

Response to Reviewer 2's Comments:

This paper investigates the dynamics of the Asian Summer Monsoon Anticyclone (ASMA) using three modern reanalysis datasets (ERA5, MERRA-2, and JRA-3Q) and introduces a potential vorticity (PV) tendency diagnostic to disentangle dynamical and thermodynamical contributions to ASMA evolution. The study identifies a trimodal structure of the ASMA (Iranian Plateau, Tibetan Plateau, and Western Pacific/Bonin High) and examines the roles of horizontal advection and diabatic heating in modulating its propagation, intensification, and eddy-shedding behavior. The topic is relevant and within the scope of the journal, and the use of multiple reanalyses combined with PV diagnostics is potentially valuable. While the topic is relevant and the use of multiple reanalyses is commendable, the manuscript in its current form has several critical issues that must be addressed before publication.

Major Comments:

1. The estimation of latent heating in ERA5 using radiation fluxes and “precipitation-related top latent heat flux (mtpm)” raises concerns. These variables do not directly represent the vertical structure of latent heating, which is crucial for PV generation. This approximation may introduce uncertainty into the diabatic contribution to PV tendency. The assumptive latent heating in ERA5 shows large difference from that in Merra2 and JRA-3Q in Fig.8. The authors should provide justification and supporting references for this approach, perhaps by showing the comparison with datasets that include explicit latent heating or the spatial patterns of “mttpm” correlate well with upper-tropospheric diabatic heating from other reanalyses. Limitations in both the methodology and conclusions should be discussed to justify its use.

Response: We sincerely appreciate the reviewer's comments on the estimation of latent heating in ERA5 and its uncertainty in the diabatic contribution to PV tendency. We fully agree that the vertical structure of latent heating is critical for PV generation, and the approximation in ERA5 requires rigorous justification, comparison, and limitation discussion.

ERA5 does not provide a direct diagnostic of latent heating rate on isentropic or pressure levels required for PV tendency calculation. To resolve this, we use a physically consistent combination,

- 1) Top net shortwave (mttswr) + top net longwave radiation (mttlwr): Represent the TOA background radiation budget, defining the large-scale thermal background.
- 2) Moist process-related top latent heat flux (mttpm-mttswr-mttlwr): Inirectly

quantifies the latent heat due to moist process.

Our previous work shows (see Fig. 1 below) that the residual heating is dominated by latent heating, the difference of latent heat among different reanalysis data is significant especially from 300-100 hPa which is core of Asian summer monsoon anticyclone. These differences exist in both longwave and shortwave radiation is also significant, see Fig. 2 (Wright & Fueglistaler, 2013). We added the limitations to methodology.

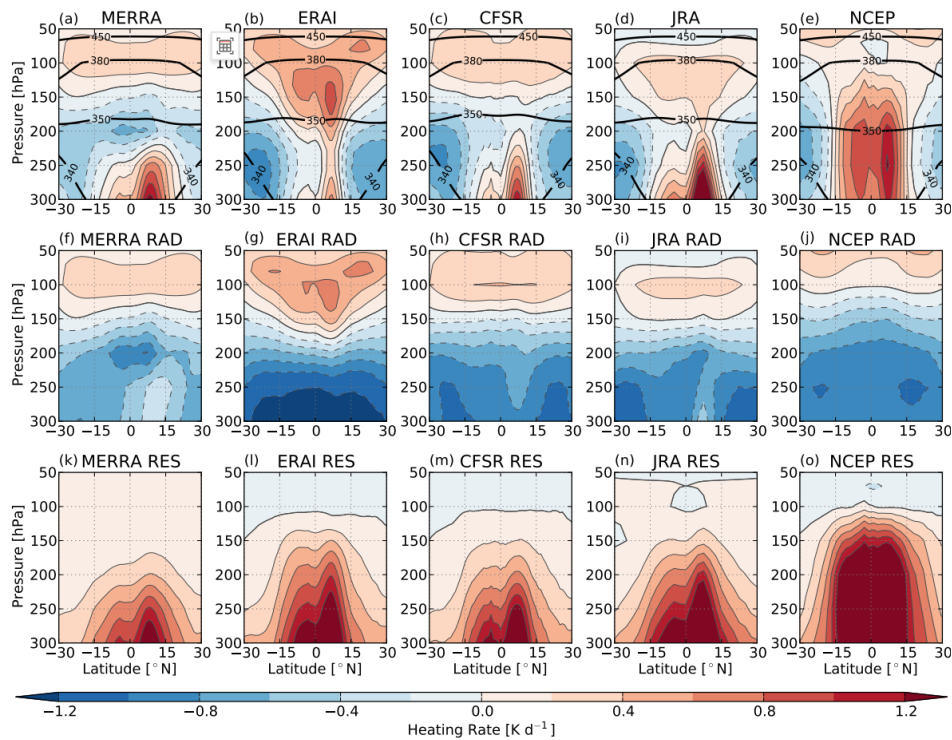


Fig. 1. Top row: zonal mean total diabatic heating averaged over the period 2001–2010 according to the (a) MERRA, (b) ERAI, (c) CFSR, (d) JRA, and (e) NCEP reanalysis data sets. The 340, 350, 380, and 450 K isentropic surfaces from each reanalysis are shown as black contours. Middle row: zonal mean radiative components of diabatic heating averaged over the period 2001–2010. Bottom row: zonal mean residual components of diabatic heating averaged over the period 2001–2010. Residual diabatic heating includes all diabatic heating due to non-radiative physics (moist physics, turbulent mixing, etc.). The figure is adapted from Wright and Fueglistaler, 2013.

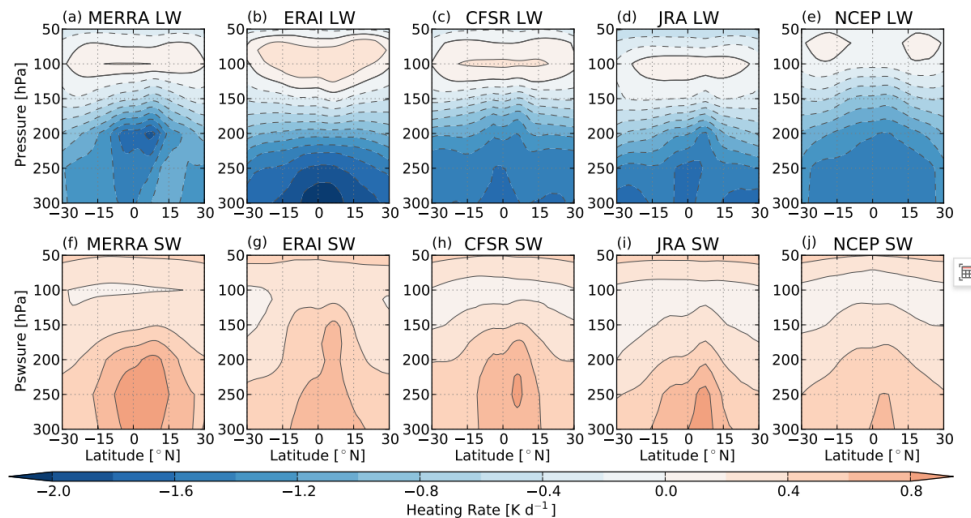


Fig. 2. Zonal mean (a)–(e) long-wave and (f)–(j) short-wave components of radiative diabatic heating averaged over the period 2001–2010.

- The vortex tracking method has already been well-documented in prior work (Siu and Bowman, 2020) and could be significantly condensed. The core novelty—the PV tendency diagnostic and its application to understanding the three modes—should be the central focus. The derivation and presentation of the PV tendency equations (Eq. 7 -- 10) are difficult to follow. Please provide a clear and consistent derivation. Some terms are introduced without sufficient explanation.

Response: Thank you. We have substantially shorten the Section 3.1 Vortex Tracking because the method is well-established in Siu and Bowman (2020). Keep only the key steps relevant to this study (370 K isentropic surface, zero-zonal wind, MSF maximum, relative vorticity filtering, persistent/transient definition). This change will make the manuscript more concise and highlight the paper’s true novelty.

We started from the simplified Ertel PV tendency equation under hydrostatic and frictionless approximation, clearly state assumptions. The PV tendency equation is derived from the full equation to pressure coordinates to isentropic coordinates and every term is in plain physical language.

Minor comments:

L100: “including zonal wind, u , MSF, ψ , and relative vorticity, ζ .” --Consider changing to “including zonal wind (u), MSF (ψ), and relative vorticity (ζ).”

Response: Thank you for noticing, we changed them.

L142: Please move Eq.2 ahead to Sec 3.1, as MSF is already mentioned there.

Response: Thank you, we did this.

L161: The second term on the right-hand side of Eq.6 appears unnecessary based on Eq.3 and Eq.5.

Response: Thank you for comment. We would like to keep the second term on the right-hand side of Eq. 6 for physical completeness and consistency with the full Ertel potential vorticity (PV) definition in pressure coordinates. Eq. 5 is a simplified form used for conceptual clarity and isentropic-level diagnosis, valid under the assumptions of small isentropic slope and hydrostatic balance. Eq. 6 presents the full, unapproximated Ertel PV in pressure coordinates, which includes both the planetary–relative vorticity component (first term) and the tilting / vertical-shear term (second term). This full form is standard in dynamical frameworks and ensures consistency with the PV tendency derivation. Although the second (tilting) term is small in the upper-tropospheric UTLS region dominated by the Asian summer monsoon anticyclone, retaining it preserves the full dynamical structure of Ertel PV and avoids premature approximation in the formal definition.

L179: Eq.8 is difficult to follow

Response: Thank you. First reviewer also raised similar questions. Therefore, we have rewritten and enhanced the derivation process of the entire method section to make it more understandable for readers.

L199-201 and caption of Fig.2: Please specify which reanalysis was used for the results.

Response: The plotted data is derived from JRA-3Q, we added this information in the caption of Fig.2.

L226: “eddy shedding events” -- Are all eddy shedding events marked by the gray and dashed circles in Fig. 4, or only some examples? Is there a clear definition of an eddy shedding event?

Response: In Fig. 4, we mark only typical, visually clear cases to illustrate the eddy shedding behavior, rather than attempting to label every weak or ambiguous event. This approach is consistent with standard visualization practice in ASMA variability studies.

There is no universally accepted quantitative threshold for defining eddy shedding in the ASMA, as it involves gradual vortex splitting, detachment, and westward/eastward propagation that is inherently continuous and difficult to discretize objectively. For consistency with previous literature, we adopt the qualitative dynamical definition widely used in relevant studies (e.g., Popovic and Plumb, 2001; Siu and Bowman, 2020; Wang et al., 2022).

L233-234: The zonal advection and vertical advection of PV are positive (negative) in the west (east) of anticyclone in Fig.5. They are not always positive or negative above 300hPa. Please rephrase this sentence for clarity.

Response: Thank you. We agree that the original statement was insufficiently precise. The pattern described at L233–234 represents the composite/statistical mean behavior derived from all analyzed cases, rather than a feature that holds in every individual event. Above ~300 hPa, in the composite mean, zonal advection tends to produce positive PV tendency to the west of the anticyclone core and negative PV tendency to the east, while vertical advection is dominated by positive values near the center and negative values farther eastward. We will revise the sentence to clearly indicate that this is a statistical composite result, not a universal feature of every case.

P15: Please include the values of PV anomaly in the black dashed contours in Fig. 5, as is done in other figures.

Response: Thank you so much. We updated the Fig. 5 and added the labels for dashed contours.

P16, Caption of table 3: “while the northward direction is taken as negative in the tripole patterns ...” -- Please confirm whether the northward direction is taken as negative or positive.

Response: Thank you. It is a typo error, the northward direction should be positive, we corrected it in the caption of table 3.

L308-310: The description of the results in Fig.8 is unclear. Consider revising to: In contrast, the effect of mean meridional advection opposes that of mean zonal advection; specifically, mean meridional advection intensifies anticyclones for all three modes in the west, and also intensifies the TP and BH anticyclone in the east, while diminishing IP anticyclone in the east.

Response: Thank you for your suggestions, we modified the sentence in L308-310 referring to your contents.

L314: The latent heating for ERA5 looks quite different from that in Merra2 and JRA-3Q in Fig.8. Is the assumption for ERA5 latent heating reasonable? Please carefully revise this whole paragraph discussing Fig.8.

Response: Thank you for pointing out this critical issue. We have carefully checked Figure 8 and found that the obvious discrepancy of latent heating in ERA5 relative to MERRA-2 and JRA-3Q was caused by a plotting code error in the original figure. We have now completely revised and replotted Figure 8, and the inconsistency of ERA5 latent heating has been limited.

The ERA5 does not provide a direct latent heating term, so we adopt the

combination of shortwave and longwave radiation and total diabatic heating to indirectly calculate latent heating. This indirect scheme has been widely validated in previous UTLS and ASMA-related studies and can well capture the spatiotemporal characteristics of latent heating. Moreover, the 370 K isentropic surface is located in the upper troposphere and lower stratosphere with low water vapor content, so the inherent magnitude of latent heating is small across all three reanalysis datasets. The revised Figure 8 further proves that our estimation assumption for ERA5 latent heating is physically reasonable.

L317: “ASMA is stronger than in eastward in TP and BH modes...” -- change to “ASMA is stronger than in westward...”. Also note that “both the intensification and propagation are negative PV tendency”, but the intensification appears as positive in Fig.9. Please clarify.

Response: We improved this phrase and made it easier to understand.

P18: The caption about Fig.8 is unclear. I had to read it several times to understand the different terms in the plot. Please revise. The “meridional mean advection” in Fig.8(a-f) -- consider change to “mean meridional advection”.

Response: Thank you. We change the caption to “Relative contributions (%) of dynamical and thermodynamic processes to the PV tendency at 370 K during anticyclone intensification for (a-c) westward propagation and (d-f) eastward propagation. Each group of three bars corresponds to JRA-3Q, ERA5, and MERRA-2 (left to right). Numbers on bars denote the percentage contribution of each term. Terms include mean zonal advection, mean meridional advection, nonlinear horizontal advection, vertical advection, and total diabatic heating.”

P19: Check the caption of Fig.9. Please confirm whether the value next to each bar shows the relative contribution to PV tendency.

Response: We checked and modified the caption. The vertical bars show q_{dev} , q_{int} , and q_{prop} derived from three reanalysis datasets. For q_{dev} (first bar), values indicate the absolute PV tendency ($PVU\ day^{-1}$). For q_{int} and q_{prop} (second and third bars), values denote the relative contribution (%) to the total PV tendency. Westward and eastward propagation are indicated by diagonal and dot textures, respectively.

P21: Please clarify what the “PV tendency anomalies” refer to in Fig.10 and Fig.11?

Response: We clarify that PV tendency anomalies in Fig. 10 and 11 are defined as the PV tendency for the three ASMA modes during May–September minus the full climatological mean PV tendency. The pseudo code is

$$PV\ tendency\ anomaly = PV\ tendency\ in\ IP/TP/WP - climatological\ mean\ PV\ tendency$$

General: Improve figure captions to clearly state main findings.

Response: The figure captions are updated.