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Interactive comment on "Population exposure to droughts in China under 1.5 °C global warming target" *by* Jie Chen et al.

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Dear Editors and Reviewers: Thank you for your letter and for the reviewer's comments concerning our manuscript entitled "Population exposure to droughts in China under 1.5°C global warming target" (ID: esd-2017-100). Those comments are all valuable and very helpful for revising and improving our manuscript. We studied comments carefully and made corrections in the manuscript. The response to the reviewer's comments are as follow:

1. The standardized precipitation evapotranspiration index (SPEI) used in this study is an index of meteorological drought. Meteorological droughts do not necessarily coincide with agricultural, hydrological, or even socio-economic drought Thus, meteo-

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rological droughts have only limited direct relevance to people. In addition, the SPEI defines meteorological drought as departure from the mean climatic water balance (precipitation minus potential evapotranspiration) in multiples of standard deviations. For example, a value of -1 marks an event that deviates by one standard deviation from mean conditions. By definition, 15.9% of all time steps will be classified as -1 or less. It is obvious that such an indicator does not provide a measure of dryness in an absolute sense. Under wet conditions with low temporal variability, most SPEI droughts are still wet in an absolute sense; under dry conditions, many very dry events may not be classified as drought by the SPEI. Despite these shortcomings, I do believe that assessing population exposure to changes in meteorological droughts under climate change is a valid research question. But the limitations of the employed indicator (and drought type) must be highlighted and discussed to avoid misinterpretation of the results. This is clearly lacking in the paper, which instead tends to overstate the meaning of population exposure to meteorological droughts (e.g., page 2, lines 8-11).

Authors' response: Thanks for your suggestions. We have added the express about limitations of the employed indicator (and drought type) in Section 4. The modifications are as follow:

P8 Line 8-11, we have added the statement "There are many kinds of droughts: meteorological, agricultural, hydrological, and socioeconomic. In this study, based on simulated climate data, we assessed population exposure to meteorological droughts under the 1.5 °C global warming target using the SPEI; however, the results do not necessarily coincide with agricultural, hydrological, or socioeconomic droughts. Therefore, we would like to assess population exposure to different kinds of droughts to determine their impacts on populations."

P8 Line 14-19, we have added the statement "For instance, SPEI was chosen in this study because it combines the characteristics of SPI and PDSI; however, it is limited by providing a measure of dryness in a relative rather than absolute sense. Selecting different drought indexes may lead to differences in drought hazard and population exposure results. Therefore, future studies could evaluate different drought indexes based on more advanced and higher resolution GCMs and RCMs (regional climate models), determine importance of sources of uncertainty, and generate assessment results that are more accurate and reasonable."

2. The basic concept of the SPEI is to transform a time series of the climatic water balance into a time series of normally distributed index values with a mean of 0 and a standard deviation of 1. For this transformation, a probability distribution function is fitted to the empirical distribution of climatic water balance values. The fitted distribution function is then used to map the climatic water balance values to SPEI values corresponding to the same quantile. Performing the transformation for present day and future time periods with independently fitted distribution functions, will yield two SPEI time series with the same statistical properties. Any attempt to identify a climate change signal will fail with this approach as the signal is lost in the transformation. Therefore, a single distribution function (preferably estimated from the reference period) must be used for the transformation of both the reference and future time series to be able to detect changes in the frequency of drought events. It is not clear whether this has been done correctly in this analysis as the method sections only provides a very vague description of the SPEI calculation. However, the results and how they are presented indicate that separate distribution functions have been fitted to the reference and the future time period.

Authors' response: Thanks for your advice. We have added detailed statements of SPEI calculation in Section 2.2 and supplemented probability distribution of SPEI for different drought grades in Table 1.

3. On page 2 line 32 the authors explain that the climate data from the five available GCMs had been averaged prior to the analysis. Averaging time series is never a good idea. But in the case of GCM time series and with the aim to calculate SPEI it is simply wrong. The argument that "combining multiple models has been to shown superior to a single model" only holds true for long term averages and only for the comparison to

observations. The SPEI analysis must be performed for each GCM individually. The results can then be averaged while properly accounting for GCM uncertainty.

Authors' response: Thanks for your comments. Our inappropriate description led to a misunderstanding of the analysis. We have calculated SPEI for each GCM initially and averaged the results for drought frequency and population exposure analysis. So we have replaced the description to "In this study, we synthesized the results of the five GCMs based on the separately calculated SPEI for each GCM, as combining results of multiple models has been shown to be superior to a single model (Zhou and Yu, 2006)." in Page 3 line 6-8 (Section 2.1). Besides, we have added uncertainty discussion including GCM uncertainty in Page 8 line 12-19 (Section 4). The statement was rephrased to"In addition, there are some uncertainties in estimating population exposure under climate change. The main sources include GHG emission scenarios (Maurer, 2007), GCMs (Kirono et al., 2011), calculating potential evapotranspiration, population prediction, and selection of the drought index (Burke and Brown, 2008). For instance, SPEI was chosen in this study because it combines the characteristics of SPI and PDSI; however, it is limited by providing a measure of dryness in a relative rather than absolute sense. Selecting different drought indexes may lead to differences in drought hazard and population exposure results. Therefore, future studies could evaluate different drought indexes based on more advanced and higher resolution GCMs and RCMs (regional climate models), determine importance of sources of uncertainty, and generate assessment results that are more accurate and reasonable."

4. The paper defines population exposure to drought as "the frequency of mild, moderate, and extreme droughts multiplied by the number of people exposed to them" and reports it as number of people. I don't think this is appropriate. Let's assume a moderate drought is found to occur over 10 % of the time in a given grid cell. Then, according to the above definition, 10 % of the total population in that grid cell would be counted as exposed to moderate drought. This is strange because intuitively one would expect that all people in that cell will experience moderate drought conditions over 10 % of the

time. It is possible that it is only the unit (population numbers) that is puzzling here and that it could be fixed by including the temporal dimension. However, under no circumstance should the population exposure obtained for different drought severity classes be added (as done on multiple occasions in the paper).

Authors' response: Thanks for your comments. There are different kinds of definition of population exposure to extreme climate events and disasters. For example, Smirnov et.al (2016) defined "populations' exposure to extreme drought as the total number of people, in the world or in a country, living in grid cells where SPEI < -2." While the definition of exposure we used is referred to Jones et al (2015), which defined population exposure to heat extremes as "the annual average number of days with a maximum temperature above 35 °C multiplied by the number of people exposed to that outcome." To state more clearly, we have change the description to "Our measure of population exposure is the number of people exposed to mild, moderate, and extreme droughts. That is, the annual average percentage of mild, moderate, and extreme droughts multiplied by the number of people exposed to that outcome, which is referred to Jones et al. (2015)" in Page 4 line 9-11 (Section 2.3).

As for calculation of population exposure of different severity classes, it is referred to studies of Smirnov et al. (2016) and Sun et al. (2017) as is mentioned in Section 1, which is also widely used in relevant studies. Smirnov et al. (2016) assessed population exposure to extreme droughts while the study did not account for mild and moderate droughts. Sun et al. (2017) analyzed population exposure to moderate, severe and extreme droughts under 1.5 °C and 2.0 °C global warming scenarios, while the study ignored the impact of demographic growth on population exposure change. In this study, calculation of population exposure of different severity classes make the results more accurate, and is useful for relative importance analysis. In addition, it is also important for vulnerability and risk assessment in further studies.

References:

Jones, B., O'Neill, B. C., Mcdaniel, L., Mcginnis, S., Mearns, L. O., and Tebaldi, C.: Future population exposure to US heat extremes, Nat. Clim. Change, 5, 592–597, 2015.

Smirnov, O., Zhang, M., Xiao, T., Orbell, J., Lobben, A., and Gordon, J.: The relative importance of climate change and population growth for exposure to future extreme droughts, Climatic Change, 138, 1–13, 2016.

Sun, H., Wang, Y., Chen, J., Zhai, J., Jing, C., Zeng, X., Ju, H., Zhao, N., Zhan, M., and Luo, L.: Exposure of population to droughts in the Haihe River Basin under global warming of 1.5 and 2.0°C scenarios, Quatern. Int., 2017.

5. The methods description is very short and lacks explanation of important aspects, which are crucial for the understanding of the analysis. It is by no means clear how ETo was calculated (e.g., climate variables used, temporal resolution) and which procedure was used to derive the SPEI (e.g., temporal resolution or number of time steps of SPEI, probability distribution type assumed for climatic water balance, fitting methods for estimating parameters probability distribution function, same or different parameters for reference period and scenario). In order to assure transparency and reproducibility of the analysis this information must be provided.

Authors' response: Thanks for your suggestions. We have supplemented detailed calculation process of ET0 in Section 2.2 including climate variables used and temporal resolution. Also, we added the procedure used to derive the SPEI and the set parameters. The statement is:

Page 3 line 23-24, "Differences between precipitation (P) and potential evapotranspiration (ET0), which reflect the water surplus or deficit in a region, were calculated to deduce the SPEI using:"

Page 3 line 27-30, "Therefore, the Penman–Monteith equation (FAO, 1998) was replaced to calculate ET0 in this study. The Penman–Monteith equation comprehensively considers the impact of both thermal and dynamic factors on ET0, i.e., temperature, wind speed, relative humidity, and solar radiation. Therefore, results are more consistent with true reference crop evapotranspiration."

Page 4 line 2-7, "Here, ET0 is the potential evapotranspiration; Rn is the net radiation; G is the soil heat flux density; T is the surface mean daily air temperature; u2 is the wind speed at 2 m height above the ground; es is the saturation vapor pressure; and ea is the actual vapor pressure. The SPEI was calculated using the R-SPEI-package (https://CRAN.R-project.org/package=SPEI). The input data are monthly time series of D (differences between precipitation and potential evapotranspiration), where the set parameters are scale=12, kernel = 'rectangular', distribution = 'log-Logistic', and fit = 'ub-pwm'. The categorization of drought grade by SPEI and its probability are shown in Table 1 (Liu and Jiang, 2015)."

6. It is not clear to me how the section 3.4 can contribute to a quantification of uncertainties.

Authors' response: Thanks for your comments. In this study, cumulative distribution functions (CDFs) were used to quantified drought frequency and population exposure change in 1.5 °C global warming scenario relative to reference period to evaluate the possible impact of climate change. Uncertainty analysis in Section 2.4 refers to uncertainty analysis of drought frequency and population exposure change, the statement may lead to misunderstanding. Thus, we have replaced the title of Section 2.4 to "Relative importance and cumulative probability analysis" and the definition of CDFs was added in Page 4 line 23-24 (Section 2.4), the statement is "The CDF of a random variable X is the function representing the probability that the random variable X takes on a value less than or equal to x".

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