Dear Referee #1

We thank Referee #1 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.

General comments

Referee comment: -

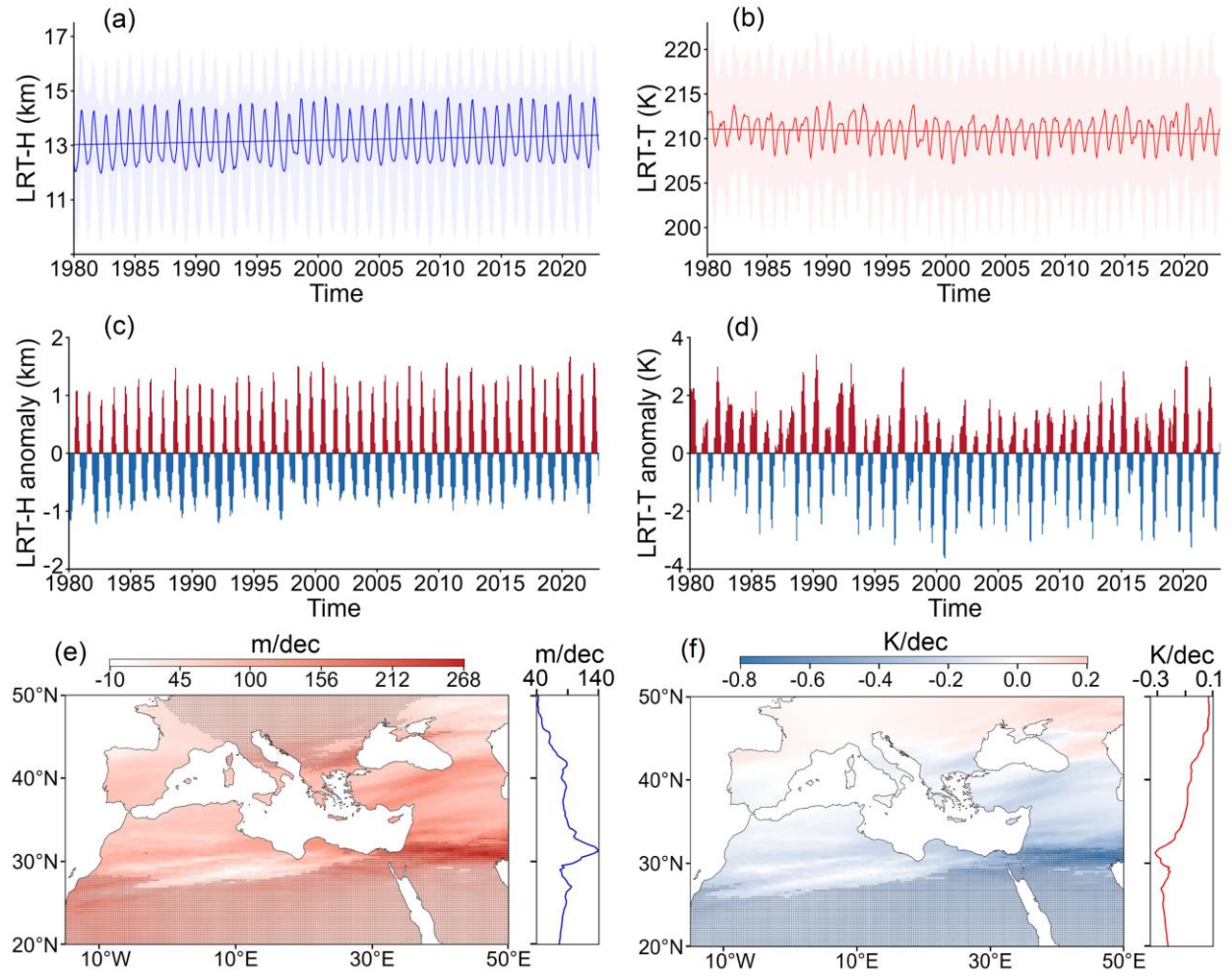
Throughout the manuscript, but especially in the figure captions the investigation period "over the period January 1980 to December 2022" is over-repeated. For example in the caption of Fig. 1 it is stated 3-times, and in the caption of Fig. 2 it is mentioned 4-times. Reduce most of the repetitions, particularly in figure captions. Moreover in the figures when time series are shown, it is not necessary to repeat the investigation period in the axis labelling – it is comprehensible from the time-axis and it is also referred to in the text. Rather state the unit e.g., "Time (years)".

Answer: -

We thank the reviewer for this helpful suggestion. The repeated statements of the investigation period (January 1980–December 2022) have been reduced throughout the manuscript, particularly in the figure captions. The study period is now stated only where necessary, mainly in the main text when first introduced. In addition, the time-series figures' x-axis labels are modified (e.g., "Time") instead of repeating the investigation period. These changes improve the readability and conciseness of the manuscript.

Example: As shown in Figure 1, the figure caption has been revised following the reviewer's suggestion. Additionally, the x-axis label of the monthly time series, previously written as "Time (Jan. 1980–Dec. 2022)," has been simplified to "Time."

Figure 1. *Monthly time series of LRT parameters in the top: (a) LRT-H and (b) LRT-T. 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.*



Referee comment: -

The mention of seasons is not consistent e.g., in Lines 196-201 seasons are stated e.g., as "summer", "winter", whereas in Lines 265-276 e.g., "Summer (JJA)", "Winter (DJF)", and in Line 278 as "Summer", "Winter". I suggest to introduce the seasons in the beginning what is meant with e.g., "summer" or use the short form e.g., "JJA" throughout the text. It does not need to be mentioned every time. Also, seasons are never capitalized.

Answer: -

The presentation of seasons has been revised throughout the manuscript to ensure consistency. The seasons are now introduced at their first occurrence in the manuscript using both the full name and the corresponding abbreviation (e.g., summer (JJA), winter

(DJF), spring (MAM), and autumn (SON)). Thereafter, only the abbreviations are used throughout the text. In addition, the capitalization of seasons has been corrected so that season names are written in lowercase.

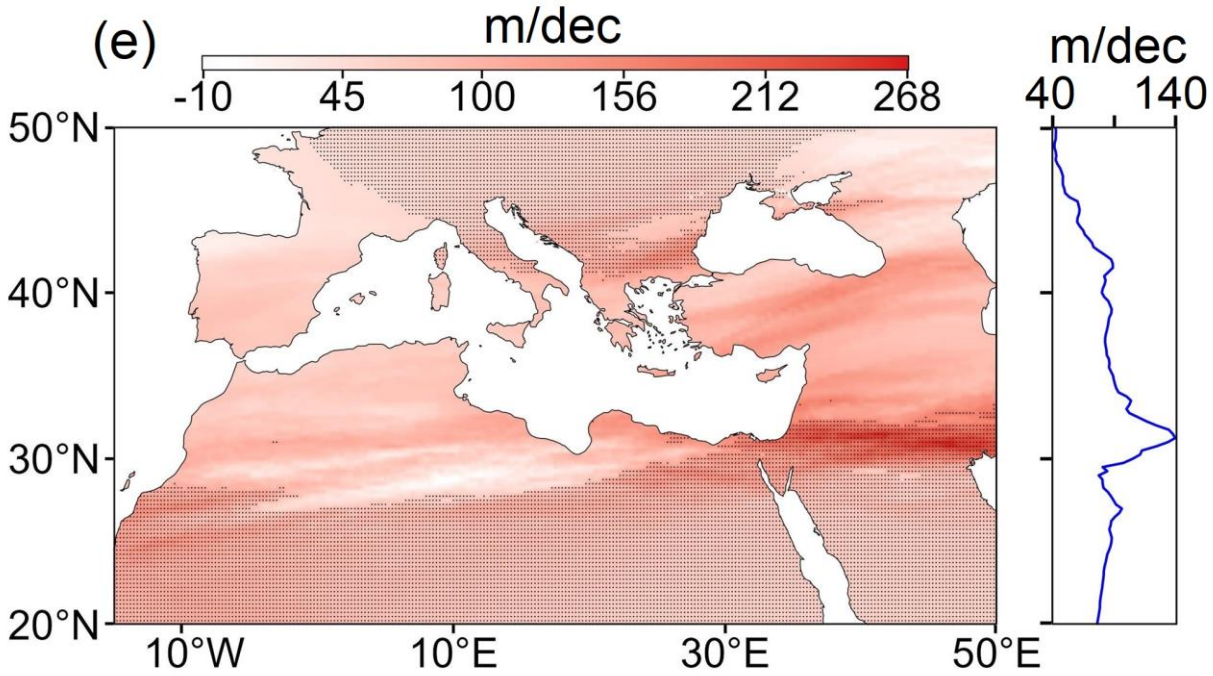
Referee comment: -

The authors state for multiple plots that "statistically significant trends at p < 0.05 at most of the grid points", could you add some hatching in the respective plots to indicate the grid points for which this statement valid?

Answer: -

In the revised manuscript, we indicated the statistically significant trends ($p \leq 0.05$) in all trend maps using stippled regions. This representation highlights the grid points where the trends are statistically significant and improves the clarity of the figures. The figure captions have been updated accordingly.

Example: As shown in Figure 1e, black stippled regions indicate grid points where the trends are statistically significant at $p < 0.05$.



Referee comment: -

The authors should be more consistent with the formatting of their figures e.g., where the labels of the sub panels are located – sometimes they are at the top left whereas in other figures they are at the top right. Also the font size of the axis labels needs to be increased in all figures. And it should be considered to add coastlines in map plots for better geographical orientation.

Answer: -

The formatting of all figures has been revised to ensure consistency throughout the manuscript. The positions of the subpanel's labels have been unified and are now placed in the top left corner in all figures. In addition, the font size of the axis labels has been increased in all figures to improve readability. Furthermore, coastlines have been added to all map plots to provide clearer geographical orientation.

Referee comment: -

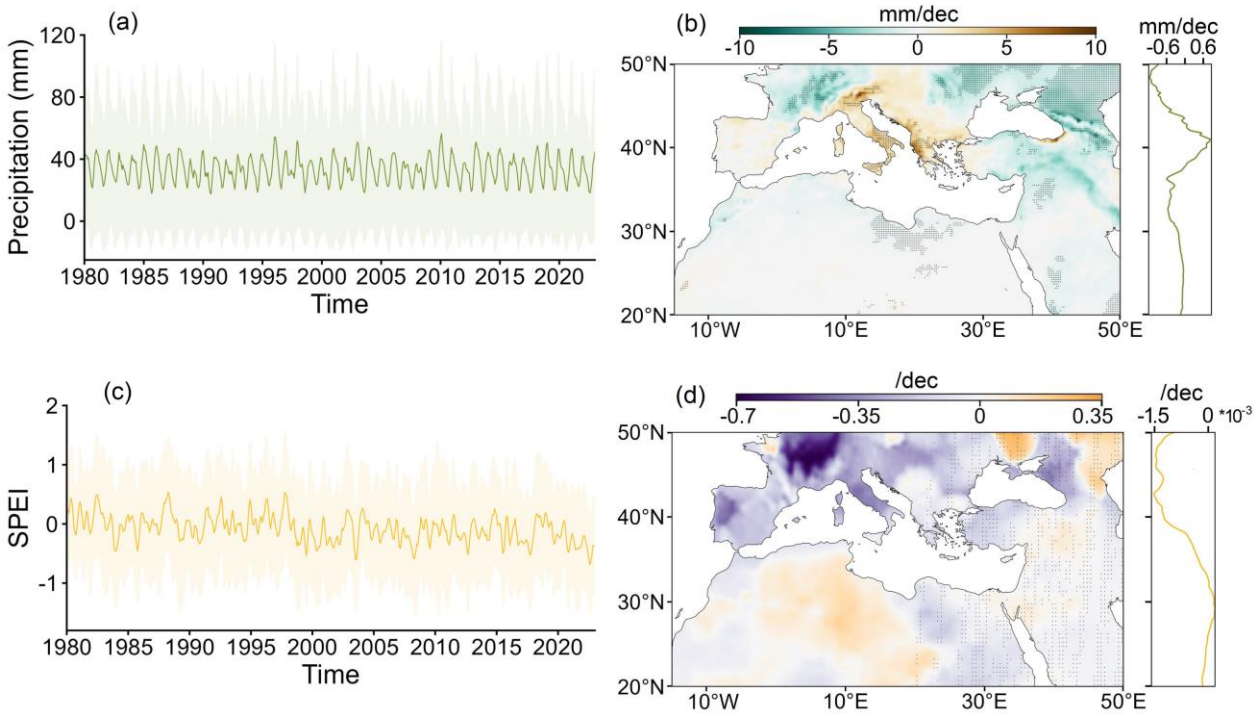
Use evenly distributed ticks for the colorbars and when possible round numbers in all the figures. This would greatly improve plot readability. Also, when using diverging colorbars, the authors should purposefully set the center, for example at zero, so that the colors are diverging from negative to positive values (e.g., Fig. 11d: Negative values are shown in teal, yellow and in brown, the same brown is then used for positive trend results. This makes the plot very difficult to interpret.)

Answer: -

All maps have been replotted to improve the readability and consistency of the figures. The colorbars now use evenly distributed ticks where it is possible, with rounded values across all figures. In addition, for plots using diverging color scales, the colorbars have been centered at zero, ensuring a clear divergence between negative and positive values. This revision ensures that negative values are represented by one color range and positive values by another, avoiding ambiguity and improving the interpretability of the plots. The colorbars in all relevant figures have been updated accordingly.

Example:

Figure 11. *Monthly time series of precipitation (a) and its linear regression analysis at all grid points with decadal trends, with the zonal mean of the regression map on the right side (b). Monthly time series of SPEI (c) and its linear regression analysis at all grid points with decadal trends, with the zonal mean of the regression map on the right side (d). Black stippled areas denote grid points with statistically significant trends at $p < 0.05$.*



Referee comment: -

Be consistent with the post comma digits (significant digits) e.g., Line 268 its 38.83°, Line 269 29.2° and Line 275 41°. Another example is Line 273 "-0.07 ± 0.001".

Answer: -

We thank the reviewer for pointing out this inconsistency. The numerical values throughout the manuscript have been revised to ensure a consistent representation of significant digits. The number of digits after the decimal point has been standardized for comparable quantities, and the specific examples noted by the reviewer have been corrected.

Referee comment: -

Throughout the manuscript there are many instances where the term "Figure" is used in text, although it should be "Fig." (e.g., Line 211 "Figure 1e" should be "Fig. 1e").

Answer: -

We have carefully revised the manuscript, and all instances of "Figure" in the text have been replaced with the journal-preferred abbreviation "Fig." where appropriate. These changes have been implemented consistently throughout the manuscript.

Examples:

Line 217: (right panel of Figure 1f) *changed to* (right panel of Fig. 1f)

Line 513: on the right panel of Figure 10b *changed to* (right panel of Fig. 10b)

Referee comment: -

Some references are missing the DOI, please check.

Answer: -

We carefully reviewed the entire reference list, and the missing DOIs have now been identified and added where available. The reference list has been updated accordingly in the revised manuscript.

Specific comments

Referee comment: -

Line 182: consider adding the period investigated from the other authors

Answer: -

We have added the investigated period reported in the cited study to the text and highlighted the modification in the revised manuscript to improve clarity and completeness. *[*consistent with Schmidt et al. (2008), who reported a global upward trend in LRT-H of 39 to 66 m/dec for the period from May 2001 to December 2007*]*

Referee comment: -

Figure 2:

• "TEL TPD" and "TEL TPG" should be "TPD TEL" and "TPG TEL", check for consistency

• In sub panels (c) and (d) remove the redundant tick marks that make it look like a barcode, this is what the distribution function is showing. Also, use the same tick marks for these two sub panels (i.e., x-axis: 25, 30, 35, 40, 45, 50).

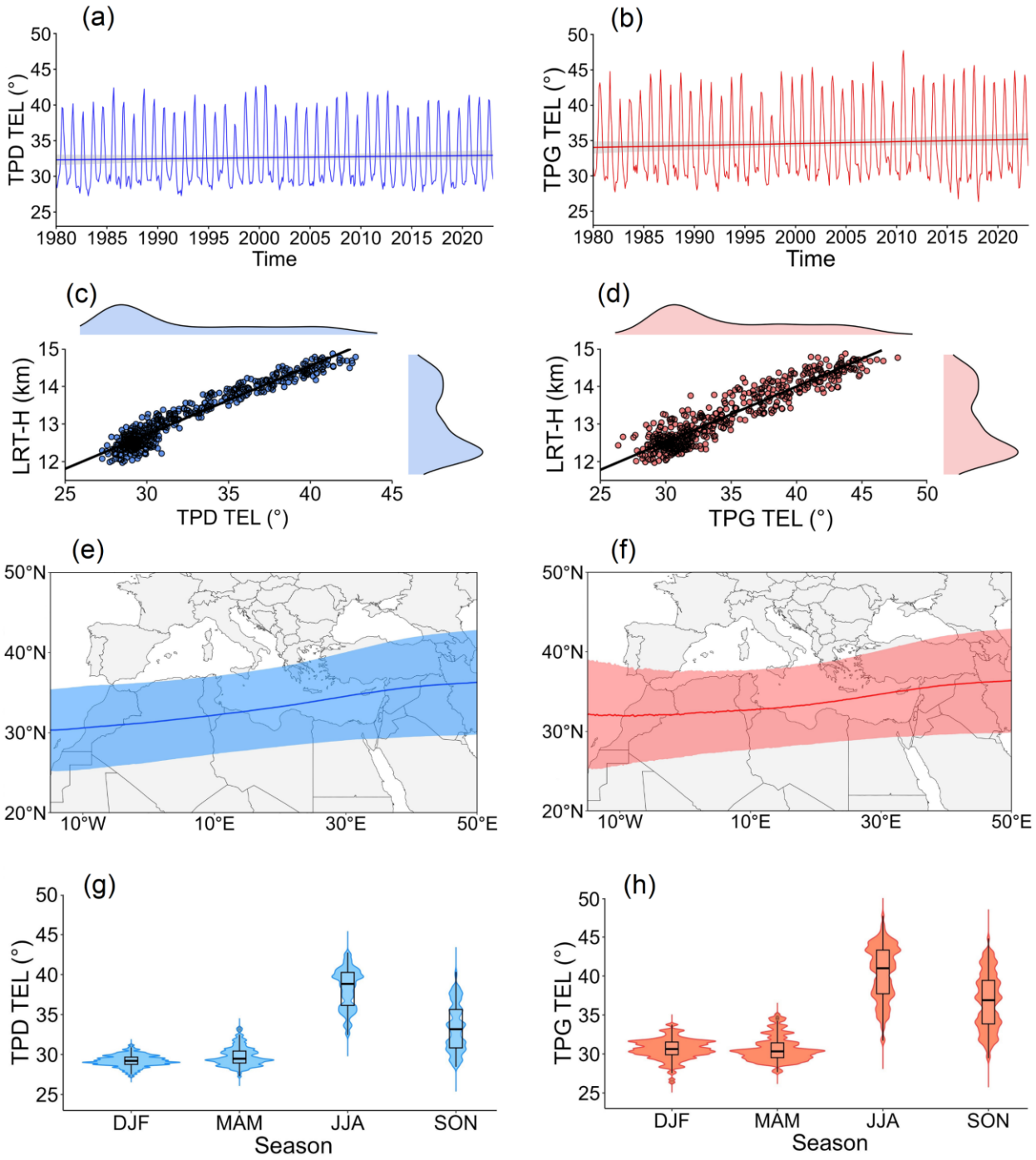
Answer: -

- The terminology has been corrected throughout the manuscript. "TEL TPD" and "TEL TPG" have been replaced with "TPD TEL" and "TPG TEL" in the entire text and in all figures to ensure consistency.
- The redundant tick marks in subpanels (c) and (d) of Figure 2 have been removed to improve clarity and to avoid the barcode-like appearance and improve the readability of the distribution functions. We also applied consistent ticks (25, 30, 35, 40, 45, 50) to the "TPD TEL" and "TPG TEL" in all subpanels of Figure 2.

  We note that applying the same tick marks (i.e., x-axis: 25, 30, 35, 40, 45, 50) to Figure 2c was not possible because the density distribution in that panel will extend beyond the actual data range, and using those ticks would not properly represent the data. Therefore, the axis ticks in Fig. 2c were kept consistent with the actual data range to ensure accurate visualization.

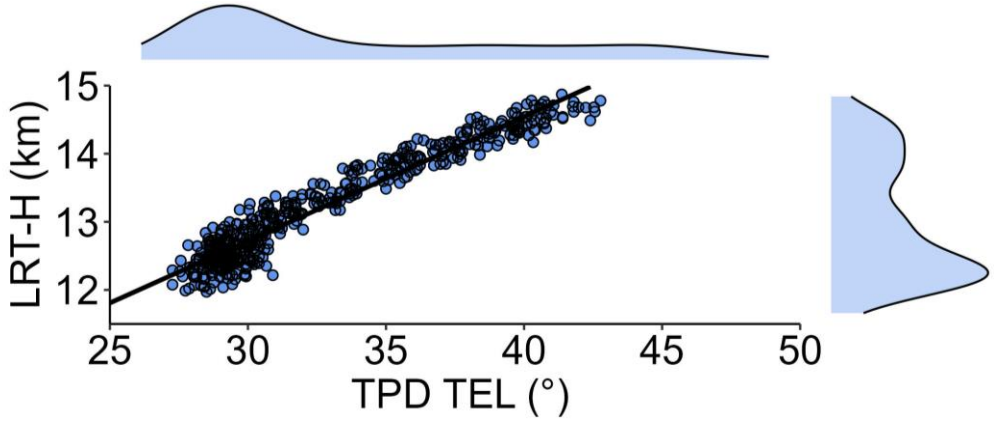
The following figures show our modifications: -

Figure 2. *Monthly time series of the (a) TPD TEL method and (b) TPG TEL method. The linear regression model between TPD TEL and LRT-H (c) and the linear regression model between TPG TEL and LRT-H (d). 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).*



If the same tick marks (i.e., x-axis: 25, 30, 35, 40, 45, 50) are applied to Figure 2c, the resulting appearance of the panel would be as shown below.

Figure 2c*. The linear regression model between TPD TEL and LRT-H.*



Referee comment: -

Line 261 & Line 262: The abbreviation for standard deviation "SD" has already been introduced in Line 203.

Answer: -

Corrected. The full-term standard deviation now appears only at its first occurrence (Line 203), and the abbreviation SD is used thereafter throughout the manuscript.

Referee comment: -

Figure 3 & Figure 4:

Be consistent with the labelling, replace TEL-D with TPD TEL and TEL-G with TPG TEL.

Answer: -

We have corrected the labeling in Figure 3 and Figure 4 to ensure consistency throughout the manuscript. The labels "TEL-D" and "TEL-G" have been replaced with "TPD TEL" and "TPG TEL," respectively. The updated figures are included in the revised manuscript.

Figure 3. *On the right side, correlation coefficients among monthly TPD TEL, TPG TEL, LRT-H, Ts, Trp, precipitation (Prec), and SPEI with 95% confidence intervals are shown. On the diagonal, the density distribution of all variables is displayed. On the left side, linear regression models between variables are depicted.*

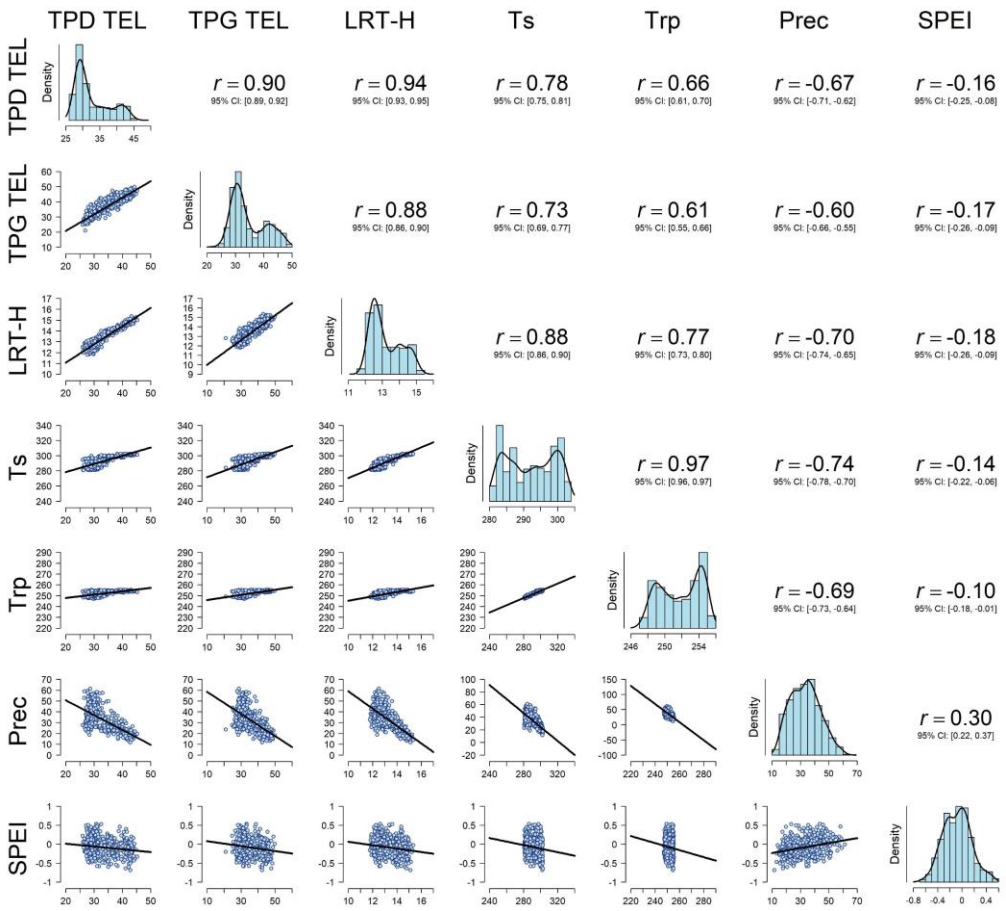
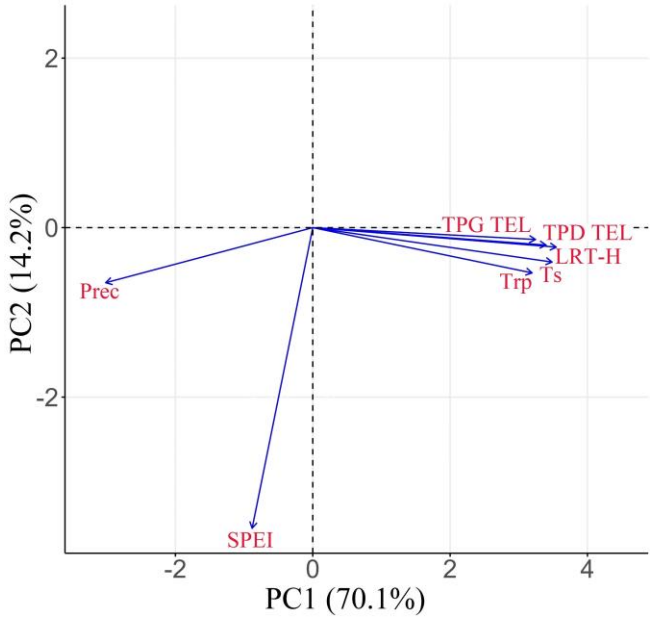


Figure 4. *PCA biplot of monthly TPD TEL, TPG TEL, LRT-H, Ts, Trp, precipitation (Prec), and SPEI.*



Referee comment: -

Line 403-405: The figure caption is unnecessary and the repetition can be misleading. Refer to the caption of Figure 5. Suggestion: "As in Fig. 5, but for TPG TEL."

Answer: -

To avoid repetition and improve clarity, the caption of Figure 6 has been shortened and now refers to Figure 5, as recommended. The revised caption now reads: *"**Figure 6.** WTC analysis as in Figure 5, but for TPG TEL and the corresponding climatic parameters."*

Referee comment: -

Figure 5 & Figure 6:

- *"TEL TPD" and "TEL TPG" should be "TPD TEL" and "TPG TEL", check for consistency*
- *Add x-axis labelling and the respective units*

Answer: -

The figures' titles "TEL TPD" and "TEL TPG" have been corrected to "TPD TEL" and "TPG TEL," respectively. Furthermore, the x-axis label has been added to clearly indicate that the analysis is based on monthly data.

Figure 5. *WTC analysis between monthly TPD TEL and climatic parameters. Arrows indicate phase differences between the two series. Variables are in phase when arrows point to the right (moving in the same direction with cyclical effects on each other). If arrows point right and upward, the first variable is leading (causing the second variable); if pointing right and downward, the first variable is lagging. Variables are out of phase (having anticyclical effects) when arrows point to the left. If arrows point left and upward, the first variable is leading; if pointing left and downward, the first variable is lagging. TPD TEL and LRT-H (a), TPD TEL and Ts (b), TPD TEL and Trp (c), TPD TEL and precipitation (Prec) (d), and TPD TEL and SPEI (e).*

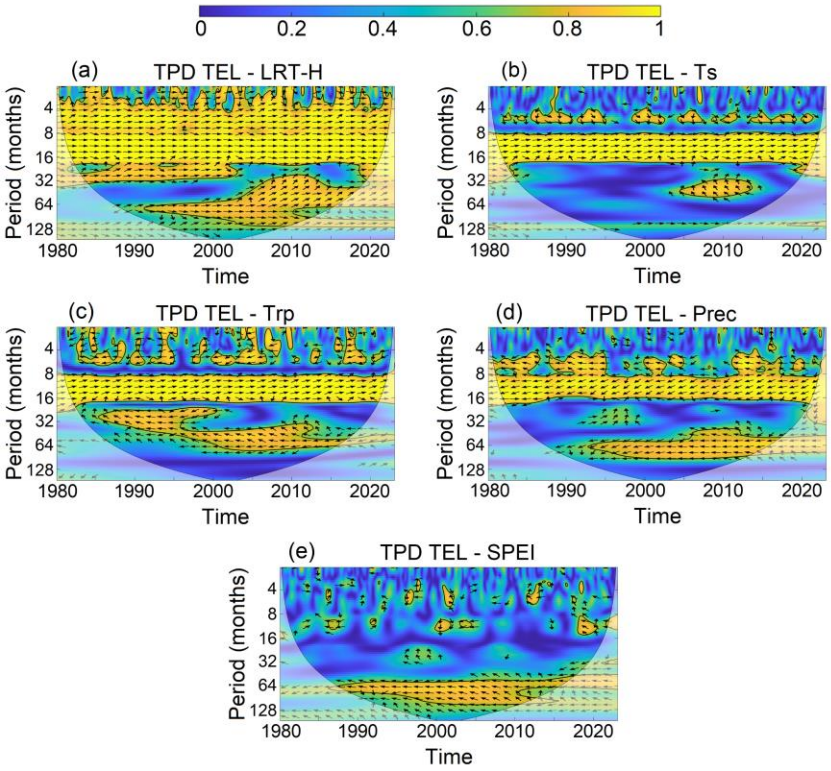
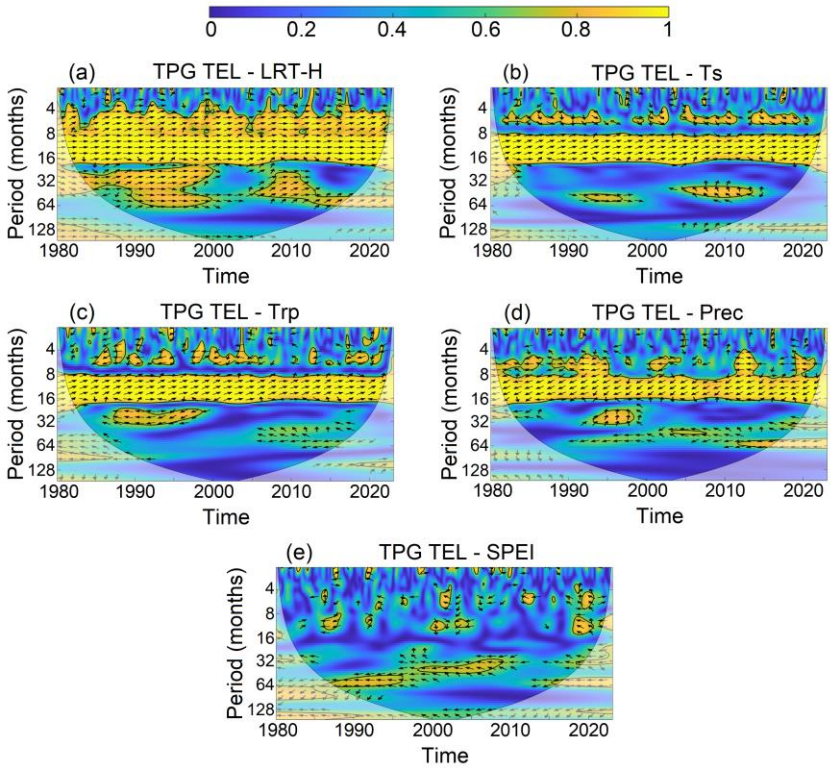


Figure 6. *WTC analysis as in Figure 5, but for TPG TEL and the corresponding climatic parameters.*



Referee comment: -

Figure 7:

• I suggest to have a uniform color range, so one can see how TPD TEL and TPG TEL correlate with the individual climatic parameters. Like this they are very hard to compare.

• Consider explaining in the text why you are now also looking at TRP-1 and TRP-2. This seems like an interesting approach, but why was it not included in the other tests and figures?

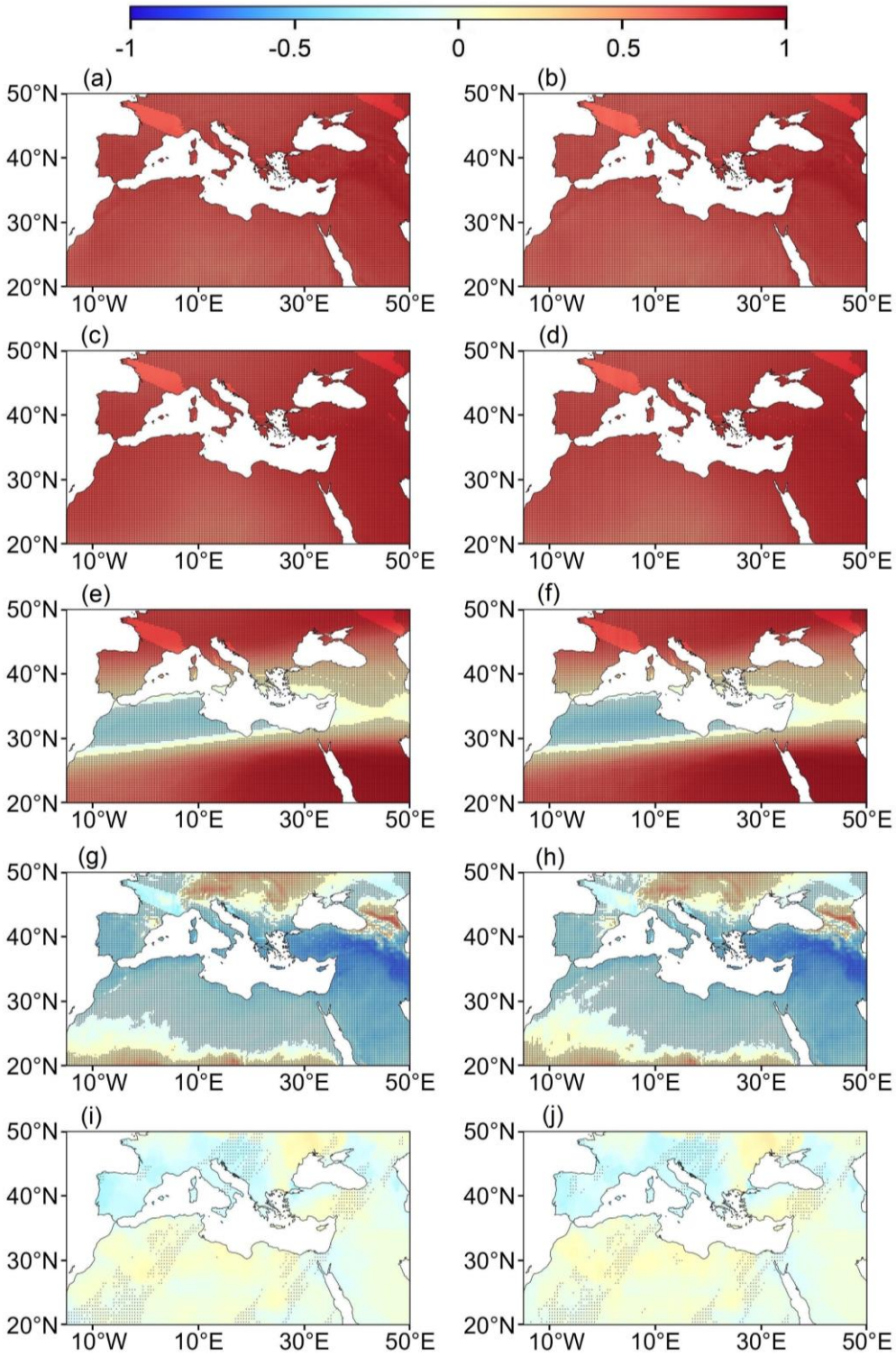
Answer: -

- To facilitate comparison between the correlation patterns, we have modified Figure 7 by applying a single uniform color scale (colorbar) for all correlation maps. This ensures that the correlations of TPD TEL and TPG TEL with the individual climatic parameters are displayed using the same range, allowing for a more consistent and straightforward comparison. The updated figure has been included in the revised manuscript.

- We studied the relation between tropospheric temperature and TPD TEL and TPG TEL. From our experience, we know that tropospheric temperature has a positive correlation with TELs, and the relation is strong near the surface and becomes weaker upward, so in this stage of analysis we investigated the troposphere as two distinct height bands (lower tropospheric temperature from surface to 5 km height (Trp-1), and upper tropospheric temperature from 5 km to LRT level (Trp-2)), and we added in the manuscript the following section:

"To examine the relationship between TEL and Trp at different altitudes, Trp is divided into two distinct height bands. The first band corresponds to lower Trp (Trp-1) from the surface to 5 km in height, and the second band corresponds to upper Trp (Trp-2) from 5 km in height to LRT level."

Figure 7. *Spatial correlation of TPD TEL (left) and TPG TEL (right) with climatic parameters. 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 $p < 0.05$.*



Referee comment: -

Figure 8 & Figure 9:

•As for Fig. 7, consider using a uniform range for the colorbar of the individual sub panels.

Line 496-500: Remove the repetitive figure caption. Refer to the caption of Figure 8. Suggestion: "As in Fig. 8, but for TPG TEL."

Answer: -

- To facilitate comparison, like in the case of Figure 7, we have modified Figures 8 & 9 by applying a single uniform color scale (colorbar) for all maps. This ensures that the coupling of TPD TEL and TPG TEL with the individual climatic parameters is displayed using the same range, allowing for a more consistent and straightforward comparison. The updated figures have been included in the revised manuscript.

- We have modified caption of Figure 9 to avoid any repetition ***"Figure 9.*** *SVD analysis as in Figure 8, but for TPG TEL and the corresponding climatic parameters."*

Figure 8. *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).*

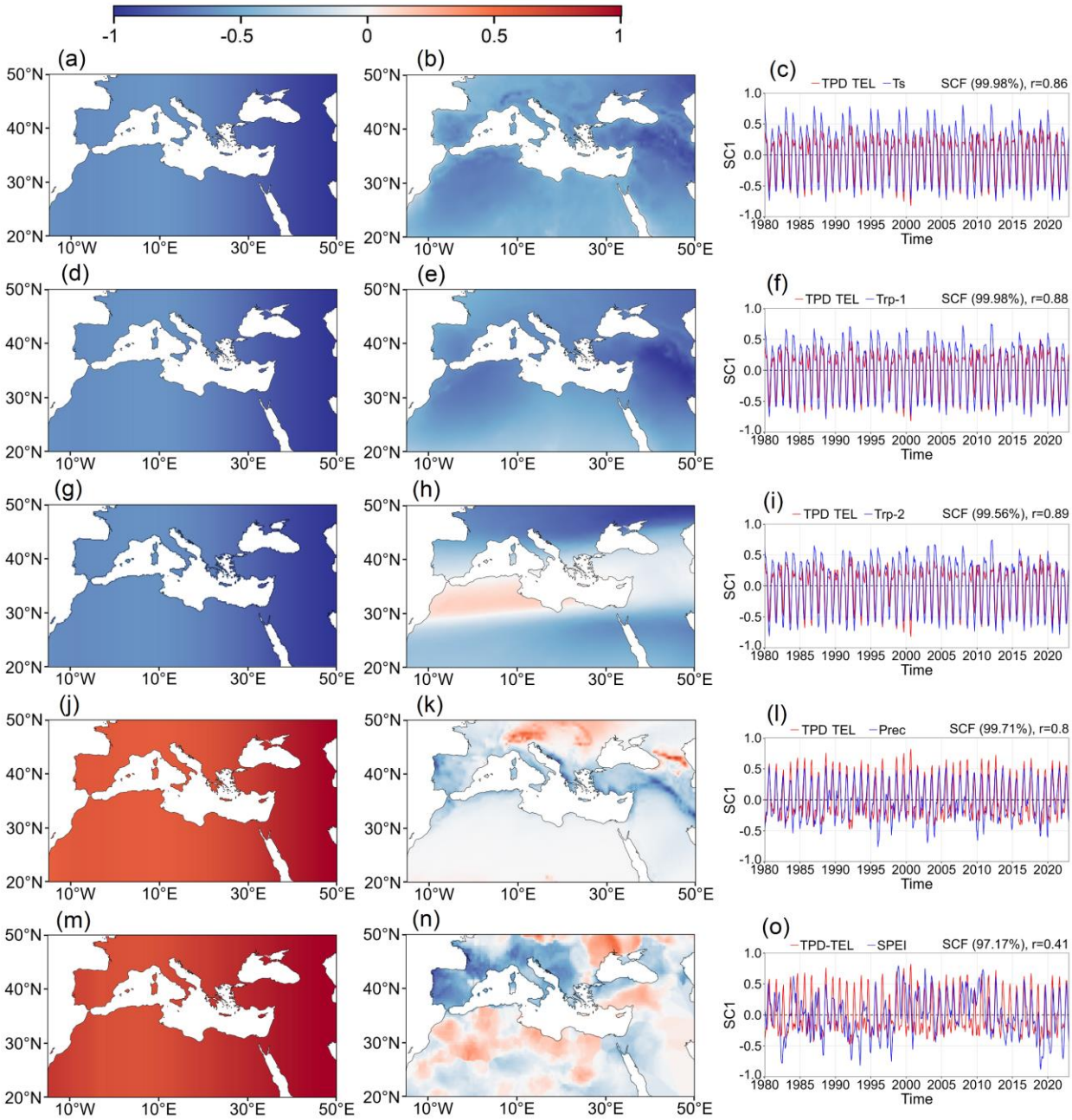
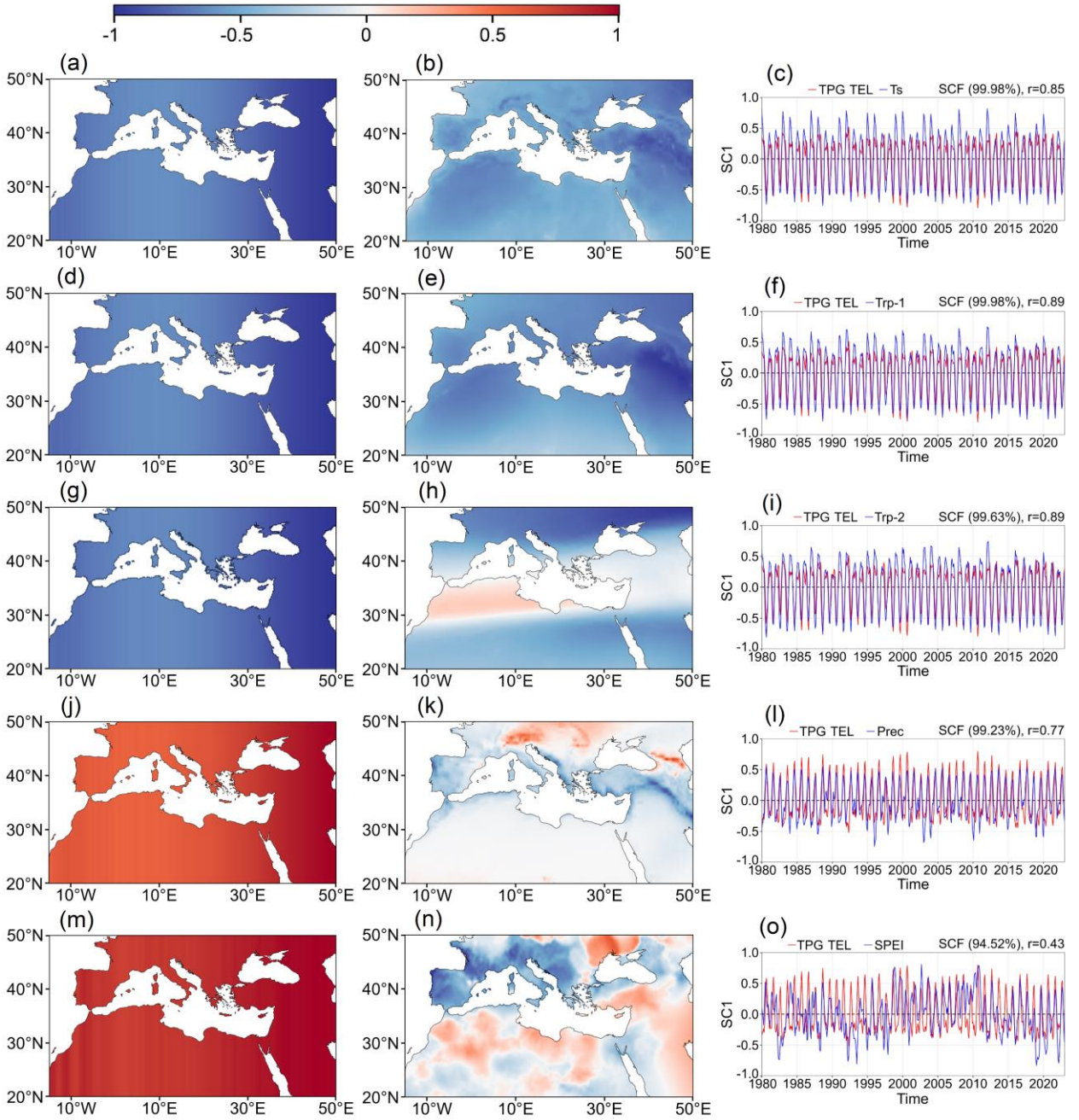


Figure 9. *SVD analysis as in Figure 8, but for TPG TEL and the corresponding climatic parameters.*



Referee comment: -

Lines 552-560: This caption is very repetitive – please improve it.

Answer: -

We have modified Figure 10's caption to be ***"Figure 10.*** *On the left, monthly time series of Ts (a), Trp-1 (c), and Trp-2 (e). 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 $p < 0.05$.*

Referee comment: -

Line 616: Consider discussing the lack of a significant relationship of SPEI.

Answer: -

We have added a discussion in the revised manuscript addressing the absence of a significant relationship between SPEI and other climatic variables. Specifically, we explain that this behavior is attributed to the composite nature of SPEI, which integrates both precipitation and evapotranspiration, as well as its sensitivity to time scale, regional variability, and lagged responses. These factors can obscure direct linear relationships with individual atmospheric parameters.

Technical corrections

Line 39: "greenhouse gases (GHGs) emissions" should be "greenhouse gas (GHG) emissions"

- Done

Line 59: it looks like a upper case zero not a "°"

- Modified

Line 69: add a "the" before "Hadley circulation"

- Done

Line 270: remove hyphen between TPD-TEL

- Done

Line 541, Line 544: "45° N-50° N" should be "45° N to 50° N"

- Done

Line 546: "20° N-30° N" should be "20° N to 30° N"

- Done

Line 595: "GHGs" should be "GHG"

- Done