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Interactive comment on "A standardized index for assessing sub-monthly compound dry and hot conditions" *by* Jun Li et al.

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Reviewer: Interesting objective, interesting method, but hard to read. Reviewer (1): (a) the paper discusses a standardized index for assessing compound dry and hot conditions. Overall, I find the paper not in a really good shape, and I have to admit that I found it really hard to read due to the excessive amount of acronyms. The paper is so technical that for a reader who does know something about the topic, it is still very hard to follow. (b) For me it did not became entirely clear what are now the new insights that can be learned by creating this new index that were not known before. (c) I also think that the authors should make a new selection of figures and reduce the paper to the essentials, because with the figures in the text and the supplementary material there are so many panels showing China that it becomes overwhelming to the reader. I put some

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comments below that could help in improving the paper. Author's reply (1): Thank you for your comments and suggestions. (a) We are sorry for the excessive number of acronyms. We will reduce the utilization of the abbreviations in the revised manuscript. (b) Much effort has been made to study the compound dry-hot event in recent years. Utilizing thresholds to define the concurrent events, the frequency of compound events has received much attention (Wu et al., 2019; Zhang et al., 2019). However, this approach fails to measure compound event characteristics (e.g., duration, severity, and intensity), and is inconvenient for comparing compound event characteristics through different climates (Wu et al., 2020). Several indices were thus proposed for analyzing the characteristics of the compound events, such as standardized compound event indicator and standardized compound dry-hot index. These indices provide useful tools to understanding compound dry-hot event characteristics. However, they are subject to some shortcomings including the fixed monthly scale and the disregard of evapotranspiration, which may limit their use in monitoring the detailed evolution of compound dry and hot events. In addition, severe concurrent drought and heat can suddenly strike a region within short duration when extreme weather anomalies persist over the same region (Röthlisberger and Martius, 2019; Wang et al., 2016). Concurrent short-term drought and heatwaves can pose great socio-economic risks (Zhang et al., 2019). There is thus a need to have indices capable of monitoring sub-monthly compound dry-hot conditions. Yet up to now there is no index available for incorporating the joint variability of dry and hot conditions at sub-monthly scale. The proposed SCDHI index provides a new tool to monitor and quantify the characteristics of compound dry-hot events at multiple time scale (e.g., daily, weekly and monthly) to provide detailed information on their initiation, development, termination, and trends. We will put more emphasis on the motivation and benefits of this new index in the introduction of the revised manuscript. (c) We agree that the figures in the first-round manuscript need to be reduced. As the results on 3, 6, 9, 12-month scale SAPEI/SCDHI in Figs. 2, 4, 6, 8, 9, 10 are generally similar, we will only show results on 3-month scale SAPEI and SCDHI, and remove the results of other time scales in these Figures. In addition, we will remove the Figs. 7 and 13 in revised manuscript. The supplementary materials mainly involve the metrics for selecting copula, and assessment of SAPEI/SCDHI ability to monitor monthly drought/compound dry-hot conditions using real-world typical events. These analyses are necessary but not essential, so placing them in the supplementary material without adding manuscript space. We will reduce the text content related to supplementary materials, and subfigures in supplementary materials, but keep essential figures and content to improve the readability of the paper. References: Röthlisberger, M. and Martius, O.: Quantifying the Local Effect of Northern Hemisphere Atmospheric Blocks on the Persistence of Summer Hot and Dry Spells, Geophys. Res. Lett., doi:10.1029/2019GL083745, 2019. Wang, L., Yuan, X., Xie, Z., Wu, P. and Li, Y.: Increasing flash droughts over China during the recent global warming hiatus, Sci. Rep., doi:10.1038/srep30571, 2016. Wu, X., Hao, Z., Hao, F. and Zhang, X.: Variations of compound precipitation and temperature extremes in China during 1961–2014, Sci. Total Environ., 663, 731–737, doi:10.1016/j.scitotenv.2019.01.366, 2019. Wu, X., Hao, Z., Zhang, X., Li, C. and Hao, F.: Evaluation of severity changes of compound dry and hot events in China based on a multivariate multi-index approach, J. Hydrol., 583, 124580, doi:10.1016/j.jhydrol.2020.124580, 2020. Zhang, Y., You, Q., Mao, G., Chen, C. and Ye, Z.: Short-term concurrent drought and heatwave frequency with 1.5 and 2.0 °C global warming in humid subtropical basins: a case study in the Gan River Basin, China, Clim. Dyn., 52(7–8), 4621–4641, doi:10.1007/s00382-018-4398-6, 2019.

Reviewer (2): It could be good to mention already in the title that this study only concerns China. The paper does not deliver a universal index for compound dry and hot conditions, but one that is only developed for application in China. Author's reply (2): Thank you for your comments and suggestions. Because developing a sub-monthly index requires datasets with high temporal resolution (e.g., daily precipitation, maximum air temperature, mean air temperature, minimum air temperature, relatively humidity, wind speed, and sunshine duration), it is difficult to collect all these daily datasets on a global scale. While the index is computed for China base on readily available datasets, the methodology is universal. Moreover, China has vast territory and complex and diverse climates, and during the past decades, it suffers from frequent and severe compound dry-hot events (Wu et al., 2019). So we think it is a favorable, representative study region to demonstrate our proposed index. We will emphasis that this method is currently used in China in title: “A standardized index for assessing sub-monthly compound dry and hot conditions: application in China” Reference: Wu, X., Hao, Z., Zhang, X., Li, C., Hao, F. (2019). Evaluation of severity changes of compound dry and hot events in China based on a multivariate multi-index approach. Journal of Hydrology, 583, 124580.

Reviewer (3): As a reviewer, it did not become completely clear to me what the exact problem is of combined dry and hot conditions. There are many examples, but their explanation does not really get to the core: why do we need an indicator for dry and hot? Please improve this in the revision. Author’s reply (3): Thank you for your comments. Different combinations of dry and hot conditions lead to different types of impacts including crop failure vegetation impacts or wild fires. Slightly hotter conditions may exacerbate impacts originated from dry conditions (Ribeiro et al., 2020). Furthermore, the correlation between hot and dry conditions renders a naive combination of univariate indicators of hot and dry events unsuitable for estimating combined impacts. A combined dry-hot indicator implicitly accounts for the dependence between hot and dry conditions and provides a univariate metric to measure the intensity of combined stress due to heat and drought. For crops it has been shown that such a bivariate indicator can explain crop yield better than typically used linear regression models (Zscheischler et al., 2017). The author’s reply (1) provides further motivation for such an index. We will reduce the number of given examples, and re-write the introduction focusing on the above-mentioned points. References: Ribeiro, A. F. S., Russo, A., Gouveia, C. M., Páscoa, P., and Zscheischler, J.: Risk of crop failure due to compound dry and hot extremes estimated with nested copulas, Biogeosciences Discuss., in review, 2020. Zscheischler, J., Orth, R., and Seneviratne, S. I.: Bivariate return periods of temperature and precipitation explain a large fraction of European crop yields, Biogeosciences, 14, 3309–3320, 2017.

Reviewer (4): I find the methods a little ill-described. There are many references back to previous papers, but please list the equations of the equations that you take from these papers, because now the reader has to look up essential information in previous papers. Also, please be exact what the source of the input data is that is needed to compute all the variables that you need. Author's reply (4): Thank you for your comments and suggestions. We are sorry for the unclear description on methods. In this study, only the SAPEI refers to a previous paper, which only involves an equation used to calculate this index, i.e., equation (1). We will add this equation in the text and clarify the input data of the two indices in method section of the revised manuscript: "The SCDHI calculation relies on STI and SAPEI. STI is calculated from maximum temperature, while SAPEI is calculated from precipitation and potential evapotranspiration. The Penman-Monteith method is used to calculate the potential evapotranspiration, requiring maximum air temperature, mean air temperature, minimum air temperature, relatively humidity, wind speed, and sunshine duration."

Reviewer (5): Line 203: how does one use a probability distribution to create daily time series, and against what is it fitted? I do not understand the procedure. Author's reply (5): Thank you for your comment. The probability is not used to create daily time series, but rather, is applied to fit a time series. We will add a case of SAPEI calculation in the supplementary materials: "Taking the calculation of SAPEI on May 1st of each year (1961-2018) as an example, with respect to 3-month scale SAPEI, the total water surplus or deficit in three months before May 1st of each year is calculated to represent the dry and wet conditions on May 1st, and thus, there are 58 values representing the dry and wet conditions on May 1st of each year. The water surplus or deficit was calculated through the difference between precipitation and potential evapotranspiration. For calculating a standardized index, a probability distribution was used to fit the daily time series (58 values), which was then transformed into a standard normal distribution (resulting in SAPEI) using the classical approach of Barton et al. (1965)." Reference: Barton, D. E., Abramovitz, M. and Stegun, I. A.: Handbook of Mathematical Functions with Formulas, Graphs and Mathematical Tables., J. R. Stat.

Soc. Ser. A, doi:10.2307/2343473, 1965.

Reviewer (6): Line 219: what is copula theory? Author's reply (6): Thank you for your comment. Developed by Sklar (1959), copulas are functions that link univariate distribution functions to form multivariate distribution functions. The merit of using copulas to construct multivariate distributions is that copulas can separate the dependence effects from the marginal distribution effects. Construction of multivariate distribution is thus reduced to study the relations among the correlated random variables if marginal distributions are given. For two random variables, Sklar's Theorem states that if FX,Y (x, y) is a two-dimensional distribution function with marginal distributions FX(x) and FY (y), and there exists a copula C such that: FX,Y (x, y) =C (FX (x), FY (y)) Conversely, for any univariate distributions FX(x) and FY (y) and any copula C, the function FX,Y (x, y) is a two-dimensional distribution function with marginal distributions FX(x) and FY (y). Furthermore, if FX(x) and FY (y) are continuous, then C is unique. Under the assumption that the marginal distributions are continuous with probability density functions fX (x) and fY (y), the joint probability density function turns out to be: fX,Y (x, y)=c(FX(x), FY(y))fX(x)fY(y) where c is the density function of C. The books of Nelsen (2006) introduce a copula theory in detail. We will add some introduction of copula theory function in the supplementary materials. Reference: Sklar, K.: Fonctions de repartition a n Dimensions et Leura Marges, Publ. Inst. Stat. Univ. Paris, 8, 229–231, 1959.

Reviewer (7): Lines 226-250: This could use some explanatory figures. It is nearly impossible to understand for a reader that is not familiar with the specialized methods that are used here. Author's reply (7): Thank you for your comment and suggestion. Fig. S4 in the supplementary materials has already illustrated the SCDHI development. We will move Fig. S4 to the main text.

Reviewer (8): Line 265: I think that there are more approprate and far older references for the definition of the POD and FAR. Author's reply (8): Thank you for your suggestion. We would add the reference: "Winston, H.A., Ruthi, L.J.: Evaluation of RADAP II severe-storm-detection algorithms. Bull. Am. Meteorol. Soc., 67(2), 145-150, 1986."

Reviewer (9): Section 3.1: What is the added value from SAPEI compared to much simpler metrics as soil moisture, or if that is not available P-E, or an simple estimation of evapotranspiration? Author's reply (9): Thank you for your professional comment. Soil moisture is accepted be the most appropriate variable for agriculture drought monitoring and analyses (Mishra and Singh, 2010). However, there are still lack of long-term and large-scale observational soil moisture datasets due to insufficient observation stations in many parts of the world, especially for developing and undeveloped countries. Because of this, using observational hydrometeorological datasets, the complex physical process models such as the Community Land Model are widely used to simulate soil moisture. However, running such models requires highly trained personnel not usually available at local agencies. In addition, when the model is used locally, it generally needs to be calibrated and verified by observational soil moisture and other hydrometeorological datasets. This certainly limits the wide use of soil moisture as a drought indicator. An evapotranspiration-based drought index provides a useful tool for drought monitoring and analyses. However, in many regions and operational settings, evapotranspiration is derived from potential evapotranspiration (PET) through parameterizations of soil-water and plant-water availabilities that are of questionable value on operational space and time scales; in such cases PET may serve as an independent drought indicator (Hobbins et al., 2016). Recently, the evaporative demand drought index (EDDI) based solely on the PET is used to analyze and monitor flash droughts (McEvoy et al., 2016). However, EDDI only considers for PET and thus is inappropriate for regions with non-constraining soil moisture conditions, e.g., humid regions, given that positive PET anomaly is not representative of actual drought conditions (Vicente-Serrano et al., 2018). The SAPEI relies on the precipitation and potential evapotranspiration. There are generally available observational precipitation and datasets for calculating potential evapotranspiration in most countries around the world. Therefore, SAPEI can be directly calculated using observed, easily accessed meteorological datasets, and the calculation process is simple. In addition, it has multiple time

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scales, and the long-time scale SAPEI is sensitive to soil moisture variation. The time scale over which water deficits accumulate becomes very important, and it functionally separates hydrological, agricultural, and other droughts. Drought indices must be associated with a specific time scale to be useful for monitoring and managing different usable water resources (Vicente-Serrano et al., 2010). Overall, the SAPEI meets the requirements of a drought index, given the fact that it shows reliable and robust ability for drought analysis and monitoring. Like SPEI and SPI, SAPEI includes multiple time scales (3-, 6-, 9-, and 12- month) to monitor droughts at monthly resolution. However, SAPEI has the advantage over SPEI regarding sub-monthly drought monitoring. Such an index could help fill the gap between science and applications in that it would be operationally feasible for detecting and monitoring both short-term and long-lasting droughts. We will add some discussion on the added value of SAPEI compared with soil moisture and evapotranspiration-based indices in the revised manuscript. References: Mishra, A. K., Singh, V. P. (2010). A review of drought concepts. Journal of hydrology, 391(1-2), 202-216. Hobbins, M. T., Wood, A., McEvoy, D. J., Huntington, J. L., Morton, C., Anderson, M., Hain, C. (2016). The evaporative demand drought index. Part I: Linking drought evolution to variations in evaporative demand. Journal of Hydrometeorology, 17(6), 1745-1761. McEvoy, D. J., Huntington, J. L., Hobbins, M. T., Wood, A., Morton, C., Anderson, M., Hain, C. (2016). The evaporative demand drought index. Part II: CONUS-wide assessment against common drought indicators. Journal of Hydrometeorology, 17(6), 1763-1779. Vicente-Serrano, S. M., Beguería, S., López-Moreno, J. I., Angulo, M., El Kenawy, A. (2010). A new global 0.5 gridded dataset (1901–2006) of a multiscalar drought index: comparison with current drought index datasets based on the Palmer Drought Severity Index. Journal of Hydrometeorology, 11(4), 1033-1043. Vicente-Serrano, S. M., Miralles, D. G., Domínguez-Castro, F., Azorin-Molina, C., El Kenawy, A., McVicar, T. R., ... Peña-Gallardo, M. (2018). Global assessment of the Standardized Evapotranspiration Deficit Index (SEDI) for drought analysis and monitoring. Journal of Climate, 31(14), 5371-5393.

Reviewer (10): There are too many references to the supplementary material through-out the text. I suggest the authors reevaluate the necessity for each of the figures and come up with a set that is crucial to the story. This is not a research letter, there is more than enough space. Author's reply (10): Thank you for your comments and suggestions. The supplementary materials mainly involve the metrics for selecting copula, and assessment of SAPEI/SCDHI ability to monitor monthly drought/compound dry-hot conditions using real-world typical events. These analyses are necessary but not essential, so placing them in the supplementary material without adding manuscript space is acceptable. If we remove these materials, the ability of the two indices to monitor monthly drought/dry-hot conditions would not be shown completely. We would like to remain them, but select the essential panels and re-write the content related to supplementary materials in the main text.

Reviewer (11): Line 462. If a hot index is based on absolute temperature, it seems trivial that places that are closer to the equator at low altitudes have the largest probability of a hot event. Can you explain more about the location where the outcome surprised you, or where new insights were found? Author's reply (11): Thank you for your comment. STI representing hot condition is calculated by temperature variation within a specific grid point (similar to common drought indices). For example, for a certain grid point, the STI on January 1st are computed based on temperature datasets observed during 1961-2018. In other words, the hot index (STI) is not affected by location and is only related to its changes within the grid point. Hot events are usually defined relative to the local climatology. Fig. 11 shows the characteristics (e.g., frequency) of the compound dry-hot events. Though the event is closely related to the extreme temperature, it reflects the concurrent dry and hot conditions. Extreme absolute temperature may be more frequent at low altitudes, but this does not mean that in such places droughts would occur frequently (as at low altitudes, e.g. equator, plenty precipitation would be expected). In this study, surprisingly, we found that a high frequency of compound events was detected in humid southern China, and the events generally lasted about 25 days (Fig. 11a). Previous studies indicate that the occurrence of extreme climate (e.g. high temperature, low humidity, and sunny skies) can appear within a

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short period without resulting in long-lasting compound events, but rather, short-term droughts and heatwave lasting a few weeks (Mo and Lettenmaier, 2015; Zhang et al., 2019). And short-term dry and hot events occur more frequently in southern regions than in other parts of China (Otkin et al., 2018; Wang et al., 2016). South China is a humid region where evapotranspiration is mainly controlled by energy supply because soil moisture is usually sufficient. The evaporation demand could increase significantly during a short period when strong, transient meteorological changes occur. Through influencing evapotranspiration variation, short-term meteorological variables (e.g., solar radiation and sunshine duration) are considered important factors driving drought and hot concurrence. For example, large increase in sunshine duration due to clear sky creates excessive evapotranspiration, which in turn decreases soil moisture; more surface sensible heat fluxes are transferred to the near-surface atmosphere to further increase air temperature and makes precipitation rare. These land-atmosphere interactions altogether create favorable conditions for concurrent drought and hot events in South China. We will discuss why southern China experience more compound dry-hot events in the revised manuscript based on the description above. References: Mo, K. C., Lettenmaier, D. P. (2015). Heat wave flash droughts in decline. Geophysical Research Letters, 42(8), 2823-2829. Otkin, J. A., Svoboda, M., Hunt, E. D., Ford, T. W., Anderson, M. C., Hain, C., Basara, J. B. (2018). Flash droughts: A review and assessment of the challenges imposed by rapid-onset droughts in the United States. Bulletin of the American Meteorological Society, 99(5), 911-919. Wang, L., Yuan, X., Xie, Z., Wu, P., Li, Y. (2016). Increasing flash droughts over China during the recent global warming hiatus. Scientific reports, 6, 30571. Zhang, Y., You, Q., Mao, G., Chen, C., Ye, Z. (2019). Short-term concurrent drought and heatwave frequency with 1.5 and 2.0 C global warming in humid subtropical basins: a case study in the Gan River Basin, China. Climate dynamics, 52(7-8), 4621-4641.

Reviewer (12): Lines 485 and further: (a) how are the RCP scenarios computed in your index? This does not seem trivial to me, how is the input acquired? (b) It would be nice to know which of the observed increases in due to temperature alone and which due to more complex interactions? Author's reply (12): Thank you for your comment. (a) To obtain the future climate scenario data, we collect eight global climate models, including CanESM2, CNRM-CM5, CSIRO-Mk3.6, MIROC-ESM, MPI-ESM-LR, BCC-CSM1-1, IPSL-CM5A-LR, and MRI-CGCM3, to project the future climate conditions. These global climate models exhibit good performance to simulate the key features of precipitation and temperature in China. We obtained climate variables (i.e., precipitation, temperature, relatively humidity, wind speed, and shortwave and longwave radiations) for the future periods for the three Representative Concentration Pathways (RCPs) including RCP 2.6 (low emission scenario), RCP 4.5 (moderate emission scenario) and RCP 8.5 (high emission scenario). The bias-corrected climate imprint method, one of the delta statistical downscaling methods, was applied to downscale the climate model output to a same resolution as the observations. Using the downscaling datasets, the SCDHI was computed, and was used to analyze future compound dry-hot events. (b) We will calculate the future SCDHI considering only temperature change, and then this SCDHI will compared to historical reference. Finally, this result will be compared with the Fig. 12 in the first-round manuscript to illustrate future changes in characteristics of the compound dry-hot events due to temperature change.

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