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 RC1

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Dear Referee,

Thank you very much for the comments on our 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 response, presented in blue font follow your comments in black font.

Your sincerely,

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

Comment:

Summary of the article

This manuscript isolates heat waves events, defined as episodes which spatially averaged surface temperature in Eurasia are above 95% percentile on at least 3 consecutive days, and compare their spatial spectra of energy anomalies of various ranges of wavenumbers with the climatology. This work finds that during heat waves, the skewness of planetary waves grows while that of the zonal mean flow goes in opposite directions, which is consistent with previous findings.

General comments

I am concerned about the fact that the analyses done in this work all confirm previous findings but provide no additional insights to how we understand heat waves/blocking. It has been well-known that heat waves are associated with blocking since blocking, by definition, refers to the phenomena in which (1) the eastward zonal wind is disrupted (increase in wave amplitude essentially implies weakened zonal wind, as implied by non-acceleration theorem) (2) the high pressure cell remains stagnant for a few days, (Therefore, reversal of zonal wind

and geopotential height anomalies have been used to define/detect blocking.) which, this manuscript essentially shows.
There have been many studies showing blocking being the culprit of heat waves in the eurasia region as confirmed by the analyses here. Therefore, in order to be accepted for publication, the authors should have shown what extra insights about heat waves can we obtain from these analyses, which I think the current version of manuscript is lacking.

Response:
We thank the Reviewer for the comments expressing a concern about the lack of added insights about heat waves in our analysis. We think that our efforts to validate the use of three-dimensional, global spectral decomposition in terms of normal-mode functions as a suitable tool for signatures of regional heat waves in global circulation, somehow masked the originality and added value of our results. While we shall re-write parts of paper to point out original aspects of our study, let us state that to our knowledge, previous studies did not quantify the skewness of global circulation at different scales of the Rossby waves during the Eurasian heat waves. We are neither aware of other research showing what aspects of the global circulation, as measured by PDFs of anomalies in the total energy, are affected by the Eurasian heat waves. Novelties of our study can be split in three parts:

1. **Method:** Our method is novel in its identification of Rossby waves using a multivariate spherical projection on the Rossby eigensolutions of the linearized primitive equations. This provides time series of Rossby waves in terms of Hough harmonics, that can be seen as the spherical equivalents of the geostrophic stream function on the midlatitude beta plane. Scale-selective Rossby wave filtering in physical space is seen as an advantage compared to univariate filtering using the Fourier series along the latitude circles. While we focus on Rossby waves or balanced dynamics, the difference to the total signal in terms of inertia-gravity modes can be used to analyse whether midlatitude ageostrophic flow (unbalanced dynamics) increases during the Eurasian heat waves. We combined the four modern reanalysis datasets to provide robust results.
2. **Statistical properties of global balanced circulation during Eurasian heat waves:** We show that the energy distribution of a single Rossby mode follows a Chi^2-distribution. Our scale-dependent statistics, performed on the normalized energy anomalies, shows that the energy distributions of the zonal mean state (zonal wavenumber k=0) and of the planetary-scale (k=1-3) circulation are more skewed than the distributions at synoptic and smaller scales, with extended right tails. During the Eurasian heat waves, the skewness in planetary waves increases while the opposite occurs in the zonal mean flow. The increase in skewness can be linked with a decrease in the number of active degrees of freedom in state space during heat waves. This aligns with the results of Lucarini and Gritsun (2020) which are based on the atmospheric stability during Atlantic blockings. Based on the Chi^2-skewness, we estimate a reduction of active degrees of freedom during Eurasian heat waves of about 25% compared to climatology.
3. **Intramonthly variance and entropy during heat waves:** We showed that intramonthly variance and entropy decrease at planetary scales (k=3) and increase at synoptic scales k=7-8, consistent with the well-known prevalence of atmospheric blocking regime during surface heat waves. However, for the limited dataset of heat waves, only the synoptic-scale variance and entropy increase is found statistically

significant. Future studies with longer datasets, such as climate model outputs are an opportunity for both models' validation and larger datasets of extreme events.

Specific comments

Comment: There is one sentence in the manuscript that I find confusing in Section 3.2: “Under the global variability spectrum, we imply the PDFs of the global energy anomalies and under signatures of heat waves, we imply significant changes in the distribution of energy anomalies.” If the authors have new findings and plan to greatly revise and resubmit the manuscript, please rewrite this sentence with clarity.

Response: The sentence is rewritten. Its revised version explains that the term global variability spectrum refers to the PDFs of the normalised anomalies in global energy, and the effects (or signatures) of heat waves imply significant changes in the distribution of energy anomalies during the Eurasean heat waves.