundary obtained using proposed method"**

    A: done

13. **L261: Replace "our method" with "proposed method"**

    A: done

14. **L255-262: Rewrite these sentences**

    A: This reviewer's comment is unspecific and unclear. Please clarify.

15. **L261: What do you mean by aligns with wind velocity?**

    A: By aligning with wind velocity we wanted to underline that the curvature of the boundary match with the wind velocity vector field. To be more clear, we revised this sentence: "...and the ASMA boundary deduced here aligns with the wind velocity..."

16. **L271 & Figures 9-10: The Authors show the seasonal mean representations of the residual MSF based on the proposed method. How are these representations different from the one obtained from the existing method? It provides a concise way to interannual variations in the ASMA boundaries as well as its horizontal structure, demonstrating the bimodality during different years.**

    A: Thank you for the suggestion. We revised our manuscript by comparing our findings with Siu and Bowman (2020) work.

17. **Figure 11: "Number of days per year during monsoon season (JJA)" would be more meaningful. Do you observe bimodality during May and September when ASMA is very weak?**

    A: Thank you for this suggestion. Figure 4 shows that May and September month doesn't have strongly pronounced clustering of the residual MSF values near multiple centers.

18. **L319-321: Rewrite the sentences**

    A: The sentence was revised as follows: A south-northward shift (and back) as well as east-west oscillation are found in the centroid position of the ASMA latitude and longitude for the individual years 2017, 2022 and 2023 (Fig. 12). It is known, that also Asian summer monsoon rainfall has a south-northward shift (and back) and east-west oscillations (Goswami 2012).

19. **L354: Overall, a good agreement. Delete study; L354-355: "Our method... variability" is redundant; L355-60: The Authors claim the comparison with Manney et al. (2021) needs to be rewritten.**

    A: We changed this paragraph as follows:

    Figures 12, 13 and 14 show a good overall agreement with the results of the study by Manney et al. (2021). Our method gives us an indication of the ASMA's evolution between May and September despite a relatively strong variability. Both centroid latitude and longitude and the aspect ratio show a similar temporal evolution as found by Manney et al. (2021). Although the area of the ASMA occupies around 10% of the hemisphere in the beginning of August in our results and the results of Manney et al. (2021) (based on MERRA-2), the shape of the time-series is more flat in our work during the peak phase of the ASMA compared to Manney et al. (2021).

20. **Subsection 3.4: (at 370 K; Fig. 15) What is the significance of the trends in the start date and end dates? Why are start dates becoming early (In May) and end dates late (in September-October) over the year?**

    A: We agree with the reviewer that the most relevant quantity is the duration of the monsoon. But the duration is of course a combination of start and end dates. The question *why* start and end dates are changing is not easy to answer; the trend in start and end dates are first of all a product of the present analysis and the statistical verification of the trends (see below). Further, we performed a permutation analysis for start, end dates and duration period at 370, 390 and 410 K (Fig. 1 of this reply). For each case a set of randomly permuted time-series was created with 100000 elements. Then we calculated the slope for each time-series in a set and built a histogram that shows the distribution of slopes. The red vertical line denotes the slope of the original time-series. We also calculated two-sided p-values that can be seen on each subfigure.

    Figure 1 of this reply shows that only 370 K has a low p-value. The slopes of the time-series at 370 K for end dates and duration show relative strong trend and hence are statistical significant. The time-series at 390 K and 410 K in contrast have a small variability between years, and hence the high p-values tells us that further analysis is needed to make any conclusions about the duration of the ASMA at these theta levels.

21. **Subsection: 3.5 Interannual variability and trends of the ASMA area and location**

    A: Done.

22. **Section 4: Discussion and Conclusions Provide implications towards the conclusions obtained in the present study**

    A: Done.

References

Manney, G. L., Santee, M. L., Lawrence, Z. D., Wargan, K., and Schwartz, M. J.: A Moments View of Climatology and Variability of the Asian Summer Monsoon Anticyclone, Journal of Climate, 34, 7821 – 7841, https://doi.org/10.1175/JCLI-D-20-0729.1, 2021.

Siu, L. W. and Bowman, K. P.: Unsteady Vortex Behavior in the Asian Monsoon Anticyclone, Journal of the Atmospheric Sciences, 77, 4067 – 4088, https://doi.org/10.1175/JAS-D-19-0349.1, 2020.

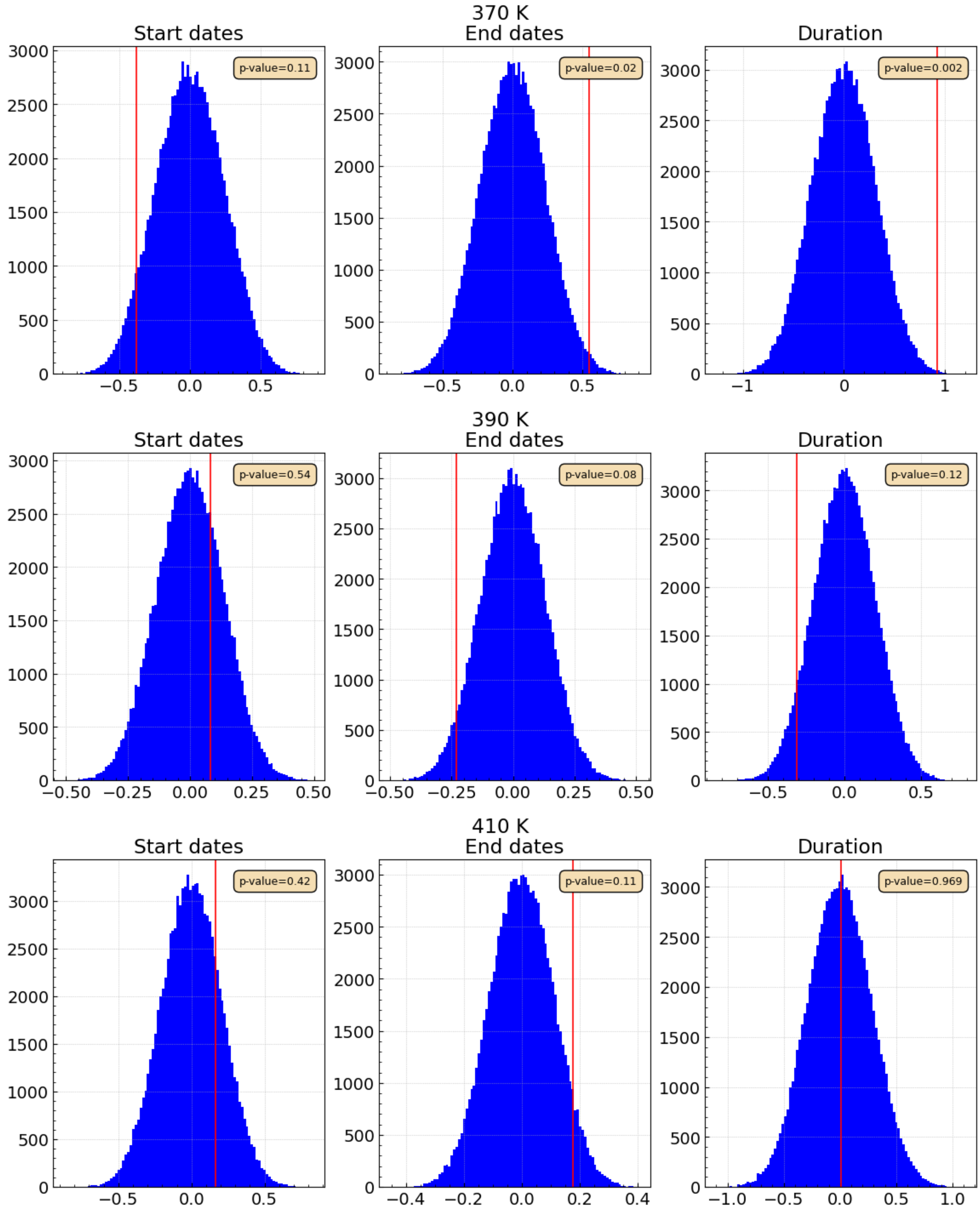

Figure 1: Permutation analysis of the slopes of the start, end dates and the duration of the ASMA at 370, 390 and 410 K. The red line denotes the slope of the original time-series. Two-sided p-value is showed in the upper-right corner of each subfigure.