Weather and Climate Dynamics

Review of "*Extratropical interactions with the tropical moist margin: a case study and the role of latent heating*"

The manuscript by *Robinson et al.* presents a case study of the physical processes associated with a subtropical-origin low-pressure system that subsequently intensified in the midlatitudes. The authors analyze the synoptic conditions during the cyclone's intensification, the observed position of the tropical moist margin, and the evolution of the upper-level potential vorticity (PV) structure and the role of latent heating.

However, the analyses and observations presented in the manuscript provide only limited, or indirect, support for the claims made in the abstract, introduction, and conclusions. Moreover, the different components of the analysis are not sufficiently integrated, making it difficult to understand how they collectively address the paper's central research question.

The manuscript's key analysis concerns latent heating within cyclones (and warm conveyor belts-WCBs) and demonstrates its well-established role in cyclone intensification and in modifying upper-level PV structure (Davis et al. 1993, Schemm et al. 2013, Steinfeld et al. 2020). This is investigated through numerical experiments with the ACCESS-rAM3 model, using different prescribed values of latent heating. However, this analysis is not convincingly connected to the tropical moist margin. Consequently, the manuscript does not yet establish the specific role of the moist margin in the event and does not clearly demonstrate the novelty of the study.

Given the potential relevance of this topic to the *Weather and Climate Dynamics Journal*, the manuscript could be given further consideration if the authors restructure the storyline and either reformulate the key research questions to align with the current analysis or revise the analysis to address the stated questions. Therefore, I recommend a major revision and restructuring.

Detailed comments are below.

Best wishes!

Major comments:

1. The abstract, introduction, and conclusions are too vague

- The abstract is overly general and does not clearly state the specific findings of the analysis. It vaguely describes the methodology and only presents broad conclusions. The authors should report the main results more explicitly and explain what the study adds to the existing literature.

- The introduction would benefit from further discussion of the relevant literature. In particular, the importance of defining the tropical margin, the need for such a definition in this context are not sufficiently explained. The authors should also clarify why this additional case study is important and what new insight it provides. Although a hypothesis is introduced, it is not clearly stated how it will be addressed in the subsequent analysis.

Citation required: *L17-20: "In particular, there exists a strong relationship between the moist margin and extratropical potential vorticity (PV) … produce long-lived and heavy precipitation over a large area extending from the tropics to the extratropics."* This statement in the introduction is central to the motivation of the study and should therefore be supported by appropriate citations.

The authors could also refer to previous studies relevant to the topics discussed in the manuscript, including latent-heating experiments, cyclone development, and Rossby wave breaking. For example:

Davis, C., Stoelinga, M., and Kuo, Y., 1993: The Integrated Effect of Condensation in Numerical Simulations of Extratropical Cyclogenesis. Mon. Weather Rev., 121, 2309-2330. https://doi.org/10.1175/1520-0493(1993)121<2309:tieoci>2.0.co;2

Grams, C. M., H. Wernli, M. Böttcher, J. Campa, U. Corsmeier, S. C. Jones, J. H. Keller, C.-J. Lenz, and L. Wiegand, 2011: The key role of diabatic processes in modifying the upper-tropospheric wave guide: A North Atlantic case-study. Q. J. Roy. Meteor. Soc., 137 (661), 2174–2193, doi:10.1002/qj.891.

Schemm, S., H. Wernli, and L. Papritz, 2013: Warm conveyor belts in idealized moist baroclinic wave simulations. J. Atmos. Sci., 70 (2), 627–652, doi:10.1175/JAS-D-12-0147.1.

De Vries, A. J., 2021: A global climatological perspective on the importance of Rossby wave breaking and intense moisture transport for extreme precipitation events. Weather Clim. Dynam., 2 (1), 129–161, doi:10.5194/wcd-2-129-2021.

- There is a substantial gap between these results and the conclusions drawn from them, as the analyses do not directly address the study's key questions.

For example, the interaction is defined as a two-way relationship between the tropical moist margin and the PV structure (*L6-9, L35-39, L387-391*). However, the statement that "*L394: results from the ACCESS-rAM3 experiments suggest that the strength of the interaction is strongly related to diabatic heating through its effects on upper-level divergence*" is not fully supported by the analysis. The experiments demonstrate that changes in latent heating affect cyclone development and the upper-level PV structure, but they do not directly establish a relationship between these changes and the tropical moist margin.

This limitation is also acknowledged by the authors: "*L410: Notably, the moist margin itself does not appear to directly affect extratropical PV, for example, as seen in the*

ACCESS-rAM3 experiments, where reducing latent heating constants results in a more poleward margin but no substantial interaction". This interpretation differs substantially from the main argument communicated in the abstract, introduction, and conclusions.

The subsequent statement that "*L412: the role of moist margin perturbation is to permit heavy convection, with the associated condensational heating interacting with the extratropics if it occurs close to strong upper-level PV gradients (i.e., the jet stream)*" is also not directly demonstrated by the analyses. It appears to be a proposed interpretation rather than a conclusion supported by the experiments and should be presented and justified accordingly.

The discussion and conclusions should clearly explain how each analysis contributes to the study, distinguish demonstrated results from proposed mechanisms, and specify which conclusions are directly supported by the evidence.

2. Relevance of the tropical moist-margin diagnostic to a midlatitude case study

The use of the tropical moist-margin concept in this case study appears somewhat forced, particularly because it is not clearly connected to the latent-heating experiments. High total column water vapor (TCWV) values, on which the tropical moist-margin definition is based, as the authors state "L13: *provides a simple diagnostic for rainfall in tropical regions (Mapes et al., 2018).*"

In the synoptic charts, the poleward extension of the tropical moist margin seems to be associated with the general high moisture near the fronts. Beyond this, the additional physical interpretation or insight provided by the diagnostic remains unclear. Moreover, the diagnostic may become less meaningful once the cyclone moves into the midlatitudes, where background TCWV values are inherently lower. Indeed, the authors acknowledge that "L147: *The moist margin is also a weaker predictor of precipitation at higher latitudes, as discussed in Robinson et al. (2024)*", an assessment with which I agree.

The usefulness of this definition in the midlatitudes is therefore uncertain, especially given the availability of established diagnostics such as integrated vapor transport, which is widely used to characterize moisture transport associated with midlatitude cyclones and atmospheric rivers. Furthermore, the tropical moist-margin diagnostic cannot, by itself, demonstrate that the moisture originated in the tropics. Therefore, the use of the tropical moist margin definition is not required for the present case study. If using the "tropical moist margin", the authors should clarify what additional information this diagnostic provides for the present case study and explain why it is preferable to, or complementary to, existing moisture diagnostics.

3. The manuscript includes too many loosely connected diagnostics

The manuscript currently presents the following analyses:

I. The ERA5 synoptic analysis introduces the case study and describes the evolution of the moist margin and PV structure. The main findings appear to be that the case involved extratropical transition, the poleward displacement of the tropical margin, and a ridge-amplification event.
II. The moisture-budget analysis examines the evolution of the moist margin, but its purpose and contribution to the central research question are unclear.
III. The trajectory analysis shows that a WCB was involved. However, the manuscript does not clearly explain how information about the origin and evolution of the airstreams associated with the moist margin and dry intrusion relates to the key research questions or informs the subsequent analysis.
IV. The latent-heating experiments show that stronger latent heating produces a more intense cyclone and greater ridge amplification. This relationship is already well established, so the authors should clarify what new insights these experiments provide. Why is the moisture budget not examined for the sensitivity experiments if the goal was to understand the tropical moist margin?
V. The analysis of the effects of scaling latent heating on the time- and domain-mean atmospheric structure appears potentially interesting. However, essential methodological information is missing, including details of how the temporal and spatial averages were calculated. The context of this analysis to the paper's central questions also needs to be explained.

Overall, the manuscript would benefit from a more focused storyline. The authors should identify the analyses that directly address the main research questions, explain how those analyses are connected, and remove or substantially justify diagnostics that do not contribute clearly to the central argument.

It is also unclear whether the proposed *interaction* concerns the moist margin and PV, because the key analysis and conclusions focused on latent heating and PV. As mentioned earlier, a direct connection between the tropical moist margin and the PV structure is still missing. Without the tropical moist-margin concept, the study essentially examines the effects of high moisture availability or latent heating within cyclones on PV modification, which is already well established.

The novelty of this case study would be clearer if the authors could demonstrate the specific role of moisture of tropical origin in this event. For example, numerical experiments that directly modify the moisture content or the tropical moist margin could be used to assess the resulting effects on the PV structure. Such an analysis would directly address the paper's central hypothesis and provide a clearer justification for introducing the tropical moist-margin concept.

4. Clarity and completeness of the manuscript

Several aspects of the manuscript suggest it was not well prepared for readers.

- For example, the tropical moist margin concept is discussed extensively before its threshold-based definition is introduced, apparently only in a later figure caption (Figure 4). This definition should be presented clearly before the diagnostic is used or interpreted.

- Some figure captions are vague or missing details and should provide enough information for the figures to be understood independently of the main text.

- Section 4.2 does not specify the time period or spatial domain used to calculate the averages. These methodological details should be provided.

Minor comments:

- L6: The abbreviation “PV” is used before it is defined. Please define it at first use.

- L51: Potential vorticity has already been introduced as PV; therefore, there is no need to define the abbreviation again.

- Figure 2 caption: Please check the description of the contour colors. Green lines in (b), (d), and (f) are not defined. There is also a typo, and it should perhaps read “blue contours.” Please also specify the contour interval for geopotential height.

- L148: The meaning of “*interaction*” is unclear in the statement, “*Despite this, we hypothesize that the initial moist margin perturbation during 01–03 January is necessary for the interaction to occur*.” Please specify which features or processes are interacting and explain how this interaction is identified.

- L150: Please indicate the figure to which the discussion refers.

- L156: The statement that “*the extratropical interaction with the moist margin occurred on 03 January, resulting in rapid cyclogenesis and upper-level ridging*” requires clarification. The synoptic charts show a poleward extension of the moist margin into the extratropics, but this does not necessarily demonstrate an “*interaction*.” Please explain what is interacting.

- L198: Please restate the duration of the backward trajectories here.

- Figures 8 and 9: The red boxes do not appear to represent the same domain as the box shown in Figure 10. Please clarify or make the domains consistent.

- The complete synoptic evolution of the different sensitivity experiments would be valuable and could be included in the Supplement.

- L291-294: The conclusion of the PV and moist margin as “coupled” or “decoupled,” based solely on the relative positions of their contours, appears too strong and should be rephrased more cautiously.

- L307 and L326: The proposed “nonlinearities or threshold-like behavior leading to the presence or absence of convection” might not be the reason for the weaker response of increased latent heating experiments. At 12 UTC on 3 January, the 1.5L experiments do not show a prominent additional intensification of the ridge anomaly relative to the control. Please consider examining later times to determine whether a stronger response emerges.

- Figure 10: Please explain what the green lines represent in panels (a), (c), (e), and (g).

- L338: The decreased near-surface humidity and increased wind speed used to explain the evaporation response could be related to dry intrusions; the authors can verify.

- L415: “*Robinson (2026, Chapter 5) demonstrates that the moist margin is strongly perturbed and heavy precipitation is produced when a cyclonic PV anomaly approaches the moist margin, but only when the cyclonic PV anomaly extends into the lower troposphere, as is evident in the cross-sections for this study (Figure 4).”*
  This seems highly relevant to the present study, and this relationship could be demonstrated more explicitly in the analysis.