

Dear Editor

We sincerely thank you for your careful evaluation of our revised manuscript. We greatly appreciate the additional comments and suggestions, which have helped us improve the scientific interpretation and clarity of the manuscript. We have carefully addressed all the comments and have revised the manuscript accordingly. Our detailed responses to each comment are provided below.

Editorial comments

Editor comment: -

In my assessment, the SVD section of this manuscript still does not meet the standards for an ACP publication. The authors have made an effort to respond to Reviewer 1's major comment, but the response (on lines 401-404) does not make sense. The method and explanation of the results in this section remain difficult to understand. The SVD methodology needs to be accessible and understandable for the reader to interpret.

Answer: -

We sincerely thank the editor for this important and constructive comment. We agree that the previous version of the manuscript did not sufficiently explain the SVD methodology or provide adequate guidance for interpreting the coupled spatial patterns. We recognize that our previous description, particularly in Lines 401–404, was ambiguous and may have caused confusion regarding the spatial representation.

Editor comment: -

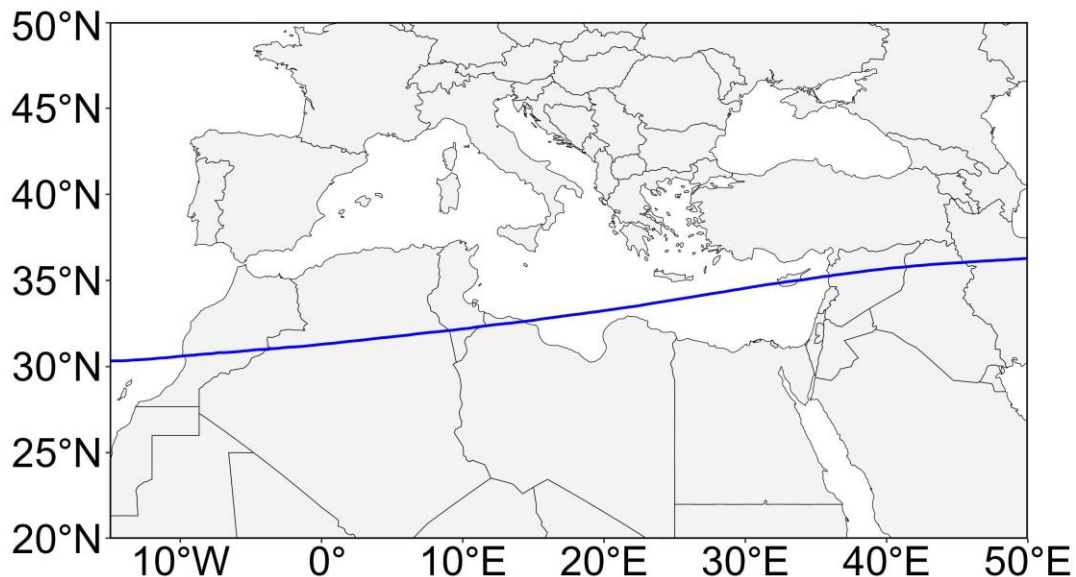
1. More carefully describe the methodology: In my understanding, there should be one TEL value at each longitude, but the authors state that they are repeating TEL values along all longitudes for each timestep. I think they mean to say that they are using the same TEL value at each longitude (i.e., repeating the same TEL value at all latitudes for a given longitude).

Answer: -

We sincerely thank the editor for identifying this ambiguity in our previous description. The editor's interpretation is correct. At each monthly time step, the TEL dataset contains one tropical-edge latitude value at each longitude. Thus, TEL is originally represented as a one-dimensional longitude-dependent field. In our previous manuscript, the description of the replication procedure was unclear and incorrectly suggested that TEL values were repeated along the longitude dimension.

To clarify, for each longitude, the corresponding TEL value was replicated along the latitude dimension, while preserving its original longitude-dependent variability. In other words, the TEL value at a given longitude remains unchanged and is repeated at all latitude grid points within that longitude column. This transformation was applied to provide a two-dimensional representation compatible with the latitude–longitude grid of the corresponding climatic variables for the correlation and SVD analyses and for visualization of the coupled spatial patterns. We have carefully revised the methodological description accordingly to avoid this ambiguity.

In the following figure, the blue line represents the monthly TEL values:



While the following table shows how the monthly TEL values were replicated along the latitude dimension:

		Long						
		10°W	0°E	10°E	20°E	30°E	40°E	50°E
Lat	50°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2
	45°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2
	40°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2
	35°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2
	30°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2
	25°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2
	20°N	30.6	31.3	32.2	33.2	34.5	35.7	36.2

Lines 401–404 were removed, and we added a describing paragraph in the methodology section of the revised manuscript [Lines 157-165]:

[For both the correlation and SVD analyses, the TEL dataset at each monthly time step consists of one latitude value at each longitude and therefore represents a one-dimensional, longitude-dependent field of TEL position. In contrast, the climatic variables are represented as two-dimensional latitude–longitude fields. To facilitate spatially consistent correlation and coupled-pattern analyses, as well as direct visualization of the resulting relationships, the longitude-dependent TEL values were replicated along the latitude dimension to construct a two-dimensional representation matching the geographical grid of the corresponding climatic field. This transformation provides a common spatial framework for examining the relationships between TEL variability and the climatic fields.]

Editor comment: -

2. Explain to readers how to interpret the coupled SVD maps in Figs. 4–7: The text in this section is entirely descriptive and does not attempt to explain to the reader how to interpret the patterns shown in Figs. 4-7. In other words, if the map in the left column of these figures shows a west-to-east gradient in TEL (Fig. 4a) and the map in the right column shows a spatially varying map (Fig. 4b), what does this mean? For example,

stating in words that Fig. 4a shows southward TELs in the western Mediterranean and northward TELs in the eastern Mediterranean and then explaining the corresponding pattern in Fig. 4b and why it is linked to the west-to-east gradient in TEL. This certainly doesn't need to be done for every panel in Figs. 4–7, but providing the reader with a few examples on how to interpret these patterns would greatly improve the readability of this section.

Answer: -

We thank the editor for this important and constructive comment. We agree that the previous version of the manuscript did not describe the SVD methodology and the physical interpretation of the coupled spatial patterns with sufficient clarity. In particular, the dimensions and construction of the TEL field, the rationale for applying SVD, the meaning of the individual SVD modes and their associated expansion coefficients, and the interpretation of the paired spatial patterns required further clarification.

To address these concerns, we have substantially revised and reorganized the SVD methodology and results sections. The revisions follow four main steps:

1- Clarification of the dimensions and construction of the TEL field

[Lines 157-165]

[For both the correlation and SVD analyses, the TEL dataset at each monthly time step consists of one latitude value at each longitude and therefore represents a one-dimensional, longitude-dependent field of TEL position. In contrast, the climatic variables are represented as two-dimensional latitude–longitude fields. To facilitate spatially consistent correlation and coupled-pattern analyses, as well as direct visualization of the resulting relationships, the longitude-dependent TEL values were replicated along the latitude dimension to construct a two-dimensional representation matching the geographical grid of the corresponding climatic field. This transformation provides a common spatial framework for examining the relationships between TEL variability and the climatic fields.]

2- Clarification of the purpose of the SVD analysis

[Lines 165-166]

[The SVD analysis was applied to identify the dominant coupled modes of variability between the TEL and the climatic fields.]

3- Clarification of SVD mode construction and interpretation

[Lines 167-170]

[This method extracts pairs of spatial patterns (one for each field) and their respective temporal variations, each pair explaining a fraction of the shared covariance. To compute the SVD, we construct the temporal cross-covariance matrix between the two space-time fields, which must cover the same period of time (Bjornsson and Venegas, 1997; Darrag et al., 2024).]

[Lines 435-456]

[For further investigation into the effects of poleward tropical belt expansion on climatic parameters in the Mediterranean region, SVD analysis is performed to reveal coupled patterns of covariability between TEL position and climatic parameters. In the case of the SVD analysis results, we consider only the first two dominant modes of covariance. Each SVD mode consists of a pair of spatial patterns representing the dominant coupled covariance structure between the TEL field and the corresponding climatic variable. SVD1 and SVD2 depict the spatial patterns for the first and second paired modes of covariability, respectively. whereas SC1 and SC2 represent the time series of the paired expansion coefficients for the same modes. For all parameters employed in the SVD examination, their expansion coefficients' time series and related spatial variability maps are scaled to range from -1 to 1 to enable comparison and description of the paired modes of covariability (Darrag et al., 2024). Figure 4 shows the first leading mode of covariance between the TPD TEL and climatic variables over the Mediterranean region. The left and middle panels show the SVD1 of TPD TEL and the corresponding climatic field, respectively. The TPD TEL map represents the spatial structure of the TEL variability contributing to the dominant covariance mode, whereas the corresponding climatic-variable map represents the spatial structure that covaries with that TEL pattern. Whereas the right panels display their paired SC1. The squared covariance fraction (SCF) indicates the proportion of the total covariance captured by the first mode, while the correlation coefficient (r) quantifies the strength of the temporal relationship between the corresponding paired SC1. The first dominant mode explains the majority of the coupled covariance between TPD TEL and the investigated climatic parameters, accounting for 56.48–86.32% of the total covariability. This signifies that the leading mode represents the dominant large-scale pattern linking tropical belt variability with the Mediterranean climate.]

4- Clarification of the interpretation of the SVD modes, a group of examples: -

[Lines 457-469]

[For the first dominant coupled mode of TPD TEL and T_s , the SCF explains 62.87% of the total covariability of both fields. The TPD TEL SVD1 exhibits a pronounced east-west gradient across the Mediterranean (Fig. 4a), characterized by a northward displacement over the eastern

Mediterranean and relatively southward displacement over the western Mediterranean. The corresponding Ts SVD1 shows an evident negative covariability relationship with TPD TEL. As it is characterized by positive covariance over western and northern regions of the study area, while it shows negative covariance over the southeastern Mediterranean and North Africa (Fig. 4b). The spatial structure demonstrates that the leading mode's covariance component does not account for the relationship between TEL variability and Ts. Because substantial TEL variability in the eastern Mediterranean is expected to be accompanied by positive Ts anomalies. The paired SC1 of TPD TEL and Ts displays a positive correlation of approximately 0.30. Furthermore, interannual oscillations dominate the SC1 for the temporal variability-paired mode of TPD TEL and Ts (Fig. 4c).]

[Lines 469-477]

[In the case of the coupled fields of TPD TEL and Trp-1, the SCF of the first prevailing mode accounts for approximately 56.48% of the total covariability of both fields. The TPD TEL SVD1 displays an east-west dipole (Fig. 4d), whereas the associated SVD1 of Trp-1 reveals enhanced positive covariance over the eastern Mediterranean and North Africa. On the other hand, it shows a negative covariance over the western Mediterranean (Fig. 4e). The first mode suggests that opposite-phase coupling between TPD TEL and Trp-1 is prevalent throughout the study area, implying that the thermal response of Trp-1 to TEL variability is not characterized in the fraction of covariance represented by SVD1. The paired SC1 of TPD TEL and Trp-1 depicts a synchronous fluctuation and has a correlation of about 0.29 (Fig. 4f).]

[Lines 487-494]

[In the case of the coupled fields of TPD TEL and precipitation, the SCF of the first leading mode explains approximately 68.59% of the total covariability of both fields. The SVD1 reveals a pronounced longitudinal gradient in the TPD-TEL pattern (Fig. 4j), while the precipitation SVD1 exhibits predominantly negative fluctuation across much of the Mediterranean basin (Fig. 4k). The opposite-phase coupling between TPD TEL and precipitation over the eastern Mediterranean, suggests that poleward widening of the tropical belt may be associated with expansion of subtropical dry zones and reduced precipitation.]

[Lines 514-525]

[For the coupled fields of TPD TEL and Ts, the SCF of the second dominant mode explains 26.77% of the total covariability of both fields. The second coupled mode of spatial variability, SVD2, shows that TPD TEL is characterized by observed negative loadings over most of the study area (Fig. 5a), accompanied by Ts fluctuations of the same sign over the majority of the eastern Mediterranean and a limited zone of the western Mediterranean. On the other hand, the SVD2 of Ts shows positive fluctuations in the central Mediterranean. The second SVD mode exhibits a pronounced positive coupling between TPD TEL and Ts over the eastern Mediterranean,

indicating that poleward displacement of the TEL is associated with enhanced surface warming in this region. The T_s spatial heterogeneity may reflect the strong land–sea thermal contrast of the Mediterranean region and differences in surface energy partitioning between continental and maritime environments (Fig. 5b). The paired SC2 of TPD TEL and T_s exhibits a correlation of about 0.29 (Fig. 5c).]

[Lines 536-549]

[For the coupled fields of TPD TEL and Trp-2, the SCF of the second prevailing mode represents only 11.05% of the total covariability of both fields, implying that most of the shared variability between these two variables is already captured by the first mode. Nevertheless, the paired SC2 of TPD TEL and Trp-2 remain strongly correlated ($r = 0.58$), indicating that although this secondary pattern contributes little to the overall covariance, it still represents a physically meaningful mode of coupled variability (Fig. 5i). The SVD2 of the TPD TEL displays an observed east–west gradient over the Mediterranean region (Fig. 5g), which is accompanied by Trp-2 fluctuations of opposite sign in the form of a narrow zonal band of alternating positive and negative covariance centered near 30°N, extending across North Africa and the eastern Mediterranean (Fig. 5h). The negative coupling between TPD TEL and Trp-2 over this narrow band is consistent with the negative relationships of tropopause and near-tropopause temperatures with both tropopause height and TEL position. Although this secondary mode of covariability between TPD TEL and Trp-2 contributes relatively little to the total covariance, it may represent regional modulation of the dominant influence of upper-tropospheric thermal variability on TEL]