Kroll et al., egusphere-2025-4391: “Increased heating of the land surface as hot-dry events persist” - Response to referee comment 2

This study investigates the roles of solar radiation (SW_down) and evapotranspiration in shaping heat onset and persistence during dry events at the global scale, and is potentially publishable. However, the current manuscript relies primarily on qualitative diagnostics, while several of the key conclusions are framed in terms of “relative importance” or “contribution” to warming. The link between the analyzed variables (SW_down, ET) and air temperature is not rigorously established, and some methodological choices weaken the strength of the attribution. Overall, the results are interesting, but the interpretation needs to be toned down or better supported.

We thank the reviewer for taking the time to read the manuscript and give thoughtful comments and suggestions. These will help us to improve the analysis and the manuscript. We will reply to every comment individually below describing the planned modifications in an updated manuscript.

Major Comments

1. **Lack of temperature-relevant quantification**

The paper compares changes in SW_down and ET and interprets their relative importance for heat stress. However, these variables affect temperature through different pathways, and their magnitude changes are not directly comparable as temperature effect. There is no step linking these changes to temperature response. As a result, the conclusions remain qualitative rather than quantitative.

We thank the reviewer for pointing out this important aspect. To make the structure of our analysis more clear, we will revise the variable selection and will improve the conceptual figure in the revised manuscript (please find a preliminary version as Figure 1 below). The main drivers of temperature change (eq. 1) are sensible heat flux (diabatic heating, eq. 2), temperature advection (eq. 3), and adiabatic processes (subsidence). We will look at net radiation and evaporative fraction in the revised manuscript as these variables more directly influence sensible heat flux and therefore affect temperature.

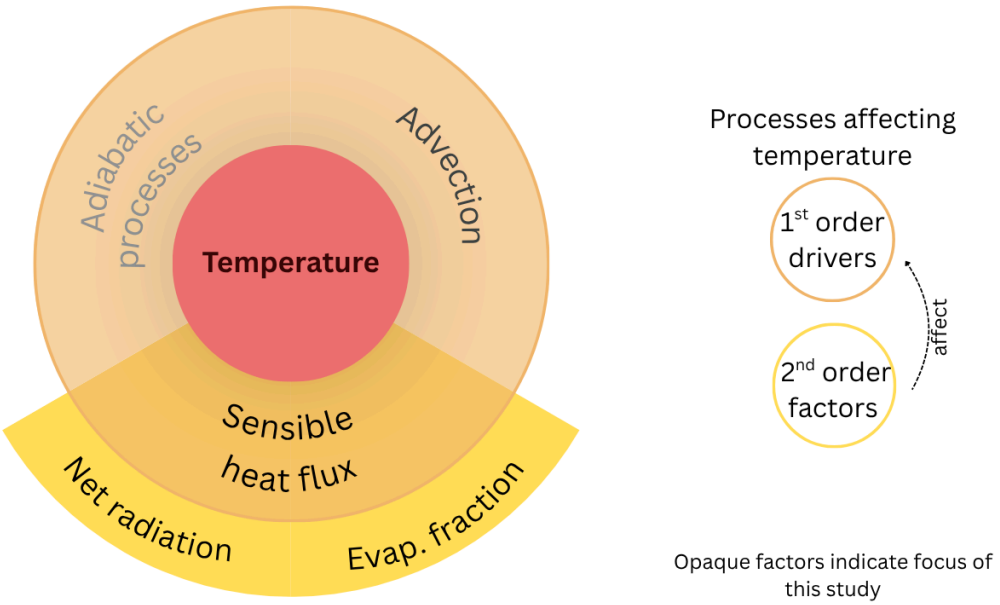

Figure 1: Adjusted schematic representation of 1st order drivers of temperature change and selected 2nd order factors influencing sensible heat flux as a focus of this study.

Setting up a first-order lower-atmosphere heat budget diagnostic, we will compare the temperature change resulting from sensible heat flux with the change caused by advection to better motivate and quantify its relevance.

$$\left(\frac{dT}{dt}\right)_{obs.} = T_t - T_{t-1} \qquad \text{eq. 1}$$

$$\left(\frac{dT}{dt}\right)_{H} = \frac{H_{t-1}}{\rho \cdot c_p \cdot z} \qquad \text{eq. 2}$$

$$\left(\frac{dT}{dt}\right)_{Adv} = -(u \cdot dTdx + v \cdot dTdy) \qquad \text{eq. 3}$$

With T referring to temperature, t referring to time, H corresponding to sensible heat flux, ρ refers to the density of the air, c_p to the specific heat capacity of air, z to the boundary layer height, u and v to the eastward and northward component of the wind, respectively.

1. **ET is not the appropriate control variable**

ET is treated as a proxy for cooling or land–atmosphere coupling, but physically, temperature is controlled by energy partitioning (e.g., evaporative fraction or Bowen ratio), not ET itself. ET is a result of the energy partitioning, not a direct control variable. This makes the interpretation of ET changes as “contribution to heat” questionable.

We thank the reviewer for this valuable suggestion and agree that evaporative fraction is the actual influence on sensible heat flux, which will drive temperature changes. Additionally, it represents the contribution of the land surface to temperature development more directly than evaporation. Instead of evaporation we will analyze the evaporative fraction in the adapted version of the manuscript. We furthermore replace incoming shortwave radiation with net radiation, as this variable more directly represents the energy input driving sensible heat flux. We will adapt the description of the variable selection and its motivation in the manuscript accordingly.

1. **Missing lag / memory effects**

The analysis focuses on week-to-week changes, but does not explicitly consider lagged effects (e.g., Tripathy et al., 2025). Soil moisture–temperature interactions are known to involve memory. Without accounting for these, the role of land processes may be underestimated or mischaracterized.

We thank the reviewer for bringing the memory effects between soil moisture and temperature to our attention. We will add a paragraph in the discussion on the importance of whether a hot week happens close to the dryness peak or start. Depending on the timing of the hot week, the relevance of the considered factors influencing temperature development might change.

1. **Weekly aggregation and weak attribution of atmospheric processes**

Using weekly means/medians aims to remove the advection effect but likely smooths out synoptic-scale variability and heatwaves. A typical heatwave lasts as about 4 days on average (Perkins-Kirkpatrick et al. 2020), though some last a week or longer.

At the same time, heat persistence is attributed to advection and entrainment, but this is not directly diagnosed—it appears to be a residual explanation. The attribution to atmospheric processes is therefore not strongly supported.

We thank the reviewer for this important comment. As described in a previous response, we will include temperature advection to better quantify its relative contribution compared to that of the sensible heat flux.

We will also clarify that the use of weekly time scales is necessary to capture the co-occurrence and evolution of dryness and heat. Weekly time scales for detecting and characterizing heat events have been used already in Uckan et al. (2025); for dry extremes the weekly time scale has been applied e. g. in Leeper et al. (2025). We will

therefore more clearly motivate the usage of a weekly time scale as it enables the detection of both i) dry and ii) hot extremes.

Spatial aggregation and weighting (Table 2 and Figure 5)

We thank the reviewer for pointing out the difficulties in spatial pooling.

The spatial pooling approach raises concerns:

> It is unclear whether latitude/pixel-area weighting is applied.
> It is not applied in the current version, but we agree that latitude weighting should be applied to account for the different sizes of grid cells in the tropics and in the high latitudes, ensuring that each grid cell contributes proportionally to its physical surface area. We will consider latitude/pixel-area weighting in the revised manuscript.
> Event pooling gives more weight to regions with frequent droughts.
> We acknowledge that our global aggregation is biased toward where compound events happen often instead of what is typical per region. Nevertheless we choose to retain the global aggregation framework because our focus is on characterizing the typical properties of drought-related conditions as experienced across all events in the dataset. We will clarify this point in the revised manuscript and include it as a methodological caveat in the discussion. We will emphasize that our results should be interpreted as event-representative rather than spatially uniform, and that regional differences in event frequency may influence the aggregated patterns.
> Aggregation across broad dryness and vegetation classes may mask regional and climatic differences.
> We agree that aggregation has disadvantages e. g. through masking out regional and climatic differences. For that reason, we will visualize both i) global spatial patterns as well as ii) regional averages, as both ways of visualization lead to important insights. We will better clarify the regions across which aggregation takes place by adding supplementary maps illustrating aggregation classes e.g. tree cover and long-term dryness (Fig. 2, combined Fig. 3) or biomes, Köppen-Geiger climate classes.

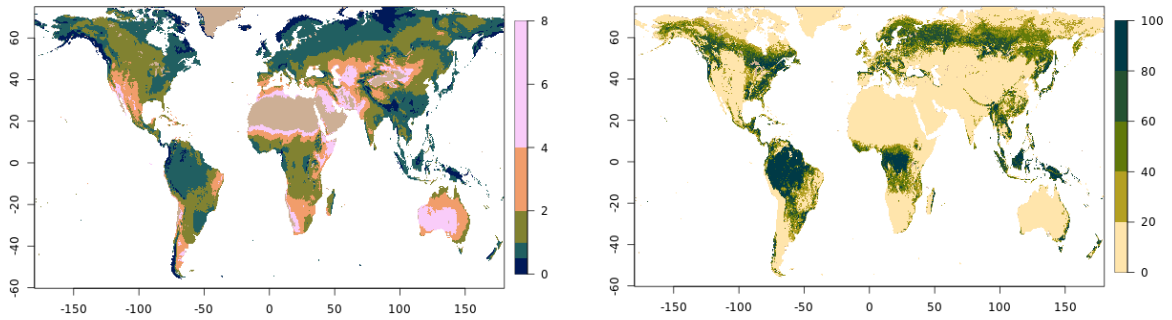

Figure 2: Illustration of spatial distribution of long-term dryness categories (left) and mean tree cover fraction (right).

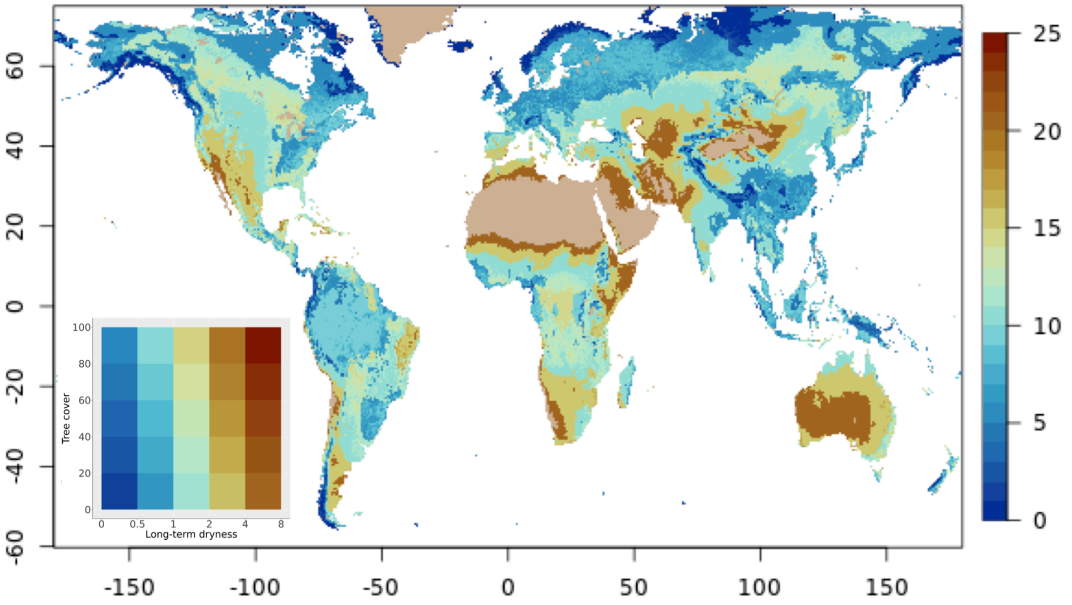

Figure 3: Illustration of tree cover and long-term dryness regimes. The heatmap in the lower left corner illustrates the color code applied in the map.

Differences between decades may partly reflect changes in sample composition.

We will acknowledge this caveat in the figure description and caption.

This weakens the interpretability of the spatial patterns.

Minor Comments

Page 1: “soil moisture extremes” should clarify both wet and dry; the study focuses on dryness.

Page 2: “that is not reflected” can be removed.

Terminology: ET is repeatedly referred to as “evaporation”; may be clarified as evapotranspiration as vegetation impact is included.

Page 3: may consider citing Hou et al. (2025) for global biophysical effects of different ecosystems and LULCC.
Page 4: “across recent decades” should be more specific (time period and spatial scale).
Page 4: explain why data are aggregated to 0.5°.
Page 4: clarify “weekly means” vs “weekly median” (used inconsistently).
Soil moisture: weighting across layers needs to be explained.
Drought definition: inconsistency between 5% (peak) and 10% (start); unclear how intermediate weeks are handled and how drought ends are defined.
Page 5: clarify interpretation of different week-to-week change cases (e.g., onset vs persistence vs internal variability).
Figure 2: readability (lines too thin).
Formatting: “week-to-week” not capitalized at sentence starts.
“small magnitude of change”: unclear relative to what baseline.

We thank the reviewer for spotting these issues and will adapt the text passages accordingly.

Refs

Hou, et al. "Radiative forcing reduced by early twenty-first century increase in land albedo." Nature 641.8065 (2025): 1162-1171.

Perkins-Kirkpatrick, S. E., and S. C. Lewis. "Increasing trends in regional heatwaves." *Nature communications* 11.1 (2020): 3357.

Tripathy, Kumar P., et al. "Lagged soil moisture controls on the persistence of drought and heatwaves in the United States." *Geophysical Research Letters* 52.22 (2025): e2025GL115811.

References

Leeper, R. D., Harrington, T., Palecki, M. A., DePolt, K., Scott, E., Runkle, J., & Diamond, H. J. (2025). The Influence of Drought on Heat Wave Intensity, Duration, and Exposure. *Journal of Applied Meteorology and Climatology*, *64*(5), 425-438.

Uckan, Y., Ruiz-Vásquez, M., De Polt, K., & Orth, R. (2025). Global relevance of atmospheric and land surface drivers for hot temperature extremes. *Earth System Dynamics*, *16*(3), 869-889.