

Dear Editor

We thank editor for the careful review of our manuscript and for the constructive and insightful comments. These suggestions have helped us improve the clarity and quality of the manuscript. Our detailed responses to each comment are provided below.

Editorial comments

Editor comment: -

“I would encourage the authors to clarify how the seasonal cycle is accounted for in the statistical analysis. To focus on climate variability and trends, most studies remove the seasonal cycle. The current figures (with the seasonal cycle retained in time series) make it difficult to see interannual variability and trends. The authors should justify that the strong relationship among variables documented here (such as in time series in Fig. 8 and 9) does not arise entirely from the inclusion of the seasonal cycle.”

Answer: -

We sincerely thank the editor for this insightful and constructive comment. We fully agree that retaining the seasonal cycle can artificially enhance the apparent covariability among climate variables and obscure the interpretation of interannual variability and long-term climate signals.

In response to the editor's suggestion, we have substantially revised our statistical analyses in the new manuscript. Specifically, all climatic variables were first deseasonalized by subtracting their long-term monthly climatological means from the original monthly observations, thereby generating monthly anomaly time series that are free from the mean annual cycle. These anomaly datasets were then used consistently throughout the subsequent statistical analyses, including the correlation analysis and Singular Value Decomposition (SVD).

In the revised manuscript, Figures 3-6 of the previous manuscript version no longer exist. The new results for anomaly, correlation, and SVD analysis are shown in the following figures:

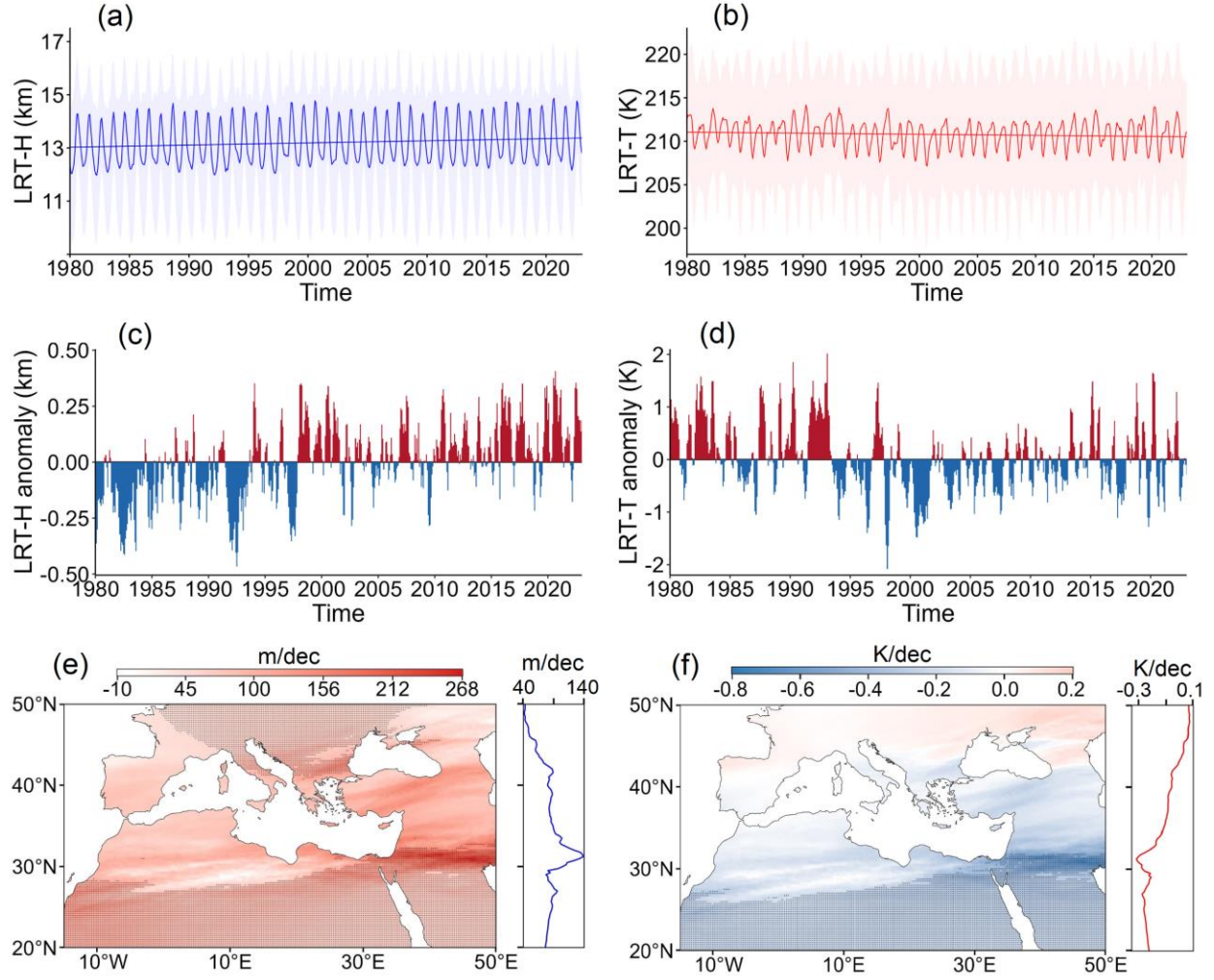


Figure 1. Monthly time series of LRT parameters in the top: (a) LRT-H and (b) LRT-T. The solid lines indicate the monthly mean values, while its surrounding light shading denotes the SD at each time step. Tropopause anomaly in the middle: (c) LRT-H anomaly time series, (d) LRT-T anomaly time series. Linear regression analysis of LRT parameters at all grid points and their decadal trends in the bottom: (e) LRT-H and (f) LRT-T. Black stippled regions indicate grid points where the trends are statistically significant at $p < 0.05$. The zonal mean is displayed on the right side of each regression map.

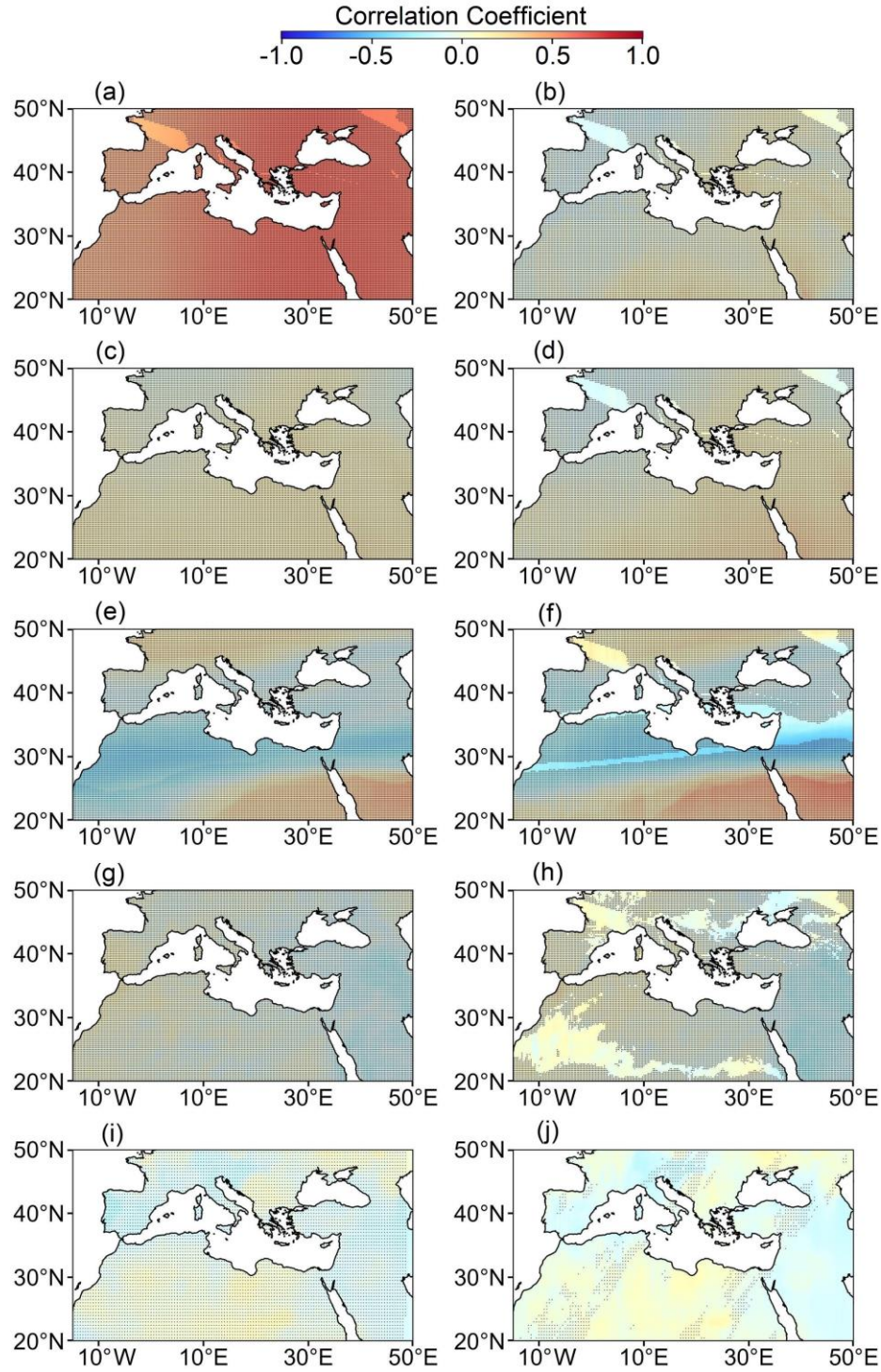


Figure 3. Correlation maps of TPD TEL (left) and TPG TEL (right) with climatic parameters, where the Pearson correlation coefficient was computed independently at each grid point. Black stippling indicates grid points where the correlation coefficients are statistically significant at $p < 0.05$.

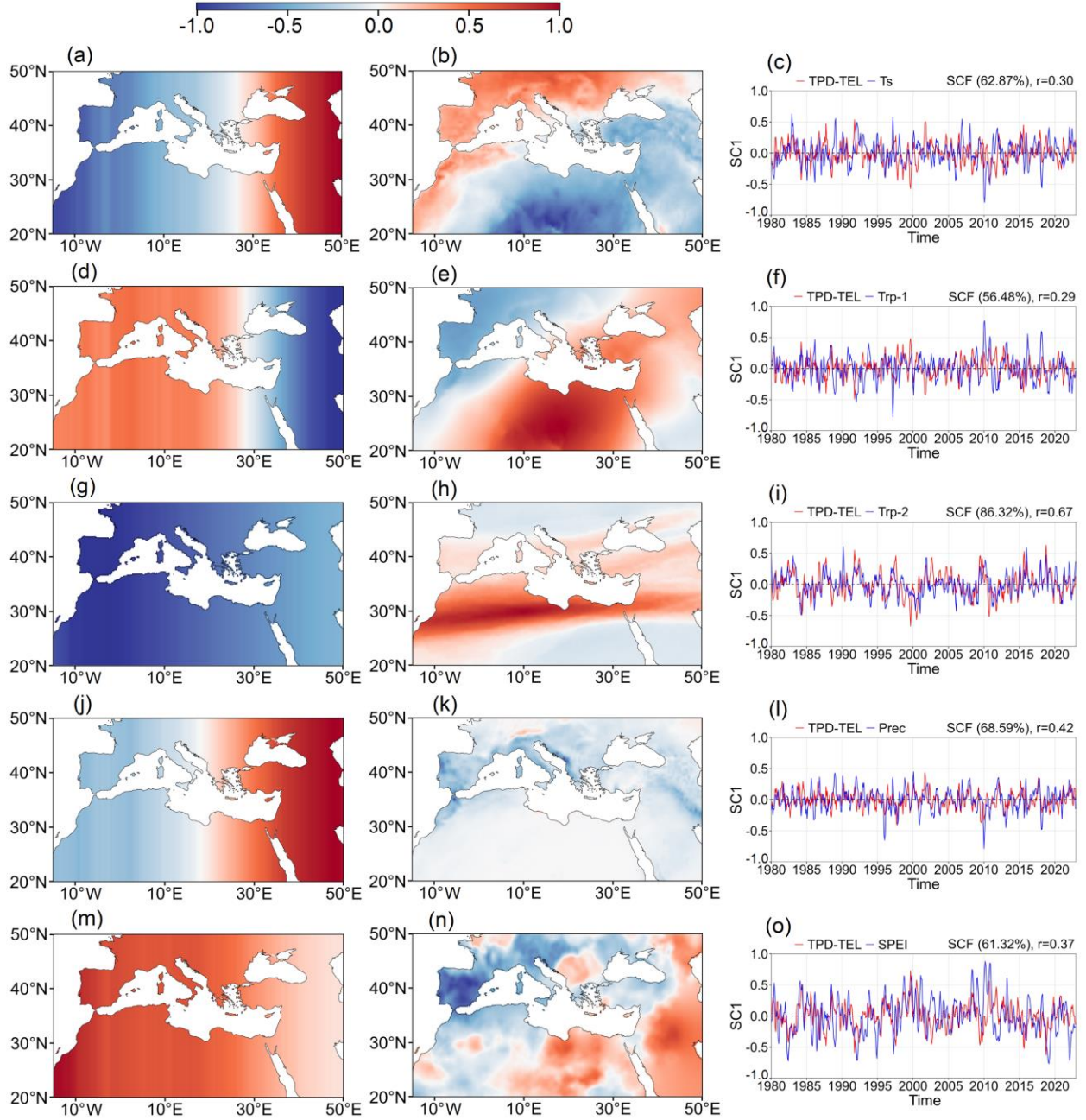


Figure 4. First leading mode of covariability for the coupled fields of TPD TEL and climatic parameters. TPD TEL and Ts (a, b, c), TPD TEL and Trp-1 (d, e, f), TPD TEL and Trp-2 (g, h, i), TPD TEL and precipitation (j, k, l), and TPD TEL and SPEI (m, n, o). The spatial patterns for the first paired mode of covariability (SVD1) of TPD TEL (left), climatic parameter SVD1 (middle), and the time series of expansion coefficients (SC1) for the paired mode of both TPD TEL and climatic parameters (right).

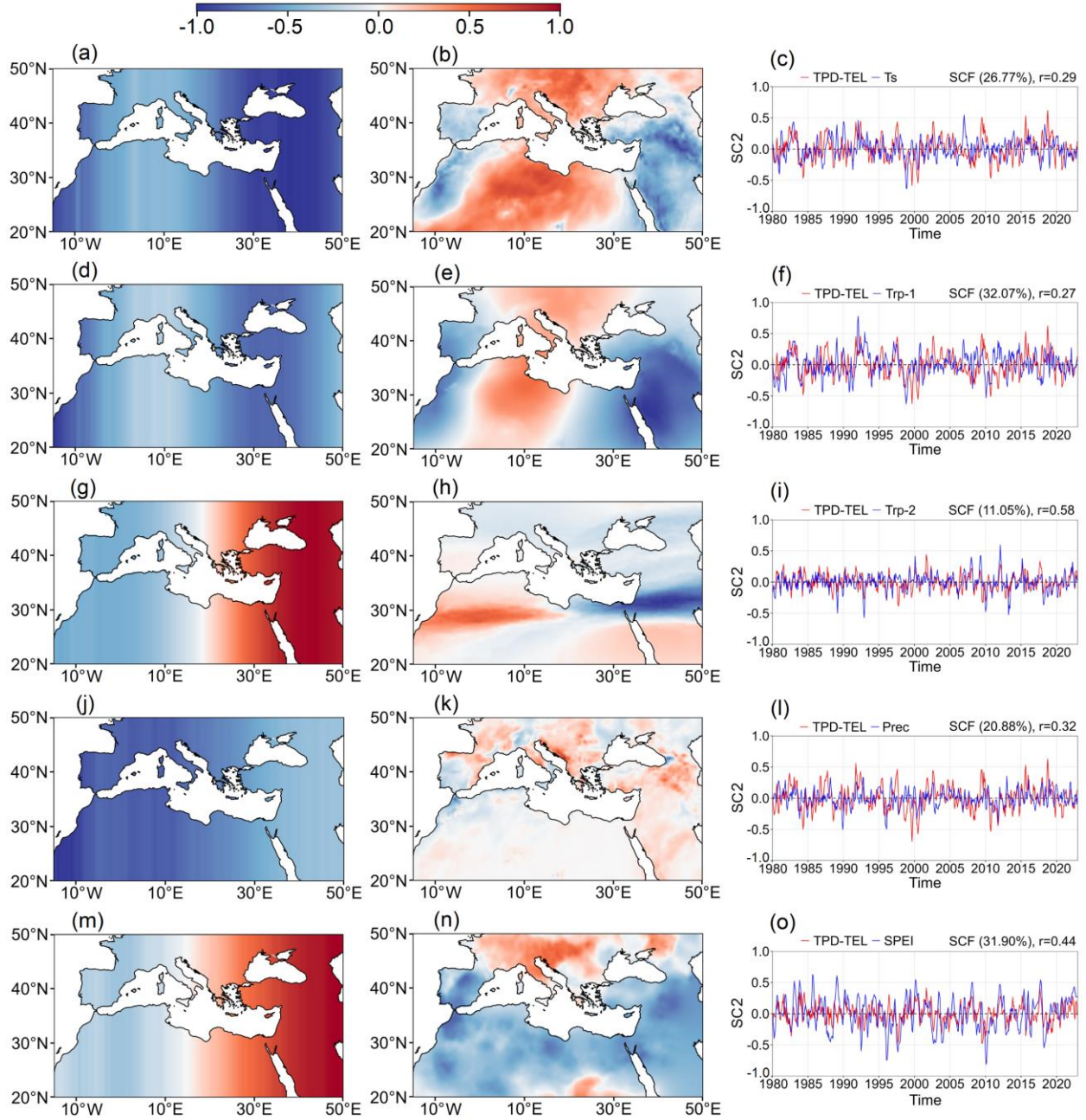


Figure 5. Second leading mode of covariability for the coupled fields of TPD TEL and climatic parameters. TPD TEL and Ts (a, b, c), TPD TEL and Trp-1 (d, e, f), TPD TEL and Trp-2 (g, h, i), TPD TEL and precipitation (j, k, l), and TPD TEL and SPEI (m, n, o). The spatial patterns for the second paired mode of covariability (SVD2) of TPD TEL (left), climatic parameter SVD2 (middle), and the time series of expansion coefficients (SC2) for the paired mode of both TPD TEL and climatic parameters (right).

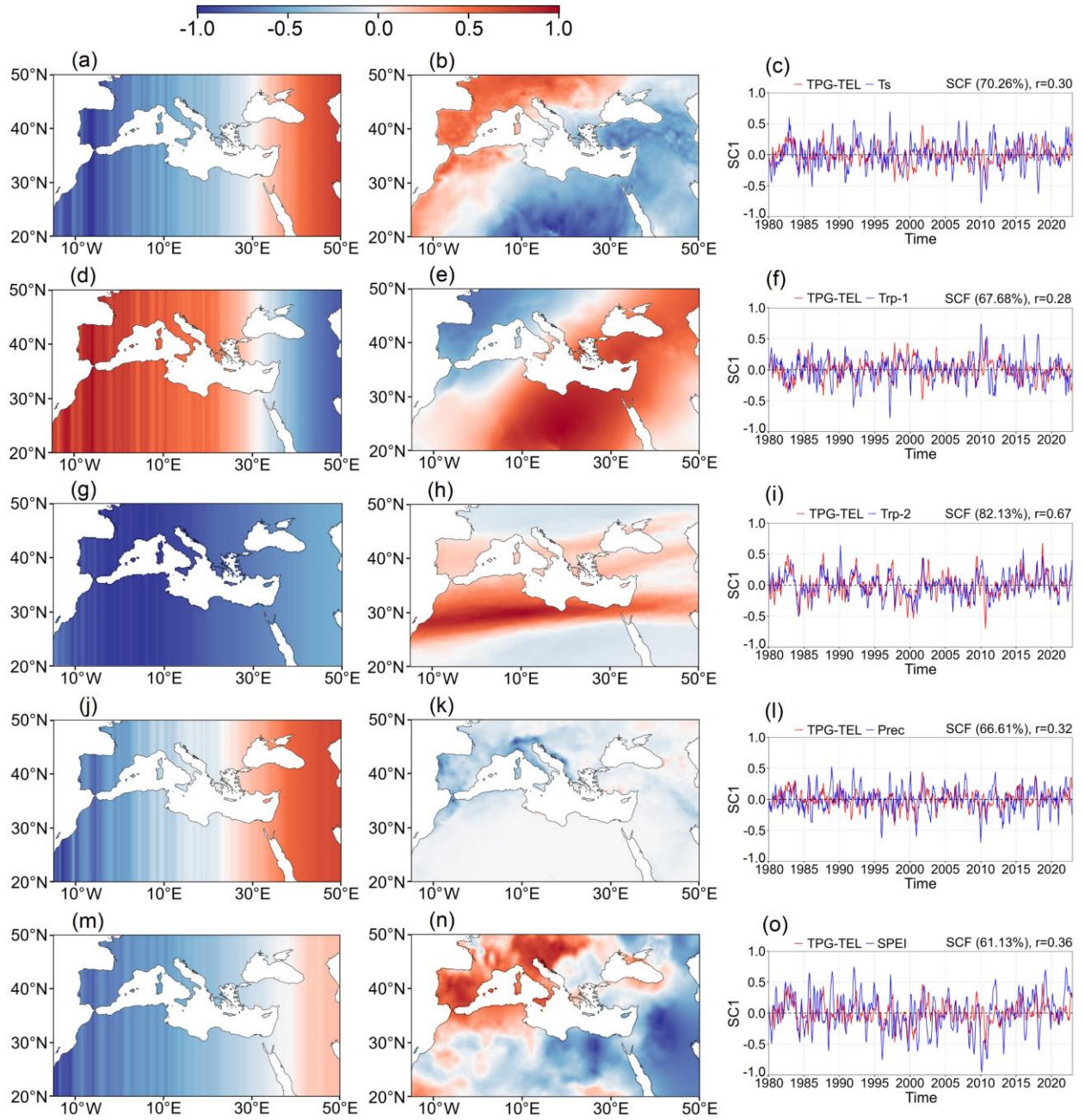


Figure 6. First leading mode of covariability as in Figure 4, but for TPG TEL and the corresponding climatic parameters.

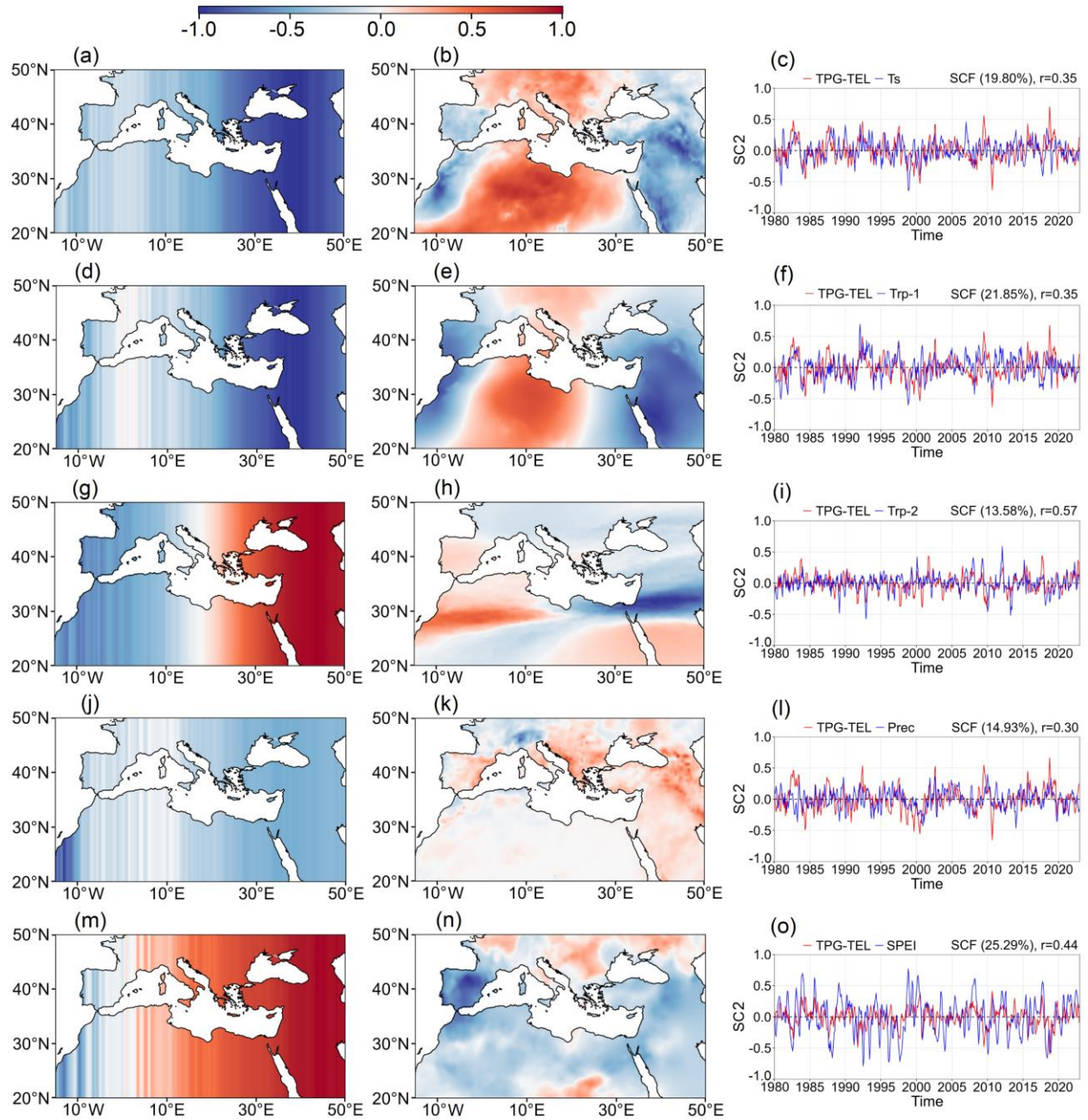


Figure 7. Second leading mode of covariability as in Figure 5, but for TPG TEL and the corresponding climatic parameters.

Minor Recommended Editorial Fixes

Editor comment: -

Lines 60–61: Good to clarify here that the seasons noted correspond to the Northern Hemisphere tropical edge. The Southern Hemisphere tropical edge would expand poleward in DJF.

Answer: -

Thank you for this helpful suggestion. We have revised and modified the text to be *[They migrate poleward during the Northern Hemisphere (NH) summer (JJA) and equatorially during the NH winter (DJF) (Davis and Birner, 2013)]*

Editor comment: -

Line 69: This value is too large. The value quoted in the IPCC sixth assessment report is 0.1–0.5 degrees per decade. I have quoted the relevant passage below:

“Since AR5 several studies based upon a range of metrics and different reanalyses products have suggested that the annual mean HC extent has shifted poleward at an approximate rate of 0.1°–0.5° latitude per decade over the last about 40 years”

Answer: -

Thank you for pointing this out. We agree that the value originally reported was larger than the range assessed in the IPCC Sixth Assessment Report (AR6). We have revised the manuscript accordingly and now state that the annual mean Hadley circulation (HC) extent has shifted poleward at an approximate rate of 0.1–0.5° latitude per decade over the past four decades, consistent with the IPCC AR6 assessment and the studies cited therein.

Revised manuscript text:

[Since the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), various research utilizing a range of metrics and reanalyses datasets have indicated that the annual mean Hadley circulation (tropics) has expanded poleward at an approximate rate of 0.1°–0.5° latitude per decade over the last about 40 years (IPCC, 2021a).]

Editor comment: -

Figure 7: The term spatial correlation is misleading, as it typically refers to the similarity between two spatial maps. In this case, I think the authors are referring to temporal correlations on a grid point by grid point basis. If so, the authors should clarify their terminology.

Answer: -

Thank you for this helpful observation. We agree that the term spatial correlation may be misleading in this context. The Pearson correlation coefficient was computed independently at each grid point between the TEL time series and the corresponding climatic variable time series, resulting in a spatial distribution of temporal correlations. To avoid ambiguity, we have replaced the term spatial correlation with *[Figure 3 exhibits the spatial distribution of Pearson correlation coefficients between the deseasonalized anomaly time series of TPD TEL and TPG TEL with climatic parameters (Ts, Trp-1, Trp-2, precipitation, and SPEI), which were computed independently at each grid point.]*

Under the new manuscript modification, the figure caption became:

Figure 3. *Correlation maps of TPD TEL (left) and TPG TEL (right) with climatic parameters, where the Pearson correlation coefficient was computed independently at each grid point. Ts (a, b), Trp-1 (c, d), Trp-2 (e, f), precipitation (g, h), and SPEI (i, j). Black stippling indicates grid points where the correlation coefficients are statistically significant at $p < 0.05$.*

Editor comment: -

Make sure the captions clearly explain all the symbols used in the figures:

- *Figure 1: Light shading behind time series in panels a and b needs to be explained.*
- *Figure 2: Shading along trend line (panels a and b), PDFs in panels c and d, and all symbols in panels g and h need to be defined.*
- *Figure 3: Axes need to be labeled with proper units for all variables.*
- *Figures 5-6: Color bar should be labeled with appropriate quantity and units.*
- *Figures 8-9: Color bar should be labeled with appropriate quantity and units.*
- *Figures 10, 11: Light shading behind time series in left column needs to be explained.*
- *Figure 11: Color schemes are incorrect in right column. Browns/oranges should indicate drier conditions.*

Proofread the following sentence for English grammar:

- *Lines 256-258*

Answer: -

- *Figure 1: Light shading behind time series in panels a and b needs to be explained.*

Thank you for this helpful comment. We have revised the Figure 1 caption to clarify the meaning of the light shading. The caption now explicitly states that the light-shaded envelope surrounding each time series represents the standard deviation at each time step.

Revised caption:

Figure 1. Monthly time series of LRT parameters in the top: (a) LRT-H and (b) LRT-T. The solid lines indicate the monthly mean values, while its surrounding light shading denotes the SD at each time step. Tropopause anomaly in the middle: (c) LRT-H anomaly time series, (d) LRT-T anomaly time series. Linear regression analysis of LRT parameters at all grid points and their decadal trends in the bottom: (e) LRT-H and (f) LRT-T. Black stippled regions indicate grid points where the trends are statistically significant at $p < 0.05$. The zonal mean is displayed on the right side of each regression map.

- *Figure 2: Shading along trend line (panels a and b), PDFs in panels c and d, and all symbols in panels g and h need to be defined.*

Thank you for this helpful comment. We have revised the caption of Figure 2 to define all graphical elements. Specifically, we now explain that the shaded bands in panels (a) and (b) represent the 95% confidence intervals of the linear trends, the marginal PDFs shown in panels (c) and (d) are the probability density functions of the plotted variables, and all symbols in the violin plots (panels g and h), including the violin shape, box, and median, are explicitly described in the caption.

Revised caption:

Figure 2. Monthly time series of the (a) TPD TEL method and (b) TPG TEL method, the shaded bands surrounding the trend lines denote the 95% confidence intervals of the fitted trends. The linear regression model between TPD TEL and LRT-H (c) and the linear regression model between TPG TEL and LRT-H (d), the marginal probability density functions (PDFs) of the variables are shown above and to the right of each scatter plot. Longitudinal variation of TEL using both methods over the Mediterranean region is displayed. The blue line in (e) represents the mean TPD TEL at each longitude over the study period, while the blue shading depicts its SD. In (f), the red line represents the mean TPG TEL at each longitude over the study period, with the red shading indicating its SD. Seasonal variation of TPD TEL (g) and TPG TEL (h) shown as violin plots. The width of each violin represents the probability density of the seasonal TEL values. The central box indicates the interquartile range (25th–75th percentiles); the horizontal line inside the box marks the median.

- *Figure 3: Axes need to be labeled with proper units for all variables.*

Figure 3 has been removed from the revised manuscript during the revision process as part of the reorganization of the results and figures.

- *Figures 5-6: Color bar should be labeled with appropriate quantity and units.*

Figures 5 & 6 have been removed from the revised manuscript during the revision process as part of the reorganization of the results and figures.

- *Figures 8-9: Color bar should be labeled with appropriate quantity and units.*

Thank you for this valuable comment. The spatial patterns shown in Figures 8 and 9 represent the normalized singular vectors obtained from the SVD analysis rather than the original physical variables. To facilitate direct comparison of the coupled spatial patterns and their corresponding expansion coefficient time series across all variables, both the spatial variability maps and the associated expansion coefficients were normalized to the range -1 to 1 . Consequently, the color bars are dimensionless and do not have physical units. In the revised manuscript, the SVD analysis results represented by Figures 4, 5, 6, and 7.

- *Figures 10, 11: Light shading behind time series in left column needs to be explained.*

We have revised the Figures 10, 11 captions to clarify the meaning of the light shading. The caption now explicitly states that the light-shaded envelope surrounding each time series represents the standard deviation at each time step. In the revised manuscript Figures 10, 11 became Figures 8, 9

Revised caption:

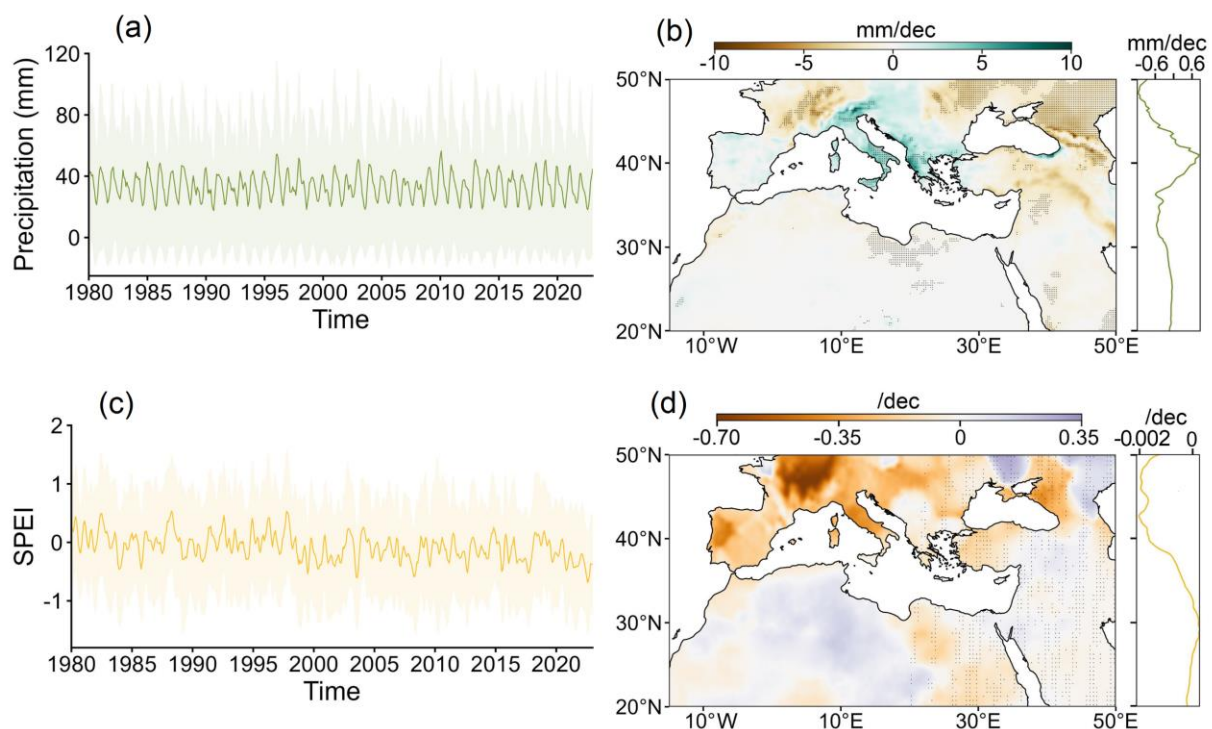
Figure 8. On the left, monthly time series of Ts (a), Trp-1 (c), and Trp-2 (e). The solid lines indicate the monthly mean values, while its surrounding light shading denotes the SD at each time step. On the right, decadal trends regression maps and their corresponding zonal mean, Ts (b), Trp-1 (d), and Trp-2 (f). Temperature trends in the troposphere and lower stratosphere (0-20 km) in addition to LRT-H represented by the red line (g). Black stippling indicates regions where the trends are statistically significant at $p < 0.05$.

Figure 9. Monthly time series of precipitation (a) and SPEI (c). The solid lines indicate the monthly mean values, while its surrounding light shading denotes the SD at each time step. The precipitation linear regression analysis at all grid points with decadal trends and its zonal mean on the right side (b). While SPEI linear regression analysis at all grid points with decadal trends and its zonal mean on the right side (d). Black stippled areas denote grid points with statistically significant trends at $p < 0.05$.

- *Figure 11: Color schemes are incorrect in right column. Browns/oranges should indicate drier conditions.*

Thank you for this helpful comment. We agree that the original color scheme for the precipitation and SPEI regression maps could lead to ambiguity in the interpretation of dry and wet conditions. Accordingly, we have revised the color schemes in the right column of Figure 11. In the revised figure, brown/orange colors represent drier conditions. This modification provides a more intuitive and consistent representation of hydroclimatic conditions. In the revised manuscript Figure 11 became Figure 9.

Figure 9:



Proofread the following sentence for English grammar:

- *Lines 256-258*

Thank you for pointing this out. We have carefully proofread and revised the sentence in Lines 256–258 to improve its English grammar, clarity, and readability.

Revised text:

[Our results are in agreement with previous studies, which reported a pronounced seasonal cycle of the TEL, characterized by a poleward shift during JJA and an equatorward shift during DJF, with a seasonal migration amplitude of approximately 5–10° latitude.]