Response to Reviewer 1's Comments:

The study by Li et al. investigates the dynamics of the Asian monsoon upper-level anticyclone (ASMA) based on three different reanalysis datasets (JRA-3Q, ERA5, MERRA-2) and using vortex tracking and PV tendency diagnostics. It is argued that the ASMA exhibits a trimodal structure, with ASMA centers frequently occurring over the Iranian and Tibetan Plateaus and the Western Pacific, respectively. The analysis further shows that mean horizontal advection is the primary driver of the PV tendency in the ASMA region, with additional modulations due to diabatic heating.

I find the topic of the study, understanding ASMA dynamics, very relevant and clearly within the scope of the journal. However, I see two major issues with the current manuscript, regarding (1) the overall comprehensibility and fluency of the main text and (2) the comprehensibility and clarity of the method description (as further explained below). Because of these issues I'm not able to follow and fully understand the study based on the current manuscript version, and can't provide a full review and assess the scientific value at this time. Therefore, I recommend rejection but encourage resubmission after the paper had been carefully revised.

Response: We appreciate your time and feedback. We recognize the issues you raised about the fluency of the text and the clarity of the method. We have conducted a full revision of the manuscript, with a focus on improving readability and detailing our methods. We hope that these changes have clarified any aspects that were previously difficult to follow.

In the following, I give a few specific examples which led me to this recommendation. These examples primarily come from the earlier sections of the paper, but in my opinion, the descriptions in the later sections also lack clarity. Therefore, the authors should not only address the following examples but also carefully review the entire paper before resubmission.

Response: Thank you very much for your careful reading and detailed comments, which have greatly helped us improve the manuscript. We respond to each of your specific points as follows:

1.) Comprehensibility and fluency of the main text:

Overall, I see several places where the wording needs to be improved. A few examples are provided below, but there are many additional issues throughout the paper which make it very difficult to read and understand what is actually meant. I would recommend a thorough language edit, e.g. by the native English speakers among the co-authors. Here a selection of a few examples:

L5: Split the sentence "Using multiple ..." into two.

We have split the long sentence starting with "Using multiple ..." into two separate sentences to enhance readability and logical flow: “In this study, we investigate the dynamic behavior of the ASMA using the reanalysis products JRA-3Q, ERA5, and MERRA-2 during 2000-2020. The ASMA is primarily trimodal …” (L5-6)

L8: I don't fully understand the "... while ... that ..." construction in this sentence.

We have rephrased the ambiguous "... while ... that ..." construction to clarify the intended relationship between the clauses: “Although potential vorticity (PV) tendencies are dominated by mean zonal and meridional advection, total diabatic heating plays a critical modulating role in the evolution of anticyclonic vortices” (L8-10)

L46: I think the grammar in the sentence "... eddy-shedding behavior that the ..." is not correct.

We have corrected the grammatical error in the sentence describing "... eddy-shedding behavior that the ...": “These zonal shifts are often accompanied by structural instability, resulting in vortex splitting and merging, as well as episodic eddy shedding events wherein subsidiary anticyclonic vortices break off from the primary circulation” (L39-41)

L56: diagnostics

Changed as suggested.

L102: Either "zero-wind contours are" or "zero-wind contour is", not a mixture of both.

We have standardized the subject-verb agreement: “This approach is motivated by the observation that the zero-zonal wind contour is nearly zonal within the ASMA” (L112-113)

L106: "Montgomery stream function" or "... potential".

L115: Same.

Changed as suggested.

Fig. 1, caption: grid point closesT

We have corrected the typo and revised the sentence for clarity: “The four reanalysis grid points directly adjacent to this closest point” (Fig. 1 caption)

L120: Sentence structure in "... search window that ..."

We have restructured the sentence "... search window that ..." to improve clarity and readability: “Local maxima of MSF along the ridgeline are required to be unique within a span of length $2\Delta s$ around s_i ($s_i \pm \Delta s$), where Δs is a half-angle search window.” (L123)

L124: centerS

Changed as suggested.

L126: Think there should be an "and" after "anticyclonic" and a "the" before "Northern".

We have revised this section to clarify the algorithm: “The relative vorticity ζ at the identified center and its four nearest grid points (blue crosses) must be anticyclonic (i.e. $\zeta < 0$ in the Northern Hemisphere).” (L128-129)

L127: must be of / characterized by ...

We have revised the wording to "must be characterized by". (L130)

L144: "local rate of change" of what?

We have deleted "the local rate of change of potential vorticity (PV)".

L144: I don't understand the construct "isentropic density of pressure p with potential temperature"

We have rephrased the confusing construct "isentropic density of pressure p with potential temperature" to a clear, physically meaningful expression: “the isentropic mass density σ (the inverse of static stability)”. (L150-152)

L151: Similarly for the sentence "Also, the Psi has a relationship with p and has a formula by Exner function..."

We have removed this sentence, as we have opted to keep only the isentropic form of the PV analysis in the revised manuscript (see below for details).

L154: Sentence incomplete: "Based on the momentum and continuity equations on the isentropic surface."

We have completed the incomplete sentence: “Building on the momentum and continuity equations on isentropic surfaces (Andrews et al., 1986), we use PV to diagnose the boundaries, area, and strength of each anticyclonic vortex.” (L153-154)

L155: Sentence structure confusing.

We have restructured the confusing sentence to improve its logical flow and readability: “Under a hydrostatic and small-slope approximation, the simplified Ertel's PV is defined as…” (L155)

L159: What is meant by "the quantity conserved adiabatic-frictionless flow"?

This clause has been revised and moved to later in the section: “Isentropic surfaces, which are defined as surfaces of constant potential temperature θ, are intrinsically aligned with adiabatic air parcel motion. This alignment simplifies interpretation of PV evolution because PV is conserved under adiabatic, frictionless conditions…” (L178-181)

L188: Rethink the wording in "due to the wind blowing different values of PV ...".

We have rephrased the wording to emphasize that we are referring to advective transport as a key component of the Eulerian PV budget.

All changes are shown in the revised manuscript. We have also substantially revised the text to improve the flow and make the content easier for readers to understand.

2.) Comprehensibility and clarity of the method description:

I found the methods section extremely difficult to understand, likely due to the lack of text fluency mentioned earlier, as well as an unclear structure and ambiguities in the description of formulas and mathematical symbols. This made it challenging to fully grasp the methodology, and consequently, hindered my ability to assess the rest of the paper. I strongly recommend improving the methods section to enhance clarity. Below are a few examples where I struggled to understand the content:

We greatly appreciate the reviewer’s comments on the clarity of the methods section. We improved the overall readability and logical flow, reorganized the structure for better readability, and clarified all formulas and symbols with more precise and explicit wording.

L87: The levels used for the analysis should be also described.

We have added a clear description of the vertical levels used in the analysis. Specifically, the isentropic analysis is conducted primarily on the **370 K isentropic surface**. The isobaric analysis has been removed from the revised manuscript.

L91: How is latent heating explicitly calculated? It would be good to describe that in
We have added details on how latent heating is derived across each reanalysis dataset:

- ERA5: estimated by subtracting mttswr and mttlwr (shortwave and longwave radiative heating) from mttpm (temperature tendency from all parameterized physics);
- JRA-3Q: sum of lrghr (condensation/evaporation) and cnvhr (convective);

- MERRA-2: taken directly as DTDTMST (moist physics).

For **ERA5**: since no direct latent heating product is provided, we use non-radiative heating (total minus radiative) to represent latent heating. Contributions from other processes, such as parameterized gravity wave drag and turbulent mixing, are typically 1-2 orders of magnitude smaller (see below; also Wright & Fueglistaler 2013; Tegtmeier et al. 2022).

For **JRA-3Q**: latent heating is directly obtained as the sum of temperature tendencies due to large-scale condensation (lrghr) and parameterized moist convection (cnvhr).

For **MERRA-2**: latent heating is directly taken as the total temperature tendency from moist physics (DTDTMST).

The combination of these variables allows consistent representation of latent heating across all three datasets and captures its spatiotemporal variations throughout the study period.

Section 3.1: The entire description of the "vortex tracking" is difficult to follow and understand. I suggest to include a bullet point list of the individual steps, in addition to the other specific points below.

Eq. 1 and following paragraph: I don't fully understand the notation here. i is the index of the grid point. The zero-wind contour not necessarily passes through the grid points - so why should any grid point lie on the contour? Hence, to me "s_i is the distance along the contour, e.g. from point x(i-1) to x(i)..." seems not well-defined. Maybe I misunderstand something here? Please clarify, and perhaps include the x(i), s_i, ... also into Fig. 1 to enhance clarity.

Thank you for this valuable suggestion. We have now included bullet points for the three key filtering criteria (L128-133):

1. Vorticity sign: The relative vorticity ζ at the identified center and its four nearest grid points (blue crosses) must be anticyclonic (i.e. $\zeta < 0$ in the Northern Hemisphere).
2. Zonal wind direction: The three grid points immediately poleward of the center must be characterized by westerly flow ($u > 0$), while the three points equatorward must be characterized by easterly flow ($u < 0$).
3. Contour length: The corresponding $u = 0$ contour must occupy a minimum great-circle arc length greater than $2R_e\Delta a$ (Siu and Bowman, 2020).

After identifying one or more closed zero-wind contours (where zonal wind $u = 0$)

within the study region, the next step is to locate potential vortex centers along these contours. We have also revised the text and updated the schematic figure to make this process easier to understand. (L116-L126).

L133: After having read the "Vortex tracking" section I'm still unsure how the tracking of vortices was exactly done. Please describe clearly how the vortices diagnosed at different times are related to identify connected tracks.

The last step in our process is to track how these small vortices (sub-vortices) move and how long they last over time. To do this, we repeat the same vortex-tracking analysis at each set of time points we study (e.g., every 6 hours).

We define a vortex as **persistent** (long-lasting) if two conditions are met:

1. From one time step to the next (e.g., from 6 AM to 12 PM), the vortex center moves no more than 10° along the Earth's surface (measured as a great-circle distance).
2. The vortex remains visible (continuous) for at least four time steps (equivalent to > 18 hours, since each time interval is 6 hours).

Any vortices that do not meet these conditions (i.e., no vortex is identified within 10° of great-circle distance over a sufficient number of time steps or the vortex lasted less than 18 hours) are classified as **transient** (short-lived).

As we show in the Fig. 2 and 4, this simple classification helps to clarify how vortices move over time. It also helps us identify when vortices split apart, merge together, or disappear entirely.

L153: I think R_d should be the gas constant not specific heat?

Thank you for catching this error; indeed, R_d is the gas constant, and we have corrected it in the revised text.

L158: The (Joseph, 1981) is surely not the original paper to cite here. Similarly for the citations in L162.

Thank you for this comment. We agree that Joseph (1981) is not the original source for this formulation of potential vorticity and that more appropriate, foundational references should be cited. In the revised manuscript, we have replaced this citation with widely recognized original sources, including the seminal works on potential vorticity (e.g., Charney, 1948; Ertel, 1942), to more accurately reflect the origin of this formulation (L155-157).

Eq. 7: What is the Q on the right-hand side of the equation exactly? The text says "Q is total diabatic heating". In most text books, Q denotes the diabatic heating rate, with units K/day. But this cannot be meant here, as the units wouldn't match. The PV tendency equation should include a diabatic forcing term including also derivatives of the diabatic heating rate and I guess this term is meant here with Q - but this is not said. This is just one example of the inconsistent notation that appears throughout the paper, making it nearly impossible for the reader to fully understand the methodology.

We apologize for our imprecise wording and notation here. We further clarify that Eq. 7 was the PV tendency equation in pressure coordinates (now Eq. 3 in potential temperature coordinates), and the term Q_θ represents the diabatic forcing term due to the vertical divergence of diabatic heating. Diabatic heating itself is designated as $\dot{\theta}$ in the revised manuscript.

To address the issue of inconsistent notation throughout the manuscript, we have conducted a comprehensive check and standardization of all symbols. We have explicitly defined each symbol (including Q_θ when first introduced; Eq. (4)), clarified their units, and ensured consistency in their usage across all equations, text, and figures.

Eq. 8: Why is the vertical advection term not expanded into mean plus fluctuation?

The vertical velocity (now determined by $\dot{\theta}$ rather than ω) is not decomposed into mean and fluctuating components in the budget analysis under the assumption that the local background flow for vortices centered along the ridgeline is adiabatic and zonal. Although equation (5) now includes decomposition of PV in the vertical advection and source terms, these terms are combined in the budget analysis (Fig. 13) for concision. Decomposition into mean and fluctuation parts is only applied to horizontal terms (zonal/meridional advection), as these are the primary drivers of ASMA variability we aim to isolate.

L184: Clearly explain at the beginning of this paragraph that and why isentropic coordinates are considered in the following (e.g. their advantages for the analysis). Then explain the differences to the pressure coordinate version of the equations. Furthermore, why is the isentropic version of the PV tendency equation not given in its version decomposed into?

Thank you. We have added a clear opening statement at the start of the paragraph (L177)

explaining why we adopt isentropic coordinates (and specifically the 370 K surface) for our subsequent analysis. We highlight the key advantages:

1. Isentropic coordinates naturally align with adiabatic flow, simplifying the interpretation of PV advective and diabatic forcing effects.
2. Vertical velocity vanishes under adiabatic conditions, eliminating vertical advection and emphasizing the horizontal processes that dominate vortex variability within the ASMA.

Eq. 5 now introduces the decomposition of the PV tendency equation into mean state and fluctuation components.

L185: "Therefore, the second term ..." comes after Eq. 8 without further explanation. Therefore, the reader thinks that the second term in Eq 8 is meant. However, I guess what is indeed meant is the second term in Eq. 6... ? Similarly for "expression" in L186 it is not clear which expression.

Thank you for pointing out our ambiguous reference to "the second term" and “expression”. Your interpretation was correct; we meant the tilting term. With the removal of the isobaric formulation, this has been revised to “Under a hydrostatic and small-slope approximation, the simplified Ertel's PV is defined as…”

L279: Here, one example from the later parts of the paper. L280 states that q_dev is the "minimum PV inside each box", while L286 states that "q_int and q_prop are the PV tendencies". As Eq. 11 relates both, there seems to be a mismatch to me: Is it PV or PV tendency here?

L279: We apologize for the confusion: q_dev, q_int, and q_prop all represent PV tendencies, not PV itself. The description at L280 incorrectly referred to PV, we have revised it to clearly state that q_dev is the minimum PV tendency inside each box, consistent with Eq. 6, 7 and the definition in (L330-340).