

Manuscript Number: egusphere-2025-4820

Revision notes: We sincerely thank the Editor and the editorial office for their time and effort in handling our manuscript, coordinating the review process, and identifying suitable reviewers. We are also very grateful to both reviewers for their careful reading, constructive comments, and valuable suggestions. These comments have helped us identify several weaknesses in the previous version and have provided important guidance for improving the scientific rigor, methodological clarity, and overall quality of the manuscript. We have revised the manuscript carefully according to the Editor's and reviewers' suggestions. The revised portions have been marked in red in the revised manuscript. Below, we provide a point-by-point response to all comments and summarize the corresponding changes made in the manuscript.

Responses to the editor's comments

Comment 1: Figures: I received comments from several participants about the readability of the figures. This is summarized well in the points below copied from one of the reviews:

- Beautiful images in general. However, all of the images are detailed but their size is too small to appreciate and look deeper.
- Figure 1: A and C can be a single figure that describes VPD and the monthly variations. B and D can be a single figure that describes global and monthly variation of EVP.
- Figure 2: I think this figure should be broken up into 3 figures. (A) global map, (B), variation of sensitivity, and (C) variation of latitudinal distribution.
- Figure 3: Too many subfigures. Best to break it up accordingly. The Pearson correlation figures could be a single figure
- Figure 4: way too small to see anything.

For the final figures, please make sure all fonts are readable and have the same font size consistently throughout the subpanels. Consider splitting up figures if this improves the readability.

Response: We sincerely thank the editor for the constructive suggestions regarding

figure readability and presentation. We agree that the original figures contained too many subpanels, which reduced the readability of individual components. Following these suggestions, we have carefully reorganized and redesigned the figures to improve clarity, consistency, and visual interpretation.

For Figure 1, we have substantially simplified the figure structure. In the original version, the spatial trends, monthly variations, and annual anomaly series of VPD and E were presented together, resulting in excessive information density. In the revised manuscript, we removed the redundant temporal anomaly panels because the spatial trend maps already clearly illustrate the long-term changes in VPD and E, while the remaining temporal variations were partly overlapped with the interannual anomaly analysis presented in the revised Figure 3. In addition, the climatological monthly variations provide sufficient information to describe seasonal variability at the annual scale. Therefore, we reorganized Figure 1 to focus on the spatial distribution of long-term VPD and E trends and their seasonal climatological characteristics, which provides a clearer representation of the spatiotemporal patterns of VPD and E.

For Figure 2, we considered that the global sensitivity pattern and its climatic dependence are closely connected. Therefore, we retained the spatial distribution of $dE/dVPD$ and its relationship with temperature–precipitation gradients within one main figure because these two components together describe the global pattern and environmental controls of apparent VPD sensitivity. However, following the reviewer’s suggestion, we separated the land-cover-related sensitivity analysis from the original multi-panel figure. The former subpanels showing sensitivity variations among different land-use categories were reorganized into an independent figure, with each land-use type presented more clearly to improve interpretation of the latitudinal and ecosystem-specific patterns.

For Figure 3, we divided the original figure into two separate figures. The global annual anomaly time series of VPD and evapotranspiration components were retained as one independent figure, while the spatial Pearson/partial correlation analyses were separated into another figure. This modification reduces the number of subpanels and allows the spatial correlation patterns and temporal variability to be examined

independently with larger figure dimensions.

For Figure 4, we have completely redrawn the figure following the reviewer's suggestion. The original four-panel figure was too compressed, making the breakpoint relationships and statistical information difficult to read. In the revised version, each climate-zone analysis is presented with a larger individual panel. We increased the overall figure size, enlarged all text elements, standardized font sizes across all panels, and improved the placement of legends and annotations. These modifications ensure that threshold values, fitting relationships, and statistical indicators can be clearly interpreted.

In addition, we have revised all figures throughout the manuscript to ensure consistent font style and size among subpanels. The revised figures use larger and uniform fonts, improved panel spacing, and simplified layouts where necessary to enhance readability. We appreciate the reviewer's valuable suggestions, which have substantially improved the clarity and presentation quality of the manuscript.

Revised text in the Figures:

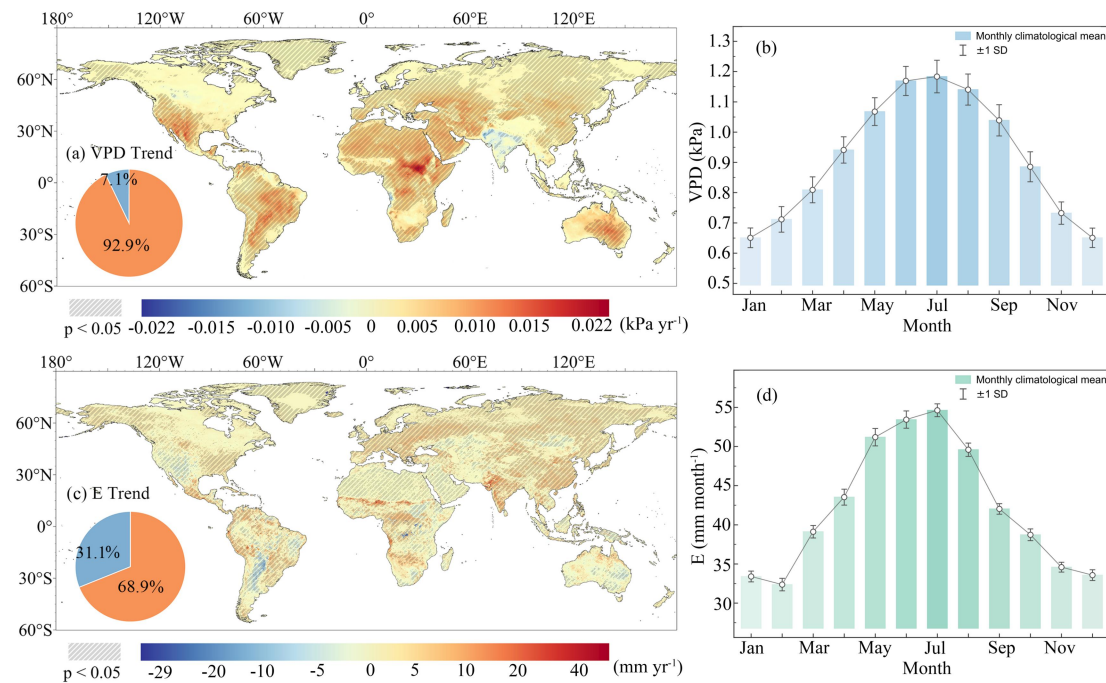


Figure 1. Spatial trends and seasonal cycles of terrestrial VPD and E during 1981–2020. a, Sen's slope of VPD. Red colors indicate increasing trends, and blue colors indicate decreasing trends. Hatched areas indicate trends significant at $p < 0.05$. The inset shows the percentages of valid land

pixels with positive and negative VPD trends. b, Global land monthly climatology of VPD during 1981–2020. Bars represent the climatological monthly means, circles indicate the corresponding mean values, and error bars represent ± 1 standard deviation (SD) across years. c, Sen’s slope of terrestrial E. Red colors indicate increasing trends, and blue colors indicate decreasing trends. Hatched areas indicate trends significant at $p < 0.05$. The inset shows the percentages of valid land pixels with positive and negative E trends. d, Global land monthly climatology of E during 1981–2020. Bars, circles, and error bars are defined as in panel b. In the insets, orange indicates positive trends and blue indicates negative trends.

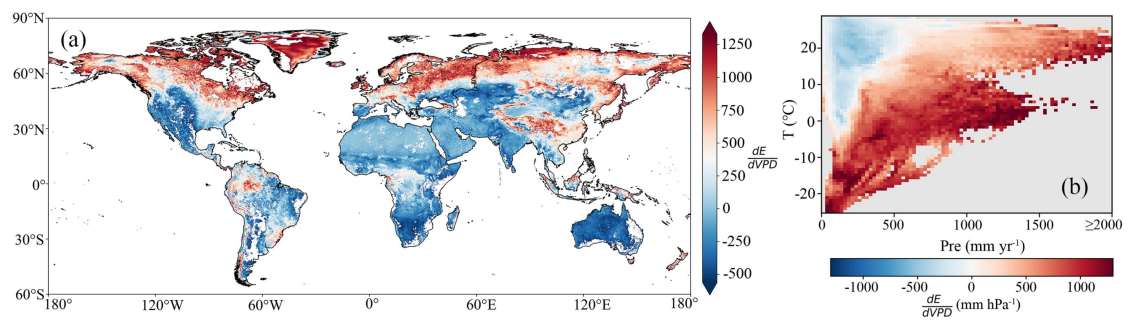


Figure 2. Apparent sensitivity of terrestrial E to VPD during 1981-2020. (a) Spatial distribution of the sensitivity coefficient $dE/dVPD$. Red colors indicate positive apparent sensitivity, and blue colors indicate negative apparent sensitivity. (b) Variation in $dE/dVPD$ across climate gradients. The x-axis represents mean annual precipitation during 1981-2020, and the y-axis represents mean annual air temperature during 1981-2020. Each climate bin contains valid land pixels within a given T-Pre range, and the color shows the area-weighted mean $dE/dVPD$. Values with precipitation greater than 2000 mm yr^{-1} were included in the last precipitation bin. The unit of $dE/dVPD$ is mm hPa^{-1} .

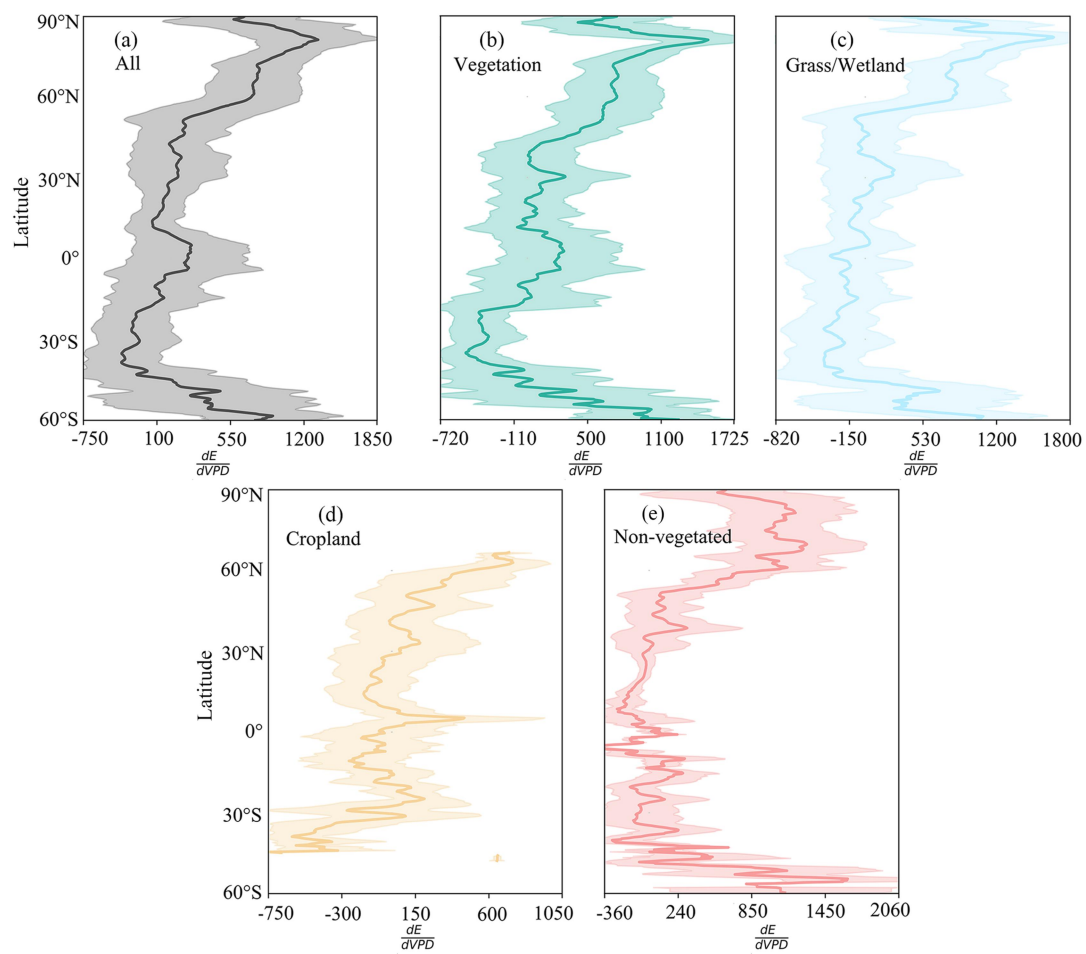


Figure 3. Latitudinal distribution of the apparent sensitivity of terrestrial E to VPD during 1981–2020. Latitudinal profiles of $dE/dVPD$ are shown for all valid land pixels and different land-use classes. Solid lines represent the mean $dE/dVPD$ within each latitude band, and shaded areas represent the corresponding standard deviation. The unit of $dE/dVPD$ is mm hPa^{-1} .

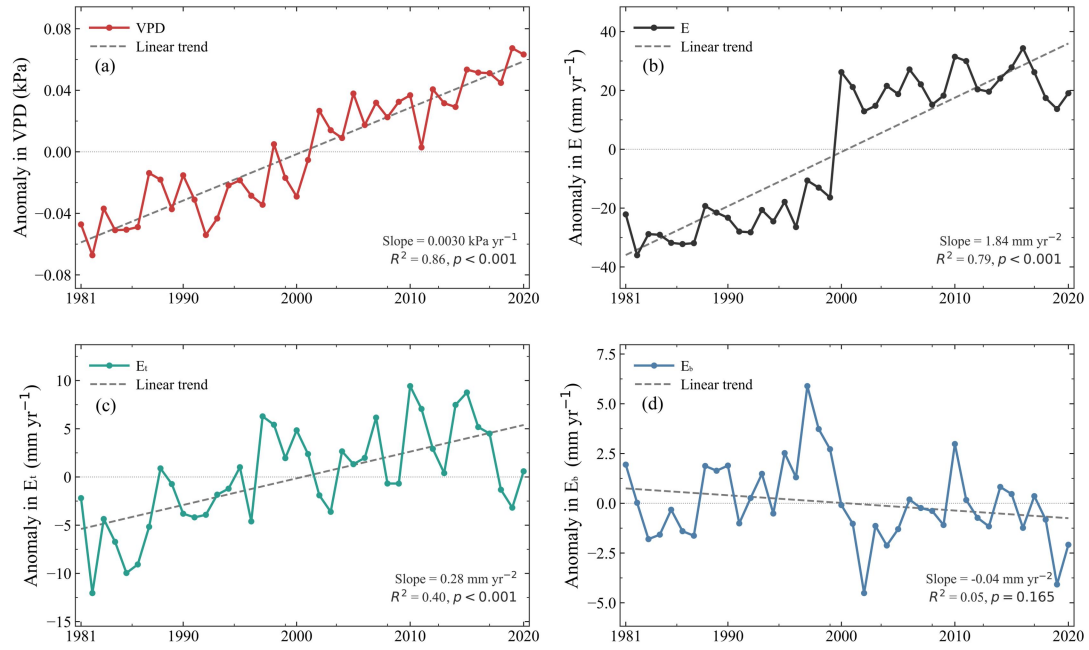


Figure 4. Interannual variability of global mean annual anomalies of VPD and evapotranspiration components during 1981-2020. (a) Global mean annual anomaly of vapor pressure deficit (VPD).

The dashed line indicates the linear trend. (b) Global mean annual anomaly of total evapotranspiration (E). The dashed line indicates the linear trend. (c) Global mean annual anomaly of transpiration (E_t) over valid land pixels. The dashed line indicates the linear trend. (d) Global mean annual anomaly of bare-soil evaporation (E_b) over valid land pixels. The dashed line indicates the linear trend.

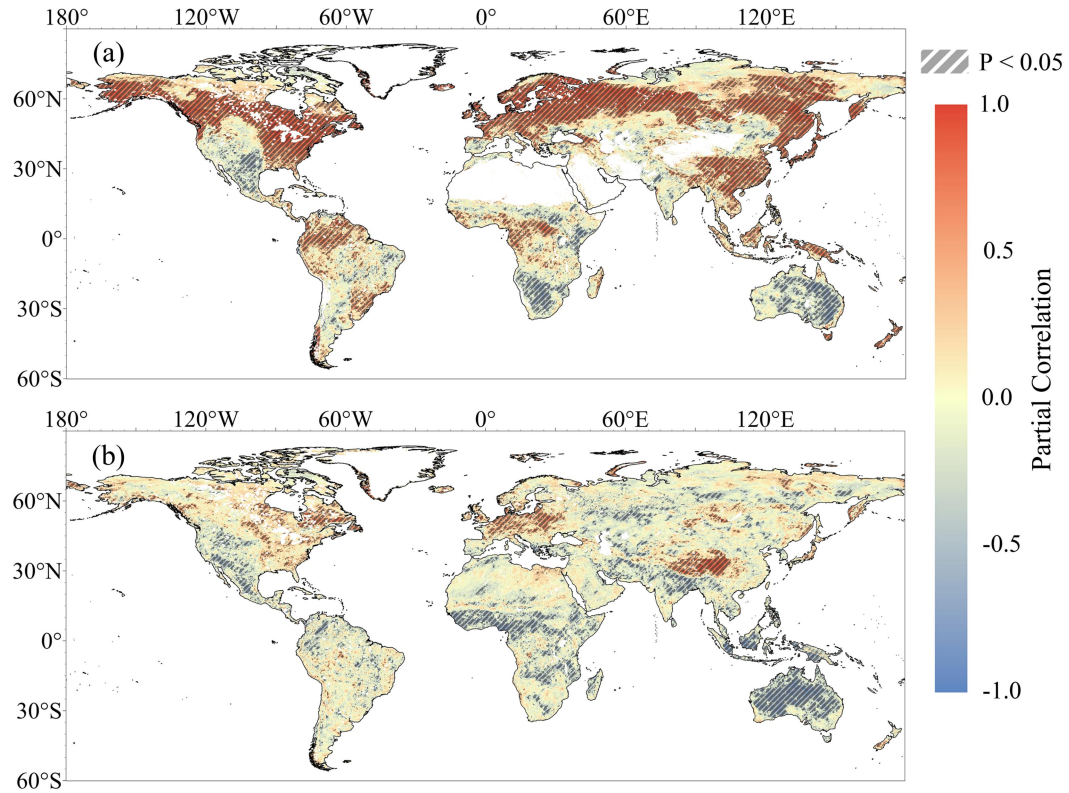


Figure 5. Spatial partial correlations between VPD and evapotranspiration components during 1981-2020. (a) Spatial distribution of partial correlation coefficients between VPD and transpiration (E_t) after controlling for root-zone soil moisture (SM_{rz}) and precipitation (Pre); the partial correlation was calculated using detrended annual series, and hatched areas indicate statistically significant correlations at $p < 0.05$. (b) Spatial distribution of partial correlation coefficients between VPD and bare-soil evaporation (E_b) after controlling for surface soil moisture (SM_s) and precipitation (Pre); the partial correlation was calculated using detrended annual series, and hatched areas indicate statistically significant correlations at $p < 0.05$.

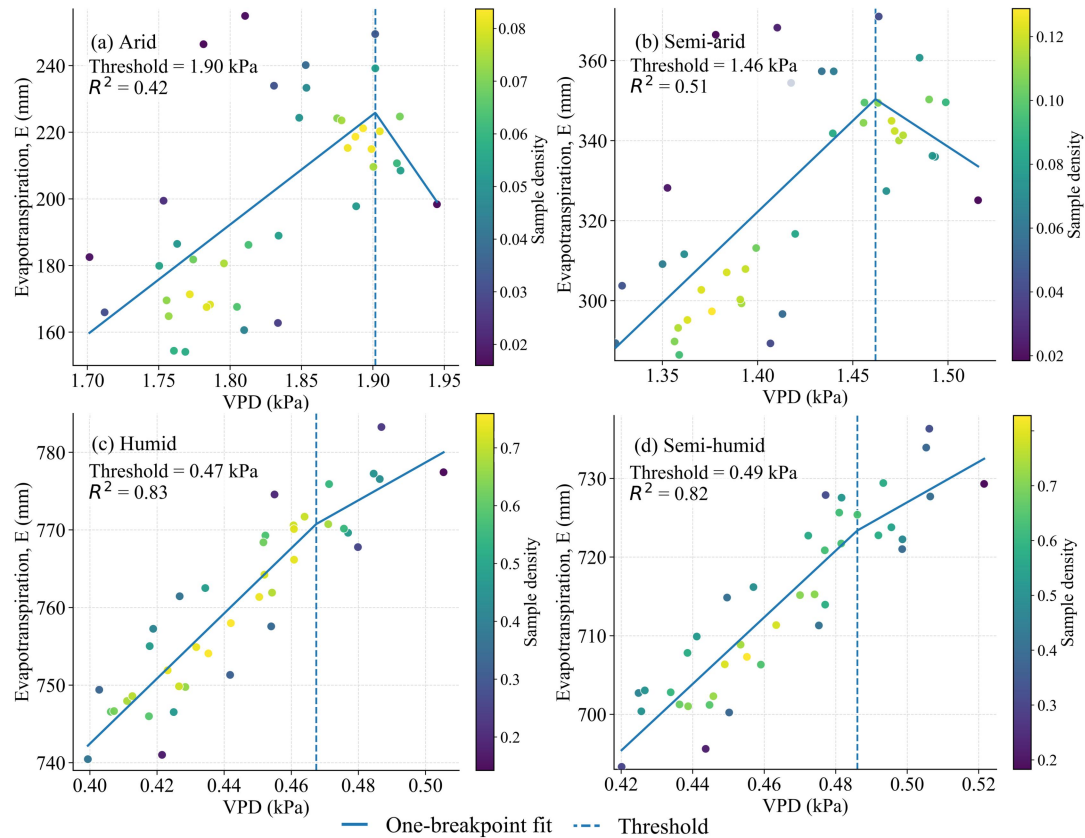


Figure 6. Aridity-dependent thresholds in the nonlinear response of terrestrial evapotranspiration to vapor pressure deficit. a–d, One-breakpoint piecewise fits between VPD and E for the arid, semi-arid, humid, and semi-humid aridity zones, respectively. Points show annual area-weighted means, coloured by sample density. Solid lines indicate fitted relationships, and dashed vertical lines indicate the estimated VPD transition points. The AI-based aridity zones are shown in Supplementary Fig. 5.

Comment 2: Precision: (also copied) Is it necessary to show 2 decimal places when displaying percentages and sensitivity? I would suggest keeping to 3 significant figures and or single decimal place.

Response: We agree that excessive decimal places may imply an unrealistic level of accuracy for global-scale datasets and analyses. Therefore, we have revised the numerical presentation throughout the manuscript to improve consistency and readability.

Specifically, all percentages and sensitivity values reported in the main text have been rounded to one decimal place. For example, the proportion of global land areas with positive apparent sensitivity to VPD and the corresponding sensitivity estimates

have been revised accordingly. We have also checked and updated the relevant values in the figures and supplementary materials to ensure consistent numerical precision.

For the VPD threshold values identified through the breakpoint analysis, we retained two decimal places because these values represent critical transition points derived from statistical fitting and are central to comparing differences among aridity classes. Maintaining two decimal places allows clearer discrimination among threshold values while avoiding excessive numerical precision.

These revisions ensure that all reported values provide an appropriate balance between readability and meaningful scientific interpretation.

Comment 3: Study period: (also copied) In the introduction, there has been no mention on why these years (1981 to 2020) were settled. Would it be possible to elaborate why?

Response: We agree that the reason for selecting the period of 1981–2020 should be clarified. We have therefore added an explanation in the final paragraph of the Introduction. Specifically, we now state that the analysis period of 1981–2020 provides relatively consistent temporal coverage of global satellite observations, reanalysis products, and land-surface datasets, while also capturing substantial climate variability and increasing atmospheric dryness under global warming. This clarification highlights the suitability of this period for assessing long-term VPD–E interactions at the global scale.

Revised text in the Introduction:

“Against this background, this study explores how VPD influences E across different land surfaces and AI-based aridity zones worldwide. The analysis was conducted for the period of 1981–2020, during which global satellite observations, reanalysis products, and land-surface datasets are available with relatively consistent temporal coverage. This period also captures substantial climate variability and increasing atmospheric dryness under global warming, enabling an assessment of long-term VPD–E interactions at the global scale. Specifically, we used VPD and E data derived from multiple remote sensing sources to examine the global response of E to VPD changes during this period. The research focuses on the following scientific questions:

(1) How does VPD influence global terrestrial E? (2) How does VPD affect the spatial and temporal heterogeneity of global E? (3) What are the implications of the rapid rise of VPD under global warming for land–atmosphere feedback? Addressing these questions will not only improve our understanding of the mechanisms by which VPD regulates E but also provide a stronger basis for developing targeted global climate adaptation strategies.”

Comment 4: Study period: (also copied) In the introduction, there has been no mention on why these years (1981 to 2020) were settled. Would it be possible to elaborate why?

Response: We thank the reviewer for pointing out that the statistical significance of the correlation results should be more explicitly presented. We agree that the significance information is important for interpreting the spatial patterns of the partial correlations. In the revised manuscript, we have clarified the significance assessment procedure in the Methods section by stating that the p-value was calculated for each pixel and that correlations with $p < 0.05$ were considered statistically significant. We have also added the significance information to the Results section by specifying the spatial distribution of significant positive and negative correlations. In addition, the caption of the revised Figure 5 now indicates that regions with statistically significant correlations are marked by hatching.

Revised text in the Methods 2.2.3:

“ We calculated the associated p-value for each pixel and considered correlations with $p < 0.05$ as statistically significant. The spatial distribution of statistically significant correlations was indicated by hatching in the corresponding correlation maps. We retained only pixels with at least 20 valid yearly observations. We also calculated the global annual mean series of VPD, E, E_t , and E_b over valid land pixels for 1981–2020 to describe their interannual variability.”

Revised text in the Results 3.3:

“After controlling for SM_{rz} and Pre, VPD showed mainly positive partial correlations with E_t across global land areas (Fig. 5a). Significant positive correlations ($p < 0.05$) were mainly distributed across the Northern Hemisphere, particularly in North America, Europe, and northern Asia. Positive partial correlations were observed in

65.8% of valid pixels. Positive correlations also occurred in parts of East Asia, South America, and tropical regions, whereas negative correlations were limited and spatially scattered. Overall, after reducing the effects of water supply, VPD remained positively associated with E_t across most land regions, especially in northern extratropical areas. After controlling for SM_s and Pre, VPD showed a weaker relationship with E_b , with a more heterogeneous spatial pattern (Fig. 5b). Significant negative correlations ($p < 0.05$) were mainly concentrated in dry and water-limited regions, including Australia, southern Africa, and parts of central Asia. Negative partial correlations were observed in 59.1% of valid pixels. Negative correlations also appeared in other low-latitude and subtropical regions, while positive correlations occurred mainly in parts of Europe and East Asia with scattered distributions elsewhere.

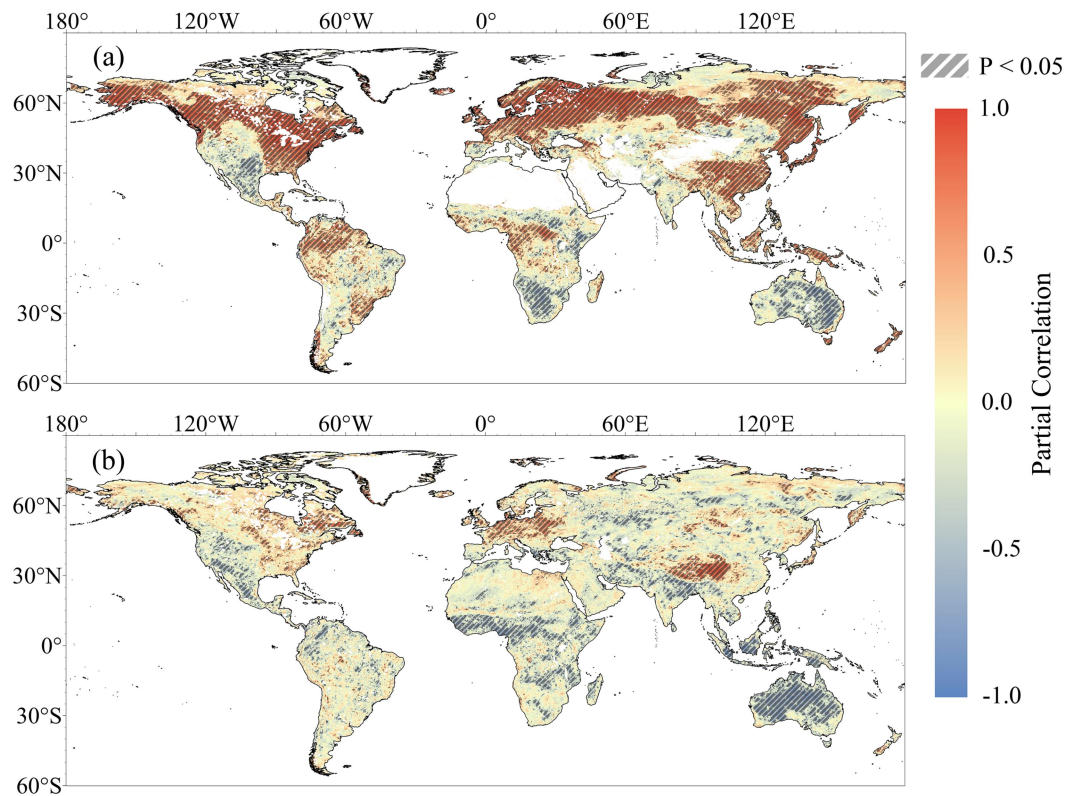


Figure 5. Spatial partial correlations between VPD and evapotranspiration components during 1981-2020. (a) Spatial distribution of partial correlation coefficients between VPD and transpiration (E_t) after controlling for root-zone soil moisture (SM_{rz}) and precipitation (Pre). (b) Spatial distribution of partial correlation coefficients between VPD and bare-soil evaporation (E_b)

after controlling for surface soil moisture (SM_s) and precipitation (Pre). The partial correlations were calculated using detrended annual series, and hatched areas indicate regions with statistically significant correlations ($p < 0.05$).”

Comment 5: SEM model: (copied, nrs refer to initial version) The SEM's directional structure does not obviously accommodate the feedback loop discussed later in the paper. The SEM in Section 2.2.5 is specified as a one directional path model (T, PRE point to VPD; T, PRE, VPD point to SM, LAI; VPD, SM, LAI point to E), which by construction cannot represent reverse or bidirectional influences. Yet Section 4.3 explicitly describes a bidirectional "SM and atmospheric water vapor" feedback loop, in which "declining SM reduces E, weakens atmospheric water vapor flux, suppresses cloud formation and precipitation, and further intensifies regional drought" (Lines 408 to 410); that is, E and SM feed back onto atmospheric moisture and, implicitly, onto VPD itself. This feedback is not represented in, nor acknowledged as a limitation of, the directed SEM structure used to generate the path coefficients discussed in Section 4.2. Please either justify why a one directional structure is appropriate despite this feedback, or explicitly note it as a limitation of the SEM approach.

Response: We agree that the SEM used in this study represents a predefined directional structure and does not explicitly capture reciprocal feedbacks among evapotranspiration, soil moisture, and atmospheric moisture. The purpose of the SEM analysis in this study is to quantify the statistical pathways linking VPD with terrestrial E under different aridity conditions, rather than to fully represent dynamic land–atmosphere feedback processes.

In the revised manuscript, we have clarified the interpretation of SEM results by emphasizing that the estimated pathways represent aridity-zone-scale statistical associations within the specified framework rather than direct causal effects. We have also revised the discussion of land–atmosphere feedbacks to avoid implying that these bidirectional processes were directly quantified by the SEM analysis. In addition, we have added a limitation statement in Section 4.4 to acknowledge that the current SEM framework cannot explicitly represent bidirectional land–atmosphere feedback

processes.

Revised text in the Results and Discussion Section 4.2:

“The SEM results should still be interpreted as aridity-zone-scale statistical pathways rather than direct causal effects at the individual pixel scale. Because SEM relies on a predefined directional structure, the estimated pathways describe the relative associations among climatic, hydrological, vegetation, and energy factors within the specified framework, but do not explicitly represent reciprocal feedbacks among evapotranspiration, soil moisture, and atmospheric moisture.”

Revised text in the Discussion Section 4.2:

“The SEM results should still be interpreted as aridity-zone-scale statistical pathways rather than direct causal effects at individual pixels. Because SEM relies on a predefined directional structure, the estimated pathways describe the relative associations among climatic, hydrological, vegetation, and energy factors within the specified framework, but do not explicitly represent reciprocal feedbacks among evapotranspiration, soil moisture, and atmospheric moisture. The restricted and full SEM comparison also supported the retention of the residual VPD-LAI association in the final model (Supplementary Table S1).”

Revised text in the Discussion Section 4.3:

“The projected increase in VPD is expected to further influence land–atmosphere interactions by modifying terrestrial E , with potential consequences for regional to global water cycling (Yuan et al., 2019). In the AI-based aridity zones, the threshold analysis shows clear differences in how E may respond under future VPD increase. In the arid and semi-arid regions, the one-breakpoint thresholds are high (1.90 and 1.46 kPa, respectively). This interpretation is consistent with the negative $dE/dVPD$ areas shown in Fig. 2a and with the Aridity-zone-specific SEM results, which showed negative statistical associations between VPD and SM_{rz} across all aridity zones, especially in semi-arid and semi-humid regions. These results suggest that high VPD may be associated with stronger water limitation in dry regions, which may constrain E .

In the humid and semi-humid regions, the thresholds are much lower (0.47 and

0.49 kPa, respectively). This result suggests that ecosystems in wetter regions may reach the response transition under much lower VPD. These regions may therefore experience earlier response transitions as atmospheric dryness continues to increase, even though E can still rise with VPD over part of the observed range (Fig. 2a). This contrast suggests that future VPD increases may lead to different responses among climate zones, with humid and semi-humid regions potentially reaching response transitions earlier, while dry regions may experience stronger E suppression once water limitation dominates. Such differences may influence ecosystem vulnerability and alter water and carbon cycling, especially in forests and water-limited agricultural systems (Will et al., 2013; Gentine et al., 2019).

Collectively, the sustained rise in VPD may modify land–atmosphere interactions and introduce additional uncertainties into global water and carbon cycling (Gentine et al., 2019). Climate models and risk assessments should therefore better represent the threshold differences among arid, semi-arid, semi-humid, and humid regions. These threshold differences also imply that adaptation measures should be region-specific. Semi-humid and humid regions may need earlier warning because of their lower thresholds, while arid regions require stronger water-management measures under chronic water limitation. Targeted water resource management and ecological conservation measures are therefore needed to strengthen ecosystem resilience and reduce the ecological risks associated with rising VPD.”

Revised text in the Section 4.4:

“Methodological uncertainty also deserves attention. In this study, threshold estimates describe the main transition in the observed VPD–E relationship but should not be treated as exact ecological thresholds. Their values may be affected by model choice and data uncertainty. In addition, the SEM framework represents directional statistical pathways and does not explicitly capture bidirectional land–atmosphere feedbacks among E, soil moisture, and atmospheric moisture.”