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Future changes in precipitation extremes over China using the NEX-GDDP high-resolution daily downscaled data-set

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ABSTRACT

Recently, a new high-resolution daily downscaled data-set derived from 21 CMIP5 model simulations has been released by NASA, called 'NASA Earth Exchange Global Daily Downscaled Projections' (NEX-GDDP). In this study, the performance of this data-set in simulating precipitation extremes and long-term climate changes across China are evaluated and compared with CMIP5 GCMs. The results indicate that NEX-GDDP can successfully reproduce the spatial patterns of precipitation extremes over China, showing results that are much closer to observations than the GCMs, with increased Pearson correlation coefficients and decreased model relative error for most models. Furthermore, NEX-GDDP shows that precipitation extremes are projected to occur more frequently, with increased intensity, across China in the future. Especially at regional to local scales, more information for the projection of future changes in precipitation extremes can be obtained from this high-resolution data-set. Most importantly, the uncertainties of these projections at the regional scale present significant decreases compared with the GCMs, making the projections by NEX-GDDP much more reliable. Therefore, the authors believe that this high-resolution data-set will be popular and widely used in the future, particularly for climate change impact studies in areas where a finer scale is required.

摘要

最近, NASA发布了一套基于CMIP5 21个耦合模式输出的高分辨率降尺度逐日数据集, 简称NEX-GDDP。本文评估了NEX-GDDP对中国极端降水的模拟性能。研究发现: (1) 相比CMIP5直接输出结果, NEX-GDDP能够更好刻画中国极端降水的空间分布; (2) 未来中国极端降水事件明显增多、强度增强, NEX-GDDP在区域尺度上给出了更多的气候变化信息; (3) NEX-GDDP预估的中国未来极端降水变化的不确定性范围相比CMIP5直接输出结果明显减少, 使得预估结果更加可靠。

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关键词

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1. Introduction

Future changes in extreme climate events, including extreme temperature and precipitation events, will result in large losses for society, the economy, and natural ecosystems, due to the potentially severe impacts of such changes, as emphasized in the reports of the Intergovernmental Panel on Climate Change (IPCC; Field et al. 2014; Stocker et al. 2013). Evidence shows that most weather and climate events have become more extreme and will continue to worsen in the future, both globally (Field et al. 2012) and across China (e.g. Chen 2013; Chen and Sun 2015; Jiang et al. 2012; Wang et al. 2017; Wu, Zhou, and Xu 2015; Xu et al. 2015, 2017; Zhou et al. 2014, 2016). However, large uncertainties exist in these projections (Chen, Sun, and Chen 2014; Knutti 2008), due to the complex nature of

the climate system, which is poorly understood and inadequately modeled (Jiang, Tian, and Lang 2016; Zhou and Chen 2015), particularly at regional levels.

A variety of downscaling methods, including dynamical and statistical downscaling approaches, have been developed and widely used for reliable projections of climate changes at finer scales. In China, two regional climate models (RCMs) have been implemented to generate centennial-scale data for future climate projections, including RegCM and WRF models (Gao, Shi, and Giorgi 2011; Yu et al. 2015). Results have indicated that warm events tend to occur more frequently across China, and precipitation events tend to be more extreme over most parts of China, using an RCM-based dynamical downscaling method (Gao et al. 2017; Xu et al. 2013).

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However, it is quite difficult to identify the confidence levels of climate changes because of the few ensembles that mainly result from its huge computing cost for the RCM runs. Compared with dynamical downscaling, a relatively lower computing resource is required by statistical downscaling, and the method can be easily transferable to any other region (Fowler, Blenkinsop, and Tebaldi 2007). The statistical approach has been widely used in seasonal climate predictions worldwide (Fowler, Blenkinsop, and Tebaldi 2007), as well as in China (Chen, Sun, and Wang 2012; Sun and Chen 2012), during recent decades. It has also been applied by NASA to general circulation model (GCM) simulations from the Coupled Model Intercomparison Project, Phase 5 (CMIP5), to generate a high-resolution data-set for long-term projections, called 'NASA Earth Exchange Global Daily Downscaled Projections' (NEX-GDDP), which was released to the Earth science community in June 2015 (Thrasher et al. 2013). Based on this data-set, the projected near-term and long-term changes in mean precipitation and temperature over China were evaluated by Bao and Wen (2017) and found to be robust. However, the nature of extreme climate changes over China have yet to be revealed using this high-resolution data-set, which is the topic of the present study.

2. Data and methods

The bias-correction spatial disaggregation (BCSD) method was used to generate the NEX-GDDP data-set on the basis of 21 CMIP5 model simulations (Thrasher et al. 2013). Each of the CMIP5 simulations was down-scaled to a global spatial resolution of $0.25^\circ \times 0.25^\circ$. The release of this data-set includes three climatic variables: daily precipitation, and daily maximum and minimum temperature, for the period 1950–2005 (historical run) and 2006–2100 (RCP4.5 and RCP8.5 runs). For more information on the data-set, see <https://nex.nasa.gov/nex/projects/1356/>.

The changes in precipitation extremes, including annual maximum one-day precipitation (rx1d) and annual maximum five-day precipitation (rx5d), are analyzed over China using this high-resolution data-set. The rx1d index represents the magnitude of extreme daily precipitation, whereas rx5d is the cumulative value, which is relevant in assessing the risks of flooding. For comparison, the corresponding simulations from 21 CMIP5 models are also used, which were resampled onto a common global grid of $1.5^\circ \times 1.5^\circ$ using the first-order conservative remapping procedure. Additionally, observational gridded precipitation data from the CN05.1 data-set developed by Wu and Gao (2013) is employed, with a high resolution of $0.25^\circ \times 0.25^\circ$ across China.

3. Results

3.1. Model performance in NEX-GDDP

The high-resolution NEX-GDDP data-set has significantly improved the performance of GCMs in simulating the spatial patterns of precipitation extremes (rx1d and rx5d), and can provide much information at finer scales, especially over regions with complex topography (figure not shown). The multi-model median ensemble (MME) result from CMIP5 GCMs can reproduce the climatological patterns of precipitation extremes over China, but the NEX-GDDP data-set shows a relatively better performance. This is clear from Figure 1, which presents a metric-based evaluation of model performance in simulating the spatial patterns of precipitation extremes across China and six sub-regions. The metrics used are Pearson's correlation coefficient (R) and model relative error (MRE). The MRE provides a measure of how well a given model simulates the patterns when compared with the typical model error (MME; Gleckler, Taylor, and Doutriaux 2008). A negative value of MRE generally indicates a higher skill than typically seen, while a positive value indicates a lower skill. Clearly, the improvement is significant in China, and most models in NEX-GDDP show higher performance than the GCMs from CMIP5, with 13 of 21 models and 19 of 21 models showing higher R and lower MRE in NEX-GDDP in simulating rx1d and rx5d, respectively. Better performance can be observed in the MME than in individual models, and higher performance is obvious from the NEX-GDDP data-set (Figure 1(a)).

Considering the effect of its topography, China is separated into six sub-regions (Figure 2(a)) for further comparison, including Northeast China (NEC), North China (NC), South China (SC), Southwest China (SWC), eastern Northwest China (ENWC), and western Northwest China (WNWC). Similar to the whole of China, the NEX-GDDP data-set presents visible improvement in simulating the patterns of rx1d and rx5d for each sub-region, and the improvement in rx5d seems to be more prominent than in rx1d (Figure 1(b)–(g)). Additionally, the improvement seems to be more obvious in the regions with complex terrain (e.g. SWC and WNWC present a higher increase in R), at least from the MME results. This is because the effect of topography, which occasionally excites or intensifies local precipitation extremes, has been incorporated in the high-resolution NEX-GDDP data-set (Bao and Wen 2017).

In addition to climatological analyses, the model performance in simulating the threshold values of precipitation extremes with a 50-year return period is also evaluated, as shown in Figure 2. Both the CMIP5 GCMs and NEX-GDDP successfully reproduce the threshold values of these two precipitation extreme indices, which decrease from southeastern to northwestern China. However, NEX-GDDP generally reproduces the high threshold values over the lower

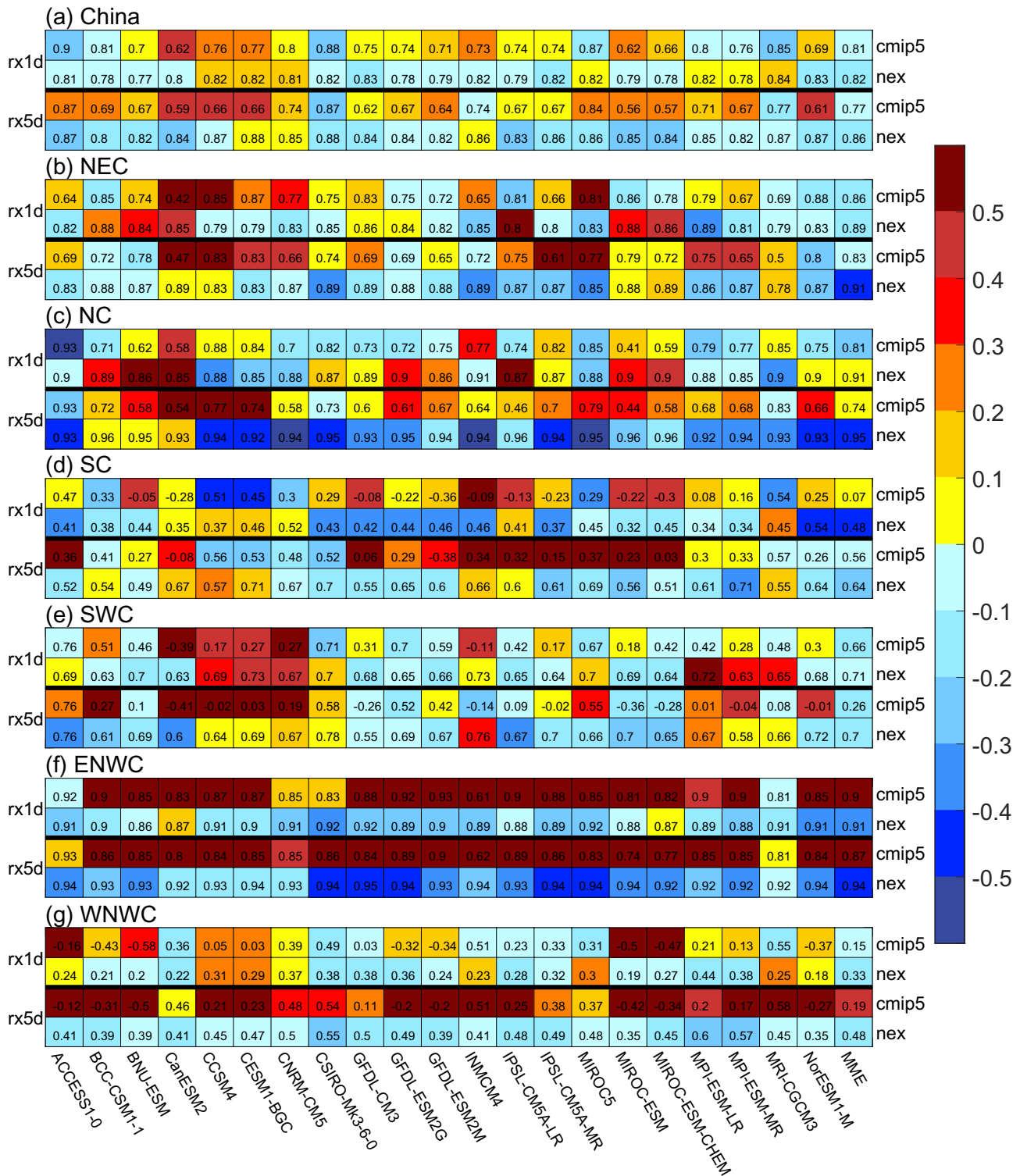


Figure 1. Comparison of model performances in simulating the spatial patterns of rx1d and rx5d over China and six sub-regions between CMIP5 and NEX-GDDP. The metric analysis includes estimations of Pearson's correlation coefficient (numbers) and model relative error (shading), in which 'colder' colors indicate better performance and 'warmer' colors the opposite.

reach of Yangtze River, eastern coast region, and Sichuan basin, much closer to the observations than GCMs. Similar results can be observed for both rx1d and rx5d.

For the past several decades, both rx1d and rx5d over China present increasing trends, which are reasonably

reproduced by both the GCMs and NEX-GDDP (figure not shown). Furthermore, the increasing trends in NEX-GDDP are in general identical to those in the GCMs, because the trends in daily precipitation have been preserved following the BCSD step (Thrasher et al. 2013).

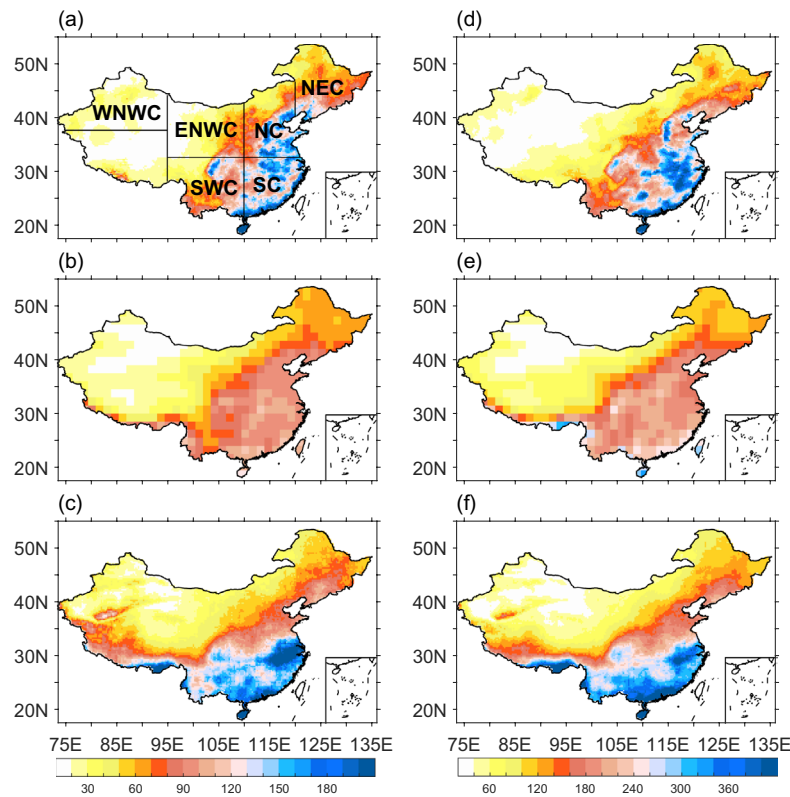


Figure 2. Spatial distributions of the threshold values of the 50-year return period events estimated from observation (top panels), CMIP5 GCMs (middle panels), and NEX-GDDP (bottom panels), for rx1d (left) and rx5d (right), across China.

3.2. Long-term changes in precipitation extremes

Based on the results presented in Section 3.1, more accurate information is successfully reproduced by NEX-GDDP compared with the GCMs for the precipitation extremes over China. Therefore, in this section, the future long-term changes in rx1d and rx5d are investigated using the NEX-GDDP data-set.

Figure 3 presents the projected changes in rx1d and rx5d over China for three future periods with respect to the current climatology. For rx1d, the MME results show an obvious increase across China, with a smaller increase in the near-term (2016–2035) and a larger increase in the long-term (2080–2099) future. Furthermore, the model consistency of projected changes is also observed to increase with time. Higher agreement is generally observed over ENWC, SWC, NEC, and the Tibetan Plateau (TP), especially at the end of this century. For the period 2080–2099, the regional mean rx1d in China is projected to increase by 15% under RCP4.5 and 27% under RCP8.5, against 1986–2005. The largest increase happens over the TP, with an increase of 26% under RCP4.5 and 49% under RCP8.5; while the smallest increase occurs over WNWC, with increases of 12% and 22%, respectively. Significant increases are also found in the other regions, with 12% (23%) over NEC, 14% (21%) over NC, 13% (24%) over SC,

14% (28%) over SWC, and 12% (22%) over ENWC, under the RCP4.5 (RCP8.5) scenario.

Increases of rx5d in the future are also identified, but with a relatively larger magnitude than for rx1d (Figure 3). The regional means of rx5d over China are projected to increase by 16% (RCP4.5) and 29% (RCP8.5) at the end of this century with respect to 1986–2005. Additionally, the rx5d over the NEC, NC, SC, SWC, ENWC, WNWC, and TP regions are projected to increase by 12%, 13%, 15%, 16%, 11%, 12%, and 28%, respectively, under the RCP4.5 scenario; and increase by 23%, 20%, 23%, 34%, 23%, 22%, and 55%, respectively, under the RCP8.5 scenario.

Additionally, we also investigate the projected changes over China in 50-year return period events based on rx1d and rx5d (figures not shown). The results indicate that the threshold values of these extreme events may increase significantly across China, implying a prominent increase in the probability of occurrence of these extremes in the future. Estimation shows that the threshold values of 50-year return period events may increase by 20% under RCP4.5 and 31% under RCP8.5 by the end of this century for rx1d, and by 27% under RCP4.5 and 41% under RCP8.5 for rx5d. In contrast, the return periods of these extremes are projected to decrease if the current threshold values are considered. Spatially averaged results across China

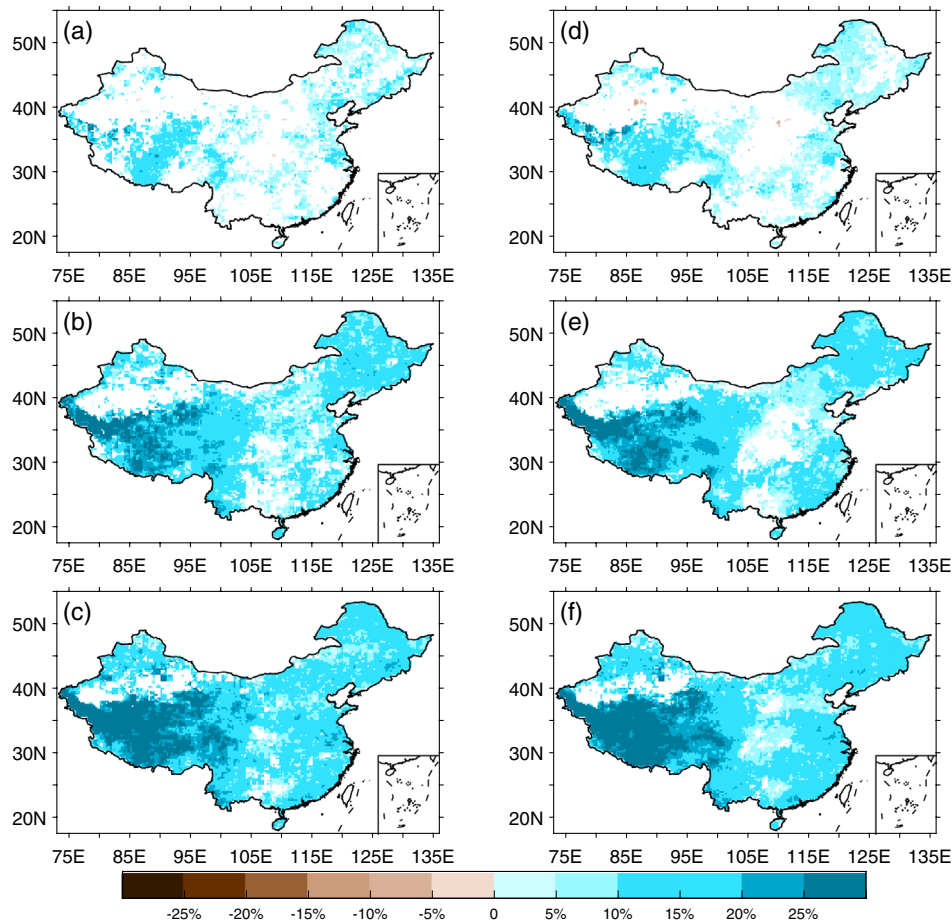


Figure 3. Projected changes of rx1d (left) and rx5d (right) in three future periods under the RCP4.5 scenario with respect to 1986–2005: 2016–2035 (top panels); 2046–2065 (middle panels); 2080–99 (bottom panels).

Note: Color shading is only applied for areas where at least 66% of the models agree on the sign of the change.

indicate that a 50-year event under current climate conditions is expected every 26 years under RCP4.5, and 21 years under RCP8.5, by the end of this century for rx1d. For rx5d, the event is expected to occur more frequently in the future, at once every 24 years under RCP4.5 and once every 18 years under RCP8.5, by the end of this century. Events over the sub-regions are also evaluated, revealing an expected occurrence of once every 24–28 years for rx1d, and 21–27 years for rx5d, under RCP4.5 during 2080–2099. Under the RCP8.5 scenario, the probability of occurrence is apparently much higher for each sub-region, and the return periods are estimated to vary from 18 to 26 years for rx1d, and from 14 to 25 years for rx5d, by the end of this century.

3.3. New features of NEX-GDDP

The high resolution of the NEX-GDDP data-set allows us to conduct studies of climate changes at local to regional scales, even at the spatial scale of individual towns, cities, and watersheds (Thrasher et al. 2013). Here, the projected changes in precipitation extremes are compared

with CMIP5 GCMs for three key regions, including the Jing-Jin-Ji (JJJ) region, Yangtze River Delta (YRD) region, and Pearl River Delta (PRD) region, which are the three fastest developing areas in China. The aim of this analysis is to check the new features of the NEX-GDDP data-set compared with GCMs.

Figure 4 presents the projected changes of rx5d in the future under the RCP4.5 scenario for the three key regions over China with respect to their current climates. Clearly, both NEX-GDDP and the GCMs present obvious increasing trends of rx5d in the future over these three key regions; however, relatively larger variability can be observed in NEX-GDDP than in the GCMs. For JJJ, the rx5d is projected to increase obviously across this region by both NEX-GDDP and the GCMs, but additional information can be observed from the NEX-GDDP projection. For example, the rx5d over Beijing in the GCMs, which covers just one grid, presents a uniform increase by the end of this century; whereas, NEX-GDDP shows a relatively larger increase over the western and northern parts of Beijing and a relatively smaller increase over its southeastern part. A greater level

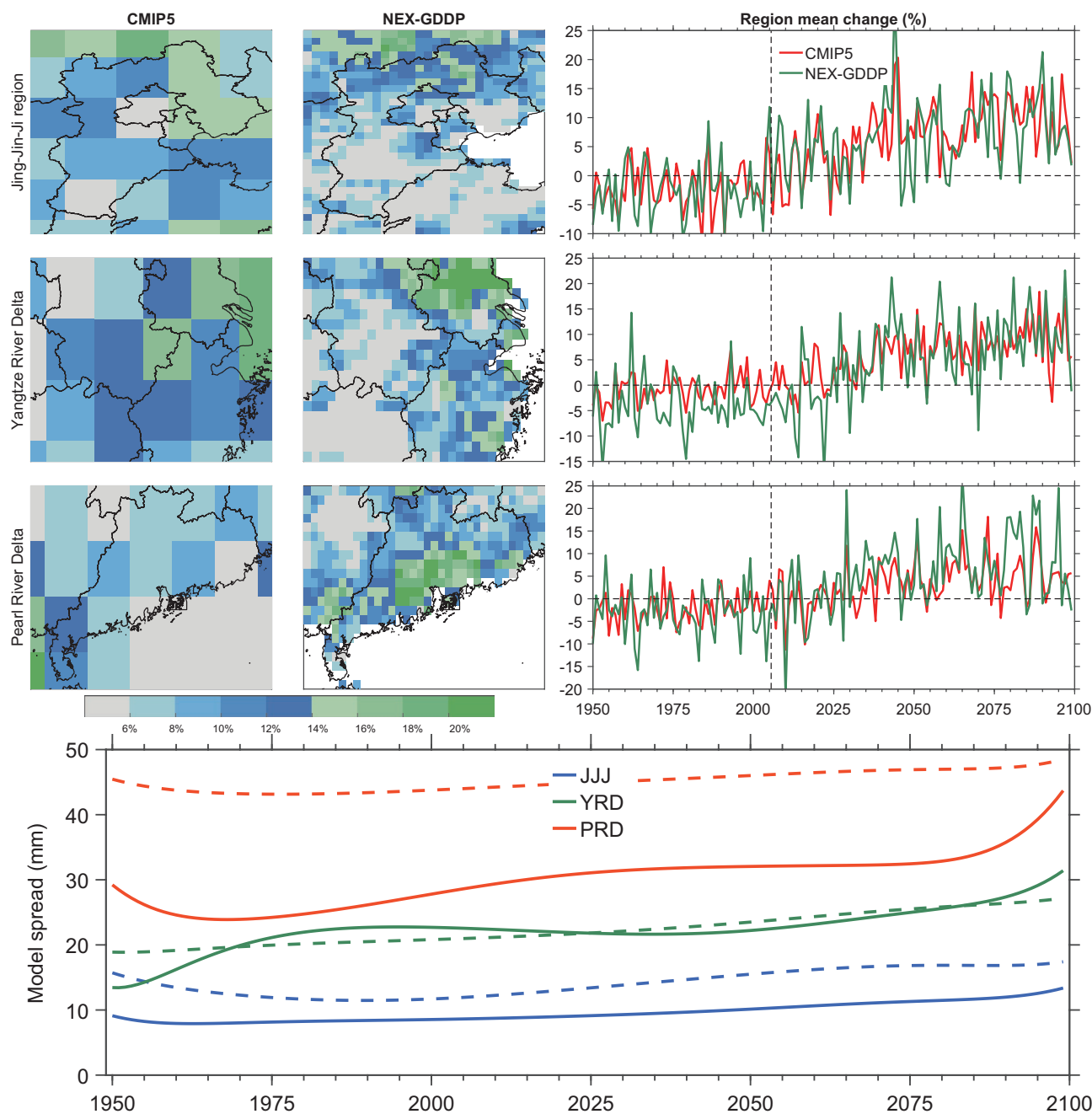


Figure 4. Comparison of projected precipitation extreme (rx5d) changes over three key regions: Jing-Jin-Ji (JJJ), Yangtze River Delta (YRD), and Pearl River Delta (PRD) in China, estimated from the RCP4.5 scenario.

Note: The bottom panel shows the inter-model spreads for the projected changes of rx5d for the future years estimated from CMIP5 GCMs (dotted line) and NEX-GDDP (solid line).

of detail in NEX-GDDP compared with the GCMs is also found for the YRD and PRD regions. The higher and lower increasing centers of rx5d are clear from the NEX-GDDP results, whereas the GCMs completely fail to show such an evident spatial pattern because of its coarse resolution. This additional information can also be observed in the change of rx1d, as well as under other greenhouse emissions scenarios, over these three key regions (figures not shown).

Furthermore, the inter-model spreads of the projected changes in precipitation extremes are also compared between NEX-GDDP and the GCMs. Here, we define the inter-model spread as the multi-scenario mean of the variances in the different model projection fits estimated using the ordinary least-squares method with a fourth-order polynomial over the target period (Hawkins and Sutton 2011). Taking rx5d as an example (Figure 4), the model spreads of the projections present obvious decreases over the JJJ and

PRD regions, which decrease by 32% and 34% on average, respectively. However, the decrease in model spread in the YRD region is quite weak, at approximately 0.2%, when compared with the GCMs. Similar features can be obtained for the changes in rx1d, with the model spreads decreasing by approximately 41%, 1%, and 29% for the JJJ, YRD, and PRD region, respectively. Therefore, we believe that the projected changes in precipitation extremes over China are substantially more robust from this downscaled data-set than when taken directly from the CMIP5 simulations, especially at the city scale.

4. Conclusion and discussion

As a new generation statistically downscaled climate data-set, the high-resolution NEX-GDDP data-set has significantly improved the performance of CMIP5 GCMs in simulating precipitation extremes at regional to local scales. NEX-GDDP can successfully reproduce the climatological spatial patterns of rx1d and rx5d over China, with increased *R* and decreased MRE for most models, and being much closer to the observations than the CMIP5 GCMs. In particular, the improvement in the complex-topography region is relatively higher than in other regions, mainly due to the effect of the topography that occasionally excites or intensifies local precipitation extremes having been incorporated in this high-resolution data-set. The improvements in these spatial patterns of extremes are closely associated with the level of spatial detail provided by this observationally derived data-set having been utilized to interpolate the GCM outputs to a high-resolution grid via the BCSD algorithm. However, we note that the data-set is deficient in simulating precipitation extremes over some regions of China, such as in Yunnan Province, where extreme values of 50-year return period events are overestimated (Figure 2).

Because the long-term increasing trends of climate changes in the CMIP5 GCMs have been preserved, the precipitation extremes of rx1d and rx5d are projected by NEX-GDDP to increase significantly across China with continued global warming. For rx1d, the average over China is reported to increase by 15%–27% by the end of this century with respect to 1986–2005, and increase by 16%–29% for rx5d. The largest increases in precipitation extremes generally happen over the TP region, while the smallest increases are generally reported over the WNBC region. With the increase in rx1d and rx5d, an extreme event expected once every 50-year under current climate conditions is expected once in every approximately 25 years by the end of this century across China.

Compared with the CMIP5 GCMs, more local climate change information can be observed in this high-resolution data-set. Taking the JJJ, YRD, and PRD regions as examples, the higher and lower increasing centers of

precipitation extremes are generally clear at the city scale in NEX-GDDP, but only uniform increases are observed in the GCMs. Furthermore, the uncertainty in future climate change derived from the inter-model spread shows a significant decrease in this high-resolution data-set compared with the GCMs, making the projections of future climate changes much more reliable at regional to local scales. Consequently, we believe that NEX-GDDP has great potential to become a popular and widely used high-resolution data-set in studies on the impacts of future climate change at regional to local scales, and even at individual town, city, and watershed scales.

Disclosure statement

No potential conflict of interest was reported by the authors.

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