Paper: wcd-2022-23, entitled “Signatures of midlatitude heat waves in global Rossby wave spectra”,

By Iana Strigunova, Richard Blender, Frank Lunkeit, and Nedjeljka Žagar

Response to the comments by Referee RC2

https://doi.org/10.5194/wcd-2022-23-RC2

Dear Referee,

Thank you very much for your constructive comments on the manuscript.

Following your comments and comments from another reviewer and the editor, we have been largely rewriting the manuscript in an effort to highlight the original aspects of our method and the originality and added value of our results. While the results of statistics remain unaltered, we plan to extend the analysis by showing the zonal- and meridional-scale dependent entropy reduction during the Eurasian heat waves in relation to intramonthly variance reduction. For this purpose, the results section is being extended and some new figures will be added. We also plan to replace ‘midlatitude’ by ‘Eurasian’ in the title, as a more correct wording for the paper content.

Enclosed please find our responses, presented in blue font following your comments in black font.

Your sincerely,

Iana Strigunova, Richard Blender, Frank Lunkeit, and Nedjeljka Žagar

Comment

The authors have applied three-dimensional normal mode decomposition to wind and geopotential fields to investigate structural differences of European heat waves in modal space relative to climatology. They find the skewness of PDFS of planetary-scale circulation is increased by a factor of two, and variance decreases for planetary scales and increases for synoptic scales during the heat waves. Overall, I find this study can provide a unique perspective of heat wave characteristics in modal space, but they may need to put more efforts into interpreting and presenting the results. Below I list several concerns:

1. Please address the significance of the difference in Figs.6,8. Because there are limited samples for the heat waves, is it possible that the diffidence is caused by sampling?

Response: Thank you very much for your comment. We have added in Fig. 8 (to become Figure 8a) the 95%-confidence intervals of the results as obtained through bootstrapping with 1000 simulations. Preliminary figure is included showing that the intramonthly variance

reduction in zonal wavenumbers 7-8 is statistically significant whereas the intramonthly variance increase in the zonal wavenumber 3 is not. The analysis will be complemented by discussing the associated changes in the zonal mean state, not shown in Figure 8.

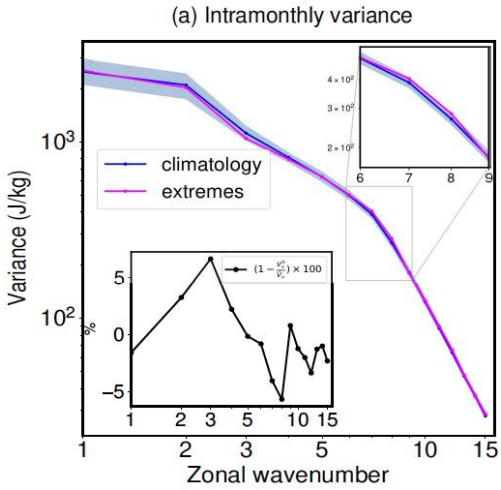


Figure 1: Time-averaged intramonthly variance spectra of Rossby waves for climatology (blue) and Eurasian heat waves (magenta). Averaging is performed over a 40-year period 1980-2019, months May-Sep of ERA5. The embedded bottom left panel shows percentage of relative change whereas the top right inset displays zoomed spectra for k=6-9. The 95%-confidence intervals (blue shading) are obtained through bootstrapping with replacement with 1000 simulations.

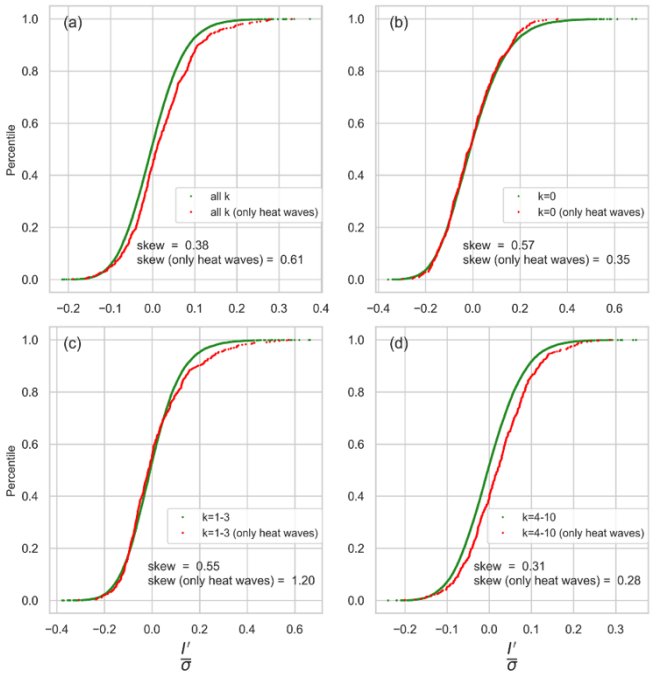
Comment: Based on the presented results, one may also get the impression that heat waves are structurally similar to climatology, except that the amplitude is higher. Should we emphasize the similarity or the difference?

Response: We emphasize differences and add information associated with our holistic method and related results while we also provide references to recent studies of extremes. The revised paper will thus include both aspects and be significantly re-written. For example, we cite previous research by Galfi and Lucarini (2021) of surface heat waves using Large Deviation Theory and by Lucarini and Gritsun (2020) of blockings as manifestations of Unstable Periodic Orbits. They found that the persistent atmospheric patterns associated with surface heat waves are not typical (in the statistical sense) compared to the climatology, but follow a dynamics which is already encoded in the natural climate variability.

Comment: Why are the amplitudes of the two PDFs so similar in Fig.6, while the total number of heatwaves is much smaller than the number of cases used to calculate climatology? I am not sure whether I understand how they defined climatology.

Response: The amplitudes are comparable due to the normalization. The normalization is necessary in order to account for the red energy spectrum with largely different amplitudes associated with various vertical modes. This can be seen from the equation for the computation of modal energy that shows that energy in a single mode involves a multiplication by the equivalent depth. The differences between the climatology and Eurasian heat waves are illustrated in the enclosed figure that shows empirical distribution functions (ECDFs) of normalized total energy anomalies (a) all zonal wavenumbers k, (b) the zonal mean state (k = 0), (c) planetary-scale waves (k=1-3), (d) synoptic-scale waves (k=4-10). Reanalysis dataset

distributions are depicted as green dots for extended boreal summer (MJJAS) 1980-2014 (1980-2019 for ERA5). The distributions during heat waves (denoted “only heat waves”) are depicted as red dots with the values of skewness indicated in the panels.



Comment: What’s the reason to normalize energy anomalies? Does it impact the major results?

Response: The normalization is necessary in order to account for the red energy spectrum with largely different amplitudes associated with various vertical modes. This can be seen from the equation for the computation of modal energy that shows that energy in a single mode involves a multiplication by the equivalent depth. The normalization thus allows us to easily perform statistics in various vertical modes, and to combine visually otherwise different PDFs. We shall explain this aspect in more detail in the revised paper.