Author Comment to Referee #2

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

We thank Referee #2 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. **Siu and Bowman (2020) investigates the modality of ASMA and has some extensive discussions on the variability of ASMA having one, two, or more vortices. I notice that you do not refer to this work; I suggest looking at their research and adding some discussion on consistencies or differences between your work and theirs.**

   A: We would like to thank reviewer #2 for drawing our attention to this paper. We added the discussion about the modality of ASMA investigated in this work to the Discussion section:

   Siu and Bowman (2020) developed an algorithm that is able to track multiple simultaneous subvortices of the ASMA. They used the ERA-Interim reanalysis and showed that the ASMA contains two or three distinct subvortices 69% of the time simultaneously. Siu and Bowman (2020) show that in many cases there is two broad peaks of the ASMA – between about $40°$ *E and* $100°$ *E and near* $150°$ *E.*
   Our results are similar to Siu and Bowman (2020) but instead we work with residual MSF on isentropic surface and consider first climatological horizontal plots to see qualitatively the existence of multiple peaks at 370, 390 and 410 K between June and September (Fig. 4; Fig. C1); the Hovmöller diagram of normalized zonal mean residual MSF values for each year to see the distribution of peaks and count number of days when there is a simultaneous presence of two peaks on the both sides relative to the longitudinal centroid separation line.
   It is clear that there is clustering of peaks during 1980-2023 near $50°E$ *and near* $150°E$ *(for some years) that indicates a bimodal state of the ASMA similar to the findings Siu and Bowman (2020).*

2. **In addition a recent work Qie et al. (2025) also investigated the trend of the ASMA. I think incorporated the finding of Qie et al. in their discussion and result interpretation.**

   A: Thank you for pointing out this work. Unfortunately, it is hard to directly compare Qie et al. (2025) and our results due to differences in methodologies. Qie et al. (2025) consider geopotential height anomalies, PV and stream function and work with zonal mean values to show that there is a significant weakening of the ASMA. In our study we show the temporal and spatial evolution of the ASMA and the only thing that can potentially align with Qie et al. (2025) study is the fact that the ASMA area has decreased in size over the period 1980-2023.

3. **Throughout the interpretation of results, the three flight campaigns (StratoClim, ACCLIP, PHILEAS) are mentioned and the corresponding years are chosen for analysis, but your results for these years lack impact if we don't know what the**

campaign had found. Are any of the campaign's results explainable with your findings? If so I think they should be included in your discussions.

A: We showed the individual years during with the campaigns took place only to illustrate that our method can be used for analysis on a finer time-scale without requiring averaging procedures. To clarify this point, we added the following paragraph to Section 3.3:

Three years are highlighted when measurement campaigns took place to show that it is possible to provide a comprehensive analysis on a finer time-scale without the need to fix one specific constant value of the MSF. This might help the scientific community to thoroughly analyse the results of those campaigns in future work. This is also the motivation why a method is needed that works on any time-scale without depending on averaging the data.
A strong variability are found in the centroid position of the ASMA latitude and longitude for the individual years 2017, 2022 and 2023 (Fig. 12) with an increased variability of the latter two years. In all three years time periods exist in which the variability of the centroid position of the ASMA is lower or greater than the standard deviation of the climatological data.
In particular during August 2022, there is a strong shift of the ASMA to the east compared to the climatological mean data. Therefore aircraft flights inside the ASMA could be performed during the ACCLIP campaign over South Korea (Pan et. al, 2024) contrary to the original campaign goal to measure the eastern outflow of the ASMA.
But also during the PHILEAS campaign (Riese et al. 2025) to measure the eastern outflow of the ASAM over Alaska, there was a strong shift of the ASMA to the east compared to the climatological mean data during the first half of both August and September 2023.

4. **It seems like one of the advantages of your method is its ability to capture complex shapes of the ASMA. For instance, in Figure 8 your method shows the tail to the west at 30N while the Ploeger method does not.**

   A: Yes, we updated the text to address this finding:

   In contrast to Ploeger et al. (2015) our method suggests a western tail of the ASMA between $0°\mathrm{E} - 10°\mathrm{E}$.

5. **Line 142: ASIA box is from 0E to 180E. Though this is not the norm but we often observe anticyclone stretching west of 0E. You can see this in your Figure 6. Is it possible to shift the box westward?**

   A: There are different ways to define the ASMA box. For example, Santee et al. (2017) define ASMA region $(15° - 45°N, 10° - 130°E)$, Nützel et al. (2016) – $(15° - 45°N, 30° - 140°E)$. In this work a larger ASMA box was used $(0° - 90°N, 0° - 180°E)$ but in addition we provide the sensitivity analysis (Appendix B) to show the limits of the method by moving the ASMA box position. It is possible to shift the box westward but in our opinion it won't affect the determination of the optimized background value.

6. **Starting at line 196, the statement "During the developing (May-June)... the Santee et al. (2017) method gives lower values than our method, which means that some unwanted noise is still preserved... " Though Fig 3 does show lower values the Santee method, I think it should be explicitly shown (perhaps with some cases) that the method Santee et. al indeed performs worse. Likewise, for**

the anticyclone peak phase, the authors can show that their method defines the anticyclone better.

A: We can provide two examples: in the first case we choose the background values for both methods during the formation phase of the ASMA. Figure 3 from the paper shows that the optimized background value is higher than Santee et al. (2017); in the second case we choose the background values during the peak phase (the optimized background value is lower than Santee et al. (2017)). Fig. 1 (top) of this reply shows the residual MSF values for the first case. The Santee et al. (2017) methodology (bottom) preserves “small noise” compared to this work. Fig. 2 of this reply shows the second case in which this work outlines a larger area of the ASMA than for the Santee et al. (2017) methodology.

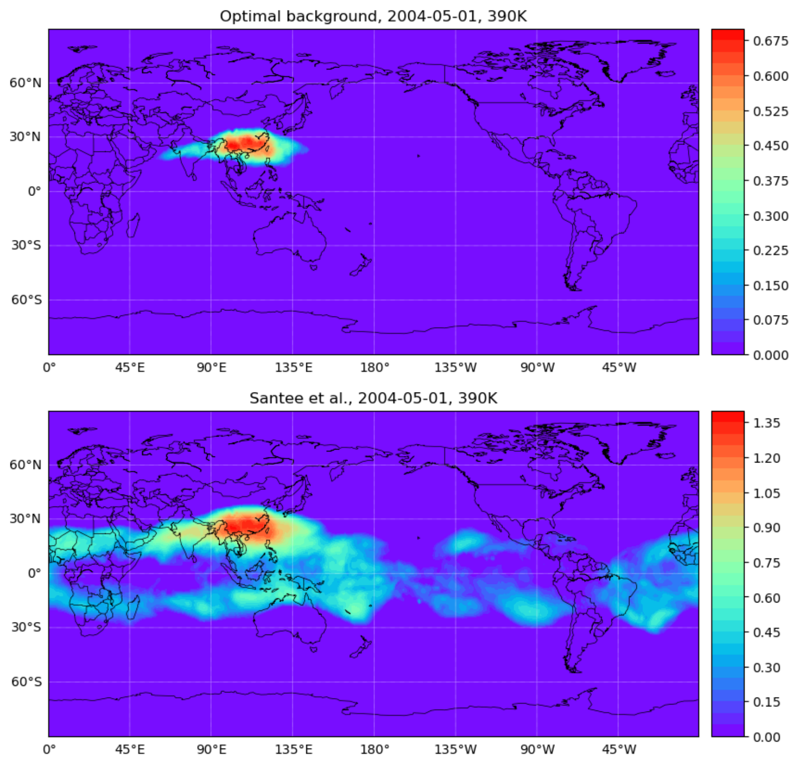

Figure 1: Comparison of residual MSF values between this work (top) and Santee et al. (2017) (bottom) during the formation phase of the ASMA.

The explanation was added to the appendix of the paper.

7. **Line 202 states that the ASMA at 350 K does not exist. I think this statement is not true. Figure 1 below is Montgomery streamfunction at 350 K and it is evident that a closed contour (i.e. anticyclone exists).**

   A: We agree that the formulation should be changed. The ASMA at 350 K is weak and hard to capture for every day. The difficulty of working with the ASMA at 350 K can be even seen in Fig. 3 of the paper. There is small variability of the optimized background value during the whole season. We updated the sentence accordingly:

   Our method shows $\widetilde{\mu}_b$ values for 350 K that have a small variation during the whole Asian monsoon season reflecting that at 350 K the ASMA is weak and capturing it poses a challenge.

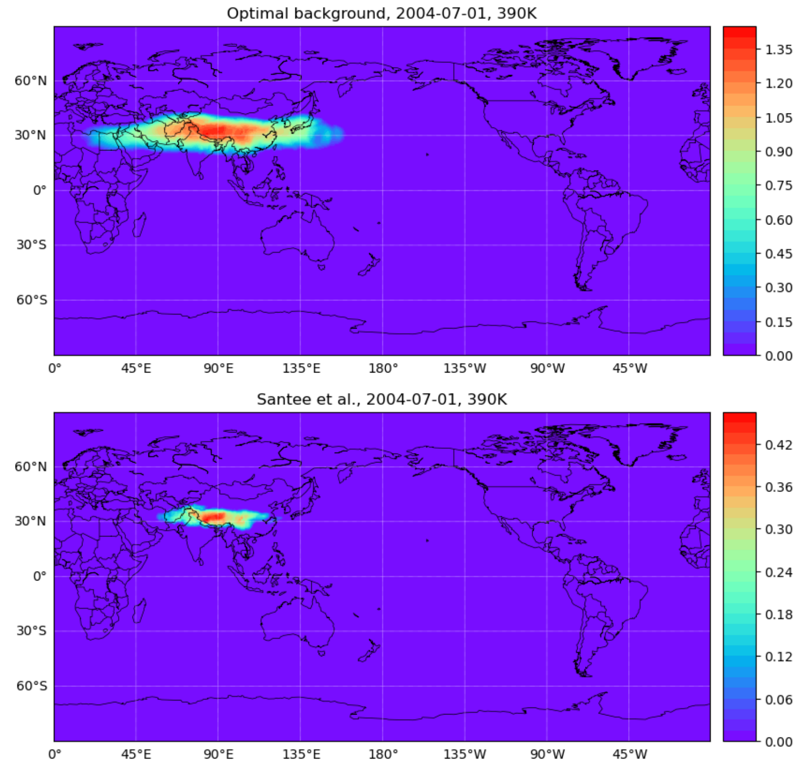

Figure 2: Comparison of residual MSF values between this work (top) and Santee et al. (2017) (bottom) during the peak phase of the ASMA.

8. **Line 250; Figure 5/6/7 - The "angle" quantity is discussed without much context. I think there needs to be some explanation on how to interpret this angle (perhaps a schematic or idealized cases) and what its implications are. For Figure 6, why is the angle related to the curvature at 60E but not the western side (e.g. 40E?).**

   A: Matthewman et al. (2009) define ψ as the angle between the x axis and the major axis of the ellipse which can be obtained as

   $$\psi = \frac{1}{2} \tan^{-1} \left(\frac{2J_{11}}{J_{20} - J_{02}} \right),$$

   where J_{kl} is the relative vortex moments:

   $$J_{kl} = \int \int [\hat{q}(x, y) - q_b](x - \bar{x})^k (y - \bar{y})^l dxdy,$$

   where q is the PV field used in Matthewman et al. (2009).

   As you can see, the residuals $(\hat{\mu}(x, y) - \mu_b)$ are involved in the calculations, which means that not the contour per se impacts the angle but the distribution of weights inside of the contour.

   The revised introduction of the angle (Line 126) reads now:

"the angle between the equatorial axis and the major axis of the ellipse (the calculation of which depends not only on the boundary of the ASMA but also on the residual MSF values. See A2 and A3)"

9. **Figure 9/10 – Could you consider adding a subplot to show whether a JJA has 1, 2, or more maxima? I wouldn't demand this be done but think it can help us see whether a specific JJA tended to be bimodal or not.**

   A: Figures 9 and 10 do show the number of maxima and their position for each year. The coefficient is given in fraction relative to an individual year's max value. For the discussion we can plot zonal mean residual MSF for 1994 at 370 K.

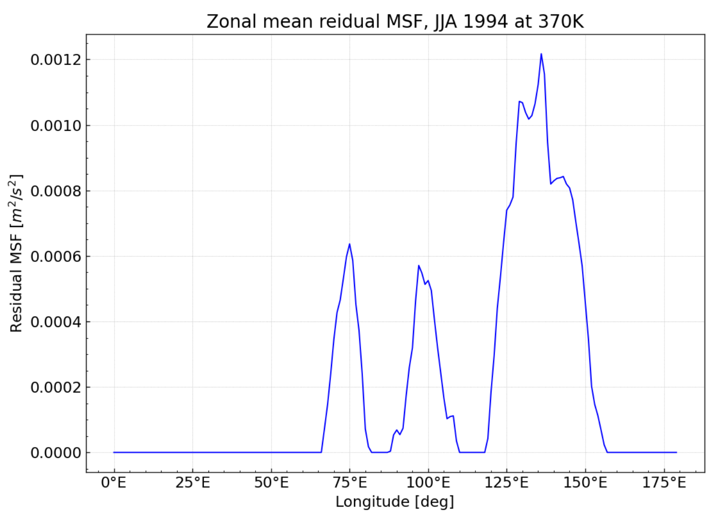

Figure 3: Zonal mean ($15°N - 45°N$) residual MSF values in JJA 1994 at 370 K.

On Fig. 3 of this reply we can clearly see that during JJA months the anticyclone's residual MSF values clustered near 3 positions - $75°E$, $95°E$ and $140°E$. This fact doesn't yet prove the bimodality of the anticyclone because the ASMA might have just shifted during JJA along longitudinal axis. For this reason we provide Fig. 11 in the paper that counts whether a specific day in a year is bimodal or not.

10. **Line 346 – "The temporal evolution of the EK during 2022 shows that in June-September period there are more splitting like events than in 2023 at 390K." Do you infer this by seeing more higher values of blue dots verses red dots? Just asking for clarification.**

    A: Yes, especially at 390 K it is clear that for 2022 (blue dots) there is more peaks during June-September than for 2023 (red dots).

11. **There are many short paragraphs, some with one sentence. I suggest revising the writing to reduce the number of these.**

    A: Thank you for your suggestion. We adjusted the text accordingly.

12. **Line 102 – Is this supposed to be 0.25 degrees?**

    A: Thank you for the correction. Indeed, the horizontal resolution should be $0.25° \times 0.25°$.

13. **Figure 5, 6: I suggest changing the colormap. The choice of colormap depends on what you want to highlight (i.e. red/blue diverging colormap if you want to highlight positive/negative values.)**

    A: Majority of the PV values in the region are positive or near zero so in our opinion the change of the colormap won't provide additional details.

14. **160-170 is hard to follow.**

    A: Thank you for your feedback. We changed the paragraph with the following text:

    "We discuss two cases of MSF grid data:

    1. Many of the grid values inside of the ASMA box are larger than values outside of the ASMA box.
    2. Regions outside of the ASMA box have MSF values that are comparable or larger to the values inside of the ASMA box.

    Let's consider two specific days that correspond to the above described scenario: 1st August 2008 at 390 K (case 1) and 6th September 2008 at 390 K (case 2). We can sample the objective function for the given days – Fig. 1 and Fig. 2 respectively.

    For case 1 the objective function is low for small μ_b which means that the sum of all values inside of the ASMA box are comparable to the sum of all values outside of the ASMA box. But eventually, when we increase μ_b (e.g., subtracting higher value from the given MSF grid data) the values outside of the ASMA box converge to zero more rapidly than the values inside of the ASMA box and the objective function rise (Fig. 1). At some point we reach such μ_b that will give us the highest sum of residual MSF values inside of the ASMA box while keeping the values outside of the ASMA box near zero. This μ_b value gives us a position of the maximum of the objective function. Increasing further μ_b will just decrease the values inside of the ASMA box (the values outside of the ASMA box are already zero) so the objective function starts to decrease and reaches zero.

    For case 2, when a strong circulation outside of the ASMA box is present, the same steps described for case 1 remain true with the exception that when we reach some relative high μ_b the values outside of the ASMA box do not become zero. This is why the objective function has a different shape but still the global maximum points at such μ_b that will keep the sum of all residual MSF values inside of the box highest while the sum of residual MSF values outside of the ASMA box will be the lowest.

    Both cases allows us to find the optimized background value $\tilde{\mu}_b$ that will provide a contour line that will encircle the ASMA."

15. **Line 256 – "Both methods capture the curvature of the northern side ..." Are you referring to the trough?**

    A: The sentence tries to point out that both methods shows the push of the northern part of the boundary near $80°E$ inside of the anticyclone and how both methods follow the wind velocity vectors there.

16. **Figure 12/13/14 - Not easy to distinguish between red and orange dots. Perhaps plot the mean with a line? And maybe distinguish the years with different symbols. There's too many dots, and it's difficult to compare the years.**

A: Many thanks for your feedback. We changed the Figures 12, 13, 14 so the data can be better distinguished. On Fig. 4 of this reply you can see an example of the new style:

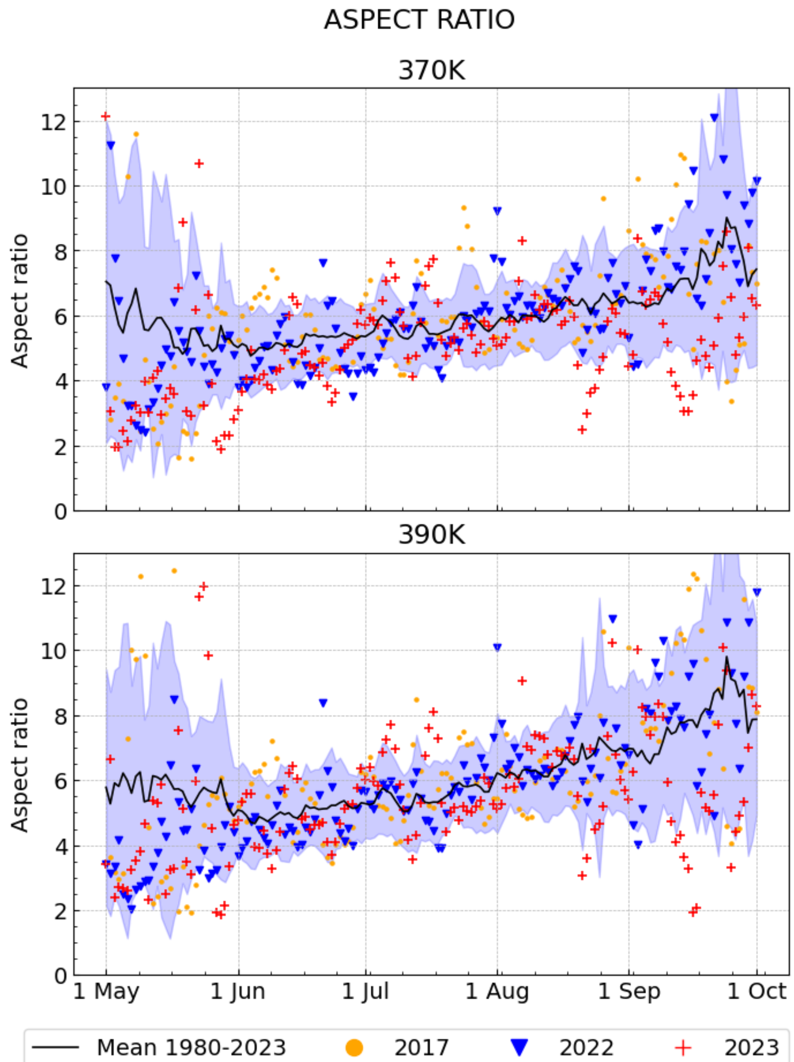

Figure 4: Aspect ratio time-series with new markers.

17. **Line 422 - " ... other studies that have not shown ASMA bimodality" I suggest revising this statement as Siu and Bowman (2020) have investigated the splitting behavior.**

A: Thank you for this suggestion. We updated the sentence accordingly:

We show that horizontal plots of the residual MSF values provide the information about splitting-like behavior of the anticyclone in July, August and September supporting the recent study of Siu and Bowman (2020) who showed multiple simultaneous peaks of the ASMA.

References

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