

# Review

## Sensitivity of the Lagrangian temperature anomaly decomposition to model choice: Lessons from the 2021 Pacific Northwest heatwave

*Albenis Pérez-Alarcón, Raquel Nieto, Luis Gimeno*

### General comment:

In this paper, the authors test the sensitivity of the Lagrangian temperature anomaly decomposition of Röthlisberger and Papritz (2023) to the choice of Lagrangian model. More specifically, for the case of the 2021 Pacific Northwest heat wave, they compare the adiabatic, advective and diabatic contributions obtained from pure-trajectory models with those obtained from simulations with a dispersion model. In their analysis, the authors find substantial differences between the two model types: all pure-trajectory models consistently attribute the largest contribution to the heat anomaly to diabatic warming, whereas all simulations with the dispersion model attribute the largest contribution to adiabatic warming. The authors then show that this difference does not stem from differently simulated horizontal air parcel origins but from differently simulated vertical origins. More precisely, the trajectories from the dispersion model reveal much stronger subsidence than those from the pure-trajectory models, while all trajectories follow a similar horizontal path. In a last step, the authors identify turbulence, rather than convection or mesoscale effects, as the primary source of the discrepancy between the results of the two model types. They conclude that the study reveals a critical sensitivity of the relative contributions of the individual processes when the Lagrangian decomposition of Röthlisberger and Papritz (2023) is applied. Furthermore, they warn that the inferred dominance of any process may reflect the characteristics of the specific model rather than the underlying physics alone.

Unlike Reviewer 1, I do consider the study to be of value to the community — and notably for the very reason Reviewer 1 gives against it. Reviewer 1 argues that calculating pure trajectories in the boundary layer is essentially pointless; there is, however, an abundance of studies of heat extremes that do exactly this, neglecting any effects of turbulence. It is precisely in order to demonstrate how sensitive such trajectory calculations are that this study should be published. Of course, it has long been known that any trajectory calculation is prone to error and that certain assumptions inherent in the parcel approach may not be entirely valid. However, especially within the literature on Lagrangian studies of temperature extremes, there seems to be only limited awareness of the uncertainties associated with the Lagrangian diagnostics used, and the calculated numbers are often taken at face value. This paper highlights this concern.

One key question — deliberately provocative, I admit — that this paper raises is: if the decomposition of Röthlisberger and Papritz (2023) is so sensitive to the model used that it yields even qualitatively different results, is it then useful at all? Mayer and Wirth (2025) proposed a new decomposition based on *anomalous* adiabatic, advective and diabatic contributions, which is argued there to be more useful than the decomposition of Röthlisberger and Papritz (2023). It would be

interesting to know whether the different models would yield more similar results if this anomaly-based decomposition were applied. This seems plausible, because the respective model climatologies are subtracted, so that model-specific characteristics may cancel out. Such an analysis would be a valuable addition.

Overall, the paper is clear and carefully written, and most figures are presented clearly. However, I do have a significant concern regarding how the study by Mayer and Wirth (2025) is presented and how the manuscript relates to it. My detailed comments on this major concern, together with some further thoughts and suggestions, are given below.

### **Major comments:**

1) My main concern relates to the references to Mayer and Wirth (2025), which in places do not reproduce their findings accurately. I think that the references to Mayer and Wirth (2025) are important and precisely for this reason it seems essential to me that what Mayer and Wirth (2025) actually state is reproduced correctly.

L71–73: Here, the authors should state more clearly what is meant by "approaches" in Mayer and Wirth (2025). The key point of that study is the proposal of a new decomposition based on anomalies of the individual contributions, which is argued there to be more helpful for understanding a temperature anomaly. This reasoning is not yet reflected in the current manuscript.

L69/73: I may have overlooked an explanation, but I find the argument difficult to follow. On the one hand, the authors characterise Mayer and Wirth (2025) as a "key theoretical development" with "profound implications"; on the other hand, they retain the original approach of Röthlisberger and Papritz (2023) without further justification. This apparent inconsistency should be resolved explicitly, either by explaining why the earlier approach remains valid, by stating what the implications of Mayer and Wirth (2025) actually are for the present analysis, or by applying the decomposition approach of Mayer and Wirth (2025).

L244/245: It is true that Mayer and Wirth (2025) report diabatic heating as the largest contribution during the Pacific Northwest heat wave, but this holds only for the decomposition in terms of absolute fields (i.e. the Röthlisberger and Papritz approach). That study also shows, however, that if the decomposition is applied in terms of anomaly fields, the relative importance of the contributions changes substantially, with horizontal advection emerging as the largest contribution. This distinction appears central to the argument of Mayer and Wirth (2025) and should be made explicit here.

L344/345: Here, the authors write that "Ultimately, the question of which physical process drove a HW event may have no unique answer; it depends on the perspective (and the model) from which the event is examined." I agree with this statement in principle. However, I do not see that the manuscript actually demonstrates any dependence on the perspective. In Mayer and Wirth (2025), "perspective" is used in the sense of the two different decomposition approaches. It would therefore be helpful if the authors clarified what they mean by the term here.

2) This relates to my general comment and to comment 1): Would it be possible to extend the same analysis to the anomaly-based approach proposed by Mayer and Wirth (2025)? While the main

challenge would be the need for a climatology of the contribution terms for each model, I wonder whether this could be feasible for at least a subset of the models. If I understand correctly, long-term datasets are available for some of them, which could make such an analysis achievable without an excessive amount of additional work. I believe this could be a valuable extension of the analysis. If such an analysis is not possible, I would at least expect a detailed discussion of this topic.

3) What I find interesting is that the two model types yield very similar horizontal pathways, yet the contribution from horizontal advection differs between them. I think this needs some discussion.

### **Minor comments:**

L82: I do not understand why the divergence in findings between models could be understood through the physical mechanisms typically associated with heat waves.

Formula (1): Why does  $t_g$  carry the superscripts sea, adia and dia in the lower limit of the integrals? Furthermore,  $x_g$  (and other variables) are not explained.

L232: Well, it is not too surprising that Röthlisberger and Papritz reported very similar contributions, given that they used the same data. ...

L266: What are Lagrangian parcels? Are parcels not always Lagrangian?

Figure 3: It is not clear to me what is shown here. In particular, what is meant by a parcel distribution for LAGRANTO? Regarding panel (h): is this panel really needed?

Figure 4: What is the red rectangle in the left panel?

L399: "the anomaly" instead of "the warming" in "the largest fraction of the warming".