Response to Editor and Reviewers

Manuscript ID HESS-2021-541

Journal: *Hydrology and Earth System Sciences*

Article title: Analysis of flash droughts in China using machine learning

Author list: *Linqi Zhang, Yi Liu, Liliang Ren, Adriaan J. Teuling, Ye Zhu, Linyong Wei, Linyan Zhang, Shanhu Jiang, Xiaoli Yang, Xiuqin Fang, Hang Yin*

Dear reviewers and editor:

Thank you so much for valuable comments and kind suggestions on our paper. Your illuminating comments and suggestions give us the possibility to properly fix several questionable issues, and to improve the overall quality of the paper. We highly appreciate your time and effort. Please find our point-to-point responses to your comments below.

Response to reviewer #1

The authors have addressed my questions on the first round of the manuscript. I recommend the paper for final publication in HESS.

Response:

We thank the reviewer for the positive comments on our study. Hope this manuscript can be accepted by HESS journal.

Response to reviewer #2

Zhang et al. (2022) quantified the relationship between the rate of intensification (RI) of flash drought and nine climate variables using three machine learning methods across China. This manuscript is written clearly, and it is an interesting study, particularly by linking different climate variables to the rate of intensification of drought. The results show that the random forest is preferable for estimating the flash drought rate of intensification and monitoring flash droughts in adjacent weeks of drought onset. This is my first time reviewing this manuscript. As I read the earlier discussions with Reviewers and the Author's replies, the manuscript has improved significantly since the original submission (e.g., analysis of the spatial distribution of frequency of occurrence of flash droughts in different seasons over China). The manuscript is written clearly. I have just a few extra comments, which authors should clarify.

Response:

We thank the reviewer for the positive comments on this work and please see our responses in detail below.

Comment 1: The reanalysis ERA5-Interim soil moisture product is independent of the meteorological data used in the study. Did you consider checking the differences in the observed-based meteorological forcing data and the ERA5-Interim in-built meteorological forcing data? Additionally, please clarify why you are using ERA-Interim and why you did not use the ERA5; on the website of your data link, it is written: "ERA Interim is being phased out. Users are strongly advised to migrate to ERA5."

Response:

Thanks for your comment. Indeed, we used observed meteorological forcing in this study, though the ERA-Interim product has its meteorological forcing data. There are two reasons: On the one hand, ERA-Interim in-built meteorological forcing data in China were constructed based on a few meteorological stations, while 756 national observations were employed in this study. On the other hand, we considered moisture-limited and energy-limited factors to reflect meteorological driving forces conditions, while some of these data (e.g., potential evapotranspiration, relative humidity) were not included in the ERA-Interim dataset. Based on the above consideration, we used ground-based meteorological forcing data.

About the reason we chose ERA-Interim soil moisture in this study, we have three points to explain. Firstly, ERA-Interim and ERA5 soil moisture show good consistency in temporal against in-situ soil moisture. In the study of Ling et al., (2021), they evaluated the difference between satellite remote sensing (i.e., ESA CCI) and global reanalysis of soil moisture datasets (i.e., ERA-Interim, and ERA5). They found that both ERA-Interim and ERA5 soil moisture can reflect the tendency of time series and display a good agreement with observed stations relative to ESA CCI soil moisture. Secondly, we converted the original soil moisture to soil moisture percentile in this work, which alleviated the difference between ERA-Interim and ERA5 soil moisture values. Flash drought events were identified based on soil moisture percentile. Finally, this manuscript mainly focuses on evaluating the performance of machine learning (i.e., MLR, LSTM, and RF) on flash drought simulation from the perspective of meteorological driving forces. Therefore, the regulation and conclusion are not significantly changed even if we selected ERA-Interim soil moisture to conduct this study. We carefully considered your suggestions and will replace the ERA-Interim with ERA5 soil moisture in future research. Thanks again for your valuable comments.

Page 5 Line 143-145:

"*Meanwhile, ERA-Interim SM data were converted into SM percentile to identify flash droughts over China, which alleviates the influence of soil moisture value on identification results.*"

Reference:

Ling, X., Huang, Y., Guo, W., Wang, Y., Chen, C., Qiu, B., Ge, J., Qin, K., Xue, Y., Peng, J.: Comprehensive evaluation of satellite-based and reanalysis soil moisture products using in situ observations over China, Hydrol. Earth Syst. Sci., 25, 4209–4229, https://doi.org/10.5194/hess-25-4209-2021, 2021.

Comment 2: I missed some discussion; if you tried to link the results of your study with the impacts and mention in the discussion/outlook, how the results of your study can be linked with impacts on agricultural production. Is the flash drought more impactful than the slowly evolving drought?

Response:

Thanks for your comments. As we know, flash drought is a rapid onset and high-intensity extreme drought. Its onset and development generally require the precipitation deficit along with other climate anomalies (e.g., high temperature, strong wind, and enough sunshine) that enhanced evaporative demand (Otkin et al., 2013; Anderson et al. 2013). These meteorological factors work together to quickly decrease soil moisture, gradually increase vegetation stress, and further cause the onset of flash drought (Hunt et al., 2009; Ford et al., 2015). This situation easily occurs during the growing season of vegetation and crops with the highest evaporative demand. If flash drought occurred during the critical phase of crop development, such as pollination in corn and the grain filling stage in soybeans, it would lead to large losses in agricultural production (Otkin et al., 2013; Hunt et al., 2014). For example, the 2012 flash drought in the Midwest of the U.S. aroused much attention, because this expensive natural disaster caused about 7.62 billion dollars in agricultural losses (Hoerling et al., 2014). Thus, the occurrence of flash drought poses a potential threat to agricultural production.

There is a discrepancy between the effects of flash drought and slowly evolving drought on agricultural production. With the rapid onset of flash droughts, farmers and ranchers had little time to prepare for its detrimental effects, thus, it may result in a large reduction in crop yield (Otkin et al., 2016). While long-last traditional droughts had a persistent adverse impact on agricultural production. Therefore, it is hard to say that flash drought is more impactful that slowly developing drought on agricultural production. We need to conduct a comprehensive evaluation according to the actual drought situation. However, both flash drought and conventional drought have negative effects on agriculture, therefore, it is of significance to monitor and simulate them. In the revised manuscript, we added a new paragraph to discuss the effects of flash drought on agricultural production (Page 29-30 Lines 543-559):

"5.4 Impact of flash droughts on agricultural production

Flash drought is a rapid onset and high-intensity extreme drought. Its onset and development are generally not only due to the precipitation deficit but also owe to other meteorological anomalies (e.g., high temperature, strong wind, and abundant sunshine) that enhanced evaporative demand (Otkin et al., 2013; Anderson et al. 2013). These moisture-limited and energy-limited factors work together to quickly decrease soil moisture, gradually increase vegetation stress, and then induce the onset of flash drought (Hunt et al., 2009; Ford et al., 2015). This situation is most likely to occur during the growing season of vegetation and crops with the highest evaporative demand. When flash drought occurs during the critical stage of crop development (e.g., pollination in corn and the grain filling stage in soybeans), it may lead to a large agricultural reduction (Otkin et al., 2013; Hunt et al., 2014). For instance, the 2012 flash drought in the Midwest of the U.S. was an expensive natural disaster with agricultural losses of about 7.62 billion dollars (Hoerling et al., 2014). All in all, the occurrence of flash drought poses a potential threat to agricultural production. It is worth mentioning the effects of flash drought on crop yield are different from that of conventional drought. With the rapid onset of flash drought, farmers and ranchers had limited time to prepare for its detrimental effects, thus, it may result in a large reduction in crop yield (Otkin et al., 2016). While long-last traditional drought had persistent adverse impacts on agricultural production. Generally, the impact of flash *drought on agricultural production is more severe than slowly developing droughts during a short period. However, it is necessary to conduct comprehensive evaluations on their effects combined with the actual drought status and background field. In addition, the accurate prediction of the RI of these droughts will be contributed to mitigating the negative impact of flash droughts on agriculture."*

References:

Anderson, M. C., Hain, C., Otkin, J., Zhan, X., Mo, K., Svoboda, M., Wardlow, B., Pimstein, A.: An intercomparison of drought indicators based on thermal remote sensing and NLDAS-2 simulations with US Drought Monitor classifications, J. Hydrometeorol., 14(4), 1035-1056, https://doi.org/10.1175/JHM-D-12-0140.1, 2013.

Ford, T. W., McRoberts, D. B., Quiring, S. M., Hall, R. E.: On the utility of in situ soil moisture observations for flash drought early warning in Oklahoma, USA, Geophys. Res. Lett., 42:9790–9798, https://doi.org/10.1002/2015GL066600, 2015.

Hoerling, M., Eischeid, J., Kumar, A., Leung, R., Mariotti, A., Mo, K., Schubert, S., Seager, R.: Causes and Predictability of the 2012 Great Plains Drought, Bull. Amer. Meteor. Soc., 95, 269–282, https://doi.org/10.1175/BAMS-D-13-00055.1, 2014.

Hunt, E. D., Hubbard, K. G., Wilhite, D. A., Arkebauer, T. J., Dutcher, A. L.: The development and evaluation of a soil moisture index, Int. J. Climatol., 29(5), 747–759, https://doi.org/10.1002/joc.1749, 2009.

Hunt, E. D., Svoboda, M., Wardlow, B., Hubbard, K., Hayes, M., Arkebauer, T.: Monitoring the effects of rapid onset of drought on non-irrigated maize with agronomic data and climate-based drought indices, Agric. For. Meteor., 191, 1–11, https://doi.org/10.1016/j.agrformet.2014.02.001, 2014.

Otkin, J. A., Anderson, M. C., Hain, C., Svoboda, M.: Examining the Relationship between Drought Development and Rapid Changes in the Evaporative Stress Index, J. Hydrometeor., 15, 938–956, https://doi.org/10.1175/JHM-D-13-0110.1, 2013.

Otkin, J. A., Anderson, M. C., Hain, C., Svoboda, M., Johnson, D., Mueller, R., Tadesse, T., Wardlow, B., Brown, J.: Assessing the evolution of soil moisture and vegetation conditions during the 2012United States flash drought, Agric. For. Meteor., 218–219, 230–242, http://dx.doi.org/10.1016/j.agrformet.2015.12.065, 2016.

Comment 3: Last but not least: Code and data availability statement is missing in your manuscript. Please make sure that for reproducibility, you make your analysis available to general public.

Response:

Thanks for pointing out this. In the revised manuscript, we have added the data availability statement.

Page 30 Line 589-593:

*"**Data availability statement***

ERA-Interim SM data used in this study are available through https://apps.ecmwf.int/datasets/data/interim-full-daily/levtype = sfc/. ERA-Interim SM data are gradually being superseded by the ERA5 reanalysis (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land). Meteorological observation records can be downloaded from the China Meteorological Administration website (CMA, http://data.cma.cn/)."

Others: Line 61: typo: researches => researchers

Line 188: blow => below

Line 188: decreases => decrease

Figure 1: correct typo in figure legend: "anmoly" => "anomaly"

Line 195: represent => represents

Line 277: not => do not

Line 283: captured => are captured

Line 294: were serves => served

Line 347: remove "model"

Line 362: were => was

Response:

Thanks for pointing out this. All these mistakes have been corrected, for example, the typo in Fig. 1 legend has been revised as below. In addition, we have checked other mistakes throughout the original manuscript and recorded them in the revised manuscript.

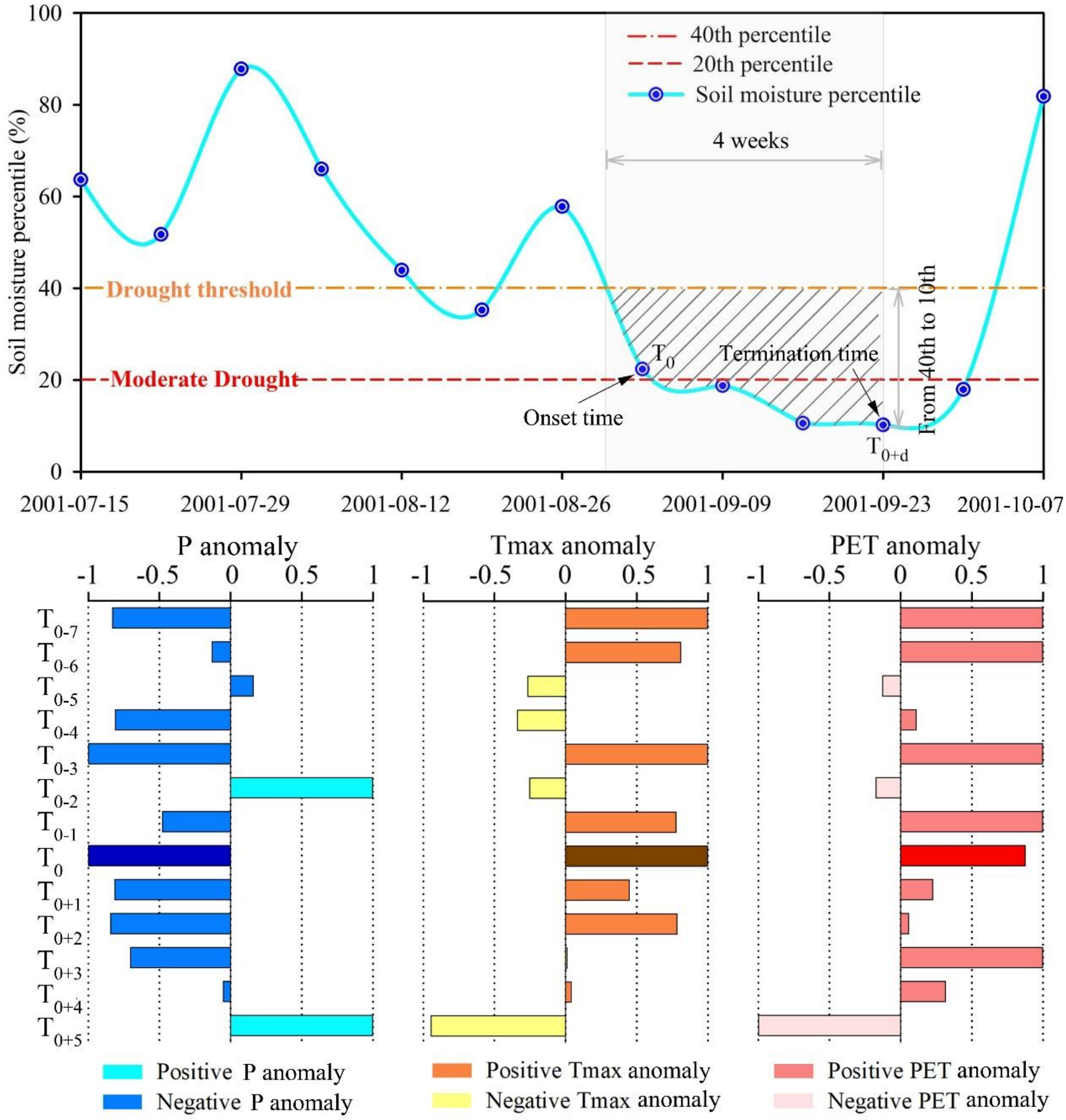

Fig.1 A concept map for identifying flash droughts.