**Hydrology and
Earth System
Sciences
Discussions**

# Dryness/wetness variations in China during the first 50 years of the 21st century

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## Abstract

This study investigates future changes of dryness/wetness in China during the first 50 years of the 21st century according to the Standardized Precipitation Index (SPI), which is calculated by monthly precipitation data of ECHAM5/MPI-OM. Three anthropogenic greenhouse gas emission scenarios SRES-A2, SRES-A1B and SRES-B1 have been considered. The frequency of dry/wet periods in ten river basins is counted and the trend is analyzed and detected by a linear regression model and the Mann-Kendall non-parametric test. The results reveal that there is a trend towards drier conditions from Northeast to Southwest China in scenario A2 and a similar spatial distribution pattern in scenario A1B and B1. Areas with a high frequency of drought are detected under three scenarios. In the next half century, the Haihe River basin is expected to show a significant trend towards drier conditions, which pass the 95% confidence level in scenario A2. In the Yellow River basin, the Huaihe River basin, the Yangtze River basin and the Pearl River basin an obvious trend towards wetter conditions has been detected in scenario A1B. The Songhuajiang River basin, the Haihe River basin, the Yellow River basin and the Huaihe River basin show a trend towards wetter conditions, which passed the 90% confidence level in scenario B1. In addition, a decadal variation of dryness/wetness is projected for all the river basins.

## 1 Introduction

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air temperature. There is also observational evidence from all continents and most oceans that many natural systems are affected by regional climate changes (IPCC, 2007). Under the background of global climate change, it is one of the most important frontier fields of presently global change research to study the changing characteristics of regional climate. Drought is one of the major natural hazards that bring about billions of dollars in loss to the agricultural commu-

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nity of the world every year (Narasimha and Srinivasan, 2005; Su et al., 2007). Bordi and Sutera (2002) presented a study on the drought occurrence in Italy based on the NCEP/NCAR reanalysis precipitation rates covering the period from 1948 to 2000. They implied that drought conditions have been more frequent and extended in the recent past. Li et al. (2004) analyzed the change trend of the Palmer Drought Severity Index and the possible response of the drought change rate to global warming in the main arid regions of the world for the recent hundred-odd years by using global grids of 2.5°×2.5°. The results showed that there is an obvious trend towards drier conditions in the main arid regions of South America, South Africa, North America, Central Asia and Northwest China.

It is also important to analyze the variation of dryness/wetness in China. Many studies have been conducted regarding to climate drought in China in the past years. Li et al. (1996) drew a conclusion that there were four large drought centers in China and there was a linear tendency of drying in the whole country and in most areas. Zhai and Zou (2005) analyzed the characteristics of drought in China during 1951 to 2003 according to the data of 606 meteorological stations. They pointed out that precipitation was the most important factor for drought changes. In the past fifty years, areas of drought had an increasing trend while this trend is not significant. Ma and Ren (2007) analyzed the relationship between climate change and a trend towards drier conditions based on the monthly mean surface air temperature and monthly precipitation data of 160 meteorological stations over China from 1951 to 2006. They found that there were trends towards drier conditions in North China, Northeast China, the east part of Northwest China, and Southwest China. Phase and duration of the drying processes would be different in the above mentioned regions. Many other researches detected a trend towards drier conditions in North China and Northeast China in the past fifty years (Zhang, 1998; Xie et al., 2003; Wang and Zhai, 2003; Wei, 2004; Bordi et al., 2004). All of these studies concentrate on the variation of dryness/wetness in the past. Now, this study is subject to an objective drought assessment of China during the first fifty years of the 21st century.

The aim of this study is to apply the SPI in order to indentify dry/wet periods during the first fifty years of the 21st century in China. Data and analytical methods, which are used in this study, are described in Sect. 2. In Sect. 3 the simulation ability of the ECHAM5 model is tested on annual averaged precipitation. The results of cal-
5   culating the SPI derived from the monthly precipitation data of the three scenarios of ECHAM5/MPI-OM and the analysis of dryness/wetness in China are shown in Sect. 4. Discussion and conclusions are presented in Sect. 5.

This study will help to understand variations of water resources in the future fifty years in China.

10 **2   Study area, data and methods**

2.1   Study area and data

China is divided into ten large river basins i.e. the Songhuajiang River basin, the Liaohe River basin, the Haihe River basin, the Yellow River basin, the Huaihe River basin, the Yangtze River basin, the Pearl River basin, the Southeast River basins, the Southwest
15   River basins and the Northwest Inland River basins (Fig. 1). Because of spanning many degrees of latitude and complicated terrain, climate of China varies sharply. Annual averaged precipitation gradually decreases from Southeast China to Northwest China. Due to the uneven distribution of precipitation for different regions and different seasons, droughts and floods occur frequently.
20   Considering the data quality, continuity, homogeneity and the length of data record, monthly precipitation of 483 meteorological stations (1960.01–2000.12) were provided by the National Climate Center of China Meteorological Administration, which is used to test and verify the simulate ability of ECHAM5 Model. Monthly precipitation data (2001.01–2050.12) of three scenarios (SRES-A2, SRES-A1B and SRES-B1) from sim-
25   ulations with the GCM ECHAM5/MPI-OM were used for the calculation of the SPI. The ECHAM5 data were provided by the Max Planck Institute for Meteorology (MPIM). The

resolution of the atmospheric model ECHAM5 is triangular T63 (1.875°×1.875°) with 31 vertical levels. The atmospheric model is coupled with the ocean model MPI-OM with 1.5° resolution without flux correlation (Blender and Fraedrich, 2006).

## 2.2  Methods

The nature of SPI allows comparing the frequency of dry/wet periods among the regions with different climate and water supplies. It can measure how much precipitation for a certain time period has deviated from historically established norms. The categorization of the dryness/wetness grade by the SPI is given in Table 1 (McKee et al., 1993).

The SPI was developed by McKee et al. (1993) for the identification of dry/wet periods and to evaluate their severity (Moreira et al., 2006). The calculation of the SPI can be based on a long-term precipitation record for any location (Hayes et al., 1999). This long-term precipitation record is fitted to a gamma distribution at first. Then, the cumulative probability of an observational precipitation event for each time scale of interest would be deduced. The value of the SPI can be obtained by transforming the cumulative probability to a standard normal random variable with zero mean and a variance of one. Positive variables indicate greater than median precipitation, and negative variables indicate less than median precipitation, with values ranging from about −3 to 3. This study is based on the Standardized Precipitation Index (SPI, introduced by McKee et al., 1993). As the SPI characterizes water deficit and surplus, derived from precipitation alone, it can be easily computed and as the index is standardized, it is also suitable for comparing different regions or water-sheds (Bordi et al., 2004).

The trend tests applied in this study are the non-parametric Mann-Kendall test and the simple linear regression method. Mann-Kendall analysis is a rank-based procedure suitable for detecting non-linear trends. More details can be found in the previous studies (Mann, 1945; Kendall, 1975).

The inverse distance weighted interpolation method is used to detect the spatial distribution of drought.

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In this paper, SPI was calculated at the 12-monthly time scale at every grid. The month with the value of SPI less than −1 was counted in every grid. Then the areas more than 100 dry months were detected in the figure which was interpolated with IDW method. Linear trend was calculated in every grid. Spatial patterns of trend of dry/wet could be detected in the figure. At last, spatial averaged SPI was calculated in ten large river basins and change of years about dry/wet was analyzed.

## 3  Test of the precipitation simulation ability of the ECHAM5 Model in China

Annual averaged precipitation and precipitation anomaly are calculated not only based on observational monthly precipitation derived from 483 meteorological stations but also according to monthly rainfall which is simulated by ECHAM5 model in China during 1961–2000. The results indicate that there is a decreasing trend from Southeast China to Northwest China with annual precipitation ranges from over 1600 mm to less than 50 mm both for observational and projected annual averaged precipitation, although the magnitude of the projected means annual precipitation is more than that of the observational rainfall (Fig. 2). Precipitation anomaly also indicates that the annual changing trend is different before 1980 but coincident between observational precipitation and projected rainfall during 1980–2000 (Fig. 3). All in all, the ECHAM5 model roughly simulated the spatial distribution and decreasing and increasing trends of annual averaged precipitation in China. So it is some useful to project the character of dry/wet based on the ECHAM5 model in China.

## 4  Results

### 4.1  Spatial distribution of dryness/wetness

The number of months, which have been classified as drought months regarding the SPI (SPI≤−1), is counted for the three scenarios for the first 50 years of the 21st

century. In the scenario A2, one high value area exists in North China with more than 100 dry months during 2002–2050. This region includes the Songhuajiang River basin, the north part of the Liaohe and Yellow River basins, and some areas of the Northwest River basins. In addition, two high value centers are located in the Jinshajiang River catchment and the Hanjiang river catchment. There are two high value areas with more than 100 dry months in the eastern part of the Huaihe River basin and the south part of the Pearl River basin (Fig. 4a). Figure 4b shows that other high value areas are located in the Songhuajiang River basin, the south part of Yellow River basin, the Jinshajiang River catchment, the Pearl River basin, the Southwest River basins and some parts of Northwest River basins in the scenario A1B. In the scenario B1, the areas with high frequency of dryness may include the Haihe River basin, the east part of Yellow River basin, the Dongting lake catchment of the Yangtze River basin, the Southeast River basins and some parts of Northwest River basins (Fig. 4c).

4.2   Trend analysis of dryness/wetness

The spatial distribution of the linear trend of every grid cell is shown in Fig. 5. The positive and negative trends, which represent trends towards wetter and drier conditions, are detected.

It is known from the trends of the SPI index that there is a negative trend from Northeast to Southwest China which covers the Songhuajiang River basin, the Liaohe River basin, the Haihe River basin, the Yellow River basin, the south part of Jianshajiang River catchment of the Yangtze River basin and the west part of Pearl River basin in the scenario A2 (Fig. 5a). But positive trends dominate in the northwest and the southeast of China, including the northwest parts of the Inland River basins, the middle and lower Yangtze River basin and the Southeast River basins (Fig. 5a). This situation is similar with the observational trend during 1961–2005. Figure 5b indicates a different spatial distribution; the area covered by a negative trend is greatly reduced. The trend towards drier conditions only occurs in the Liaohe River basin, the River source basin of the Yellow River and the Yangtze River, the Southwest River basins and the northwest

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part of the Northwest River basins. In some regions of the Dongting lake catchment and the Yangtze estuary a negative trend can be detected. The trends in scenario B1 have shown a similar spatial distribution pattern with those of Scenario A1B, as was illustrated in Fig. 5c. The areas showing significant trends towards drier conditions are still located in Northwest China and the upper reaches of the Yellow River, the Yangtze River and the Southwest Rivers. The main difference between the Fig. 5b and c is that the most parts of South China show an obvious trend towards drier conditions in scenario B1.

### 4.3 Change of dryness/wetness in all large river basins

Basin averaged SPI are calculated and their trends are tested by the Mann-Kendall non-parametric method. Table 2 shows that only in the Haihe River basin a significant trend towards drier conditions can be detected, which pass the 95% confidence level in the scenario A2. The trend towards wetter conditions passed the 90% confidence level in the Yellow River basin (99% confidence level), the Huaihe River basin, the Yangtze River basin (95% confidence level) and the Pearl River basin (99% confidence level) in scenario A1B. Similar trends towards wetter conditions occur in the Songhuajiang River basin, the Haihe River basin, the Yellow River basin and the Huaihe River basin in scenario B1 (Table 2).

Based on monthly averaged basin-wide SPIs (Figs. 6, 7, 8), in scenario A2, there are three stages in the Songhuajiang River basin during 2002–2050 (Fig. 6a): a trend towards wetter conditions during 2002–2022; a trend towards drier conditions during 2022–2040; another wetness stage from 2040–2050. An slowly wetter period exist in the Liaohe River basin during 2002–2022; then the period from 2022 to 2038 is a dryness stage; at last, a dryness period begins in 2040 and ends in 2048 (Fig. 6b). In the Haihe River basin, there is a ten years period which is alternative between dryness and wetness (Fig. 6c). There is a dry period from 2022–2040 in the Yellow River basin (Fig. 6d). It is a almost same dryness period in South China including the Huaihe River basin, the Yangtze River basin, the Pearl River basin and the Southeast River basins

in 2010s, 2020s, 2030s (Fig. 6e–h). Wet period begins from 2030 in the Southwest River basin (Fig. 6i). It is almost wet period before 2030 in the Northwest River basin (Fig. 6j).

Figure 7 shows the change of dryness/wetness in ten large river basins in the scenario A1B. There are not obviously changes of dryness/wetness in almost every river basin. In the 2030s and the 2040s, a dryness stage exists in the Haihe River basin (Fig. 7c). In the Yellow River basin, there is a dryness period from 2002–2020 (Fig. 7d). There is a dry period in the Huaihe River basin in the 2030s (Fig. 7e). In the Pearl River basin is a dry period (Fig. 7g).

Figure 8 indicates the change rules of dryness/wetness in ten large river basins in the scenario B1. An obvious dry period occurs in the Songhuajiang River basin and the Liaohe River basin in the 2010s (Fig. 8a, b), and in the Haihe River basin during 2006–2012 (Fig. 8c), the Yellow River basin in the 2020s, and the 2030s (Fig. 8d), and in the Pearl River basin in the 2020s, and the 2040s (Fig. 8g).

## 5 Summary and conclusions

Drought exerts tremendous influences on agriculture and human society. Characteristics of dryness/wetness in three scenarios (A2, A1B and B1) were analyzed in this study based on the SPI, which was calculated based on the monthly precipitation data derived from ECHAM5/MPI-OM. Some results are summed up as follows.

The areas with high frequency drought differ for the three scenarios in China during 2002–2050. In scenario A2, an arid zone exists in North China including the Songhuajiang River basin, the Liaohe River basin, the north of the Yellow River basin and most parts of the Northwest River basins. High values were also found in the Huaihe River basin, the Jingshajiang River catchment and the Hanjiang River catchment of the Yangtze River basin and the Pearl River basin. In scenario A1B, high value regions with over 100 dry months are located in the Songhuajiang River basin, the south of the Yellow River basin, the upper river of the Yangtze River and the Southwest River

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basins. However, just the Haihe River basin, the east parts of the Yellow River basin and the Southeast River basin show a high frequency of droughts.

A negative trend (trend towards drier conditions) was found from northeast to south-west of China including the Songhuajiang River basin, the Liaohe River basin, the
Haihe River basin, the Yellow River basin, the upper reach of the Yangtze River and the west part of the Pearl River basin in the scenario A2. While in the scenario A1B, a negative trend only exists in the Liaohe River basin, the Southwest River basins and in the south part of the Northwest River basins. A similar spatial distribution pattern is found in the scenario B1. The main difference is that a trend towards drier conditions
occurs in most parts of South China.

By analyzing monthly SPIs, different dry periods can be found in the ten large river basins for the future 50 years.

Although ECHAM5/MPI-OM can simulate the precipitation in China, the uncertainty should be paid attention.

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**Table 1.** Categorization of the dryness/wetness grade by the SPI.
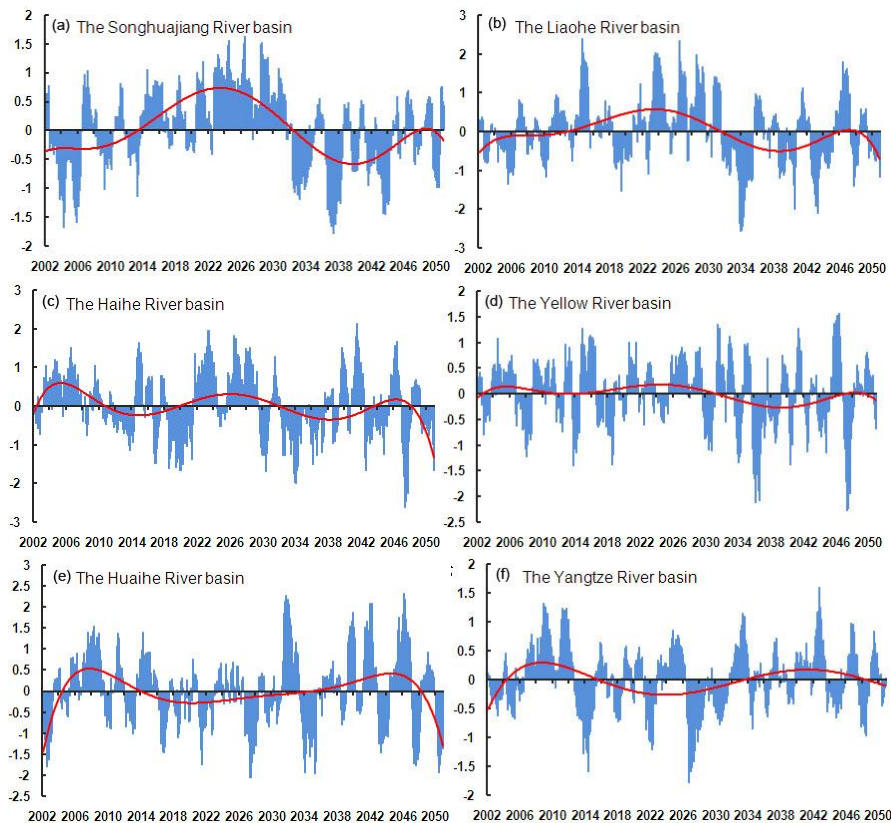
| Categories | SPI values |
|---|---|
| extremely dryness | $\leq -2.0$ |
| severe dryness | $-1.99 \sim -1.5$ |
| moderate dryness | $-1.49 \sim -1.0$ |
| near normal | $-1.0 \sim 1.0$ |
| moderate wetness | $1.0 \sim 1.49$ |
| severe wetness | $1.5 \sim 1.99$ |
| extremely wetness | $\geq 2.0$ |

**Table 2.** Trend of dryness in ten large river basins of China during 2002–2050.

| Scenarios | Songhuajiang River Basin | Liaohe River Basin | Haihe River Basin | Yellow River Basin | Huaihe River Basin | Yangtze River Basin | Pearl River Basin | Southeast River Basins | Southwest River Basins | Northwest River Basins |
|---|---|---|---|---|---|---|---|---|---|---|
| A2 | −0.33 | −0.84 | −1.83** | −0.45 | 0.12 | 0.24 | −0.21 | 0.69 | 0.97 | 0.78 |
| A1B | 1.07 | 0.98 | 0.36 | 2.6*** | 1.29* | 1.84** | 2.62*** | 0.78 | −0.34 | 0.72 |
| B1 | 1.5* | 0.53 | 1.79** | 1.29* | 2.64*** | 0.36 | −0.59 | −0.55 | −0.41 | −0.38 |

* denotes pass 90% confidence level;
** denotes pass 95% confidence level;
*** denotes pass 99% confidence level.
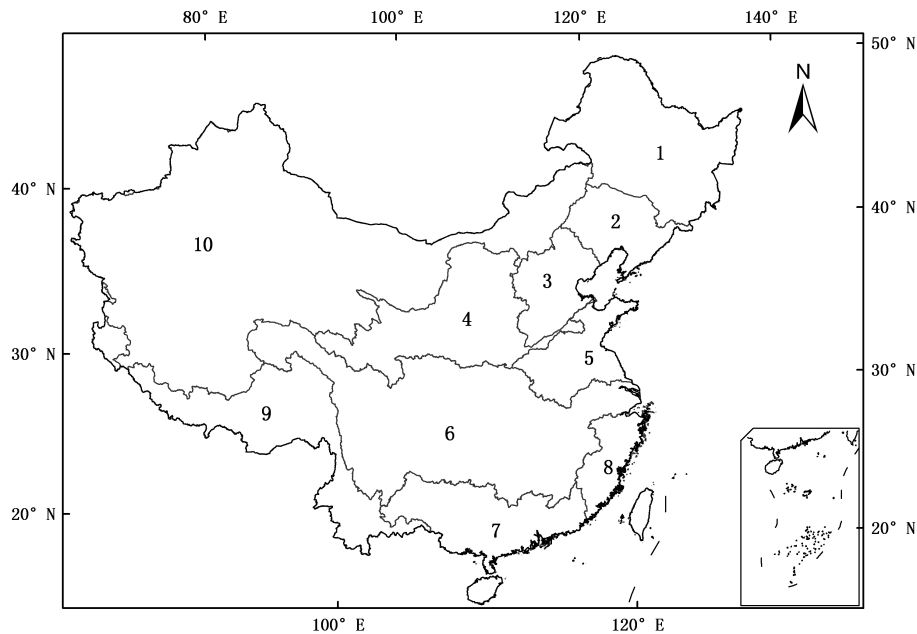
**Fig. 1.** Ten large river basins in China.
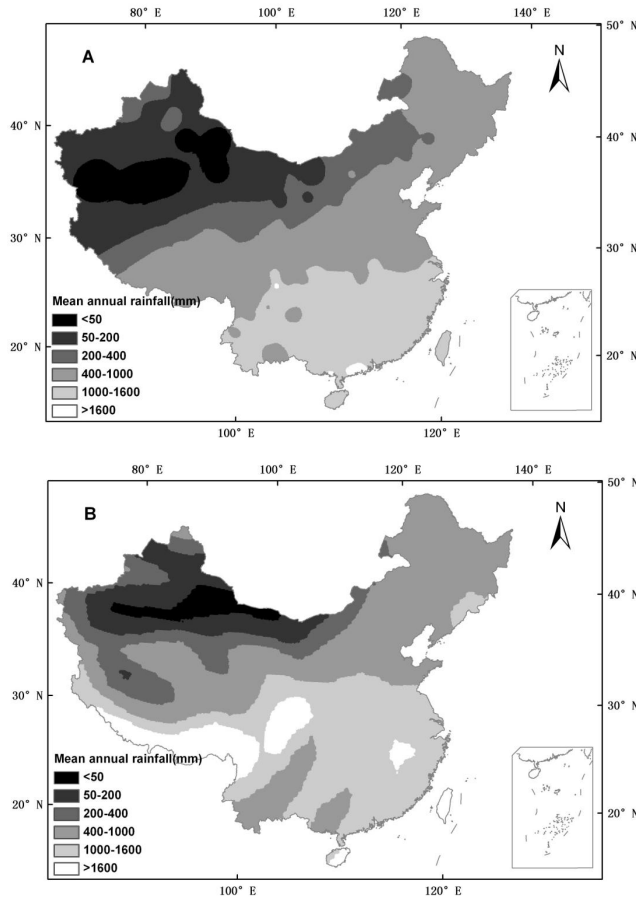
**Fig. 2.** Spatial distribution of mean annual rainfall during 1961–2000 – **(A)** data from 483 observational meteorological stations; **(B)** data from ECHAM5 Model.
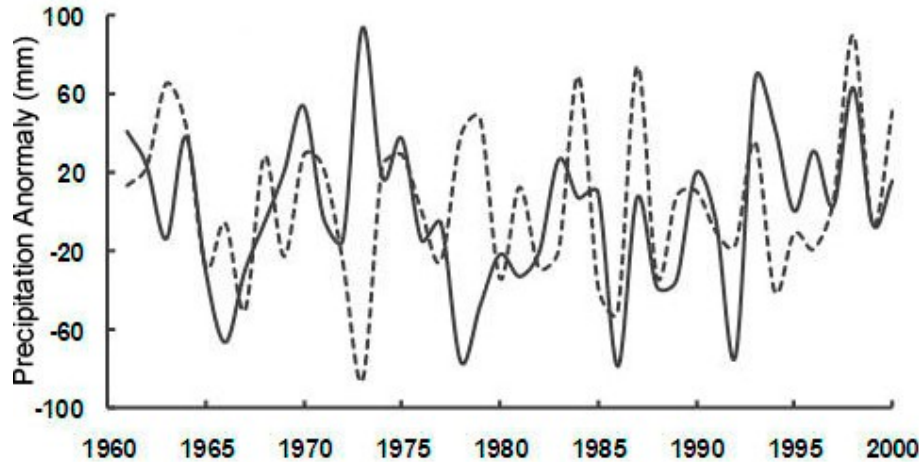
**Fig. 3.** Precipitation anomaly during 1961-2000 in China (dark line: precipitation from observational meteorological station; dotted line: precipitation from Echam5 Model).
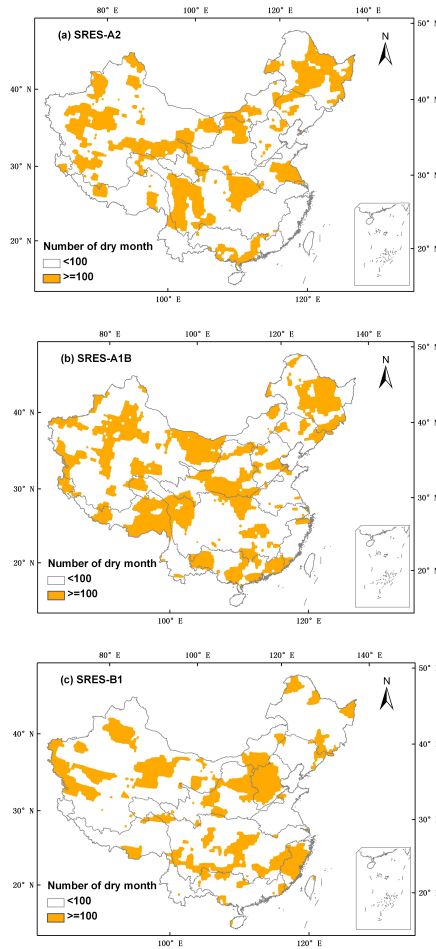
**Fig. 4.** The number of all dry months during 2002–2050 (588 months).
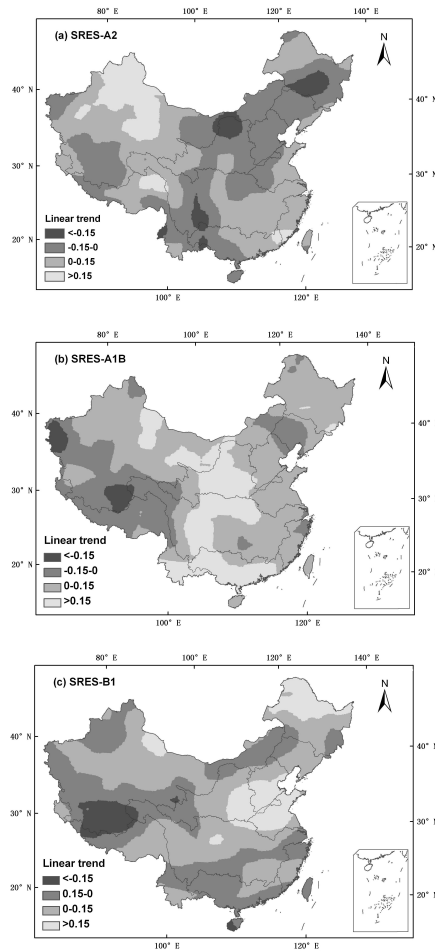
**Fig. 5.** Spatial distribution of the trend of dryness/wetness in China during 2002–2050.

**Fig. 6.** Variation of dryness/wetness in ten large river basins of China during 2002–2050 in scenario A2.

**Fig. 6.** Continued.

**Fig. 7.** Variation of dryness/wetness in ten large river basins of China during 2002–2050 in scenario A1B.
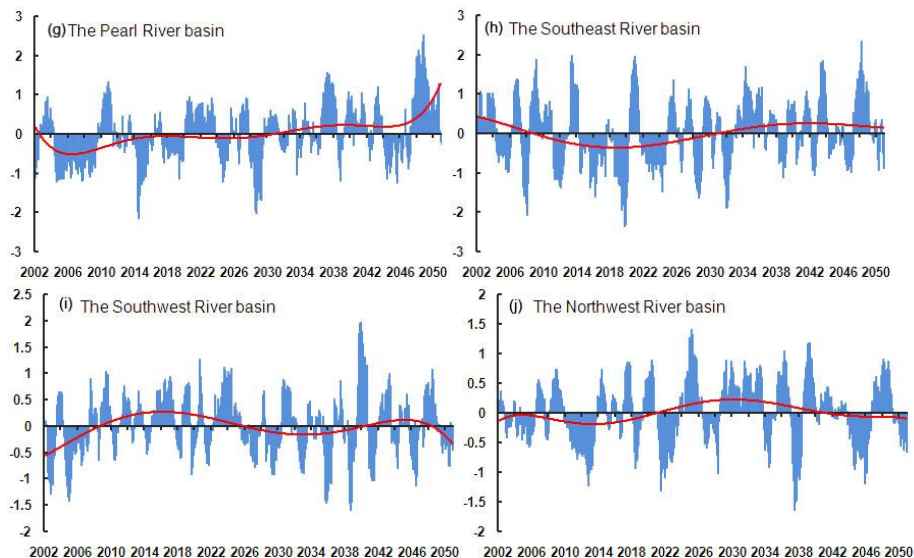
**Fig. 7.** Continued.
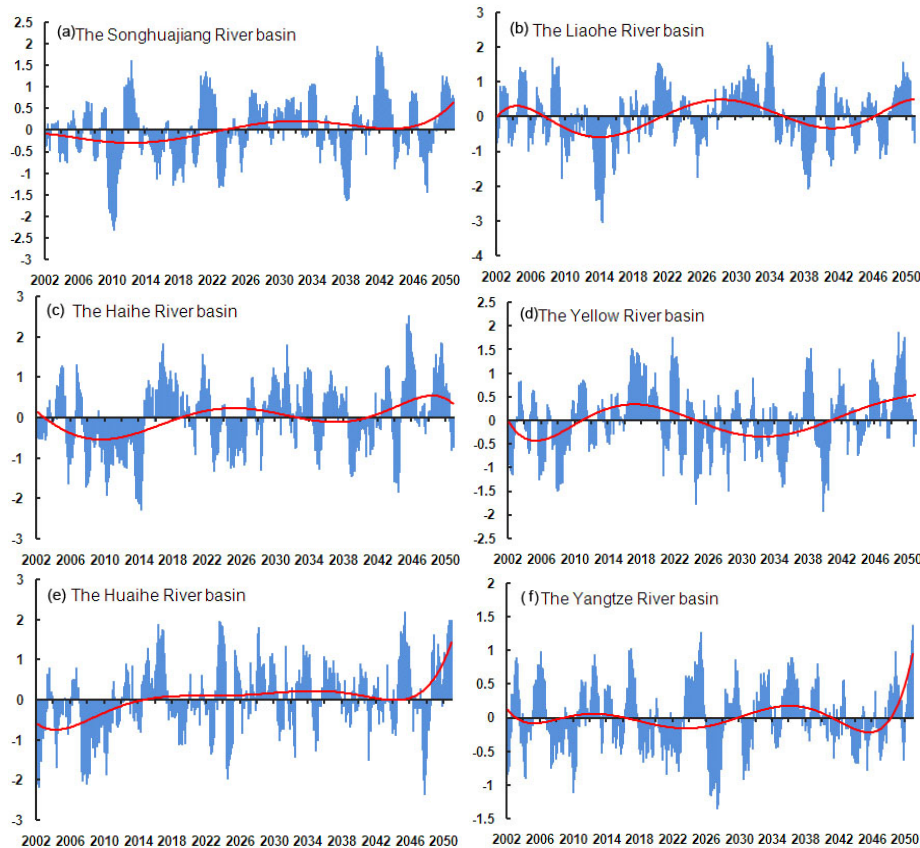
**Fig. 8.** Variation of dryness/wetness in ten large river basins of China during 2002–2050 in scenario B1.

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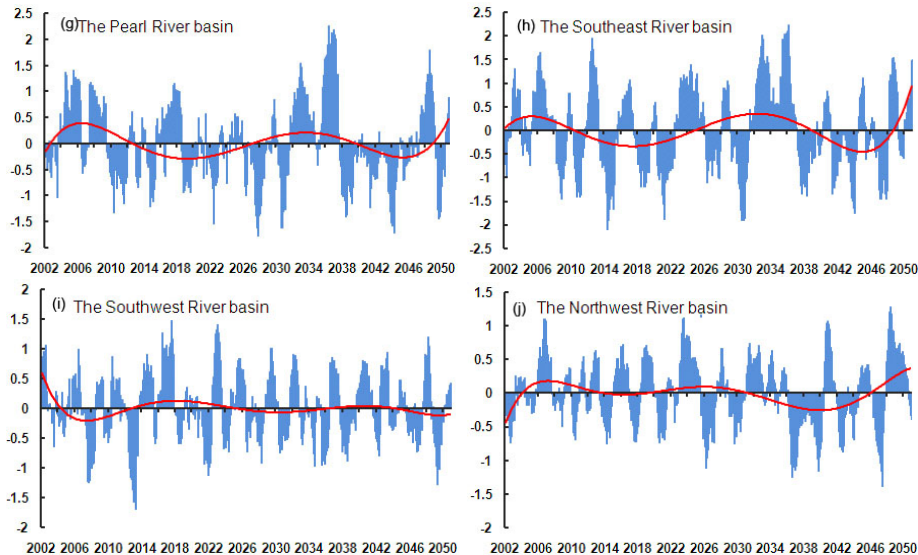Dryness/wetness variations in China

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**Fig. 8.** Continued.