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Summary

This paper analyses global soil moisture drought using data derived from the SoilClim and mHM models from 1980 to 2022. A drought catalog was compiled based on severity and dynamic drought classifications utilizing a threshold approach and the OPTICS clustering technique. The authors identified hotspot regions for extremely severe and extremely dynamic drought events in the South American region and North America. The longest and most extensive droughts occurred in Eurasia. The authors highlighted an increase in global land drought events over the past decade. Furthermore, they also suggest that this study may serve as a basis for future investigations into drought drivers and impacts.

Assessment

This paper presents a new technique to analyze drought classification based on severity and dynamic classifications. The manuscript is interesting and well written. I have a few minor comments below and three general comments, but only for clarification and improvement. I believe this work is well suited for publication in HESS.

Response: We would like to thank the reviewer for his in-depth assessment of our manuscript.

General Comments

I have two general comments regarding the manuscript but all of them are only for clarification, suggestion, and improvement of the manuscript.

I am curious as to why did the authors combine Europe and Asia continents into a single region called Eurasia? This combination results in a significantly high number of Global Land Drought Events (GLDEs) in this region, as depicted in Figures 3, 6, and 10. Furthermore, as a reader, I would prefer to see separate results for Europe and Asia. I suggest splitting the Eurasia results into distinct sections for Europe and Asia. This approach would likely be more engaging for readers from these two continents.

Response: We understand that our use of Eurasia as one continental area is an unusual or not so frequently used approach. We understand, that division of Europe and Asia might be rooted very deep from political, economic, societal and cultural standpoints, but from the standpoint of physical geography the border is practically non-existent and just divides artificially a large continental area in two parts. Moreover, during the data processing we found out, that there is a surprisingly large number of GLDEs with large areas in both Europe and Asia, particularly among the largest GLDEs. The area around the geographical border of Europe and Asia, particularly Eastern Europe, Central Asian and Western Siberia, comprises of extensive plains, almost without any orographic barriers and therefore it is ideal for both formation and movement of large GLDEs. From these reasons, the division of these GLDEs between Europe and Asia for the statistical summaries seems very problematic and impractical, so we would like to keep the entire area as one “continent”.

I am confused about the ongoing drought occurrences from November 2004 to December 2022 in Table 1, which spans over 18 years. How did you analyze this multi-year, prolonged drought duration in Eurasia? I believe this period likely consists of multiple drought events in Europe and Asia occurring from November 2004 to December 2022 in different regions. Please correct me if I am mistaken. Additionally, how does this analysis account for the European drought of 2003?

Response: The SoilClim model results delimited this GLDE as continuously existing area of drought, moving particularly through Siberia, Eastern Europe, Central and Eastern Asia without ceasing to exist for the entire period since November 2004. It needs to be noted that it was not always extremely large or intensive, but it fulfilled our basic conditions for its delimitation and it had multiple "peaks" during the period. The mHM results are not entirely different in this instance, however, this event was separated into two (still quite long) GLDEs. Concerning a deeper analysis you mention – this is actually a next step we are planning to take in the future, when we want to focus on these few extremely large, intensive and dynamic events and investigate them further. However, this is something that could not be fitted into this manuscript, which serves a purpose of presenting our methods of GLDEs delimitation and their basic statistical overview.

In this paper, the authors present many figures but the explanation about the findings is limited. For example, Figures 1 and 2 are described in a single paragraph, whereas a more detailed discussion of the findings would be beneficial. In Figure 1, why is the scatter in (a)-(c) greater than in (b)-(c)? Similarly, in Figure 4, why is the relationship in (a)-(b) more linear than in the other panels? Additionally, I believe it would be more useful to provide the average findings from both the mHM and SoilClim models.

Response: Accepted, to follow your recommendations for more detail discussion of figures, we added further description as follows:

… Some plots of pairs from the four characteristics in Fig. 1 display the grouping of GLDEs into lines because there are many GLDEs with the same value (meaning the same score assigned to them) in the case of a single-digit number of 10-day intervals. The largest scatter is present in the duration and maximum extent relationship, which shows that drought with longer duration does not necessarily have to reach large extent. On the other hand, the relationship between duration and total extent is much stronger, as it is a cumulative value. The described features of the scatterplots in Fig. 1 are confirmed in the boxplots of these categories,…

… Compared to the four characteristics of severity classification (Fig. 1), they show more consistent patterns with more concentrated fields of related points, particularly for categories that include GLDEs with average movements (category 4d) to extremely static droughts (1d). The very strong relationship between maximum and total centroid distance proves that GLDEs with long trajectory are usually not just oscillating around the same area but actually move through continents. The box plots of these categories are shown in Fig. 5, …

Concerning the "average findings" from mHM and SoilClim results, the aim of the article was to present enough robust methodology of GLDEs cataloging and document its employment for two independent data sources represented for both mHM and SoilClim models to demonstrate that

the classification method works well for both models. The aim of the paper is not comparison of the two different model outputs. From these reasons we took results from both models separately and we compared them directly in Figure 15 and Table 5. In our future research we suppose to combine the data from both models before the clustering itself. Moreover, we have been aware not to add additional layer of uncertainty to the first use of our clustering and cataloguing approach.

Line by line comments

L refers to line and P refers to page.

P2L41: Maybe write examples of traditional meteorological drought indices, e.g., SPI and SPEI?

Response: Accepted, the paragraph was extended as follows:

… To understand the spatiotemporal variability and severity of droughts, meteorological drought indices (e.g., Standardized Precipitation Index – SPI, Standardised Precipitation-Evapotranspiration Index – SPEI or Palmer Drought Severity Index – PDSI) have traditionally been used (e.g., Spinoni et al., 2014, 2015, 2019; Chiang et al., 2021; Fuentes et al., 2022; Vicente-Serrano et al., 2022), …

P3L87: The evapotranspiration method should be mentioned.

Response: Accepted, the paragraph was extended as follows:

… The daily minimum, maximum, and mean temperatures are also used to obtain potential evapotranspiration estimates (Hargreaves and Samani, 1985), for which the Penman-Monteith method as described by Allen et al. (1998) was used. Our simulations are based …

P4L100-101: Please write what is D2 and what is S2 for readers who are not working with the US drought monitor and Czech drought monitor, respectively.

Response: Accepted, the names of both categories used withing the drought monitors were added as follows:

… Drought occurrence has been identified using the 10th-percentile drought, which is in line with using this threshold in US Drought Monitoring (Svoboda et al., 2002) since 1995 for the "D2" category ("Severe Drought") definition and in the Czech Drought Monitor System (Trnka et al., 2020; Intersucho, 2024) since 2012 as the "S2" ("Moderate Drought") category. To assess the most severe drought, the 2nd-percentile drought (i.e., 50-year return period) was calculated using the same approach. …

P4L115: What do the authors mean with the total sum of areal extent of 2nd percentile drought? Why not 10th percentile as well?

Response: The 10th percentile serves as our basic threshold. However, we wanted to include information about intensity of given GLDE into the classifying process. Therefore, we calculated

the extent of area of even much more extreme drought, based on 2nd percentile (return period of 50 years), within the every 10th-percentile-based GLDE and used it as fourth characteristic.

P5L150: Maybe replace the word “are variable” with “vary”?

Response: Accepted and corrected.

P6: Figure 1. Maybe make the legend (colored circles) bigger? Also I prefer to label all figures with letter a, b, c, and so on.

Response: We made the legend larger, but we would like to preserve our marking (a)–(b) etc., because it identifies a corresponding pair of the characteristics used in figure.

P7: Figure 2. What are upper and lower quartile? Are they 75th and 25th percentiles?

Response: Accepted, we changed the caption of Figure 2, to … median, 75th and 25th percentiles, maximum and minimum…

P8: Please use comma to write number million in all tables. For example: 6,701,638.

Response: Accepted and corrected.

P12L227-228: Here the authors mention about centroid movements. However, I could not see these values in the Table 2. These values should be written in the Table or somewhere.

Response: The centroid movements are represented in Table 2 by the “Dynamic scores”, corresponding to the movement characteristics defined in Section 3.3

P17L295: The authors may move the word “(Fig. 11)” to the end of sentence.

Response: Accepted and corrected.

P24L380: Maybe provide references about the uncertainties of SoilClim model.

Response: Accepted, following publications were added as reference for SoilClim uncertainties:

… In the SoilClim model, there are uncertainties related to the schematization of individual processes, soil profile vertical discretization, and other scale-related assumptions (e.g., each grid cell is represented by dominant landcover), described in detail in Hlavinka et al. (2011), Trnka et al. (2020) and Řehoř et al. (2021). …

P24L397: The authors could explain the potential alternatives for drought clustering as proposed by the cited literature.

Response: Accepted, the paragraph was extended as follows:

... Potential alternatives for drought clustering have been proposed for example by Andreadis and Lettenmaier (2006), Vidal et al. (2010) or Samaniego et al. (2013), including stepwise selection of continues drought areas, k-means cluster analysis or Density-based spatial clustering of applications with noise (DBSCAN), which is alternative to OPTICS, using similar approach. …

P25L402-403: Here the authors mention drought event in North America, which appeared around the center of the continent. However, I could not see any Figure showing the centroid of the drought events. Why don't the authors provide this figure in the appendix or supplementary material?

Response: We added a figure depicting all centroid positions of this event into the supplementary material.

P26: Table 5. Maybe in this table the authors can provide the average results of SoilClim and mHM.

Response: Because both model outputs lead to a different number of GLDEs, simple averaging of these data in terms of long-term trend seems not to be suitable from methodological point of view.