Review for Earth System Dynamics egusphere-2025-3360

Title: "Quantifying changes in seasonal temperature variations using a functional data analysis approach"

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General Comments

The study offers a novel approach to study the annual daily cycle of temperature over the globe by means of a FDA (functional data analysis) applied to reanalysis (CERA20C and ERA5) and an ensemble of CMIP6 ESMs for the whole XXIst century. It looks quite interesting in terms of a better description of this very relevant feature to characterize the climate of each region of the globe. The comparison among reanalysis and global models, differences of regions, and how this is being modified when looking at different periods, and so how anthropogenic climate change is expected to modify temperature in terms of its annual cycle. Therefore, it looks that it could be considered by the journal for publication, once the different comments and suggestions were considered by the authors.

Specific Comments

1. An accurate and direct title is always welcomed, but, at the same time, as precise as possible should also be important. I miss some reference to "annual cycle features" and time periods and spatial coverage (global, present/future), for a first understanding of what the work is about.

2. I miss several references to previous studies, apart from the ones mentioned on the introduction: For example, apart from the Lopez-Franca et al., 2022, mentioned on line 45, also Lopez-Franca et al., 2013: "Changes in the onset and length of seasons from an ensemble of regional climate models over Spain for future climate conditions", DOI: 10.1007/s00704-013-0868-2, although only focused on one region, seems to be of interest, based on temperature (maximum and minimum). More references can also be found when searching "thermal seasons" expression: Ruosteenoja K, Markkanen T, Räisänen J. "Thermal seasons in northern Europe in projected future climate". Int J Climatol. 2020; 40: 4444–4462. https://doi.org/10.1002/joc.6466; Tu, K., Yan, Z., & Qian, C. (2024). Understanding seasonal cycle of daily extreme temperatures based on generalized additive model for location, scale and shape with smoothing spline. Int. J. Climatol., 44(6), 1883–1897. https://doi.org/10.1002/joc.8430 or Hekmatzadeh, A.A., Kaboli, S. & Torabi Haghighi, A. "New indices for assessing changes in seasons and in timing characteristics of air temperatur". Theor Appl Climatol 140, 1247–1261 (2020). https://doi.org/10.1007/s00704-020-03156-w; Liu, F., Song, F., & Luo, Y. (2024). "Human-induced intensified seasonal cycle of sea surface temperature". Nature Comms, 15(1), 3948, among others, could be mentioned. I know it is hard to make a complete overview of bibliography, but I miss some more references for example when talking about summer lengthening (line 55), such as Peña-Ortiz, C., Barriopedro, D., & García-Herrera, R. (2015). Multidecadal variability of the summer length in Europe. J. Climate, 28(13), 5375-5388, for example.

3. FDA is first pointed on the abstract, but for a non-expert reader, perhaps a more intuitive description of it could be made there?.

4. I have concern about the precise definition of "absolute temperature", first on line 21. What does it exactly mean?. Mean daily temperature in K?

5. More widely talking about the variable used on the work, did the authors made a thought about applying it to other temperature variables, such as daily maximum, minimum or daily range of temperature?. Could it potentially add interest to the proposed analysis or methodology?. Something is said on conclusions (line 363), but perhaps some comments could be made on methods or introduction, or at least on an answer to this question here.

6. When talking about temperature cycle changing on the recent decades (lines 52-63), which of then are based on observations, reanalysis or models?

7. Regional features are mentioned on line 74. What about using also regional climate models on a study like the one presented here?. I understand that it is not possible to study all the elements of climate, but probably it could be indicated as one of the several lines of further analysis, I guess.

8. On line 89 the data used in the study is presented, and so it is stated that "the mean annual cycle of near-surface air temperature" is going to be used. What about being more precise, indicating that mean daily data is used?.

9. On line 153 when starting the analysis indices with the annual cycle shape, annual extremes are defined in some way from 10th and 90th percentiles. Did the authors tested more extreme percentiles (95-5) as more extreme representation of changes extreme conditions?.

10. Going back to the potential usage of maximum and minimum temperature, to further inspect annual cycle of temperature, as from a purely physical perspective, at least max and min temperatures are a good representation, much more than mean daily values to processes of the climatic system that determine both values, related to local or synoptic mechanisms. I do not mean to add those variables to the study, but maybe the authors could make a comment about this idea, at least on these answers.

11. The word "shape" is used for the first index, and it is measured in degrees. Maybe accumulated/integrated temperature change could better define what is obtained there?.

12. Related to the parameter named "shift" of the maximum, I understand the reason for obtaining it from the proposed methodology, but that date is strongly and mainly related to astronomical features and thermal inertia more than to climatic conditions. On the contrary, season length and start/end of them seems to be more interesting, as widely studied by previous works. Do the authors have a comment about this topic?.

13. On line 109 climatological regions are indicated, using the IPCC (Iturbide et al., 2020) definitions. It is clear that they are many times too big to distinguish real regional climates, although it is clear that it would be impossible to have more spatial detail without making the work too long. But would it have been possible to have, at least on the supplementary material some purely global map grid by grid of some of the indices for some period and all the reanalysis and models to see how they look like in terms of spatial distribution?.

14. Even with that spatial distribution of regions, and considering the discussion presented on the work, perhaps a little bit more of analysis could be made about land/ocean differences.

15. A couple of big concerns when reading the results section is about the structure, that I would like to hear from the authors. One is about the time periods, and the other is about the order of the presented results, both are connected on my question. Comparison of two observational/historical periods (1951-1980) vs (1981-2010), and then future vs present periods (2071-2100) vs (1961-1990) are studied. In both cases, trends or differences are studied, and somehow compared. But both historical periods, purely in terms of temperature are not expected to present large changes, on the contrary to future scenarios analysis, and sometimes comparison of differences between both(e.g., 2°C, line 186 for historical periods, 10°C for future against present in line 201) makes a little bit confusing the interpretation of changes. Of course, differences on the first comparison is of 30 years, and it is of 90 years on the second comparison, when climate change signal is much more important. Perhaps directly study historical period comparing reanalysis against models, and then climate change signal would have been a more clear approach?.

16. My other concern is, related to this point, that if would have been a better results structure to first use the four indices for that historical period analysis (or the evaluation commented just before), and then the same for the climate change signal?. How do the authors would feel about that view?.

17. Several times, changes of the indices could be roughly related to global temperature trends or greenhouse gases rhythm of changes during the analysed periods. I guess if some idea about a potential relation with them could be added or commented during the analysis of the obtained results.

18. Some comments are made about the precipitation role on the annual cycle over some parts of the globe (line 244), and so the dry/wet seasons more than the warm/cold seasons over extratropical regions. Do the authors think that perhaps over some regions the annual cycle of temperature is not very relevant, and so their potential changes?.

19. One final remark: on line 358 it is said that many methods based on monthly variables, but most of the references studies seem to be using daily values, perhaps a more clear statement should be made when talking about other methods.