Spatial and temporal variability of precipitation in the context of climate change: A case study of the Upper Yellow River Basin, China

Z Y Lv1,2, J X Mu1,2,3, D H Yan1,2 and T L Qin1,2
1State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing, China
2China Institute of Water Resources and Hydropower Research, Beijing, China
E-mail: lvzyiwhr@163.com

Abstract. Trends, mutations and periodicity of precipitation variation in the Upper Yellow River Basin (UYRB) were studied using a fitted liner model, Mann-Kendall test, moving t-test and Morlet wavelet based on the measured daily data in 34 meteorological stations from 1957 to 2010, and the spatio-temporal variation characteristics of precipitation from 2011 to 2100 were predicted through building statistical downscaling model using BP network. The inter-annual precipitation variation in the basin showed a non-significant increase trend during the measurement period. However, in terms of monthly variation, the precipitation increased between January and June (except April) while decreased between July and November (except October), in addition, it has no obvious change in December. The spatial distribution of precipitation during the whole measurement period mainly showed decreased trend in rainy zone while increased trend in arid zone. The Moving-t test results showed that the annual precipitation in the basin has no significant mutation points between 1957-2010, the most possible one was in 1992. Due to the geographical location of the meteorological stations, the precipitation got some different mutation points. Furthermore, significant differences occurred in the results between M-K and Moving-t test in change-point analysis. There were two considerable time scale periodical variations in basin annual precipitation which were the four to seven years and the over 30 years. Projected precipitation in the future in three different forecast periods under the A1B, A2 and B1 emission scenarios were bigger than the ones measured, except in 2025s under A1B emission scenarios. However, the projected monthly precipitation variation showed different characteristics under these three emission scenarios compared to the measured ones. For the spatial distribution of precipitation variation in the future, it increases firstly and then decreases from southwest of the basin to northeast under A1B scenario compared to the measured periods, while increases firstly and then decreases from northwest of the basin to southeast under A2 scenario. However, the precipitation under B1 scenario gradually increases from southwest of the basin to northeast compared to the measured periods.

1. Introduction
In recent decades, dramatic changes of the global climate were unprecedented and should be given sufficient attention, what’s worse, the situation will deteriorate further in the near future. Intergovernmental Panel on Climate Change (IPCC) Fourth and Fifth assessment report (AR5, AR4) detailed this conclusion [1,2]. In fact, climate change is likely to be an irreversible unidirectional
process in large scale, which is the result of many factors, such as the rise in temperature [1,3], spatial and temporal variations of precipitation [4], the change of transpiration and evaporation, frequent drought events as well as the changes of solar radiation are all the true portrayal of the climate change. In addition to the global scale, there have been numerous reports of dramatic climate change in various parts of the world including China [3], North America [5], France [6] as well as Australia [7], and so on.

There is a strong dependent relation between hydrological cycle and climate system due to the sensitivity and immediate reaction of hydrological process to climate change. Climate change, especially the inter-annual climate variability will produce a great influence on basin hydrological processes, changes in meteorological factors which are bound to result in variation of hydrological variables can have a dramatic impact on quantity and spatio-temporal distribution of precipitation extraordinarily [8-10]. Global warming has become an indisputable fact in the context of climate change. AR5 noted that the global average surface temperatures have risen by about 0.85°C in total between 1880-2012 with a high level of reliability and the temperature between 1983-2012 may be the warmest 30 years over the past 800 years in the northern hemisphere particularly [2]. Assuming relative humidity in a constant state, according to the Clausius-Clapeyron equation, the saturation vapor pressure increases exponentially as temperatures rise which will result in precipitation increases significantly at the same time [11,12]. Actually, the investigation results show that average annual precipitation in some areas increased by nearly 1% in the 20th century [13]. By examining measured rainfall data in the 20th century provided by the Global Historical Climatology Network, Zhang et al found that precipitation in the regions from the equator to 20°N increased by about 1mm/year while from the equator to 20°S decreased by about 2mm/year during 1925-1999 and 1950-1999 [14]. In addition, the rising temperature will also cause variations in precipitation patterns by changing the thermo-dynamics properties of air and water vapor transport [15,16]. Besides the above changes, AR5 detailed that the frequency and the proportion to annual total precipitation of heavy precipitation events in most parts of the world will increase significantly since the 20th century under impacts of future climate change. By the end of the 21stcentury, the increasing rate of global average precipitation by CMIP5 models in RCP8.5 emission scenarios 9% (average), while that in simple daily intensity index up to 12%, and that in annual maximum 5-day precipitation total (R5d) is 20% [17]. Once more, Global-scale precipitation in dry and wet regions and the allocations in dry and wet season will further polarize in the near future which will be even more likely to have serious effects on human water consumption. For China, regional precipitation changes caused by climate change have got a system verification and validation in the Yangtze River [18], the Pearl Rive [19], the Haihe River [20] and other major watersheds.

Like the other basins of China, the Yellow River basin is currently experiencing unprecedented climate change which is threatening the watershed water security and sustainable development of water resources by changing the quantity and spatial-temporal distribution of precipitation. The Yellow River is considered the cradle of Chinese civilization, which accounts for 2% of the total stream runoff of China but shouldered 15% of water for irrigation and 12% of residential water. The Upper Yellow River Basin above the Tangnaihai hydrological station known as Head Regions of the Yellow River (HRYR) is located in the northern part of the Qinghai-Tibet plateau in BaYanKaLa mountains which cover 15% of the total area in the Yellow River Basin while stores 35% of the entire watershed runoff. Fragile and unique climate and wetland system of HRYR are strongly dependent on the regional water resources, so the response of the Yellow River Basin to precipitation change is more significant than other basins [21]. At present, The quantity and temporal and spatial distribution of precipitation in the source regions are sharply changed when coupled with the impact of climate change [22,23]. Analysis of the information available, the average annual precipitation in the HRYR had a non-significant increasing trend and annual distribution of precipitation was even more extreme which had an increasing trend in flood season while decreasing trend in dry season [24,25]. In the face of the above changes over time, stream flow in watershed revealed a significant decreased trend over the past decades [26,27]. Facing with the uncertainty of future climate change in the Basin, as well as
the sensitivity of water resource to precipitation changes, to systematically and comprehensively study the tendency, the spatial-temporal variability, the mutability and the periodic variation of precipitation based on the measured data and then to forecast the future precipitation changes under IPCC emission scenarios, will provide useful theory and data support for making valid water management policies and implementing efficient and sustainable water resource management measures.

In terms of the forecast of the evolution characteristics of hydro-climatic variables, Global Circulation Models (GCMs) are considered to be the most effective large scale projection models providing future climate change information [28]. GCMs are, however, available in coarse spatial scale while unable in modeling parameters for regional hydrological impact studies such as precipitation. Directly using GCMs to study the future evolution characteristics of hydrological features in watershed under climate change may lead to larger distortion of simulation because regional and local scale forcing, processes and feedbacks such as cloud, evaporation, infiltration are not well represented in the GCMs. Therefore, it is crucial to the study of the change characteristics of precipitation variations that downscaling the information of future climate change of GCMs into basin or even smaller scale [29]. So far, there are two types of downscaling methods widely used and verified practically to transform coarse scale information to finer scale: statistical (empirical) and dynamic (physical) downscaling [30]. Although the dynamic downscaling maintains a detailed physical process, it is restricted by the boundary conditions, the influence of systematic error of GCMs and the complex computation process, therefore, the dynamic downscaling is generally effective to certain spatial domain. Independent of the GCMs, easily to calculate, convenient implementation and the simulation accuracy are equal to the dynamic downscaling, the statistical downscaling are well used around the hydrology field [31,32].

In summary, aimed at the realistic requirement of Yellow River Basin, with reference to the former primary research findings and applying fitted liner model, Mann-Kendall test, moving t-test and Morlet wavelet methods, this paper systematically analyzed the tendency, mutability and the periodicity of changes in basin precipitation on the basis of the measured daily precipitation obtained from 34 meteorological stations within the UYRB between 1957 and 2010. Future evolution characteristics of the quantity and spatial-temporal distribution of precipitation are analyzed in A1B, A2 and B1 scenarios under CMIP3 by building statistical downscaling model (SDSM). The results of this paper can provide high reliable data support for making water management policies adapting to climate change.

2. Study area and data

2.1. Study area

Originating from northern piedmont of the Ba yan Kar Mountains in Tibetan plateau, the Yellow River flows through the provinces/autonomous regions of Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong before finally emptying into the Bohai Sea. The study area of this paper is the Upper Stream of the Yellow River Basin (UYRB, lat 32°~39°N, long 96°~106°E). It is situated above Jingyuan County of Gansu Province (figure 1), and covers a total area of 252500 km². Within the study area, the HRYR above TangNaiHai (TNH) hydrometric station (35°30′N, 100°09′E) covers an area of 122000 km². Previous studies focused mainly on the HRYR where human activity impacts are relatively smaller, while did not concern the feedback effects of underlying surface conditions to climate change. This study also covers areas between TNH and JYR two densely-populated districts, and systematically expounds the comprehensive influence of climate change to precipitation under complex underlying surface conditions.

The UYRB is located in mid-latitudes with relatively complex effects from El Nino, General Atmospheric Circulation and East Asian monsoon circulation. Climate in different parts of the study area differs significantly and the climate-factors show remarkable annual and seasonal changes. During the study period, the total average annual precipitation in the study area is about 472.24 mm. It has obvious flood and dry season division; the flood season is basically between May-September accounting for about 80% of the total annual precipitation.
2.2. Data

Measured daily precipitation data of 34 meteorological stations in UYRB were obtained from the Yellow River Water Conservancy Committee. Distribution of these stations is shown in figure 1. Time horizon of these data are from 1957 to 2010, except Guoluo and Tongren stations (1991-2010). Missing data in short time during measurement periods are interpolated by weighted mean value of adjacent stations while missing data in long time are interpolated by cubic spline interpolation. In order to fully explain the overall change of precipitation in the study area, the precipitation data measured from meteorology stations were translated into watershed average precipitation by using Taison polygon modification, the results of segmentation are shown in figure 2. A total of 28 meteorology stations are used to calculate the area precipitation.

The simulated effects for future climate changes are different from various GCMs, and it has been proved that the effect from the average of many models is better than that from one single model.
Hence, after interpolating and downscaling the simulated results from over 20 GCMs with different resolutions from the fourth IPCC report, the National Climate Centre of China (NCCC) integrated these dataset into one resolution, and validated its simulated effects in East Asia. Integrating the multi-models with the Reliability Ensemble Averaging (REA) method, the NCCC come up with a set monthly average precipitation data (for short "data") between 1901 and 2100 under A1B, A2 and B1 emission scenarios. The resolution for "data" is 1°×1°. This study forecasted and analyzed the quantity and spatial-temporal distribution changes of precipitation in UYRB effectively on the basis of the "data" by statistical downscaling.

3. Methods

A simple linear fitted model, universal method in studying hydrologic meteorological elements change trend was used to analyze the annual and inter-annual changes of precipitation in UYRB in point and surface two scale and then by using a two-tailed t-test to check whether the trend arrived 90% or 95% significance level or not. Mann–Kendall non-parameter test (for short "M-K") was used to further validate the trend during the study period and combined with Moving-t test to detect precipitation jumps for annual time series. In order to explore the periodicity of UYRB precipitation, the Morlet wavelet method was used due to its effectiveness in detecting digital signal periodicity. At last, future variation features of quantity and spatial-temporal distribution of precipitation in the study area under A1B, A2 and B1 scenarios were analyzed through building statistical downscaling model between the "data" and precipitation in the study area using BP neural network.

3.1. Trend test and mutability

After getting the simple linear trend of intra-annual and inter-annual precipitation change by linear model, this study verified the trend by M-K method. M-K is a two-tailed non-parameter test method which is widely used in exploring the linear trend of hydro-meteorological factors. Firstly, assuming that there is no significant change trend in measured time series (null hypothesis), and then the null hypothesis will be tested by constructing the statistical parameter Z [33,34]. The null hypothesis of non-significant upward or downward trend in the data can be rejected at the α significance level if |Z|≥Z_{1-α/2}, where Z_{1-α/2} is the (1-α/2) quantile of the standard normal distribution [35]. A positive Z indicates an increasing trend in the time-series. In addition, by constructing statistical series UF and UB, the change trend of measured data in fixed period can be judged according to the positive or negative, and the change points cab be confirmed by determining whether there are any intersection or not and whether the intersection inside the critical values. Detailed principle of M-K and the formulas of statistical parameters can be refereed in books by Mann and Kendall [36,37].

However, mutation analysis of precipitation changes by M-K may result in distortion that occurred multiple jump points. Therefore, when in exploring the mutation problem of precipitation in UYRB, the M-K assisted Moving-t test method was adopted in this paper. The Moving-t test also judges the jump time of data series by constructing statistics, but not like the M-K, the t-test can locate the most significant mutation time of data series with relatively high precision by comparing the statistics. The formula for the t-test is:

\[
 t = \frac{\bar{x}_1 - \bar{x}_2}{s \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}
\]

and:

\[
s = \sqrt{\frac{n_1s_1^2 + n_2s_2^2}{n_1 + n_2 - 2}}
\]
where $\bar{x}_i$, $s_i$, and $n_i$ are the mean, standard variation and size of the two independent samples ($i=1,2$). The degree of freedom in the t-test is $n_1+n_2-2$.

The size of statistical parameter $t$ depends on the length of two sub-samples, in order to simplify calculations, instead of dividing the data into two subsamples for a potential jump point, we just apply the t-test to a subseries with a fixed length of 10a, therefore, the length of moving window will be 20a for the purpose of testing the potential change point. In this study, two significance level $\alpha=0.05$ and $\alpha=0.1$ were set, where when the significance level $\alpha=0.05$, the critical value $t_{0.05}=2.1$; while $\alpha=0.1$, the critical value $t_{0.1}=1.73$. If the statistical parameter $|t|\geq t_{0.05}$, then the point will be accepted as a jump point at the significance level $\alpha$, the point with biggest $|t|$ will be the most probable change point. A positive $t$ indicates a decreasing trend before and after the change point.

### 3.2. Morlet wavelet analysis

Morlet wavelet analysis is a method of signal analysis developed by Morlet in year 1980 on the basis of Short-time Fourier transformation (SFT) suggested by Gabor, used in seismic data analysis at the beginning [38]. After reviewed the present existed wavelet analysis method, Kumar and Foufoular explored the scale and turbulence characteristics of spatial variation of precipitation by orthogonal wavelet (Haar), and then wavelet analysis methods were introduced to the study of Hydrological Sciences. Up to now, the wavelet analysis methods have been widely used in hydrological multi-timescale analysis [39], characteristic analysis of hydrological time series, hydrological forecast and stochastic simulation and so on, while the most widely application of this method is to analyze the periodic features of hydrologic time series. Based on wavelet transform, the wavelet analysis methods can pinpoint the periodical variation of data signal. To meet the Wavelet Function $\psi(t)$ with certain conditions, wavelet transform of the time series $f(t)\in L^2(R)$ can be described as:

$$W_f(a,b) = \int_{-\infty}^{\infty} f(t) \bar{\psi}(t) \psi(t) \frac{t-b}{a} dt$$

(3)

where $\bar{\psi}(t)$ and $\psi(t)$ are the complex conjugate function, the $W_f(a,b)$ can be called as wavelet transform or wavelet coefficient, the coefficient $a$ which reflect the period length of wavelet is the scale factor, while the coefficient $b$ is the time factor reflecting translation on time.

Wavelet transform can also show the time and frequency domain of data signal, reflecting the time-frequency distribution of the whole data series intuitively by drawing the figure of wavelet coefficient, and then obtain the periodical variation and the range of time domain of data series. While the dominant period of time series mainly present by wavelet variance which can be described as:

$$Var(a) = \int_{-\infty}^{\infty} |W_f(a,b)|^2 db$$

(4)

Changes of wavelet variance with scaling $a$ is called as wavelet variance diagram, the peak of which represents the main period of data series. However, the oscillator energy of different periodical changes is presented by time-frequency distribution of modulus square of the wavelet coefficients (equal to wavelet power spectrum), the bigger of modulus square the more significant of periodic variation in associated times and scale [40].

### 3.3. Statistical downscaling method

Regional climate change scenarios based on a global-scale climate change information, translate the large scale and low resolution GCMs output information into regional-scale hydrological-meteorological information can make up for the limitations of GCMs to regional climate change projections. The common use downscaling methods currently include dynamic downscaling and statistical downscaling.

Statistical downscaling methods are widely used in regional climate change predictions based on the characteristics of effectively diminishing the system error of GCM, not subject to the influence of
boundary conditions, simple and flexible in application, and economical in computation et al [41]. There are three methods in building the statistical downscaling model, i.e. transfer function, circulation based differentiation, and using weather producer. The commonly used method in transfer function is multiple liner regression, in addition to this, it also includes some nonlinear methods, such as neural network. Based on the monthly precipitation data with a resolution 1°×1° downscaled by the NCCC using multi-mode interpolation method, this study further downscaled the precipitation data into watershed and stations of UYRB using BP neural network. The principle and application method of BP neural network were explained at length in literatures by Hui and Wang [42,43], and the process of downscaling is shown in the following (figure 3).

4. Results and discussion

4.1. Change trend of practical precipitation

Comparative analysis of precipitation change trend during 1957-2010 in UYRB and the representative weather stations, Maduo and Yuzhong station, which obtained bigger weight in Thiessen polygons, were made on annual and monthly scale using simple liner model combined with two-tailed t-test, the results are shown in figures 4(a1), 4(b1), 4(c1). Monthly precipitation on basin scale tended to decline in July-November (except October), with significance level up to 90% in November, and the quickest decrease was in August but non-significant. Trends in January-June (except April) were positive, with the significant level up to 90% in March and the fastest increase and significant level up to 95% in June. Precipitation on basin scale almost has no obvious change in December. Annual precipitation in UYRB showed a non-significant increasing trend with a rate about 0.004mm/a. Precipitation change trend in Maduo and Yuzhong weather stations experienced significant difference. In terms of intra-annual variation, precipitation in Maduo in February, March and May showed a significant increasing trend with the biggest increasing trend was found in May, while precipitation in other month experienced statistically insignificant increasing trend. Yuzhong experienced insignificantly positive trends in January-June (except April) with the fastest increase and significant level up to 90% in June. In July-December, however, negative trends were noted for Yuzhong with the fastest decrease in August but statistically insignificant, while significant level in November reached 90%. For inter-annual variation, precipitation in Maduo experienced significantly positive trends, while insignificantly negative trends were found in Yuzhong. Compared the change trends in two representative stations and combined with the geographic locations (figure 1) which can interpret the obvious spatial heterogeneity of precipitation change in UYRB.
Figure 4. Trends in the observed monthly and annual Precipitation at Basin (a1), Maduo (b1) and Yuzhong (c1), and trends in the ratio of the observed monthly to annual Precipitation at Basin (a2), Maduo (b2) and Yuzhong (c2). White Stars represent statistically significant trends at $p<0.1$, while Black Starts represent $p<0.05$.

The monthly to annual precipitation ratio on basin scale (figures 4(a2), 4(b2), 4(c2)) showed almost the same trends compared with the trends in intra-annual variation. Positive trends primarily occurred between January and June (except April), with June exhibiting the largest trends and reached 95% significant level. Negative trends predominantly occurred in July-November (except October), while trends in December were relatively small. As a concentrating period of precipitation, the change trends in June will result in the increase of the peak value of runoff which may increase the difficulty of water resources management in UYRB. Monthly to annual precipitation ratio in Yuzhong experienced significant increasing trend in June which reached 95% significant level while the largest negative trends in July but statistically insignificant, change trends in the remaining months are the same to the intra-annual variation. However, unlike trends in Yuzhong and basin scale, Monthly to annual precipitation ratio in Maduo showed significantly different trends compared with the intra-annual
variation of precipitation (figure 4(b1), 4(b2)). Precipitation in June-August showed an increasing trend while the monthly to annual precipitation ratio decreased with the largest trends in July. The same phenomenon also occurred in October.

4.2. Spatial variation of practical precipitation
With the influence of plateau-monsoon and the sea-land monsoon in East Asia, together with the complexity of the underlying surface, distribution of precipitation and its change trends showed significant regional differences (figures 5 and 6). To elaborate the spatial distribution characteristics of precipitation in UYRB, the annual precipitation and its change trends were analyzed systemically. Figure 5 provides spatial distribution of measured annual precipitation in the study area. Annual precipitation in UYRB is usually between 260-750mm, gradually increasing from Northwest to Southeast. Due to the barrier effects of mountain, area in north of 35°N was less affected by monsoon, so the precipitation is between 260-380 mm, but there exist a more pluvial regions between 37°N-38°N and 101°E-102°E. However, influenced by monsoon, precipitation in southeast of the study area was obviously larger, especially in area in south of 34°N, the precipitation is primarily between 600-750 mm.

The spatial distribution of annual precipitation change trends during the measured period in UYRB is shown in figure 6. Different from the distribution of annual precipitation, the change trend of annual precipitation gradually decreases from Northwest to Southeast. It is positive in area in north of 34°N and west of 102°E, while the rest regional are basically negative. In general, the annual precipitation in UYRB mainly present as that decreasing trends in rainy area while increasing trend in arid area. In the face of the above changes over time, however, the spatial distribution of precipitation in the study area may trend to uniform which could promote efficient use of water resources.

4.3. Mutation test of precipitation
Mutation of precipitation in the study area and in two representative stations was analyzed systemically by the MTT method (figure 7). There are no significant jumps during the measured period on basin scale, while the absolute value of the test statistic t maximize in the year 1992 (figure 7(a1)). Precipitation on basin scale decreased rapidly between 1991 and 1992, and the mean value experienced non-significant decrease before and after the year 1992. Singularity in Maduo appears in the year 1989 with the significant level up to 90%. Precipitation in Maduo changed form few to even more between 1988 to 1989, reaching the peak value in the year 1989 during the measured period, and then decreased. The mean value of precipitation increased remarkably before and after the year 1989 which increases by about 40 mm (figure 7(b2)). The most probable singularity at Yuzhong is in the year 1996 (pseudo singularity) but insignificant. The precipitation in Yuzhong showed a suddenly decrease trend between 1995-1996, reaching the minimum value in the year 1996 during the measured period, and the mean value before and after 1996 significantly decreased, by about 35 mm (figure 7(c2)). In summary, Mutations of precipitation in the two stations present significant difference due to
In order to further understand the mutations of precipitation in the whole study area and the precipitation change trends in various periods, mutations and tendency of precipitation in various weather stations of UYRB were analyzed systematically by M-K test, and then compared the results with MTT (table 1). Results of M-K test showed that there are more than one singularity (Include pseudo singularity) in most stations in UYRB, for instance, four singularities presented in Minhe station while more in Qilian. During the study period, precipitation of individual stations presented different change trends in several different time (table 1). Compared the results between M-K and MTT, although there are mutations detected by MTT are contained in results of M-K test in some
stations, almost half stations obtained significant different results between M-K and MTT, for example, Maduo and Yuzhong station. In addition, changes of mean value before and after the singularity also showed obvious difference, the results of M-K showed that the annual precipitation in Gangcha experienced insignificantly positive trends, however, MTT proved that there were significantly decrease of the mean value of annual precipitation before and after the singularity in the year 1989.

**Table 1.** Precipitation mutations detected by the modified M-K and MTT methods for various weather stations from 1957 to 2010.

| Stations      | Number of jumps | Timing           | Statistic Z | Variation trend | Moving T-test |
|---------------|-----------------|------------------|-------------|-----------------|---------------|
|               |                 |                  |             |                 |               |
| Tuole         | 2               | 1982,1997        | 2.67        | 1958~1963↑,1964~2010↓ (2004~2010↓**) | 1997↑**       |
| Yeniugou      | 1               | 1991             | 1.97        | 1957~1975↑,1976~2010↑ | 1970↑**       |
| Qilian        | more            | 1960,1971,1980 et al. | 0.60         | 1989~2010↑ | 1980↑**       |
| Yongchang     | 1               | 1990             | 2.45        | 1957~2010↑ (2000~2010↑*)   | -             |
| Wuwei         | 3               | 1990,1994        | 1.15        | 1957~2010↑ (1967~1974↑** ) | 1973↑*         |
| Gangcha       | 3               | 1973,1989,1990   | 1.80        | 1957~2010↑ | 1989↑**       |
| Menyuan       | -               | -                | -0.22       | 1957~2010↓ | 1980↑*         |
| Wuqiaolin     | 2               | 1975,2001        | 0.36        | 1957~1977↑,1978~2010↑ | 1975↑**       |
| Dulan         | -               | -                | 3.15        | 1957~2010↑ | 2000↑**       |
| Gonghe        | 3               | 1964,1985,1994   | 1.17        | 1970~2010↑ | 2000↑**       |
| Xining        | 1               | 1991             | 2.09        | 1966~2010↑ (1985~2010↑**) | 1991↑**       |
| Guide         | 2               | 1964,1992        | 0.49        | 1957~2010↑ | 1992↑**       |
| Minhe         | 4               | 1962,1968,1980,1991 | -0.52      | 1957~1984↑,1985~1996↑,1997~2010↓ | 1991↑**       |
| Xinghai       | 2               | 1965,1990        | 1.85        | 1957~2010↑ (1970~1982↑**) | 2000↑**       |
| Tongren       | 1               | 1999             | 0.37        | 1991~1997↑,1998~2004↑,2005~2010↑ | -             |
| **Yuzhong**   | 1               | 1980             | -1.19       | 1957~1962↑,1963~2010↓ | -             |
| Linxia        | 3               | 1964,1978,1995   | -0.48       | 1957~1961↑,1962~2010↓ | -             |
| Lintao        | 3               | 1977,1989,1992   | -1.89       | 1959~1969↑,1970~2010↑ (2007~2010↑**) | 1992↑**       |
| Qumalai       | 2               | 1964,1994        | 1.48        | 1957~2010↑ (1965~1978↑**) | 1989↑*         |
| **Maduo**     | 1               | 1959             | 1.98        | 1959~1974↑,1975~2010↑ (2001~2010↑**) | 1988↑*         |
| Qingshuihe    | 3               | 1963,1989,1996   | 0.04        | 1959~1984↑,1985~1996↑,1997~2010↑ | 1989↑**       |
| Shiqu         | 2               | 1981,2001        | -0.32       | 1961~1980↓,1981~1994↑,1995~2010↓ | 1973↑*         |
| Guoluo        | 2               | 1997,2009        | 0.25        | 1998~2010↑ | -             |
| Dari          | 1               | 1970             | 1.01        | 1957~1972↑,1973~1981↓,1982~2010↑ | 1978↑*         |
| Henan         | 1               | 1969             | -1.58       | 1967~1988↑,1989~2010↑ (1998~2008↑**) | 1984↑**       |
| Juzhi         | 3               | 1969,1978,2000   | -1.43       | 1960~1968↓,1969~1982↑,1983~2010↓ | 1989↑*         |
| Maqiu         | 2               | 1976,1986        | -0.48       | 1967~1976↑,1977~1988↓,1989~2010↑ | 1986↑*         |
| Ruoyergai     | 1               | 1962             | -0.75       | 1957~1996↑,1997~2010↓ | 1985↑**       |
| Hezuo         | 3               | 1963,1972,1999   | -0.67       | 1981~2010↓ | -             |
| Minxian       | 2               | 1971,1978        | -1.63       | 1957~1968↓,1969~1981↑,1982~2010↓ | 1992↑**       |
| Bama          | 1               | 1977             | -0.06       | 1976~2010↓ | 1977↑*         |
| Maerkang      | -               | -                | 1.52        | 1957~2010↑ | 1973↑*         |
| Hongyuan      | 2               | 1973,2006        | -0.75       | 1964~1975↑,1976~1995↑,1996~2010↓ | 1973↑**       |
| Songpan       | 3               | 1973,1980,1993   | -0.07       | 1974~1980↓,1981~1992↑,1993~2010↓ | 1980↓*         |
4.4. Periodicity

Periodic variation of hydro-meteorological factors presented complex time-frequency beating characteristics, showing multiple time scale changes, which made the detection of variation period more difficult. Using Morlet wavelet transformation, significant periodicity was detected for precipitation changes throughout the measured period (1957-2010) as shown in figure 8. There are two time scale periodic variations in the annual precipitation in the basin which are the 4-7a and more than 30a. 4-7a time scale cycle occurred during the whole time domain with central scale reaching about 5a and the periodic variation in more than 30a time scale also significant (figure 8(a)). A significant 3-6a time scale periodic cycle was detected in Maduo, mainly occurred in 1957-1980 with central scale reaching about 5a, 12-15a time scale periodic cycle obvious similarly occurred in 1957-2005 with central scale reaching about 13a, while the 25-32a time scale covered the whole measured period with central scale reaching about 30a (figure 8(c)). The precipitation in Yuzhong presented multiple time periods which include 3-6a, 7-10a, 13-16a, 19-22a and more than 30a time scale, while the most significant periodic cycle is 7-10a that occurred during 1970-2010 and the central scale is about 8a.

Figures 8(b), 8(d), 8(f) provided the time-frequency distribution of modular square of wavelet coefficients of precipitation on basin scale and in the two representative stations, which can exactly locate the energy center of precipitation periodic cycle within the whole wavelet transform domain and determine the vibrating energy of different time scale periodic cycle. Periodic variation of precipitation in basin scale exist an energy concentration in 4-7a time scale, the energy center is in about 1966a, the sphere of influence is in 1957-1975 where there is no degradation of wave energy, and then the energy decays rapidly after 1975. The other energy concentration is in more than 30a time scale (figure 8(b)). Maduo has three energy concentration that are 3-6a, 11-16a and 25-27a time scale. Range of influence in 25-27a time scale periodic cycle almost covered the whole measured period while in 11-16a time scale is 1957-2003 with the energy center in 1978a and the wave energy decreased from center to both sides. Periodic cycle in 3-6a time scale exist two energy center which are 1962 and 1974 with the sphere of influence in 1957-1980. Periodic variation of precipitation in Yuzhong has several island energy concentration, distributed in 3-6a, 7-11a and 13-16a time scale, and the energy center are years of 1965, 1982 and 1979 (figure 8(f)).
4.5. Forecast of precipitation changes under different emissions scenarios

4.5.1. Calibration and validation of SDSM. Through a lot of experiment, using optimal Nash coefficient (NSE) as the judge standard, a three layer feed-forward BP network are selected to build the SDSM between "data" and precipitation in UYRB and in various weather stations, where the number of hidden layer neurons are 50, Traingdx was selected as the training function, and the iterative times is 100 times in each group. Downscaled results are detailed in figure 9, due to space limination, this paper only provided the calibration and validation results of SDSM on basin scale under three emissions scenarios. In general, no matter in calibration period or in validation, the statistically downscaled results have reached the accuracy requirement. The simulated and measured values of NSE under three emissions scenarios are A1B (0.865), A2 (0.898) and B1 (0.855), while correlation coefficients (R) are all more than 0.93, which proved the effectiveness of SDSM. Although the simulation precision during validation period present little decrease, but the NSE under three emissions scenarios all are more than 0.8 which still meet the accuracy requirement. When compared the simulated results in more details, it can be found that the peaks of simulations in calibration period are all smaller than the measured under three scenarios, in particular under A1B scenario. In validation period, the peaks of simulations are larger than the measured under A1B and B1 scenarios while smaller under A2 scenario. Generally speaking, it is efficient to use BP network to build the SDSM, but the difference peaks between the simulated and measured peaks should be paid attention.
To further validate the simulation precision of SDSM on smaller scales, statistics on the simulated and measured NSE and R values in calibration and validation periods in various stations were made (table 2). The precision of simulated precipitation values in stations obtained by downscaling method was slightly reduced, compared with the simulated results on basin scale (table 2, figure 9). Correlation coefficient (R) in calibration period under three scenarios are greater than 0.7, mostly between 0.7-0.9, except one station under A2 scenario which is within 0.5-0.7. NSE in calibration period above is 0.5 basically, most between 0.7-0.9. In validation period, R values are mostly between 0.7-0.9 similar to the calibration period, while the number of stations between 0.5-0.7 increased. Number of stations that the NSE are between 0.5-0.7 and between 0.7-0.9 are the same and occupy the majority, while numbers distributed between 0.3-0.5 significantly increase, reaching 5 stations under A1B scenario, 3 stations under A2 scenario and 7 under B1 scenario. In summary, the simulation precision of SDSM on smaller scales was slightly reduced compared to the basin scale.
precision reduces with the decreasing of the model scale then translating the large-scale climate information into the basin or even smaller scales using the build SDSM model by BP network.

**Table 2.** Number of weather stations among a certain scope of parameters during the calibration and validation phases of SDSM under three various scenarios.

| Item  | Range  | Calibration | Validation |
|-------|--------|-------------|------------|
|       |        | A1B | A2 | B1 | A1B | A2 | B1 |
| $R^2$ | $0.5 \leq x < 0.7$ | 0 | 1 | 0 | 3 | 3 | 2 |
|       | $0.7 \leq x < 0.9$ | 25 | 23 | 24 | 29 | 30 | 28 |
|       | $x \geq 0.9$ | 9 | 10 | 10 | 2 | 1 | 4 |
| NSE   | $0.3 \leq x < 0.5$ | 0 | 1 | 1 | 5 | 3 | 7 |
|       | $0.5 \leq x < 0.7$ | 10 | 7 | 7 | 17 | 15 | 10 |
|       | $0.7 \leq x < 0.9$ | 24 | 26 | 26 | 12 | 14 | 17 |

4.5.2. **Comparative analysis of precipitation changes under different emissions scenarios.** In order to detail future dynamic change trends of precipitation in UYRB, monthly and annual data between 2011-2100 obtained by SDSM are divided into three forecast periods every 30 years, i.e. 2025s, 2055s and 2085s, and then compare the monthly distribution and the mean values of annual precipitation among the measured (1957-2010) and the three forecast periods (figure 10). the mean values of annual precipitation under A2 and B1 scenarios in various forecast periods present positive trends compared with the measured, increasing by about 19.4% under A2 scenario while 3.6% under B2 scenario by 2085s. However, the mean value under A1B scenario in 2025s decrease slightly, and then gradually increase, by 6.1% up to 2085s compared with the measured. Relative to the measured period, the annual distribution of precipitation under three emissions scenarios in various forecast periods showed different change trends. A1B experienced negative trends between July-September in various periods. The other months, however, positive trends were noted under A1B scenario especially in April and May (figure 10(a)). the precipitation under A2 scenario in various forecast periods present gradually increasing trends in each month during the whole year, in particular between April and October (figure 10(b)). the change trends in each month under B1 scenario in various forecast periods are smaller than that under A1B and A2 scenarios, the precipitation in various forecast periods are equal to the measured ones in most month, except a positive trend in August-September and negative trends in July (figure 10(c)). On the whole, the variation degree of annual distribution is A2>A1B>B2, considering the meaning of the three emissions scenarios (Nakicenovic and Swart, 2011), this would explain that there will be maximum precipitation fluctuations with population growth and slow economy development in the study area.

In addition, compared with the measured period, the peak of annual precipitation distribution will translate from July to August in forecast periods under A2 and B1 scenarios (figures 10(b) and 10(c)). In terms of the Yellow River basin which covers a large area of planted area, this change would most probably lead to changes in food production, and then threaten food security.
Figure 10. Comparison of downscaled precipitation with baseline (1957~2010) precipitation on monthly and annual scale, (a) A1B scenario precipitation with baseline, (b) A2 scenario precipitation with baseline, (c) B1 scenario precipitation with baseline. The symbol 0, 1, 2, 3 on the X-axis represent the baseline, 2025s, 2055s and 2085s respectively.

4.5.3. Spatial distribution of precipitation trends under different emissions scenarios. The large-scale climate change information was downscaled into the various weather stations of UYRB by SDSM (simulation accuracy are in table 2), forecasted the "future" (2011-2100) precipitation in each weather station, and then, compared the forecasted data with the measured ones to analyze the spatial distribution of precipitation trends under different emissions scenarios, the results are shown in figure 11. The precipitation at various stations experienced positive trends basically in various forecast periods under three emissions scenarios relative to the measured except some individual stations in 2025s. For the spatial distribution, precipitation under A2 scenario exist the most significant difference due to the difference of station location (figure 11(b)), A1B scenario comes second (figure 11(a)) while the B1 scenario faintest (figure 11(c)). Variation of precipitation under A1B scenario shows increasing trend first and then decreasing trend from Northwest to Southeast, reaching the maximum in the middle part of the study area. A2 scenario experienced increasing trend first and then decreasing trend from Southwest to Northeast, relatively large in the middle part too. Variation of precipitation under B1 scenarios increased gradually from Southwest to Northeast, reaching the maximum at upper Southeast-location of the study area.

The spatial distribution of the difference of annual precipitation were further analyzed in the whole forecast periods (2011-2100) under different three emissions scenarios, results are detailed in figure 12. The predicted values of A1B and A2 scenarios presented the most significant difference, the range of which is -205.6-133.3 mm, and the predicted value of A1B are smaller than A2 in most stations (about 85%). However, the difference of the predicted values between A2 and B1 are relatively small, the range of which is -174.0-101.9 mm, and the differences between A2 and B1 is -119.8-166.3 mm. For
Figure 11. Spatial distribution of D-value between the predicted and the observed precipitation in three different Emissions scenarios, (a) Spatial distribution of D-value in A1B scenario, (b) Spatial distribution of D-value in A2 scenario, (c) Spatial distribution of D-value in B1 scenario. Zone inside the ellipse have significant change.

Figure 12. Spatial distribution of D-value of predicted precipitation between two different Emissions scenarios, (a) Spatial distribution of D-value between A1B and A2 scenario; (b) Spatial distribution of D-value between A1B and B1 scenario; (c) Spatial distribution of D-value between A2 and B1 scenario.
the spatial distribution, difference of the predicted values between A1B and A2 are significant in the Southeast of UYRB, and most of which are negative (figure 12(a)). Difference between A1B and B1 followed a rule of decreasing firstly and then increasing from Southwest to Northwest (figure 12(b)). The spatial distribution of differences between A2 and B1 are relatively uniform and has no significant difference, increasing weakly from West of the study area to East. However, there is a special region in the lower-middle of the study area where the differences are all positive (figure 12(c)).

5. Conclusion
Global climatic fluctuations impact the variations of distribution and amount of precipitation, change the status of water resources in the basin, and result in frequent occurrence of drought and flood disasters. Meanwhile, it influences the river water quality, threatening the water security in the basin by changing the water input and its seasonal distribution. This study took the Upper Yellow River Basin as the research object, and used data observed from 34 meteorological stations in the study area from 1957 to 2010 to systematically analyze the temporal and spatial distribution of precipitation as well as the change of precipitation and the abrupt change points, and then predict the future spatial and temporal variation characteristics of precipitation in the basin by the SDSM. The conclusions are as follows:

- Among the annual variations, the precipitation showed a slight increasing trend in the whole basin, a significant increasing trend at Maduo representative weather station, and a slight increasing trend at in Yuzhong station. Among intra-annual variations, the precipitation on basin scale increased from January to June (except April) with the highest increasing rate occurred on June. During July to November (except October), the precipitation decreased with the highest rate occurred in August. In December, the precipitation has no obvious changes. As for intra-annual precipitation of representative weather stations, compared to the trend on the basin scale, Yuzhong station has the similar changes, whereas Maduo station increased in each month of the year. As to monthly to annual precipitation ratio, the variation trend of the whole basin and the Yuzhong station are the same, but the trend of Maduo station showed significant differences.

- Space distribution. The measured precipitation during the period showed an increasing trend from the northwest to the southeast, the annual precipitation gradually decreased from the northwest to the southeast, from positive to negative. Generally speaking, the spatial precipitation distribution showed decreasing trends in rainy area while increasing trend in arid area.

- Mutation situation. MTT results showed that on the whole basin scale, the precipitation variation in the observed periods has no significant mutations, and that the most likely point mutations (pseudo point mutations) is in 1992. Precipitation before and after the pseudo mutation point has no significant decrease. At representative meteorological stations, the precipitation at Maduo station has significant mutations, and the mutations year is 1989. At Maduo station, before and after the mutation point the average precipitation increased by almost 40 mm. At Yuzhong station, the most likely point mutations is 1996 (which did not reach the significant level of 90%), and before and after the pseudo point mutations the average precipitation reduced by about 35 mm. The results of M-K test and MTT were different, and the precipitation changes in the river basin were detected in years 1965, 1982, and 1998, and the precipitation changes of the meteorological stations in the basin are more than 1 point.

- Periodicity. The wavelet analysis revealed two timescale variation in the precipitation change on the basin scale: 4-7a and over 30a. At 4-7a time scale variation, the center scale is about 5a, energy center lies in 1966, and the influence range is 1957-1975. At Maduo station, there are 3-6a, 12-15a, and 25-32a a total 3 time scale variations, of which center scale were 5a, 13a and 30a respectively and the influence range was 1957-1980, 1957-2003 in the whole measured period. At Yuzhong station, there are several time scale variations.
Future trends of precipitation change. The results of inter-decadal change showed that except the A1B scenario, the predicted 2025s precipitation is less than the actual measurement period, the mean annual precipitation in the forecast period under the three emission scenarios are higher than that of the actual data. The results of monthly distribution showed that under A1B scenario, precipitation in the forecast period is less than that in the observation period in July, August and September, but the circumstances are opposite in April and May. Under A2 scenario, precipitation in the forecast period is more than that in the observation period in each month. Under B1 scenario, precipitation in the forecast period is similar to that in the observation period in all months except that in August and September, the precipitation in the forecast period is bigger in July, it is smaller in the observation period. Apart from that, under both A2 and B1 scenarios, in the forecast period, the monthly rainfall peak has shifted from July to August.

Spatial distribution of precipitation trends in the future. Compared with the observation period, under A1B scenario, the values of precipitation changes in the forecast period showed first increase and then decrease from the southwest to the northeast, reaching the maximum amount in the middle of the basin. Under A2 scenario, the values of precipitation changes in the forecast period showed first increase and then decrease from the northwest to the southeast, reaching the maximum in the middle of the basin. Under B1 scenario, the change value of precipitation gradually increased from the southwest to the northeast, reaching the maximum in the southeast of the basin. As for the mean value differences of precipitation and its spatial distribution from 2011 to 2100 under different scenarios, the results from most stations (85%) under A1B scenario are smaller than those under A2 scenario, and the values of difference lie between -205.6-133.3 mm. The biggest gap located in southeast basin. The values of the difference between results under A1B scenario and B1 scenario range from -174.0 to -101.9 mm. The difference first decreases and then increases from the southwest to the northeast, and the positive and negative distribution is even. The values of the difference between results under A2 scenario and B1 range from -117.7 to -166.3 mm. The positive and negative values scattered in the basin with no significant pattern. In the lower-middle part of the basin, there is a special region where all the different values are positive.

Acknowledgments
The authors would like to acknowledge the technological and financial supports by professor Jianxin MU, the data supports by the China Meteorological Administration (CMA).

References
[1] IPCC (Intergovernmental Panel on Climate Change) 2007 The physical science basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change S Solomon, D Qin, M Manning, Z Chen, M Marquis, K Averyt, M Tignor, H Miller eds. (Cambridge, UK: Cambridge University Press) p 996
[2] IPCC (Intergovernmental Panel on Climate Change) 2013 Summary for Policy makers Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change T F Stocker, D Qin, G-K Plattner, M Tignor, S K Allen, J Boschung, A Nauels, Y Xia, V Bex, P M Midgley eds. (Cambridge, UK and NewYork: Cambridge University Press)
[3] Ding Y H, Ren G Y, Shi G Y, Gong P, Zheng X H, Zhai P M, Zhang D E, Zhao Z C, Wang S W, Wang H J, Luo Y, Chen D L, Gao X J and Dai X S 2006 National assessment report of climate change (I): climate change in China and its future trend Adv. Climat. Change Res. 2 3-8
[4] Liang L Q, Li L J, Liu C M, et al 2013 Climate change in the Tibetan Plateau Three Rivers Source Region: 1960–2009 Int. J.Climatol. 33 2900-16
[5] Hughes M K and Diaz H F 2008 Climate variability and change in the dry lands of Western
North America Global Planet. Change 64 111-8

[6] Chaouche K, Neppel L, Dieulin C, Pujol N, Ladouche B, Martin E, Salas D and Caballero Y 2010 Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change CR Geosci. 342 234-43

[7] Roderick M L and Farquhar G D 2004 Changes in Australian pan evaporation from 1970 to 2002 Int. J. Climatol. 24 1077-90

[8] Karamouz M, Nazif S and Fallahi M 2010 Rainfall downscaling using statistical downscaling model and canonical correlation analysis: A case study R N Palmer ed. World Environmental and Water Resources Congress 2010: Challenges of Change—Proceedings of the World Environmental and Water Resources Congress 2010 (American Society of Civil Engineers, Reston, Va) pp 4579-87

[9] Liu Q, Yang Z and Xia X 2010 Trends for pan evaporation during 1959–2000 in China Procedia Environ. Sci. 2 1934-41

[10] Liu M, Tian H, Lu C, Xu X, Chen G and Ren W 2012 Effects of multiple environment stresses on evapotranspiration and runoff over Eastern China J. Hydrol. 426-427 39-54

[11] Wentz F, Ricciardulli L, Hilburn K and Mears C 2007 How much more rain will global warming bring? Sci. Exp. 317 233-5

[12] Isaac V and van Wijngaarden W A 2012 Surface water vapour pressure and temperature trends in North America during 1948–2010 J. Clim. 25 3599-609

[13] IPCC (Intergovernmental Panel on Climate Change) 2001 Reports: 2001 (Cambridge: Cambridge University Press)

[14] Zhang X, et al 2007 Detection of human influence on twentieth-century precipitation trends Nature 448 461-5

[15] Gardner L R 2009 Assessing the effect of climate change on mean annual runoff J. Hydrol. 379 351-9

[16] Zhou L T and Huang R H 2010 Interdecadal variability of summer rainfall in Northwest China and its possible causes Int. J. Climatol. 30 549-57

[17] Sillmann J, Kharin V V, Zwiers F W, Zhang X and Bronaugh D 2013 Climate extreme indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections J. Geophys. Res. Atmos. 118 2473-93

[18] Zhang J, Chen L, Bo L I, et al 2012 Research on the precipitation of precipitation change with in Upper Yangtze River Basin during 2011~2060 Water Resources & Hydropower Engineering. 43 4-9

[19] Lu W X, Liu B J, Chen J F, et al 2014 Variation trend of precipitation in the Pearl River Basin in recent 50 years J. Nat. Resour. 180-90

[20] Cao J, Qiu B and Xia J 2015 Impacts of precipitation change on water supply and demand in Haihe River Region during 1956-2010 Progress us Inquisitiones De Mutatione Climatis. 11 111-4

[21] Lan C, Zhang Y, Gao Y, et al 2013 The impacts of climate change and land cover/use transition on the hydrology in the upper Yellow River Basin, China Journal of Hydrology 502 37-52

[22] Hao Z, Shi F and Wang J 2011 Research and analysis of change of precipitation in headstream region of Yellow River by using statistical downscaling model Water Resources & Power. 3 1-4

[23] Tian Q and Yang S 2016 Regional climatic response to global warming: Trends in temperature and precipitation in the Yellow, Yangtze and Pearl River basins since the 1950s Quatern. Int. 440 1-11

[24] Xu Z X and Zhang N 2006 Long-term trend of precipitation in the Yellow River basin during the past 50 years Geogr. Res. 25 27-34

[25] Zhang Q, Peng J, Singh V P, et al 2014a Spatio-temporal variations of precipitation in arid and semiarid regions of China: The Yellow River basin as a case study Global Planet. Change 114 38-49
[26] Yao W, Xu Z and Wang Y 2009 Analysis of runoff variation in Yellow River Basin on the background of climate change Meteorol. Environ. Sci. 2 1-6
[27] Meng F, Su F, Yang D, et al 2016 Impacts of recent climate change on the hydrology in the source region of the Yellow River Basin J. Hydrol. Reg. Stud. 6 66-81
[28] Pervez M S and Henebry G M 2014 Projections of the ganges–Brahmaputra precipitation-downscaled from GCM predictors J. Hydrol. 517 120-34
[29] Shapur K, Eslamian S S, Abedi-Koupai J, et al 2016 Projection of climate change impacts on precipitation using soft-computing techniques: A case study in Zayandeh-rud Basin, Iran Global Planet. Chan. 144 158-70
[30] Chu J T, Xia J, Xu C Y and Singh V P 2010 Statistical downscaling of daily mean temperature, pan evaporation and precipitation for climate change scenarios in Haihe River, China Theor. Appl. Climatol. 99 149-61
[31] Chen S-T, Yu P-S and Tang Y-H 2010 Statistical downscaling of daily precipitation using support vector machines and multivariate analysis J. Hydrol. 385 13-22
[32] Teutschbein C, Wetterhall F and Seibert J 2011 Evaluation of different downscaling techniques for hydrological climate-change impact studies at the catchmentscale Clim. Dyn. 37 2087-105
[33] Jian H and Luo Y Z 2011 Precipitation variation feature research based on mann-kendall and waveleialysis-taking the Shapingba in Chongqing as an example Journal of Southwest China Normal University 36 217-22
[34] Zhang Q, Singh V P, Li K, et al 2014b Trend, periodicity and abrupt change in streamflow of the East River, the Pearl River Basin Hydrol. Process. 28 305-14
[35] Kendall M G 1975 Rank Correlation Methods (Griffin: London)
[36] Mann H B 1945 Nonparametric test against trend Econometrica 13 245-59
[37] Kendall M G 1948 Rank Correlation Methods (New York: Hafner)
[38] Mallat S G 1989 A theory for multi-resolution signal decomposition: the wavelet representation IEEE Trans PAMI 1989 674-93
[39] Wang W S, Ding J and Xiang H L 2002 Multiple time scales analysis of hydrological time series with wavelet transform Journal of Sichuan University 34 14-7
[40] Kozyrev S V 2007 Wavelet theory as-adic spectral analysis Izvestiya Mathematics 66 149-58
[41] Trigo R M and Palutikof J P 2001 Precipitation scenarios over iberia: A comparison between direct GCM output and different downscaling techniques J. Climate 14 4422-46
[42] Hui H E, Jin L, Qin Z N, et al 2007 Downscaling forecast for the monthly precipitation over guangxi based on the bp neural network model J. Trop. Meteorol. 4 169-75
[43] Wang J, Chen C and Wang C 2013 Statistical downscale based on BP-CCA for daily precipitation over Sichuan Basin in summer Plateau & Mountain Meteorology Research 33 35-9