Review for manuscript "Diverging hydrological drought traits over Europe with global warming"

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Summary

Cammalleri et al. present a study on low flows/droughts in Europe under three different global warming levels (1.5, 2, and 3K temperature increase). They use the hydrological model LISFLOOD to simulate streamflow for a reference period (1981-2010) and for future 30-year periods corresponding to the three warming levels using an ensemble of future climate projections as model input. The model setup allows for the consideration of human water abstraction from the hydrological cycle. They determine the drought characteristics deficit, duration, and frequency for the reference and the future periods using a fixed drought threshold at the 15th flow percentile. Drought frequency is assessed using univariate return periods with respect to the deficit variable. The characteristics of the future periods are compared to the ones of the reference period. The study shows that the response of droughts to warming differs regionally within Europe. The Mediterranean and Atlantic regions are projected to be affected by longer, more severe, and more frequent droughts in future, while the Continental and Boreal regions are expected to experience shorter, less severe, and less frequent drought events. In addition to the drought characteristics assessment, the authors present an assessment of drought exposure with respect to population and agricultural area showing that the Mediterranean region needs to expect an increase in exposure both in agricultural land and population while the opposite is the case for the Continental region.

General comments

I appreciate the additional methodological specification added to the methods section, which helped to clarify a few details. However, I still have one major concern regarding a proof for model suitability for drought analysis in Europe. I really think that presenting one summary figure of model performance in terms of different drought characteristics in the methods section would strengthen trust in the key messages of the paper. Such an evaluation seems particularly important because the model was calibrated and validated at a global scale with a focus on floods instead of droughts (l. 144-146). In addition, I have a few minor suggestions. I see further room for more explicitly working out the novelty of the paper in the introduction. Because the human demand projections seem to be the major contribution of this study, I would dedicate some more attention to them in the discussion part. I also suggest a few minor modifications to the Figures, which may facilitate reading them, and to put some additional effort into editing the paper with respect to sentence structure, the use of commas, and wording.

Specific comments

Introduction: I would still more explicitly state the two main aims of the study in the introduction: (1) quantify the impact of climate change on drought characteristics under three different global warming levels and (2) assess the effect of projected climate change on the population and agricultural land exposed to drought.

Methods: The methods section has considerably improved in clarity. However I would still expect some actual proof for the suitability of the model for drought analyses in Europe. As I suggested in my earlier review, this could be achieved by comparing observed to simulated drought characteristics (duration and deficit) for a set of example catchments. In addition, the description of the Lomax function needs to be revised.

Results: The figures are clear and the results well presented. I suggest some minor adjustments to the Figures.

Discussion: I think that the demand projections deserve some more attention in the discussion section because they distinguish this study from previous studies on future droughts in Europe. I would e.g. look at the contributions by [*Wada et al.*, 2016; *Graham et al.*, 2018] who look at future demand projections under different socio-economic pathways scenarios.

The study reads generally well on a paragraph level but would still profit from editing on a sentence level and from a consistent use of tense. I am going to make a few examples under 'suggested edits', however, this list is not exhaustive.

Minor points

- When talking about the analysis performed in this study I would consistently use the term drought instead of low flow (e.g. l. 14, l.182, l.184, l.189).
- I would appreciate a consistent use of tense when describing methods. L. 16 e.g. uses the past tense ('was') while l. 14 uses the present ('employ'). There are other instances in the text where tense is used inconsistently and I would pay particular attention to this aspect when editing the manuscript. Other examples are 'focuses' on l.120 and 'used' on l.116.
- A few phrases would profit from the specification of 'this' or 'these', which are sometimes used in isolation without a clear reference (e.g. l.54 'This is also highlights'). I suggest going through the manuscript and replacing these instances by more specific terms. On l.54 e.g. This focus on meteorological drought? Another example is: 'this issue' on l.92: which issue?
- L. 127-132: I would clearly highlight that this statement is an assumption because it is not intuitive and also not in line with some of the literature out there. I agree that this assumption is in some cases useful, I just think it should be openly declared as an assumption and not as a fact.
- L. 157: what about the non-member states such as Norway or Switzerland? They are still part of the analysis.
- L. 206-208: I think that this description of the Lomax function is not entirely correct. The Lomax function has 0 support and a mean of kappa/(alpha-1) and is only defined for alpha > 1. The statement that the 'location parameter is equal to zero' is therefore wrong. Please also provide a reference to the publication, where this distribution was first introduced.
- Would move l. 217-218 to l.211. Was this goodness-of-fit testing done for the same catchments used in this study (or a subset of them)?
- L. 289: It seems that there are just two river basins in Denmark which were actually considered in this analysis. Are they representative of the Danish hydrology? I would maybe refrain from specially mentioning it.
- Were livestock and domestic use kept constant in future? If so, why? If not, please shortly describe the estimation procedure used.

- L. 246: I agree with reviewer 2 that some significance testing would be highly desirable. If this is not done, please at least mention that no significance testing was done and that the definition of 'robustness' entirely relies on the sign but not the significance of change (l. 243-246).
- L. 442: I think this decrease in summer streamflow is not only due to less precipitation but also smaller snowmelt contributions see e.g. [*Stahl et al.*, 2016; *Jenicek et al.*, 2018].
- L. 452-454: I think that these statements need references. And as mentioned above, I think that this section about water use should be expanded.
- L. 477-482: I think that this information is partially redundant and could be merged with the introduction and methods.
- Data availability: please specify from whom the data can be requested and what subset will be made available through the JRC data hub.

Figures

- I would add lables (a), (b),… to all subfigures presented. This would facilitate referencing in the text.
- Figure 2: When I first looked at the figure, I was confused by the two inversed scales. I understand now why they are useful. Still, a note in the figure caption would be helpful.
- Figure 3: I would indicate the medians for all PDFs to facilitate following section 3.1.3. The tick marks are clearly not 'uniformly' spaced as indicated in the figure caption.
- Figure 4: I would indicate that the x-axis labels differ between subplots.
- Figure 5: I would indicate the country abbreviations on Figure 1d and I would limit the scale to +/- 4 in order to improve legibility and reduce white space.
- Figure 6: Similarly, I would limit these figures to +/- 3.
- Tables 1 and 2: I would write 'total' instead of 'tot'

Suggested edits

- L.23: suggest rephrasing to 'is expected to experience' instead of 'sees' to be less deterministic.
- I suggest replacing the keyword 'low-flow index' by 'human water use' and 'frequency analysis'.
- L.44-46: suggest rephrasing the sentence to something like: 'A specific drought type may be perceived most relevant for a given application and various indicators may experience different effects of climate change.'
- L. 49: suggest replacing 'climate projection of' to 'impact of climate change on'.
- L. 53: suggest replacing 'with the latter usually requiring' by 'whose analysis usually requires'.
- L. 66: maybe rather use 'domain' instead of 'extent'?
- L. 76: remove 'of' in front of 'past'.
- L. 81: has it already shifted or is it still shifting?
- L. 88: the word 'annual' confused me here. Was the threshold not determined using daily streamflow values?
- L. 90: remove 'a' in front of 'key'.
- L. 92: By 'this issue', do you mean 'future drought changes under the influence of climate change and water abstraction'?

- L. 95: would rephrase to: ' the threshold level method for event extraction, which allows for a detailed frequency analysis of different streamflow drought characteristics including severity, duration, and frequency.'
- L. 100: incorporate's'
- Would remove l.105-108 or merge with l.56-58 to avoid redundancy.
- L. 112-113: What is the purpose of this sentence in the introduction? Would more this to the methods section.
- L. 124: suggest replacing 'over' by 'compared to'.
- L. 126: what does 'on average' refer to? All model runs? Also suggest replacing 'at' by 'in'.
- L. 134: suggest adding 'a' in front of '5'.
- L. 140: snow accumulation and melt.
- L. 161: I wonder how relevant 'paddy-rice irrigation' is in Europe? If this is irrelevant in Europe, I would exclude its description (l. 164-165).
- L. 166: is 'a' function of…
- L. 172: what about non-urban but still populated areas?
- L. 173: corresponding to what?
- L.185: please mention that Q85 refers to exceedance probabilities.
- L. 190: 'volume' instead of 'area'?
- L. 192: suggest removing 'temporal'.
- L. 194-198: I would reorganize this sentence and swap 2) with 1) because of the order of the two elements in the first part of the sentence.
- L. 198-201: This information seems to be redundant with information provided on l.194-195 and can in my opinion be removed.
- L. 202: Following this 'drought' definition,..
- L. 203: 'was' derived. Would also remove 'huge'.
- L. 215-217: what is the purpose of this sentence here?
- L. 221-2023: I think this sentence needs rephrasing.
- L. 231-234: rephrasing recommended.
- L. 237: aggregate'd'.
- L. 251-255: I think this sentence needs rephrasing.
- L. 260: Atlantic 'region'.
- L. 266: replace 'halve' by 'half'.
- L. 287: the rest 'of the region' shows…
- L. 297: longer droughts 'with increasing GWL'.
- L. 300: longer 'than 5 days'. Applies to the whole section: longer than 'what'?
- L. 307: last longer 'than in the reference period'.
- L. 318-319: This statement does not seem to be true for the Boreal region at 3K.
- L. 324: Figure three seems to show densities not distributions.
- L. 357: clear'ly'
- L. 361: maybe specify, i.e. the rarer events.
- L. 403: 'change' patterns?
- L. 405-408: think this sentence needs rephrasing.
- L. 409: would replace 'temporal horizons' with 'time periods instead of GWL'.

- L. 414 and other instances: I would not use the word 'negative' and 'positive' because they don't seem to be used in an objective sense in terms of – and + but rather in the sense of perception. See also L. 431 'positive', which could be replaced by decreasing.
- L. 422: would replace 'symmetrically' by 'in contrast'.
- L. 425: 'are' instead of 'is'.
- L. 434: supply '(precipitation)'?
- L. 443: would delete 'for the Paris warming targets'.
- L. 447: What does 'this' refer to?
- L. 450: would delete 'months'.
- L. 467: region 'are' expected
- L. 468: would replace 'symmetrically' by 'in contrast'.
- L. 473: by 'mostly well defined', do you mean 'robust'?
- L. 487: would swap the order of 'here' and 'analysed'.
- L. 490: agricultural 'land' exposed in 'the' southern…
- L. 492: what does 'this' refer to?
- L. 494: less 'frequently'.

References used in this review

Graham, N. T. et al. (2018), Water sector assumptions for the Shared Socioeconomic Pathways in an integrated modeling framework, *Water Resour. Res.*, *54*(9), 6423–6440, doi:10.1029/2018WR023452.

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Stahl, K., M. Weiler, I. Kohn, D. Freudiger, J. Seibert, M. Vis, and K. Gerlinger (2016), *The snow and glacier melt components of streamflow of the river Rhine and its tributaries considering the influence of climate change*, Freiburg.

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