

Paper: wcd-2022-23, entitled "Signatures of Eurasian heat waves in global Rossby wave spectra "

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

Dear Dr. Rivière,

Many thanks for your detailed, constructive comments on the revised manuscript. We appreciate it a lot and hope that this second version is a further improvement.

While making changes to address your comment, we performed minor technical changes across figures to make them easier to read and compare (for example, x-axes on the panel of PDFs in Figures 4 and 6 have been made equally). We have re-written the second paragraph of the abstract and made changes throughout the Results section and the Conclusions, aiming at a better presentation of the key findings.

Enclosed please find our responses, presented in blue font following your comments in black font. We are looking forward to hearing from you again.

Your sincerely,

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

Major comments:

Comment:

1) abstract: The abstract is quite short and I am not sure it provides enough physical understanding. In particular, the second paragraph of the abstract is not easy to understand.

- a) The physical meaning of "the skewness in planetary waves" should be more clearly explained. There is space to describe the relationship between skewness and degrees of freedom.
- b) I would replace "the skewness in planetary waves" by " the skewness in planetary-wave energy".
- c) Similar to reviewer 1's comment, I found a bit strange to summarize more the results of section 3.4 and less those of sections 3.2 and 3.3. In my opinion, Fig.6d is an important figure showing the increased synoptic wave energy. Fig.8a completes Fig6d by showing this is mainly coming from wavenumbers 7,8.
- d) Maybe one way to describe the results is to start with the zonal mean flow, then planetary waves and finally finish with the synoptic waves. As it is written now, everything is mixed up in this paragraph and makes the reader confused.

Response: We have re-written the second paragraph of the abstract addressing your comments. We (a) described the relationship between skewness and degrees of freedom, (b) referred to "energy", (c) aimed at a more complete synthesis of our results using (d) the suggested structure.

Comment:

2) Fig.8a and related discussion. The text stays largely focused on what we see on the figures. But there are not enough statements providing a physical meaning of all the quantities computed (see below for more detailed comments on that aspect).

Response: First, we removed Figure 8c and the entropy discussion from the paper completely. At this stage, we think that the entropy did not provide added information on the top of temporal variance.

Comment:

3) Conclusion: there is no attempt to provide a global picture. For instance, the two results on planetary waves are an increase in the skewness and a decrease in the intraseasonal variance. Can these two results be connected to provide a broad picture of the planetary wave behavior during heat waves? Or are these two results entirely independent?

Response: At the end of the conclusions, we added a new paragraph providing a broader and more physical picture of the circulation changes during heat waves based on our results. Revised discussion of Figure 8a provide references to Figure 6. This is reflected also in changes in the Conclusion and Abstract sections.

Minor comments:

Comment: Line 218: The sentence "We apply bootstrapping with a replacement for different wavenumber ranges for a more robust statistical analysis (Fig. 5)." is not clear to me.

Response: We modified for clarification as follows: "The robustness of the statistical analysis in Fig. 5 is checked by applying bootstrapping with replacement for skewness and excess kurtosis with 1000 realizations for every presented wavenumber range."

Comment: Figure 5 / caption: "replacement with 1000 simulations" is not clear to me. I am not sure "simulations" is the appropriate wording.

Response: We removed it from the caption as it is explained in the text and write that "Vertical lines mark 95%-confidence intervals."

Comment: line 233-234: Fig5a--> Fig6a and Fig5b --> Fig6b

Response: We reformulated section 3.2.1 (the discussion of Figures 5 and 6). We now make clear which Figure we actually discuss, which was indeed misleading.

Comments:

- Paragraph from lines 233-240: Fig6d is an important figure and should be described.
- Lines 249-253: The discussion on the change in PDFs of synoptic Rossby waves is not precise enough and does not refer to any figure. In my opinion, Fig. 6d shows there is more energy in synoptic waves during heat waves as said in the text. But why is this figure not cited in the paragraph ?

Response: We reformulated section 3.2.1 (the discussion of Figures 5 and 6) to give a more thorough description and discussion of Figure 5 and Figure 6 with respect to the identified changes. As the changes are numerous, we do not copy them here but refer to the pdf of the revised paper with all changes highlighted.

Comment: Line 275-278: In my opinion, Fig7f confirms the amplification of wave-3 pattern during heat waves as shown in the cited studies. I think the authors should explicitly say this is a confirmation of previous studies (maybe in another geographical area ?).

Response: We now explicitly state that " The results in Fig.7 align with Teng and Branstator (2012) and Ragone and Bouchet (2021), where the zonal wavenumber $k=3$ pattern was found dominant for HWs that occurred in the US, France and Scandinavia. Therefore, the results demonstrate that changes in atmospheric circulation during surface extremes occur not only regionally but also in remote regions, similar to the idea of teleconnection patterns noted in recent studies (e.g. Kornhuber et al. 2019).

Comment: Line 286 / Eq (8): Is χ_{ν} the same as $\chi^k_{n(m)}$?

Response: Yes, this is defined in the 4th line of Section 2.3.

Comment: Eq. (9): what does the superscript "h" mean? I imagine it refers to heat waves. What about V_{ν} ? Is it a climatological value? or is it a value that is computed for every month?

Response: We added the clarification: "Intramonthly variance is computed for all months and averaged to create the climatological variance spectrum, V_{ν} . The averaging over all months with heat waves produced the variance spectrum V^h_{ν} (Here we drop extra signs for the averaging operator)."

Comment: The physical meaning of the decreased variance in wavenumber 3 is never provided. Does it mean that wavenumber 3 is quasi-stationary during months marked by heat waves?

Response: We have expanded the discussion of Fig 8 and added respective changes in the Conclusions.

Comment: The zooms in Fig.8a are not clear enough to conclude about the significances of the reduction in wavenumber 3 variance and the increase in wavenumbers 7,8 variance. Both cases show values very close to the 95% confidence.

Response: We added the 95%-CI also in the inset figure of Figure 8a. The fact that the values are not far inside/outside the confidence interval is now clear.

Comment: The paragraph from lines 313 to 325 is not easy to read. Please insert "to" after "close" in line 317. I am not sure "barotropicity" exists. Maybe replace by "barotropic structure". The sentence starting by "Note that Fig.9" is difficult to understand.

Response: We have re-written and simplified this paragraph.

Comment:

Line 347-348: The authors should help the reader to physically interpret the skewness in energy anomalies. If the distributions of the zonal mean state and planetary scale circulation are more skewed than that of synoptic scales, what does that mean physically? Does it mean that the planetary wave energy is concentrated in a very limited number of planetary scale modes? In my mind, the reduction of the active degrees of freedom during heat waves means that there are only very specific modes that are excited. Am I right?

Response: We tried to give a physical interpretation of the skewness during the discussion of individual results and at the end of the conclusion by adding a "broad picture". The numerous changes can be seen in the annotated pdf.

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Response to the comments by Referee RC1 (second revision)

<https://doi.org/10.5194/wcd-2022-23-RC1>

Dear Referee,

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

Following your comments and comments from the editor, we have performed the additional revision of the paper taking chance to also improve some of figures technically. We have re-written the second paragraph of the abstract and made changes throughout the Results section and the Conclusions, aiming at better presentation of the key findings.

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

Your sincerely,

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Comment:

The statement claiming that there is significant difference between intramonthly variance climatology and heat wave events is a bit weak given there were only a few heat waves events in the analysis to bootstrap from. (It is hard to read from Fig 8(a) that the percentage of relative change for $k=6-9$ has points outside the 95% confidence interval). This claim shall be verified with GCM simulations, which will be out of scope of the current study. It would be better to change the abstract a bit to focus on Results in session 3.1-3.3 and put less focus on 3.4.

Response:

As the Abstract has been largely rewritten, we do not reproduce it here. The revised second paragraph of the abstract hopefully offers a clearer presentation of all our key results.

Figure 8a has been improved by adding the confidence interval in the inset figure. We added the sentences about the sample size and the possible application of GCM simulations to gain more robust results. However, we also note that we do not expect large deviations to be found due to the global scale of analysed data.

Specific comments

Comment: I think the logic between the two sentences in lines 250-253 is not clear. Probably the authors have to add one more sentence before “More intensive cyclones and anticyclones

are found to maintain blocking...” to explain why their findings are consistent with the world of Shutts 1983 and Yamazaki and Itoh 2013.

Response: We have re-written the discussion of Figures 5 and 6 in section 3.2.1. New lines corresponding to the previous lines 25-253 state that “The shift can be interpreted as increased positive deviations in the synoptic-scale energy during heat waves. More energy in synoptic-scale circulation can be viewed as more intensive cyclones and anticyclones which are found to maintain blocking by eddy straining (Shutts, 1983) and selective absorption (Yamazaki and Itoh, 2013) mechanisms.”

Comment: Fig. 8(b) and (c) would better be changed to “variance/entropy change” instead of “variance/entropy reduction”, and have the color axis swapped such that red refers to increase and blue refers to reduction. Confusing double negative statements can be avoided.

Response: We removed Figure 8c and the entropy discussion from the paper completely. At this stage, we think that the entropy did not provide added information on the top of temporal variance. The figure title is changed to “Variance change” as suggested and the color axis has been swapped.