Interactive comment on "Global warming makes weather in boreal summer more persistent" *by* Dim Coumou and Paolo De Luca

Anonymous Referee #3

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The paper uses a new dynamical systems approach to study trends in the persistence of weather over the last 4 decades, and projected trends into the future using general circulation models. Through analysis of re-analysis data (ERA5) they show that, by this new metric, weather has become more persistent over a number of regions of the northern hemisphere since 1979, in particular over Europe. This increase in persistence is also shown in a multi-model analysis of CMIP6 models, although the models show much stronger trends than the re-analysis data, and show statistically significant trends over many more regions. Projected increases in persistence are found for the SSP585 future scenario, with weaker trends for SSP126. Overall this is an important question, and this is an interesting approach. There is certainly added value in applying multiple methods to understand how anthropogenic warming will affect the persis-

tence of weather through atmospheric dynamics. However, I have a number of major concerns with this paper that would need to be addressed before I could recommend publication.

Major concerns

- The results using sea-level pressure and Z500 differ significantly at regional levels (and the strength of the trend differs for the whole mid-latitude band). There is no discussion of this, and the implications for the results. Indeed, if one was to interpret the results for SLP, out of the 15 sub-regions, only over the Mediterranean region do we see statistically significant trends in both the re-analysis data and the model, which would be a very different conclusion. In addition, one region (NEU) seems to show a statistically significant decrease in persistence in SLP in the model data, and yet a highly significant increase in persistence in Z500? This makes me question the strength of the conclusions as stated in this version of the paper. Given that this dynamical systems approach is a relatively new method, and it is not intuitive to understand how a simple increase in temperature might influence the results at Z500 differently to those of SLP, I would like to see much more analysis and discussion of this aspect.

- The trends shown by the model are generally much stronger than those shown in the re-analysis data (this is true for both Z500 and SLP), and this is not addressed in any meaningful way. Whilst we would expect reality to be much noisier than the multi-model mean, this discrepancy between models and re-analysis results may be able to tell us something interesting about the method and how we should interpret the results. It is also relevant to the interpretation of the future projections from the model, which might be over-estimating the persistence trend based on the comparison of the last 4 decades.

- Analysis of results for low-dimensionality – this is an interesting part of this method, but these results are barely analysed or discussed, they are simply mentioned in passing on line 205, and the figures are in the supplementary material. The definitions on

lines 125-135 do not even define σ. I would like to see more discussion and interpretation of this result – does a reduction of dimensionality imply reduced variance, i.e. a reduced number of states the system ever evolves into, or is it a direct result of the increased persistence, i.e. a reduced variance of states the system evolves into from a particular state, because it is more likely to remain in a similar state for longer? This aspect could be expanded further, and would form a useful part of a larger dialogue of how to define and study weather persistence.

- Figure S6: I would be interested to see similar regression analysis figures but for the change in average temperature in the region, rather than the change in U – if we see a stronger relationship with the change in U than with T, this would support the mechanism the authors are proposing for the changes they see. It would also be interesting to see such figures for the historical period in both re-analysis data and model data, with, for example, the linear trends of U and persistence over the period. This would help answer whether the differences in results in different regions are because of regional variability in U trends. Such analysis would also help the community better understand the dynamical systems metrics and what they tell us about the climate system, which would be a valuable contribution.

- Overall: the authors argue that advanced techniques such as this dynamical systems approach are essential (e.g. line 214), but I don't see any evidence for how this approach provides better results than others. I agree with some of the arguments made in the introduction and discussion about limitations of other methods, but there is little discussion or acknowledgement of the potential limitations of this method, which, given the discrepancies and biases that can be seen in the results, I think are critical to address. Research using new metrics such as this is very valuable, but we should not start with the assumption that the results are better than those in previous literature, just because they are based on more complex analysis. I'm also unsure why the paper is structured to have so much information in the supplementary material; this material is barely referenced in the main paper, or explained fully in the supplementary material,

C3

and I think a lot of it is relevant to the bigger picture. I would recommend the authors to restructure the paper to present a more thorough and in-depth analysis of their results, with conclusions that seem more in line with the discrepancies and model biases that the results show.

Minor comments

- Line 129: what do you mean the parameters are sensible to ξ?

- Line 228: does this suggest that the recent particularly strong increases in extreme events over Europe are more to do with natural variability, and only somewhat related to anthropogenic warming?

- Lines 259-265. I would be interested to see a more detailed discussion of how these results fit in with the broader literature on this topic.

- Line 281: "similar upward trend" – the models show upward trends, but I wouldn't call them similar. The trends in the models are much stronger and more widespread in the re-analysis (see major comments).

- Reference: Anon 2016: what sort of reference is this? Is there a URL for this?

C4