Projection in Extreme Climate Events and uncertainty analysis in the Source Area of the Yellow River for the Next Three Decades

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Abstract. The spatial and temporal characteristics of extreme temperature and precipitation events were studied by using extreme climate indices based on the daily outputs of five general climate models (GCMs), including maximum temperature, minimum temperature and precipitation, in the period of 2021-2050 under the representative concentration pathway 4.5 (RCP4.5) scenario. The results show that compared with the period of 1971-2000, Warmest day and Warm days (the warm event) could increase by 1.4°C and 12.5d, respectively, and Frost days and Cool nights (the cold event) could decrease by 24.5d and 6.8d, respectively. The coldest night could increase by 2.1°C, the diurnal temperature range could decrease by 0.1°C. The precipitation frequency and intensity indices (Number of heavy precipitation days, Simple daily intensity indices, Max 1-day precipitation amount and Max 5-day precipitation amount) could increase by 1.1d, 3.1%, 8.4% and 6.3%, respectively. The very wet days could increase by 24.6% and the consecutive dry days could decrease by 12.3d. But, the spatial distributions of changes in extreme climate events are uneven. Although projected changes are still uncertain to some extent, the trends among different GCMs show a good consistency.

1. Introduction
The source area of the Yellow River is located in the hinterland of the Qinghai-Tibet Plateau and is one of the most vulnerable and sensitive regions to climate change\textsuperscript{[1]}. In recent years, there has been a significant upward trend in some extreme temperature indices, which is higher than that in other parts of China during the same period\textsuperscript{[2]}. Meanwhile, the maximum number of consecutive days of dryness decreased significantly, and the frequency and intensity of extreme precipitation increased\textsuperscript{[3]}. Under the global warming background, the significant changes in extreme climate events have had an important impact on local economic and social development and the ecological environment\textsuperscript{[4-5]}. Based on long-term meteorological observation data, the researches about evolution characteristics of historical extreme climate events in this region are abundant. However, there are few studies on the regional projections of future extreme climate events. Whether the trend of changes in extreme climate events will be further aggravated in future? This is a common concern and a problem that needs to be
solved urgently. To address this, the spatial and temporal characteristics of extreme climate events in the source region of the Yellow River (above the Longyangxia Reservoir) were studied by using extreme climate indices projected from global circulation models for the period of 2021-2050.

2. Data and Methods

2.1 Climate model data
Climate projections from the output of HadGEM2-ES, GFDL-ESM2M, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M (see Table 1 for details) under the Representative Concentration Pathways (RCP) 4.5 scenario were used in this study.

Table 1. Descriptions of the five general circulation models (GCMs) used in this study.

| Model name | Modeling Center | Country |
|------------|-----------------|---------|
| HadGEM2-ES, M1 | Instituto Nacional de Pesquisas Espaciais | Brazil |
| GFDL-ESM2M, M2 | NOAA Geophysical Fluid Dynamics Laboratory | USA |
| IPSL-CM5A-LR, M3 | Institut Pierre-Simon Laplace | France |
| MIROC-ESM-CHEM, M4 | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies | Japan |
| NorESM1-M, M5 | Norwegian Climate Centre | Norway |

The datasets were obtained from the Inter-Sectoral Impact Model Intercomparison Project (http://www.isi-mip.org) at a 0.5° × 0.5° spatial resolution and a daily time step for historical (1971-2000) and future (2021-2050). These datasets had been bias-corrected to the WATCH Forcing data enabling us to adequately represent the effects of changes in climate variability [6-7].

2.2 Extreme climate indices
A total of 12 extreme climate indices (Table 2) were applied to investigate future changes in extreme climate events. These indices are defined as absolute or threshold indices, which describe different characteristics of extremes, such as intensity, frequency, and duration. For temperature indices, fixed threshold indice is frost days (FD). Monthly extreme temperature indices, the highest and lowest daily maximum and minimum temperatures for a given month (TXx and TNn), and diurnal temperature range (DTR) are identified with maximum or minimum monthly records. Warm days (TX90p) and Cool nights (TN10p) are based on 90% and 10% percentiles threshold for a given period, respectively.

Table 2. Definitions of 12 extreme climate indices.

| Index | Definition |
|-------|------------|
| FD0   | Annual count of frost days when daily minimum temperature TN < 0 °C, d |
| TXx   | Monthly maximum value of daily maximum temperature, °C |
| TNn   | Monthly minimum value of daily minimum temperature, °C |
| TX90p | Percentage of days when monthly value of daily maximum temperature (TX) > 90th percentile during 1971–2000, d |
| TN10p | Percentage of days when monthly value of daily minimum temperature (TN) < 10th percentile during 1971–2000, d |
| DTR   | Monthly mean difference between TX and TN |
For precipitation indices, extreme precipitation events exceeding absolute thresholds of precipitation are characterized by the number of days with precipitation exceeding 10 mm (R10mm). Successive dry days (CDD) are used to examine durational characteristics of extreme precipitation events. Single-day precipitation totals are considered (RX1day), and the consecutive day accumulation at individual grid point was used to define monthly maximum 5-day precipitation values (RX5day). Annual average characteristics of precipitation events are represented in simple daily intensity index (SDII). Upper fifth (R95p) percentile is used to calculate the accumulation of extreme wet day precipitation values, which is based on relative threshold.

Total 81 grids at a spatial resolution of 0.5° × 0.5° covers the study area. Extreme climate indices at each grid points were calculated by the R-based software package RClimDex, which is freely available from the website (http://etccdi.pacificclimate.org/). The projected changes of extreme climate events were obtained by comparing the multi-model ensembles mean (MME) of the calculated indices between the baseline (1971-2000) period and the future period (2021-2050) under the RCP4.5 scenario.

3. Results

3.1 Projected changes in extreme temperature events

Anomalies of extreme temperature indices in 2021-2050 relative to 1971-2000 are shown in Fig.1. By comparing the baseline period, extreme warmer events may be more frequent and extreme cold events are likely to decrease in future under the RCP4.5 scenario. FD0 (Fig.1 (a)) and TN10p (Fig.1 (e)) could decrease by 24.5d (-4.679d/10a) and 6.8d (-0.750d/10a), respectively. TXx (Fig.1 (b)), TNn (Fig.1 (c)), TX90p (Fig.1 (d)) and DTR (Fig.1 (f)) are likely to increase by 1.4°C (0.154°C/10a), 2.1°C (0.131°C/10a), 12.5d (3.344d/10a) and 0.1°C (0.019°C/10a), respectively.
3.2 Projected changes in extreme precipitation events

The anomaly of the extreme precipitation index from 2021-2050 in the RCP4.5 scenario compared with the reference period (1971-2000) are shown in fig.3. Compared with the reference period, CDD (Fig.3(b)) shows a decreasing trend of 12.3d (-1.969d/10a), while other indices show an increasing trend. Among them, R10 (Fig.3 (a)), RX1day (Fig.3 (c)), RX5day (Fig.3 (d)), SDII (Fig.3 (e)) and R95p (Fig.3 (f)) could increase by 1.1d (0.692d/10a), 8.4% (3.717%/10a) and 6.3% (4.096%/10a), 3.1% (2.149%/10a) and 24.6% (13.493%/10a) respectively. The projected changes show that the frequency of extreme drought (CDD) may be decreased, but the frequency of strong precipitation (R10), intensity (SDII, RX1day, RX5day, R95p) may be increased.
Figure 3. Same as Fig. 1, but for (a) R10; (b) CDD; (c) RX1day; (d) RX5day; (e) SDII; (f) R95p

Fig. 4 shows that the spatial distribution of the extreme precipitation indices during the period of 2021-2050 compared with the reference period (1971-2000). The variation trend of extreme precipitation indices has a good spatial consistency. In Fig. 4, R10 (Fig. 4 (a)) shows an increasing trend with an increase of 0.0d to 2.1d; CDD has a decreasing trend with a decrease of 5.0d to 19.7d. The area in the west has a large decrease, with local areas above 15d. RX1day (Fig. 4 (c)), RX5day (Fig. 4 (d)), SDII (Fig. 4 (e)) and R95p (Fig. 4 (f)) have an increasing trend with an increase of 4.4% to 13.4%, 0.3% to 8.8%, 1.0% to 4.3%, 9.7% to 38.6% respectively.

Figure 4. Same as Fig. 2, but for (a) R10; (b) CDD; (c) RX1day; (d) RX5day; (e) SDII; (f) R95p

3.3 Uncertainty analysis

Projected changes in extreme climate indices by 5 GCMs are shown in Table 3. Except for DTR, the extreme climate event index projected by the model is the same in the change trend, which indicates that there is a good consistency between GCMs projections. However, there are significant differences in the magnitude of projected changes from different GCMs. For example, the projected change in R95p (40.3%) for the IPSL-CM5A-LR model is approximately 2.8 times of the estimated MIROC-ESM-CHEM model (14.3%). In general, the uncertainty in the prediction of extreme temperature events is relatively small compared with the prediction of extreme precipitation events. In addition, the IPSL-CM5A-LR model predicts that extreme climate events will generally have large changes.

Table 3. Projected changes in extreme climate indices by different GCMs in 2021-2050 relative to 1971-2000.

| Index   | M1  | M2  | M3  | M4  | M5  | MM  |
|---------|-----|-----|-----|-----|-----|-----|
| FD0/d   | -18.1 | -18.3 | -26.7 | -41.1 | -18.4 | -24.5 |
| TXx/°C  | 1.4  | 2.8  | 0.7  | 0.9  | 1.3  | 1.4  |
| TNn/°C  | 1.4  | 2.1  | 3.0  | 2.5  | 1.7  | 2.2  |
| TX90P/d | 9.5  | 14.1  | 11.8  | 12.8  | 14.3  | 12.5  |
| TN10P/d | -5.3 | -6.4 | -7.5 | -8.2 | -6.4 | -6.7 |
| DTR/°C  | 0.21 | 0.22 | -0.38 | -0.84 | 0.28 | -0.10 |
| R10/d   | 0.8  | 0.6  | 2.2   | 0.7   | 1.0  | 1.0  |
| CDD/d   | -3.4 | -21.0 | -16.2 | -22.5 | -1.4 | -12.9 |
| RX1day/%| 12.9 | 7.9  | 10.2  | 4.1   | 6.8  | 8.4  |
| RX5day/%| 4.5  | 4.4  | 10.3  | 2.2   | 10.0 | 6.3  |
| SDII/%  | 3.3  | 1.3  | 7.4   | 1.8   | 1.7  | 3.1  |
| R95p/%  | 29.5 | 15.7 | 40.3  | 14.3  | 23.2 | 24.6 |

4. Conclusions
Under the RCP4.5 scenario, warm events would generally increase and cold events are likely to decrease in the source region of the Yellow River. The frequency and intensity of extreme precipitation events are likely to increase. Meanwhile, the spatial distributions of changes in extreme climate events are uneven. Although projected changes are still uncertain to some extent with different GCMs, the trends among different GCMs show a good consistency. In general, the frequency and intensity of future extreme climate events are likely to increase, which mean that changes in extreme climate events in historical period might further aggravated in future.

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