Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-100
Manuscript under review for journal Earth Syst. Dynam.
Discussion started: 7 November 2017

Earth System Dynamics
Discussions
Open Access

Population exposure to droughts in China under 1.5 °C global warming target

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Abstract. The Paris Agreement proposes a 1.5 ºC target to limit the increase in global mean temperature (GMT). Studying the population exposure to droughts under this 1.5 ºC target will be helpful in guiding new policies that mitigate and adapt to disaster risks under climate change. Based on simulations from the inter-Sectoral Impact Model Intercomparison Project (ISI-MIP), the standardized precipitation evapotranspiration index (SPEI) was used to calculate drought frequencies in the reference period and 1.5 ºC global warming scenario. Then population exposure was evaluated by combining drought frequency with simulated population data from shared socioeconomic pathways (SSPs). In addition, the relative importance of climate and demographic change and the cumulative probability of exposure change were analyzed. Results revealed that population exposure to droughts on the east side of the Hu line is much more than on the west side; exposure in the middle and lower reaches of the Yangtze River region is the highest and lowest in the Qinghai-Tibet region. An additional 6.97 million people will be exposed to droughts under the 1.5 ºC global warming scenario relative to the reference period. Demographic change is the primary contributor to exposure (79.95 %) in the 1.5 ºC global warming scenario, more than climate change (29.93 %) or the interaction effect (-9.88 %). Of the three drought intensities, mild, moderate, and extreme, moderate droughts contribute the most to exposure (63.59 %). The frequency of extreme droughts is likely to decrease (71.83 % probability), while mild and moderate droughts may increase slightly (55.17 % and 51.71 % probability, respectively) in the 1.5 ºC global warming scenario.

1 Introduction

The goal of the Paris Agreement is to pursue efforts to limit the increase in global mean temperature (GMT) to 1.5 ºC above preindustrial levels, recognizing that this limit would significantly reduce the risks and impacts of climate change (UFFCCC, 2015). Studies quantifying climate extreme events and their social-economic impacts under the 1.5 ºC target are urgently needed. These types of studies are key content for the IPCC special report on the 1.5 ºC target, which will be published in 2018. As one of the most devastating natural disasters, droughts rank first in terms of globally affected populations (Mishra and Singh, 2010), and the frequency and intensity of droughts are increasing with global warming (Stocker et al., 2014; Field et al., 2012). Demographic growth in droughts-prone locations can increase the population exposed, and ultimately lead to increased risk (Forzieri et al., 2017; United Nations, 2013). Droughts have large impacts in China due to typical continental monsoon climate condition and the large population (Qin et al., 2015). The losses caused by droughts accounted for 19.4 % of all meteorological disasters from 1985 to 2014 (CMA, 2015). Therefore, research on population exposure to droughts in China under 1.5 ºC target will be important for understanding future risk.

Several studies of the 1.5 ºC target have been conducted recently (Donnelly et al., 2017; Henley and King, 2017; Huntingford et al., 2017; Guiot and Cramer, 2016). The objectives have been to evaluate the possible greenhouse gas (GHG) emissions pathways to achieve the 1.5 ºC target (ECAT, 2016; Mitchell et al., 2017) or predict changes in extreme climate events under the 1.5 ºC target (Karmalkar and Bradley, 2017; King et al., 2017; Wang et al., 2017). However, the influence of climate change on social-economic aspects, which also needs detailed assessment, has received less attention. The effects of droughts on human populations need to be quantified to identify the locations and intensity of disasters to which people will be exposed under the 1.5 ºC target. Smirnov et al. (2016) assessed changing population exposure to extreme droughts in RCP8.5 using standardized precipitation evapotranspiration index (SPEI); their results indicated that population exposure would increase 426.6 % compared to current conditions. RCP8.5 is a high emission scenario, which is far more than 1.5 ºC target, and the study did not account for mild and moderate droughts. Sun et al. (2017) analyzed population exposure to droughts under 1.5 ºC and 2.0 ºC global warming scenarios in the Haihe River Basin based on SPEI; their results indicated that population exposure under 1.5 ºC conditions would be reduced 30.4 % relative to 1986-2005. However, population data used in this study was the from sixth national population census of China in 2010, in both reference period and global warming scenarios, ignoring the impact of demographic growth on population exposure change. In addition to climate change, the number, growth, and spatial distribution of population are important contributors to exposure risk, and should be taken into consideration.

In this study, population exposure to droughts under global warming was quantified, the relative importance of different factors, and the uncertainty in exposure change were evaluated. First, SPEI was used to calculate drought frequencies during the reference period and 1.5 ºC global warming scenario based on simulations from the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP). Second, modeled population data from shared socioeconomic pathways (SSPs) were used to evaluate the spatial distribution and change in population exposure to droughts in China. Third, the relative importance of climate and demographic change was compared, and the uncertainty in exposure change was assessed using cumulative distribution functions (CDFs). This evaluation of population exposure to droughts in China under the 1.5 ºC target is expected to provide effective adaptation and mitigation strategies.

2 Materials and methods

2.1 Materials

Meteorological data used in this study were obtained from ISI-MIP (Warszawski et al., 2014), which contains five global climate models (GCMs) simulation results in representative concentration pathways (RCPs), GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M. Results from five GCMs were averaged because combining multiple models has been to shown superior to a single model (Zhou and Yu, 2006). The chosen reference period was 1986-2005, which is a common period to assess climate change effect, and is 0.61 °C warmer than preindustrial levels (Stocker et al., 2014). According to previous research (Schleussner et al., 2016; Sun et al., 2017), a stable increase of 1.5°C GMT above preindustrial level for 20 years will be in 2020-2039 under RCP2.6. According to the correspondence between RCPs and SSPs provided by the IPCC, RCP 2.6 generally corresponds to SSP1. SSP1 is a sustainable development scenario facing low mitigation and adaption challenges (O'Neill et al., 2014). Therefore, SSP1 was chosen in this study. Population data for SSP1 was obtained from the National Institute for Environmental Studies, Japan (NIES), which was downscaled from the International Institute for Applied Systems Analysis (IIASA) simulated results. Population in 2000 and 2030 was used to represent the population in reference period and 1.5 °C global warming scenario, respectively. The spatial resolution of meteorological and population data is 0.5 ° × 0.5 °.

2.2 Calculation of SPEI

SPEI was proposed by Vicente-Serrano et al. (2010) as a multi-scale index, similar to the Standardized Precipitation Index (McKee et al., 1993), but sensitive to climate warming, similar to the Palmer Drought Severity Index (Palmer, 1965). SPEI-12 was chosen in this study to well-reflect long term trends and inter-annual changes in droughts. The Thornthwaite (1948) equation for calculating potential evapotranspiration (ETo) in SPEI only takes temperature into account, ignoring the effects other dynamic factors on droughts. Therefore, the Penman-Monteith equation (FAO, 1998) was used to calculate ETo in this study. Results are more consistent with true reference crop evapotranspiration because the equation considers both thermal and dynamic factors. The categorization of drought grade by SPEI is shown in Table 1 (Liu and Jiang, 2015).

2.3 Population exposure to drought

The definition of population exposure to drought is the number of people exposed to mild, moderate, and extreme droughts, that is, the frequency of mild, moderate, and extreme droughts multiplied by the number of people exposed to them. In this study, population exposures to mild, moderate, and extreme droughts were calculated in the 1.5 ºC global warming scenario and compared to the results of the reference period. The spatial distribution and change in exposure were analyzed based on the regional separation of China's population into eight major demographic regions (Hu, 1990; Fig. S1).

2.4 Relative importance and uncertainty analysis

Population exposure change was decomposed into climate change, demographic change, and interaction effects to evaluate the relative importance using the techniques from a previous study (Jones et al., 2015). The impact of population was calculated by holding climate constant, that is, the frequency of mild, moderate, and extreme droughts in the reference period multiplied by the population in the 1.5 ºC global warming scenario. Similarly, when calculating impact of climate, the population was held constant, that is, the frequency of mild, moderate, and extreme droughts in the 1.5 ºC global warming scenario was multiplied by the population in the reference period. The interaction effect was also evaluated to assess whether the area with continued population growth is experiencing more drought events under climate change.

The uncertainty in drought frequency and exposure change were analyzed based on CDFs to evaluate the possible impact of climate change. First, the change in frequency and population exposure to mild, moderate, extreme, and all droughts were separately calculated in the 1.5 ºC global warming scenario relative to the reference scenario. Then, the probability distribution of change was calculated using CDFs.

3 Results

3.1 Spatial and temporal patterns of drought frequency and population

The frequency of mild, moderate, and extreme droughts, and their relationship with population were calculated for the reference period and 1.5 ºC global warming scenario to evaluate the spatial and temporal variation in frequency (Fig. S2) and population (Fig. S3). Generally, mild and moderate droughts will occur more frequently than extreme droughts. The frequency of mild and moderate droughts in most areas is in the range of 5-20 %, while the frequency of extreme droughts is less than 5 % in both the reference period and 1.5 ºC global warming scenario (Fig. S2). As for the spatial pattern of frequency, areas with high frequency of mild droughts are scattered, while moderate droughts are more spatially concentrated. In the reference period, moderate droughts are concentrated in southern China and the lower reaches of the Yellow River region, i.e., Beijing, Tianjin, Hebei, Henan and Shandong province. In the 1.5 ºC global warming scenario, the Shanxi-Shaanxi-Gansu-Ningxia region and Inner Mongolia-Xinjiang region also has more frequent moderate droughts. Extreme droughts occur primarily in inland areas. For example, the Qinghai-Tibet region has the highest frequency of extreme droughts in both scenarios. However, the spatial pattern of extreme droughts changed between the two scenarios. In the 1.5 ºC global warming scenario, the frequencies in the northeast region, i.e., Heilongjiang, Jilin, and Liaoning Provinces, the Shanxi-Shaanxi-Gansu-Ningxia region and middle and lower reaches of the Yangtze River region, i.e., Shanghai, Jiangsu, Anhui, Jiangxi Hunan, and Hubei province, decrease. In contrast, in the southwest region, i.e., Sichuan, Chongqing, Guizhou, and Yunnan Provinces, and the southeast coastal region, i.e., Zhejiang, Fujian, Guangdong, Guangxi, Hainan, Hong Kong, Macao, and Taiwan, the frequency increases relative to the reference period.

The population of China increases 32.56 million, from 1.26 billion in the reference period to 1.29 billion in the 1.5 °C global warming scenario. However, areas of increasing population do not expand in size, and most areas decrease. The variation in demographic change is clear when comparing the two sides of the Hu line (Hu 1935), but the spatial pattern of demographic change in number and percentage is different (Fig. S3). The number of people decreases significantly on the east side of the Hu line, especially in the lower reaches of the Yellow River region and middle and lower reaches of the Yangtze River region, while the decrease in population by percentage is clear on the west side of the Hu line, such as the Inner Mongolia- Xinjiang region and east of the Qinghai-Tibet region. The reason for this dichotomy is the differing demographic distribution on both sides of the Hu line. The west side occupies 56.2 % of total land area in China, but the population only occupies 5.9 %; the population density is so small that changes in percentage are clearer.

3.2 Spatial distribution and change in population exposure to droughts

The aggregate population exposure in the reference period is 179.17 million and increases to 186.14 million in the 1.5 ºC global warming scenario. Comparing the population exposure to different droughts in the two scenarios (Fig. 1), the exposure to mild and moderate droughts increases while that to extreme droughts decreases. Moderate droughts account for 53.01 % of total exposure in the reference period and 53.34 % in the 1.5 °C global warming scenario, accounting for the most exposure. In comparison, mild droughts ranks second, extreme droughts ranks third accounting for 2.31 % and 1.69 % in the two scenarios. The spatial pattern of population exposure to droughts is similar to the population demographic distributions in China, i.e., divided by the Hu line. Exposure on the east side is much greater than on the west side (Fig. 2). Exposure in the Yellow River region and middle and lower reaches of the Yangtze River region is the highest, and lowest in Inner Mongolia-Xinjiang region and the Qinghai-Tibet region.

Comparing the changes in exposure to mild (Fig. 3a), moderate (Fig. 3b), extreme (Fig. 3c), and total droughts (Fig. 3d), we found that, except for extreme droughts, the others show similar spatial patterns. The exposure in southeast China increases, while that in the northwest part decreases. For mild droughts, exposure increases more clearly in the lower reaches of the Yellow River region, southeast region, and southeast coastal region. For moderate droughts, the increases in the northeast region, Shanxi-Shaanxi-Gansu-Ningxia region, and southeast coastal region are apparent. In these regions, the combination of mild and moderate droughts dominates the overall pattern for total exposure. As for extreme droughts, the exposure for most of China decreases, except for the south of southwest region and west of southeast coastal region.

3.3 Relative importance analysis

The relative importance of different factors, i.e., climate change, demographic change, and interaction effects, and different droughts were analyzed (Fig. 4). For different factors, climate change and demographic change have positive impacts on the total exposure change (29.93 %, 79.95 %), while the interaction effect has a negative impact (-9.88 %). These results imply that the areas experiencing more droughts have decreasing populations in the 1.5 ºC global warming scenario. For different droughts, the effect of mild and moderate droughts is positive and of similar magnitude, whereas extreme droughts have a lesser effect. Except for the constant climate scenario for analyzing the demographic change effect, the effect of extreme droughts is negative. In total change in exposure, the contributions from mild and moderate droughts are 54.03 % and 63.59 %, respectively, leaving -17.62 % for the effect of extreme droughts. In summary, the demographic change and moderate droughts are the dominant contributors to exposure change in two scenarios.

3.4 Cumulative probability analysis

Figure 5 shows CDFs for drought frequency and population exposure for changes in the 1.5 ºC global warming scenario relative to the reference period. For the change in drought frequency (Fig. 5a), extreme droughts are in the minimum range, with changes of -5 to 5 %, whereas total droughts are in the maximum range, -18 to 16 %. The cumulative probability of an increase in drought frequency under the 1.5 ºC global warming scenario for mild, moderate, extreme, and total droughts is 50.14 %, 46.48 %, 38.23 %, and 49.86 %, respectively. Apart from extreme droughts, which show a clear downward trend, the probabilities of an increase or decrease in mild, moderate, and total droughts are equal. In terms of change in population exposure (Fig. 5b), extreme droughts show a minimum, at -5 to 5 %, and total droughts show a maximum, -25 to 25 % probability. Extreme droughts decrease, with a cumulative probability of 71.83 %, while mild, moderate, and total droughts increase, with a cumulative probability of 55.17 %, 51.71 %, and 53.01 %, respectively. The probability of an increase in mild droughts is the highest, while the probability of an increase in extreme droughts is the lowest in both drought frequency and exposure under the 1.5 ºC global warming scenario.

4 Discussion

Extensive studies have focused on changes in extreme climate events under global climate change (Hirabayashi et al., 2013; Huang et al., 2017; Kharin et al., 2013). Currently, with the 1.5 ºC target, the social-economic impacts of 1.5 ºC global warming on factors, such as population exposed to disasters, need to be further studied. In this study, the population exposure to droughts was calculated for the 1.5 ºC global warming scenario and reference period by combining drought frequency and population simulations. The relative importance of different factors, as well as evaluating the cumulative probability of exposure change were analyzed. There are some uncertainties in estimating exposure under climate change, which are due to differences in scenarios, GCMs, selection of drought index, calculation of potential evapotranspiration, and population predictions (Maurer, 2007; Burke and Brown, 2008; Kirono et al., 2011).

Our results indicated that population exposure to droughts in the 1.5 ºC global warming scenario would increase by 6.97 million compared to the reference period. Among the three different droughts, exposure to moderate droughts will be the largest because the areas with a high frequency of moderate droughts coincide with high population density. Drought frequency and population are two important factors that contribute to exposure. To determine which one has a larger impact, the relative importance of this two factors, and the interaction effect, were analyzed. Results revealed that exposure change is mainly due to demographic change (79.95 %), and climate change is responsible for 29.93 % of the change; the interaction effects explain the remaining -9.88 %. These results are different from previous studies applying contribution analysis. Jones et al. (2015) calculated future population exposure to US heat extremes under the Special Report on Emission Scenarios (SRES) A2 scenario; they found that the growth in exposure is mainly due to climate change. Smirnov et al. (2016) analyzed the relative importance of climate change and demographic growth for exposure to future extreme droughts in RCP4.5 and RCP8.5, and their results indicated that climate change is more responsible for exposure change than demographic change in both scenarios.

The contradiction may be due to the different scenarios used in the studies. SRES A2, RCP4.5, and RCP 8.5 are scenarios with higher GHG emissions relative to RCP2.6, which corresponds to the 1.5 ºC target used in our study. This 1.5 ºC target is an important constraint because it is relevant to the requirements for large GHG emission reductions. The difference of GHG emission also explains the cumulative probability analysis result for drought frequency. Drought frequency is not likely to increase in 1.5 ºC global warming scenario compared to the reference period. Therefore, the effect of climate change to exposure is reduced compared to higher emission pathways, which results in demographic change acting as the primary contributor to exposure. In future studies, we would like to account for more demographic characteristics in addition to growth, i.e., age, sex, education, and income, which are likely to be stronger factors for demographic change in the 1.5 ºC target. However, we currently lack of the required sophisticated data.

5 Conclusions

These results lead to four key conclusions. First, population exposure to droughts on the east side of the Hu line is much higher than that on the west side, which corresponds to general demographic distributions in China. Among the eight demographic regions, exposure in the middle and lower reaches of the Yangtze River region is the highest, and the lowest occurs in the Qinghai-Tibet region. Second, in the 1.5 ºC global warming scenario, population exposure to droughts has a substantial increase, 6.97 million more residents exposed, relative to the reference period. Third, variations in both population and climate are important factors in this change in exposure, but demographic change is the primary contributor (79.95 %) in the 1.5 ºC global warming scenario. Moderate droughts contribute most among three droughts (63.59 %). Fourthly, the frequency of extreme droughts is likely to decrease (71.83 % probability) while mild and moderate droughts may increase (55.17 %, 51.71 % probability) in the 1.5 ºC global warming scenario. Results suggest that reaching the 1.5 °C target is a potential mechanism for mitigating the impact of climate change on droughts. In addition, demographic change should be regarded as a significant component to control the growth in exposure to droughts.

Acknowledgements

This study was supported by the National Key Research and Development Program of China [Grant No.2016YFA0602402]; National Natural Science Foundation of China [Grant No. 41671037, 41301091]; the Key Research Program of Frontier Sciences, CAS (QYZDB-SSW-DQC005); and the Youth Innovation Promotion Association, CAS [Grant No. 2016049]. We also thank ISI-MIP and NIES for data support.

References

Burke, E. J., and Brown, S. J.: Evaluating Uncertainties in the Projection of Future Drought, J. Hydrometeorol., 9, 292-299, 2008.

China Meteorological Administration (CMA). China meteorological Disaster Yearbook. Meteorological Press of China, Beijing, 2015.

Donnelly, C., Greuell, W., Andersson, J., Gerten, D., Pisacane, G., Roudier, P., and Ludwig, F.: Erratum to: Impacts of climate change on European hydrology at 1.5, 2 and 3 degrees mean global warming above preindustrial level, Climatic Change, 143, 535-535, 2017.

Ecofys Climate Action Tracker (ECAT). The Ten Most Important Short Term Steps to Limit Warming to 1.5C, 2016.

FAO: Crop Evapotranspiration for Computing Crop Water Requirement, FAO Irrigation & Drainage Paper, 56, 1998.

Field, C. B., Barros, V., and Stocker, T. F.: Managing the risks of extreme events and disasters to advance climate change adaptation. Special report of the Intergovernmental Panel on Climate Change (IPCC), J Clin. Endocr. Metab., 18, 586-599, 2012.

Forzieri, G., Cescatti, A., Silva, F. B. E., and Feyen, L.: Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study, Lancet Planet Health, 1, e200-e208, 2017.

Guiot, J., and Cramer, W.: Climate change: The 2015 Paris Agreement thresholds and Mediterranean basin ecosystems, Science, 354, 465, 2016.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Dai, Y., Watanabe, S., Kim, H., and Kanae, S.: Global flood risk under climate change, Nat. Clim. Change, 3, 816-821, 2013.

Henley, B. J., and King, A. D.: Trajectories toward the 1.5°C Paris target: Modulation by the Interdecadal Pacific Oscillation, Geophys. Res. Lett., 44, 2017.

Hu H.Y.: The distribution of China's Population. Acta Geol. Sin., 2, 33-74, 1935.

Hu H.Y.: The distribution, regionalization and prospect of China's Population. Acta Geol. Sin., 2,13-19, 1990.

Huang, J., Zhai, J., Jiang, T., Wang, Y., Li, X., Wang, R., Xiong, M., Su, B., and Fischer, T.: Analysis of future drought characteristics in China using the regional climate model CCLM, Clim. Dynam., 1-19, 2017.

Huntingford, C., Yang, H., Harper, A., Cox, P. M., Gedney, N., Burke, E. J., Lowe, J. A., Hayman, G., Collins, W. J., and Smith, S. M.: Flexible parameter-sparse global temperature time profiles that stabilise at 1.5 and 2.0 °C, Earth Syst. Dynam. Disc., 8, 1-11, 2017.

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.

Karmalkar, A. V., and Bradley, R. S.: Consequences of Global Warming of 1.5 °C and 2 °C for Regional Temperature and Precipitation Changes in the Contiguous United States, Plos One, 12, e0168697, 2017.

Kharin, V. V., Zwiers, F. W., Zhang, X., and Wehner, M.: Changes in temperature and precipitation extremes in the CMIP5 ensemble, Climatic Change, 119, 345-357, 2013.

King, A. D., Karoly, D. J., and Henley, B. J.: Australian climate extremes at 1.5°C and 2°C of global warming, Nat. Clim. Change, 2017.

Mckee, T. B., Doesken, N. J., and Kleist, J.: The relationship of drought frequency and duration to time scales, In Proceedings of the 8th Conference on Applied Climatology, 17, 179-183. Boston, MA: American Meteorological Society., 1993.

Kirono, D. G. C., Kent, D. M., Hennessy, K. J., and Mpelasoka, F.: Characteristics of Australian droughts under enhanced greenhouse conditions: Results from 14 global climate models, J. Arid Environ., 75, 566-575, 2011.

Liu K, and Jiang D. Analysis of dryness/wetness over China using standardized precipitation evapotranspiration index based on two evapotranspiration algorithms. Chinese J. Atmos. Sci., 39 (1): 23−36, 2015.

Maurer, E. P.: Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios, Climatic Change, 82, 309-325, 2007.

Mishra, A. K., and Singh, V. P.: A review of drought concepts, J. Hydrol., 391, 202-216, 2010.

Mitchell, D., Achutarao, K., Allen, M., Bethke, I., Beyerle, U., Ciavarella, A., Forster, P. M., Fuglestvedt, J., Gillett, N., and Haustein, K.: Half a degree additional warming, prognosis and projected impacts (HAPPI): background and experimental design, Geosci. Model Dev., 10, 571-583, 2017.

Nakicenovic, N., Alcamo, J., Grubler, A., Riahi, K., Roehrl, R., Rogner, H.-H., and Victor, N.: Special Report on Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2000.

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R., and Vuuren, D. P. V.: A new scenario framework for climate change research: the concept of shared socioeconomic pathways, Climatic Change, 122, 401-414, 2014.

Palmer, W.: Meteorological drought, U.S. Department of Commerce Weather Bureau Research Paper, 1965.

Qin, D., Editor, C., and Edi, D. C.: China national assessment report on risk management and adaptation of climate extremes and disasters, Science Press, 2015.

Schleussner, C. F., Lissner, T. K., Fischer, E. M., Wohland, J., Perrette, M., Golly, A., Rogelj, J., Childers, K., Schewe, J., and Frieler, K.: Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 °C and 2 °C, Earth Syst. Dynam., 7(2):327, 2016.

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.

Stocker, T. ed. Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 2014.

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.

Thornthwaite, C. W.: An approach toward a rational classification of climate, Geogr. Rev., 38, 55-94, 1948.

UNFCCC Conference of the Parties (COP), Adoption of the Paris Agreement, 2015.

United Nations, D. O. E. A. S. A., Population Division (2013) World Population Prospects: The 2012 Revision Retrieved from: http://esa.un.org/wpp/Excel-Data/population.htm

Vicenteserrano, S. M., Beguería, S., and Lópezmoreno, J. I.: A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index, J. Climate, 23, 1696-1718, 2010.

Wang, G., Cai, W., Gan, B., Wu, L., Santoso, A., Lin, X., Chen, Z., and Mcphaden, M. J.: Continued increase of extreme El Niño frequency long after 1.5 °C warming stabilization, Nat. Clim. Change, 2017.

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O., and Schewe, J.: The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): project framework, Proceedings of the National Academy of Sciences of the United States of America, 111, 3228-3232, 2014.

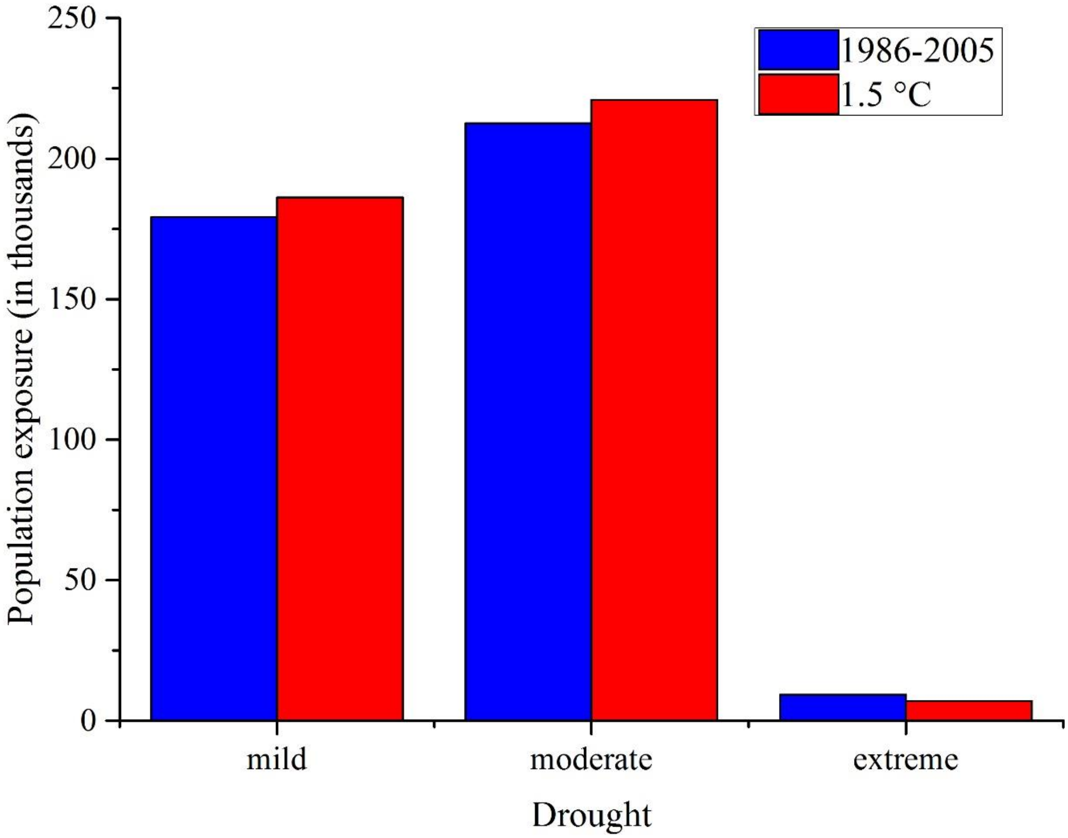
Zhou, T., and Yu, R.: Twentieth-Century Surface Air Temperature over China and the Globe Simulated by Coupled Climate Models, J. Climate, 19, 5843, 2006

Tables

Table 1. Drought grade categories in the SPEI.

SPEI	Categories
>-0.5	Normal and wetness
-1.0~-0.5	Mild drought
-2.0~-1.0	Moderate drought
⩽-2.0	Extremely drought

Figures



5 **Figure 1. Population exposure to mild, moderate, and extreme droughts for the reference period (1986-2005) and 1.5 °C global warming scenario.**

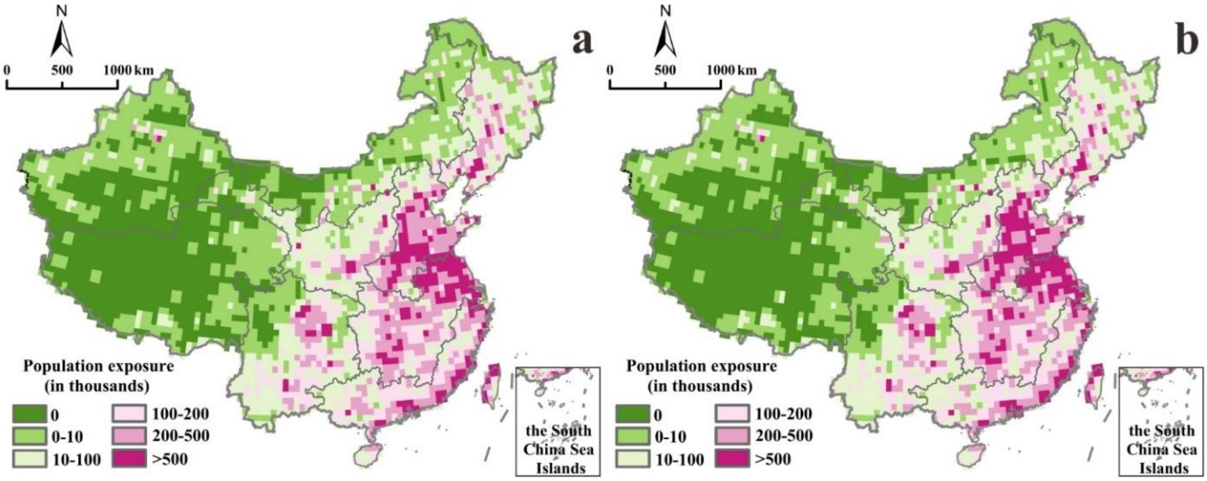
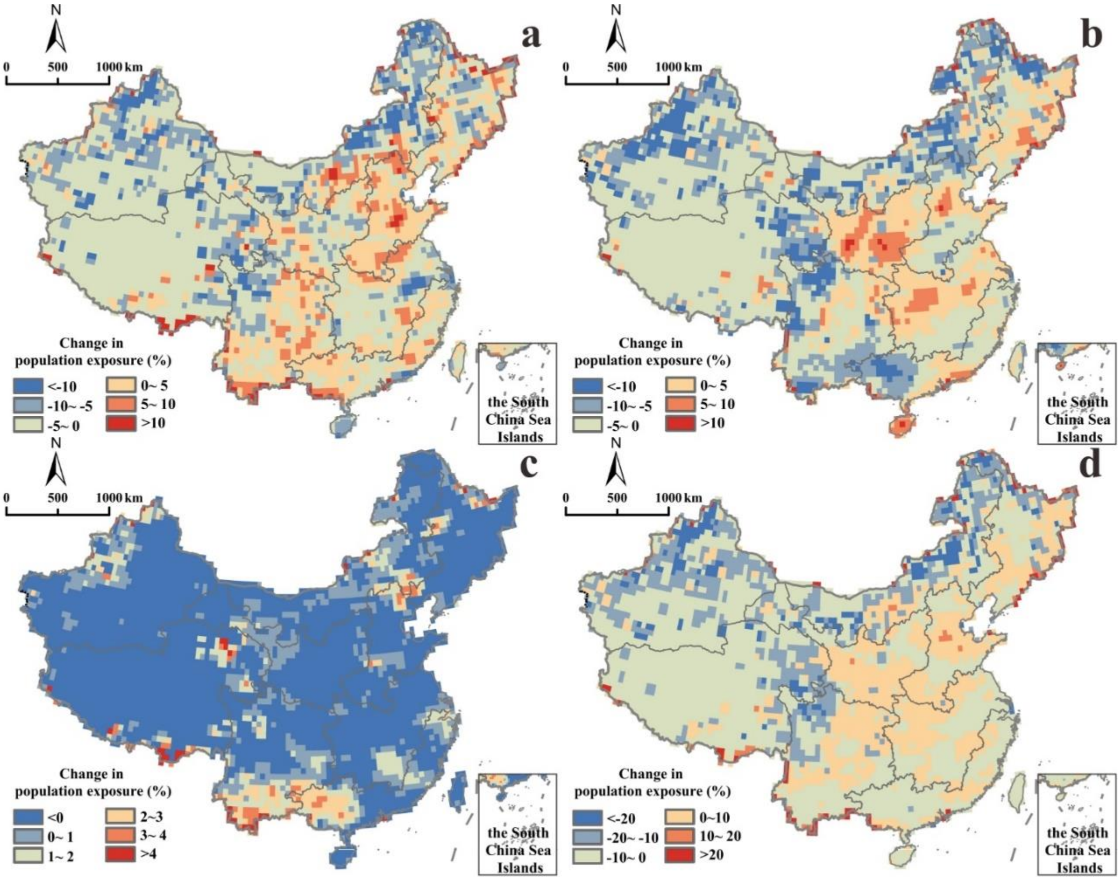


Figure 2. Spatial distribution of population exposure to droughts in (a) the reference period (1986-2005) and (b) 1.5 °C global warming scenario (2020-2039 in RCP2.6).



5 **Figure 3. Change in population exposure to droughts between the reference period and 1.5 ºC global warming scenario, (a) change in exposure to mild droughts, (b) change in exposure to moderate droughts, (c) change in exposure to extreme droughts, and (d) change in exposure to all droughts.**

Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-100
Manuscript under review for journal Earth Syst. Dynam.
Discussion started: 7 November 2017

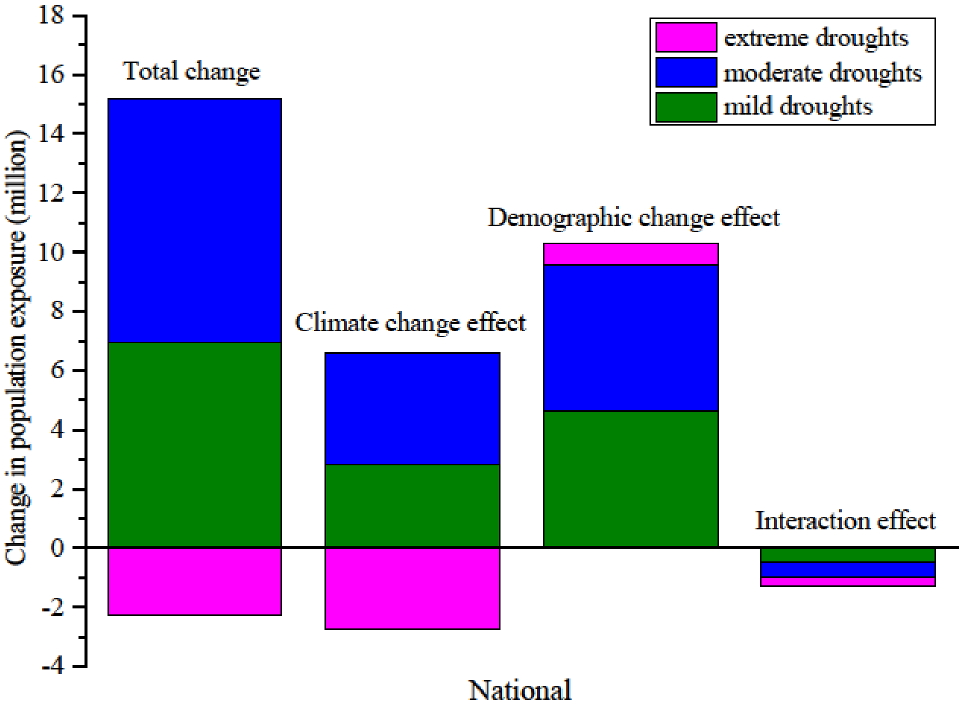
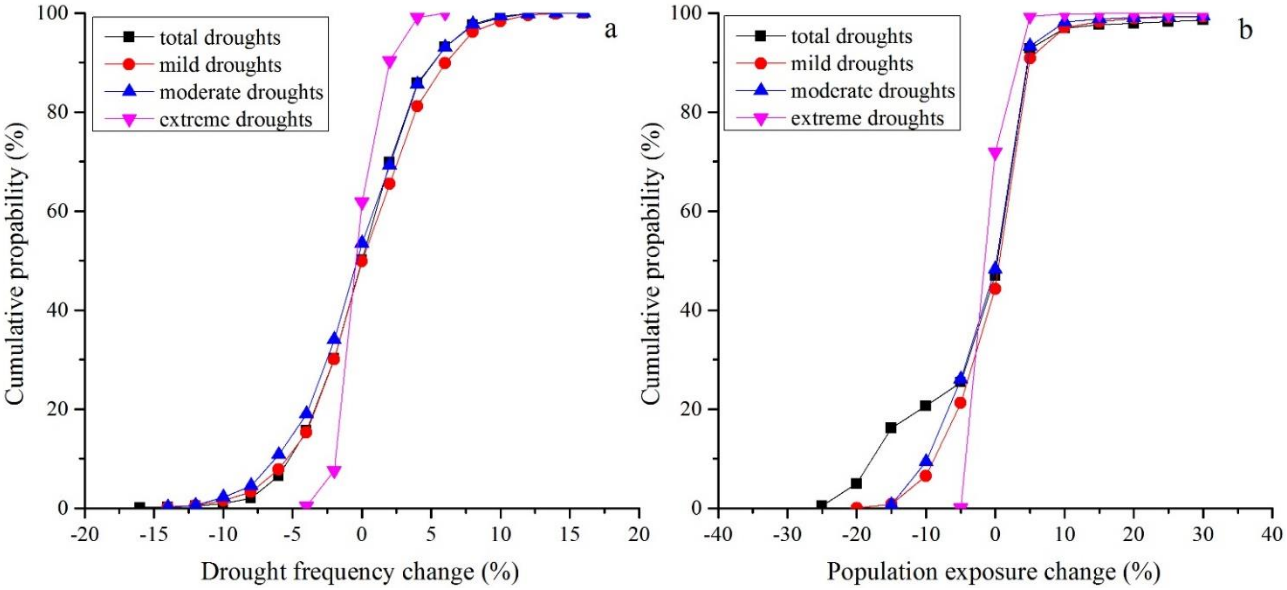


Figure 4. Decomposition of population exposure based on different effects, climate change, demographic change, and their interaction, and droughts of mild, moderate, and extreme.



5 **Figure 5. Cumulative probability projected change drought frequency (a) and population exposure (b) to mild, moderate, extreme, and total droughts**