Response to Reviewer 5

We thank the reviewer for the careful and constructive review. In the revised version of the manuscript, we will revise the interpretation of the T850 residual, add absolute analogue distances and an amplitude analysis, separate the land-surface hypothesis from the results, and toned down the concluding statements. Reviewer comments are shown in italics; our responses follow in plain text.

General comments: This study provides a timely and in-depth case study of the record-breaking late-June 2026 heatwave over Germany by utilizing high-resolution gridded datasets, centennial meteorological station records, ERA5 reanalysis data, and a flow-analogue decomposition framework. The overall structure of the manuscript is well-organized, offering valuable empirical insights into the spatial-temporal intensity and thermodynamic amplification characteristics of this extreme event. However, several critical methodological, logical, and phrasing issues in the text require revision. The overall comments for the manuscript are detailed below:

Comment 1: *The study sets out to explain the record-breaking surface daily maximum temperature (TX, Lines 97–100). However, the flow-analogue decomposition is performed entirely using 850 hPa temperature (T850, Lines 170–174), and the resulting ~3-4 ℃ residual is directly equated with the "background thermodynamic warming" of the surface heatwave (Lines 331–340, 421–446, 461–463). This creates a clear physical disconnect. T850 reflects conditions in the lower free troposphere, whereas surface TX is heavily modulated by local boundary-layer dynamics, soil moisture deficits, and radiative heating. A 3-4 ℃ warming at 850 hPa does not automatically translate into an equivalent 3-4 ℃ warming at the surface. By conflating T850 with surface temperature, the manuscript overstates the physical meaning of the diagnosed residual. I recommend explicitly defining T850 as an indicator of lower-tropospheric thermal conditions and briefly discussing its limitations as a proxy for near-surface thermodynamic warming. If the authors insist on using T850 as the core metric for quantifying background warming, they must objectively justify the use of data at this pressure level as a proxy for near-surface thermodynamic warming.*

> **Response:** We agree with the aforementioned comments/suggestions. We use T850 because it characterizes the lower-free-tropospheric air mass, is less affected by boundary-layer and land-surface processes, and is the standard variable in flow-analogue decompositions of European temperature extremes (Cattiaux et al., 2010; Jézéquel et al., 2018). In the Methods we will define the decomposition explicitly as a characterization of lower-tropospheric thermal conditions, state that it should not be translated one-to-one into a surface response, and the abstract and conclusions will refer to the “lower-tropospheric (850 hPa)” anomaly. We will no longer equate the residual with a surface warming.

Comment 2: *Lack of absolute quantitative assessment of analogue distance: Although the paper demonstrates that the algorithmically selected analogue days outperform random sampling, it fails to provide the absolute Euclidean distance between the historical analogues and the 2026 extreme circulation. Given the exceptional uniqueness of the ridge/blocking circulation during the June 2026 heatwave, if the absolute discrepancy of the best historical analogues remains large, the calculated positive residual may be contaminated by significant analogue mismatch errors. Consequently, it cannot be definitively confirmed that the residual stems purely from background thermodynamic warming.*

> **Response:** We will report the distances in physical units: the analogues differ from the observed Z500 anomaly fields by 65 m (area-weighted RMS; range 53–71 m), compared with 115 m for random days from the same calendar window and an RMS anomaly of the event itself of 94 m; the median pattern correlation is 0.72. The reviewer is right that the remaining mismatch matters: the analogues reach only 62% of the observed Z500 anomaly over Germany (131 vs. 211 m). A linear adjustment for this amplitude deficit attributes 2.6–3.3 °C of the 5.9 °C residual to analogue mismatch, leaving 2.5–3.2 °C as a conservative estimate of the non-circulation contribution. We will state this explicitly in the revised version of the manuscript.

Comment 3: *Lines 338–340: In Section 3.5, the statement that the analogue residual "should not be interpreted as a purely thermodynamic effect alone" implicitly attributes the residual to local land–atmosphere interactions. However, this claim is made without providing any supporting land-surface data (such as soil moisture or surface energy fluxes) in the Results section. Furthermore, it directly contradicts the authors' statement in Section 4 (Lines 454–455) that quantifying land-surface contributions is beyond the scope of this study. To maintain logical consistency and keep the Results section strictly empirical, please remove this qualifying phrase from Line 340 and restrict any speculative discussion on land-surface feedbacks to Section 4 as a tentative hypothesis.*

Response: We agree with this suggestion/comment. The reference to land-surface feedbacks will be removed from the Results, which now only state that the residual is the part of the anomaly not explained by the analogue circulation, together with the quantitative amplitude and advection diagnostics. The role of dry soils will be discussed in Section 4 explicitly as a hypothesis.

Comment 4: *Line 465: The concluding assertion that such events "must be expected to recur with increasing frequency and intensity" is an overclaim that exceeds the empirical evidence presented in this paper. The manuscript relies strictly on historical trend analysis; it provides no climate model projections (e.g., CMIP6), counterfactual attribution simulations, Return Period calculations, or Extreme Value Theory (EVT) modeling to support explicit predictions about future event frequency or severity. Historical trends alone cannot be directly extrapolated to guarantee future recurrence behaviors. Please tone down this statement by framing future risks strictly within the context of observed historical trends rather than making definitive predictive assertions about future events.*

Response: We agree and we will replace the statement. The Conclusions will state that an event of this magnitude remains rare in the present climate and that, combined with the observed upward trends in early-summer heatwave duration and frequency, the results suggest that heatwaves similar to the June 2026 event could become more frequent and intense as warming continues.

Comment 5: Line 465: There is a minor capitalization typo in the sentence *"…that the HW event In June 2026…"*. The preposition *"In"* should be lowercased to *"in"* for grammatical consistency.

Response: The text will be corrected following the aforementioned suggestion.

Comment 6: *Lines 473–478: Overinterpretation of Provisional Mortality Data. Quoting the specific figure of ~23,700 deaths from provisional Destatis data presents two main issues: (1) "All-cause mortality" includes deaths unrelated to heat, and no causal attribution was performed to isolate heat-driven excess deaths; (2) provisional statistics are subject to future revision. Please tone down this claim by explicitly stating that these figures are preliminary, unadjusted indicators, or clarify that a rigorous epidemiological attribution of excess mortality is beyond the scope of this study.*

Response: We agree and we will state explicitly that these provisional figures refer to all-cause mortality, and are subject to revision and have not been adjusted or attributed to heat, and that a rigorous epidemiological attribution of heat-related excess deaths is beyond the scope of this study.