《国家重点基础研究发展规划》项目
我国生存环境演变及北方干旱化趋势预测研究(G1999043400)(四)

北方干旱化对农业、水资源和自然生态系统影响的研究

林而达　周广胜　任立良　等编

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内容提要

本集是《国家重点基础研究发展规划》"我国生存环境演变和北方干旱化趋势预测研究"项目论文集的第四集。它集中反映了本项目在人类活动与干旱化相互关系以及我国北方典型生态系统对干旱化的响应和适应等方面的研究内容。本集共收入有关论文25篇,主要包括了以下几部分的研究成果:

(1) 近50年北方干旱/半干旱地区土地利用,水资源和水利用状况的变化特征,未来干旱化对农业及相关经济部门影响的模拟、评估;

(2) 我国北方干旱/半干旱区典型生态系统对干旱化的响应与适应机制;

(3) 水分驱动下的多尺度集成生态模式与趋势预测;

(4) 北方地区生态系统对干旱化的适应对策与优化生态系统范式探讨。

本书可供从事大气科学、环境科学、生态保护、农业科学的有关科研、管理部门和有关院校师生参考,并可供防灾减灾部门和从事全球变化研究的科研人员参考。

Beifang Ganhanhua dui Nongye、Shuiziyuan he Ziran Shengtai Xitong de Yingxiang

北方干旱化对农业、水资源和自然生态系统的影响

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序

北方干旱化是我国最严峻的生存环境问题之一。20世纪90年代中期以来，这一问题进一步加剧，其中1999～2001年的干旱面积超过了北方地区总面积的40%。近5年（1999～2003年）干旱所造成灾害的面积占所有气象灾害面积的60%以上，比前10年平均增长了10个百分点。科学地认识北方干旱化的形成机理及其发展规律、预测其未来发展趋势（继续加剧还是缓解、甚至逆转）并评估其社会经济影响，进而提出合理的适应对策是国家在战略决策层面上的迫切需要。

在国家科学技术部的《国家重点基础研究发展规划》“我国生存环境演变和北方干旱化趋势预测研究（G1999043400）”的资助下，来自中国科学院有关研究所、教育部有关院校、中国农业科学院和中国气象局等十九个单位的九十多位专家组成的项目研究队伍针对国家对北方干旱化趋势预测、影响评估和对策问题上的重大需求，围绕“干旱化的发展规律和形成机理”的关键科学问题，以全球变化科学理论为指导，运用多学科交叉的集成分析、生态系统的观测实验和数值模拟方法，重点研究由水、土、气、生组成的生存环境变化的自然规律，揭示全球增暖以及人类活动对干旱化影响的过程和机理。在此基础上发展干旱化趋势预测和影响评估的理论和方法，以及组织有序人类活动、适应和缓解干旱化的科学途径。

5年来，项目组成员围绕以上关键科学问题，通过野外考察和取样、实验室分析、数据的处理和计算分析、生态系统的观测实验、数值模拟等，重建了我国北方生存环境干旱化长期演变历史，为认识干旱化的发展规律和形成机理提供了重要的自然背景；系统地分析了北方干湿变化的规律，检测全球增暖对干旱化的可能影响；发展了区域环境系统集成模式并应用于项目研究，为干旱化趋势预测和有序人类活动的虚拟试验提供了工具；系统分析了土地和水资源利用与干旱化的关系，建立了干旱化对水、土、农影响评估模拟模型，并对未来50年的干旱化影响做出了系统评估，给出了地理分布；系统地开展了北方典型生态系统对干旱化的响应和适应的观测实验和模拟研究（包括植株、种群和生态系统三个层次）并提出了相应的适应对策；开展了人类对干旱化有序适应的观测、数值虚拟试验和生态示范区的建设。另外，围绕项目的科学目标，分别就干旱指数的建立和比较、干旱化发展趋势集成预测、综合影响评估和形成机理进行了项目层次上的跨课题的集成研究，取得了明显效果。

项目执行5年来，科研人员取得了一批重要的研究结果，在国内外产生了重大影响，提高了我国科学家在国际全球变化研究领域的学术地位。为了集中总结和交流本项目的研究成果，项目专家组编辑了这套论文集：

第一集：中国北方干旱化的历史证据和成因研究

第二集：北方干旱化的趋势分析和预测研究

第三集：区域环境系统集成模式的发展和应用研究

第四集：北方干旱化对农业、水资源和自然生态系统影响的研究

第五集：人类对北方干旱化的有序适应——观测、虚拟试验和实验研究

《国家重点基础研究发展规划》项目（G1999043400）

我国生存环境演变和北方干旱化趋势预测研究

项目首席科学家　符淙斌　安芷生

2004年9月15日

前　言

本集是《国家重点基础研究发展规划》“我国生存环境演变和北方干旱化趋势预测研究”项目论文集的第四集。它集中反映了本项目在人类活动与干旱化相互关系以及我国北方典型生态系统对干旱化的响应和适应等方面的研究内容。本集共收入有关论文25篇，主要包括了以下几部分的研究成果：

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2004年10月10日

目 录

Macroscale Hydrological Modeling over the Huaihe River Basin*

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Abstract

The Xin'anjiang Model is used as the basic model to develop a monthly grid-based macroscale hydrological model for the assessment of the effects of climate change on water resources. The monthly discharge from 1953 through 1985 in the Huaihe River Basin is simulated and sensitivity analysis on runoff is made under assumed climatic scenarios. There is a good agreement between the observed and simulated runoff. Due to the increase of time interval and decrease of precipitation intensity on monthly time scale, no monthly runoff appears in some girdded cells as the monthly hydrological model is applied to the Huaihe River Basin. Two methods of downscaling monthly precipitation to daily resolution are validated by running the Xin'anjiang model at a daily time step from the monthly data, and the model outputs are more accurate than the monthly hydrological model. The methods of downscaling of monthly precipitation to daily resolution may provide an idea in solving the problem of the shortage of daily data. In the research of the climate change on water resources, the daily hydrological model can be used instead of the monthly one.

Key words: macroscale hydrological model, Xin'anjiang model, Huaihe River Basin, downscale

1 Introduction

The study of macroscale hydrologic modeling has been inspired by two requirements. One is to improve the capability of prediction for climate change and its effects on water resources and water related aspects. The other is to improve the understanding of hydrologic processes in global water and energy cycle. Increased concentration of greenhouse gases is expected to alter the radiative balance of atmosphere, causing increases in temperature and changes in precipitation patterns and other climatic variables (Houghton et al. 1990). It is very important for water resource managers to be aware of and prepared to deal with the effects of climate change on streamflow and related variables. It is demonstrated in the study of General Circulation Models (GCM) that land surface processes have a great deal to do with the climate. Hydrological processes, as a significant component of land surface processes, interact with the climate, i.e. being subject to the climate as well as giving feedback to the climate. The coupling of hydrological model with the atmospheric model would improve the description of land surface processes, and increase the prediction accuracy resulting from the climatic model as well.

Traditionally, The hydrological models are categorized into the statistical, the physically-based, and the conceptual. The physical model aims at describing the physical processes but limited in practical use due to the shortage of detailed data. While the conceptual model may have a more empirical approach based on variability parameters with only limited relationships between

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model parameters and the conditions in the basin. Hence, the conceptual model is more appropriate for applications at larger scales (Becker 1992). Today, numerous conceptual hydrological models based on water balance have been developed for simulating patterns of streamflow over large basins for resource estimation purposes, e.g., HBV model (Vehvilainen and Huutunen 1997), SLURP model (Kite 1997b), and Macro-PDM model (Arnell 1999)

The VIC model has been developed in a series of articles (Wood et al., 1992; Liang et al., 1994). The initial motivation for the development of the model was to improve the representation of land surface processes within atmospheric models, more recently the model has been used to simulate continental-scale river basin dynamics (Abdulla et al., 1996; Nijssen et al., 1997).

The Xin'anjiang Model (Zhao 1992) is proved to be an effective conceptual model. It is developed on the basis of numerous practical work of storm-flood forecasting and successfully applied both at home and abroad. It considers some non-uniformity of distribution of rainfall and underlying conditions and has some features of distributed model. The feature of the Xin'anjiang Model structure provides a parameterization scheme for lumping, which more recently is considered as a simple and effective spatial parameterization method for use in the macroscale hydrological modeling (Wood 1992; Todini 1992).

In this article, the Xin'anjiang Model is used as the basic model to develop a grid-based macroscale hydrological model for the purpose of exploring the sensitivity of water resources to climate change. The watershed chosen for analysis is the Huaihe River Basin in China. This article firstly discusses some issues related to the grid-based hydrological model: (1) precipitation interpolation; (2) parameter estimation in the grid cell; (3) modification of evaporation estimation. It then describes the application of the Xin'anjiang monthly-distributed hydrological model in the Huaihe River Basin. Due to the increase of time interval and decrease of precipitation intensity within a month, no monthly runoff in some gridded cells appears as the Xin'anjiang monthly model is applied to the Huaihe River Basin. In the following section, the Xin'anjiang model is run at a daily time step from monthly data, and the model output is at a monthly interval. Two methods of downscaling of monthly precipitation to daily resolution are considered and the model results are compared. The final part of the article gives primary conclusions and discussions.

2 Grid-based Hydrological Model

2.1 *Precipitation Interpolation*

The Xin'anjiang Model is used as the basic model to develop the grid-based distributed hydrological model. The model structure may be regarded as being independent of the size and shape of computational units, and can be directly applied to the grid-based computation. That's to say, the attention is not paid to the model structure, but to the computational programming and some related techniques for the hydrological parameters and variables to be handled.

The values of precipitation in each grid cell can be interpolated by the following methods:

· Minimum distance method, i.e. the value observed at the nearest rain gauge station is taken as the mean value of a grid.

· Linear interpolation weighted by the distance between a rain gauge station and a grid cell to be studied.

As regards evaporation, the minimum distance method is used for interpolation.

2.2 *Parameter Estimation in the Grid Cell*

Model calibration is another important issue in the distributed hydrologic modeling. Usually the parameters of hydrological model are calibrated through measured data. The accuracy of the model calibration is dependent on errors in observations. The model could be over-parameterized during the model calibration to fit the simulated results to observed data (Yu, 1999). There is a high degree of uncertain in estimating the average values of various hydrologic parameters for each grid cell (Yu, 1999). On the other hand, the case without ganged data must be involved in macro-scale hydrological modelling. So an attempt should be made to establish the quantitative relationship between the parameters and land surface characteristics, and to seek for the geographical distribution of the parameters.

W_m, tension water capacity, is a parameter controlling runoff generation in the Xin'anjiang model. It is one of the most sensitive parameters in the monthly and daily hydrological model, and plays a control role in the estimation of generated runoff and actual evapotranapiration. A good relationship exists between W_m and the drought index (α), which is defined as the ratio of the annual mean potential evaporation to the annual mean precipitation. The relationship can be quantitatively expressed as the following formula:

$$W_m = A \times \alpha \tag{1}$$

where A is a coefficient. The analysis from real data has shown that the value of A is about 160 mm in the Huaihe River Basin.

All the other parameters in the Xin'anjiang Model have their definite physical meanings, and may be estimated on the basin basis of physiographical characteristics with the development of information technology.

2.2 *Evaporation Estimation*

The potential evaporation could not be measured. The traditional method to solve the problem in the hydrological model is by means of the conversion of pan-based observation data. The values of the potential evaporation are mainly distributed with the climatic conditions, such as temperature and moisture, which especially reflect in the aspects of elevation and latitude. There will not be pan-based evaporation data when studying the effects of future climate change on water resources. Thus, an evaporation estimation model should be re-built instead of pan-based data in the Xin'anjiang grid-based hydrological model. *A* feasible way to do that is to utilize parts of meteorological elements, such as precipitation, air temperature, wind velocity, air pressure, radiation, etc., which could be predicted by GCM.

There are various kinds of empirical and physical models to estimate the potential evaporation. The empirical is easily used but short of physical mechanism. The physical one is usually applied only to the small scale of pilot area because of the lack of real data. In this study, the empirical approach is adopted due to its simplicity. The fundamental factors to determin the potential evaporation are the energy that comes from solar radiation. Generally speaking, the value of monthly evaporation is directly proportional to the value of monthly mean air temperature. So, temperature is considered as the main factor in the establishment of empirical evaporation formula. In the study of monthly hydrological model, a potential evaporation formula is established.

$$E = A \times T + B \tag{2}$$

where E is monthly potential evaporation; T refers to monthly mean air temperature.

3 Application of the Xin'anjiang Monthly Hydrological Model

Monthly hydrological model is considered to be a useful and indispensable tool in assessing climate change on water resources over a large geographic domain (e.g., Gleick, 1986; Arnell, 1992; Mohseni and Stefan, 1998). In this study, the Xin'anjiang monthly hydrological model (Lu 1993) is used as the basic model to develop a grid-based hydrological model. The Huaihe River Basin with the area of 270000 km^2 is selected as the research area. A 30 km × 30 km squared-grid is adopted and combined with drainage network. There are totally 341 grid cells. The inputs to the model are P, the measured monthly mean rainfall depth on sub-basins, and E, the measured evaporation in the same time step and unit as P. The outputs are the monthly discharge from each sub-basin and from the whole basin, and the actual evapotranspiration from the whole basin. The state variables are the tension water storage, the free water storage, and generated runoff. The data series for calibration and validation comprise 33 years (1953 – 1985) monthly hydrological data from the whole Huaihe River Basin, including observed precipitation, air temperature, and streamflow. The three types of data come from 210 precipitation stations, 29 evaporation stations, and 36 streamflow control stations respectively. So the model is run at a monthly time step.

In order to verify the grid-based monthly hydrological model, the Huaihe River Basin is partitioned into 17 sub-areas, in which 15 sub-areas have monthly-observed discharge data. As regards two ungauged sub-areas, the model parameters are transplanted from the gauged sub-areas. The model is run in two different situations:

A. Calibrated parameters are directly used in grid-based hydrological model, and values observed by evaporation pan are taken as potential evaporation;

B. Tension Water Capacity, W_m, the runoff generation parameter in the Xin'anjiang Model, is estimated from formula (1), and potential evaporation is estimated from formula (1).

The model results in the two situations are shown in Table 1. Results indicate that the model efficiency is greatly improved when temperature is used to estimate evaporation. The results of scheme B also show that the monthly hydrological model perform a better model efficiency with over 0.75 out of 15 sub-catchments. The reasons that the model efficiency of the other catchments is correspondingly lower may be related with the representation of inputs and human activities.

Table 1. Annual runoff results from the monthly grid-based hydrological model (unit: mm)

Sub-area number	Control station	Observed discharge	Scheme A		Scheme B	
			Calculated	Efficiency	Calculated	Efficiency
1	Xixian	382.5	382.47	0.868	382.54	0.8768
2	Bantai	249.59	249.67	0.8198	249.71	0.8504
3	Luohe	212.38	211.04	0.8045	212.69	0.8515
4	Zhoukou	148.69	148.96	0.814	148.84	0.8680
5	Boxian	87.72	87.88	0.4197	87.17	0.6653

(continued)

Sub-area number	Control station	Observed discharge	Scheme A		Scheme B	
			Calculated	Efficiency	Calculated	Efficiency
6	Jiangjiaji	386.93	386.35	0.7896	386.97	0.8438
7	Hengpaitou	791.81	791.41	0.6071	791.64	0.6632
8	Fuyang	159.53	159.89	0.7828	159	0.8525
9	Wangjiaba	300.1	300.63	0.7813	300.01	0.8007
10	Lutaizi	251.71	254.85	0.7496	251.24	0.7621
11	Bengbu	238.01	237.65	0.6361	238.09	0.6504
12	Minguang	175.07	179.3	0.493	182.74	0.6016
13	Guzhen	115.96	115.38	0.7162	115.73	0.7758
14	Linyi	233.57	232.2	0.8347	233.68	0.8471
15	Daguanzhang	243.93	231.22	0.7487	243.75	0.7894
16	Hongze Lake	0	214.87	0	220.91	0
17	Plain area	0	196.23	0	158.24	0
Average				0.724		0.780

The observed and simulated average monthly discharge in the year from 1953 to 1985 at Lutaizi with the control area of 91620 km^2 is shown in Fig. 1. There is a good agreement between the observed and simulated values.

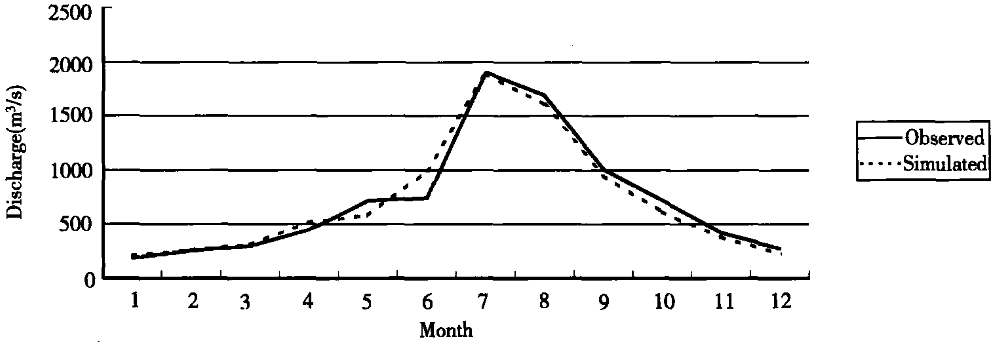

Fig. 1. Observed and simulated average monthly discharge in the year from 1953 to 1985 at Lutaizi with the control area of 91620 km^2

Based on the above monthly distributed hydrological model, sensitive analysis on runoff in the Huaihe River Basin are performed under assumed climatic scenarios, e.g. a change in temperature of −2, −1, 0, 1, 2 combined with −20%, −10%, 0, 10%, 20% changes in precipitation. Giving an example of the prediction, Table 2 lists the results of modeling that was performed according to the assumed climate scenarios.

Table 2. Relative changes of mean annual runoff estimated by the monthly hydrologic model of the Huaihe River Basin upstream of Bengbu responding to climatic changes (%)

Temperature / Precipitation	−2 °C	1 °C	0 °C	1 °C	2 °C
−20%	−33.2	−40	−46.4	−52.1	−57.2
−10%	−9.2	−16.9	−23.9	−30.6	−36.7
0	16.1	7.8	0	−7.3	−14.3
10%	42.3	33.6	25.2	−17.2	9.7
20%	69.1	60.0	51.2	42.8	34.7

4 Application of Precipitation Downscaling Methods

4.1 *Problems in the Xin'anjiang monthly hydrological model*

In section 2 and section 3, the Xin'anjiang Model was used as the basic model to develop a monthly grid-based macroscale hydrological model. And the monthly discharge of the 17 sub-basins in the Huaihe River Basin from 1953 through 1985 was simulated. Though most of the simulated results fitted well to the observed data, some problems exist in the monthly hydrological model.

The error mainly happened in the runoff production because of the monthly time step. According to the assumptions in the Xin'anjiang model, only when $P - E > 0$, could the runoff be calculated, where P is precipitation; E is potential evaporation; $P - E$ is effective rainfall. For example, there is a month only having one rainy day: the magnitude of rainfall is 50mm; the monthly potential evaporation is 300 mm; then the even daily potential evaporation is 10 mm. When the model is run at a daily time step, the effective rainfall is 40 mm($50 - 10 = 40 > 0$). Then the runoff can be calculated. But if the model is run at a monthly time step, $P - E = 50 - 300 < 0$. Then no runoff is simulated. Obviously, this is unrealistic. The increasing of the time step reduces the accuracy of the representation of sub-daily processes. So in the application of the monthly hydrological model to the Huaihe River Basin, the monthly runoff of some grid cells appeared unrealistic zero. Fig.2 shows the gridded precipitation in Huaihe River Basin in October 1953, and Fig.3 the gridded runoff simulated by the monthly hydrological model at the same time. It can be seen that there is not calculated runoff in the most grid cells while precipitation existing.

																			23											
																		82	62	80	73									
												17	21	25	32	32	72	54	73	73	75									
											17	17	23	25	32	44	72	60	51	55	75	79	79							
										22	22	23	23	35	32	44	44	45	44	54	79	79	79							
									23	32	22	24	35	35	44	41	41	41	43	43	42	97								
				24	19	14	13	30	23	23	32	24	24	25	35	30	38	41	39	35	42	97	97	72						
		15	27	27	13	18	14	14	23	23	26	24	25	25	28	30	30	44	32	32	54	97	34	72	34	41				
	16	19	12	17	17	17	14	13	28	30	26	24	25	25	28	28	49	34	27	24	54	37	34	28	41	41				
14	14	27	8	8	18	13	12	13	28	30	28	35	39	39	31	28	28	20	24	24	46	37	37	28	60	60	60			
14	27	24	11	13	13	11	11	27	24	21	26	28	28	29	25	33	22	23	41	41	46	21	29	20	55	58	26			
			23	23	32	11	9	9	27	19	19	33	29	37	42	27	27	23	21	21	21	29	29	29	55	26	26	26		
				23	28	12	26	21	15	26	19	33	28	45	45	27	28	17	19	19	19	29	33	30	39	22	26	41		
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				29	20	15	3	3	19	19	44	41	30	29	28	43	34	34	17	21	28	28	28	43	26	38	38	41	66	66
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								51	60	82	82	82	81	78																
											82	81	108	117																
													108	117																

Fig.2. Distribution of precipitation (mm) in the Huaihe River Basin in October 1953

The best way to solve the above problem is to run the model at a daily time step with daily input. Unfortunately, in most cases, only monthly-observed average data is available. In this study, the Xin'anjiang model is run at a daily time step from monthly data, and the model output

																			0											
																		5	0	1	2									
												0	0	0	0	0	0	0	2	3	2									
											0	0	0	0	0	0	2	0	0	0	2	0	0							
										0	0	0	0	0	0	0	0	0	0	0	4	0	0							
									0	0	0	0	0	0	0	0	0	0	0	0	0	1								
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0						
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
					0	0	0	0	0	0	0	0	0	0	0	0	0													
						0	0	0	0	0	0	0	0	0	0															
								0	0	0	0	0	16	5																
											0	13	43	51																
													43	51																

Fig.3. Distribution of the simulated runoff by the monthly hydrological model in the Huaihe River Basin in October 1953

is at a monthly resolution. Two methods of downscaling of monthly precipitation to daily resolution are considered and the model results are compared.

4.2 Data and Methods

The monthly precipitation data for 33 years (1953 – 1985) from 210 rainfall stations, and daily precipitation data for 6 years (1980 – 1985) from 430 rainfall stations upstream of Bengbu in the Huaihe River Basin are used.

The first downscaling method is a simple stochastic method, where the rainfall on rainy days is set to be equal to the average daily intensity in a month and there is no variability in rainfall amounts between rainy days. The magnitude of rainfall on rainy days can be expressed as the following formula:

$$PP(I) = P/P_d(I = 1,2, \cdots, P_d) \tag{3}$$

where $PP(I)$ is the magnitude of rainfall on rainy days; P is the monthly precipitation; P_d is the number of rainy days in a month.

The number of rainy days in any month is estimated using an empirical relationship developed from rainfall data in the Huaihe River Basin. The relationship can be quantitatively expressed as the following formula:

$$P_d = 2DN(J)/\pi \text{Arctg}(AP + B) \tag{4}$$

where P is the magnitude of rainfall in a month; $DN(J)$ is the number of days in any month ($J = 1,2,\cdots,12$); A and B are coefficient, which can be obtained from the analysis of the real daily rainfall data.

The second method stochastically generates the magnitude of rainfall on the rainy days from an exponential distribution:

$$F(x) = \alpha e^{-\beta x} \tag{5}$$

where x is the magnitude of rainfall on rainy days; α and β are coefficient. So the rainfall amount on rainy days can be expressed as the formula:

$$x_i = F^{-1}(u_i) = -\alpha_1^* \ln(u_i) + \beta_1 \quad (6)$$

where F^{-1} is the inverse function of F; u_i is uniform [0,1] random number; α_1 and β_1 are coefficient.

In both methods, the generated monthly sum is constrained to be equal to the monthly rainfall. And the probability of rain on any day is considered to be equal. So the generated daily precipitation is distributed at random through a month.

4.3 Application in the Hydrological Model

The research area is upstream of Bengbu in the Huaihe River Basin with the area of 121330 km^2. The model spatial resolution is still 30 km × 30 km. There are totally 153 grid cells. The inputs to the model are monthly precipitation P and monthly evaporation E. The model outputs are accumulated to monthly discharge. Research area is divided into 11 sub-areas. Thirty-three years (1953 - 1985) of monthly-observed precipitation, evaporation and discharge are available.

The Xin'anjiang model is run in three situations:

A. Model is run at a monthly time step with observed monthly input;

B. Using uniform method to generate daily precipitation from monthly data, then the model is run at a daily time step;

C. Using exponential distribution method to generate daily precipitation from monthly data, then the model is run at the daily time step.

Model output is at a monthly resolution in all the situations (table 3).

It can be seen from the table 3 that the average model efficiency of scheme A, B and C is 0.8019, 0.8649, and 0.8708 respectively. When the Xin'anjiang model is run at a daily time step from the monthly data, the model results are more accurate than the monthly hydrological model. The results of the exponential distribution method are some better than the uniform one comparatively. In both methods, the probability of rain on any day is considered to be equal. So the generated daily precipitation is distributed at random through a month. The estimation of runoff will change with the changing of precipitation distribution. So in the future study, the generated daily precipitation should be distributed more reasonable based on the analysis of real data.

Table 3. Model results in different situations

Sub-area	Station	Efficiency (A)	Efficiency (B)	Efficiency (C)
1	Xixian	0.8768	0.9244	0.9173
2	Bantai	0.8504	0.8536	0.8764
3	Luohe	0.8515	0.8386	0.8307
4	Zhoukou	0.8680	0.8404	0.8477
6	Jiangjiaji	0.8438	0.8682	0.8698
7	Hengpaitou	0.6632	0.842	0.84
8	Fuyang	0.8525	0.7842	0.8157
9	Wangjiaba	0.8007	0.8632	0.87
10	Lutaizi	0.7621	0.9245	0.9273
11	Bengbu	0.6504	0.9095	0.9127
	Average	0.8019	0.8649	0.8708

																			5											
																		26	18	23	22									
												1	2	3	5	4	14	14	23	23	21									
											1	1	2	3	4	7	22	17	14	15	21	16	16							
										2	2	2	2	5	4	7	7	11	11	13	22	16	16							
									2	4	2	2	6	5	7	5	5	6	6	10	6	20								
				3	1	0	0	5	3	2	4	3	3	3	5	3	5	6	6	4	6	20	19	13						
		2	4	4	0	1	1	1	3	3	4	3	3	3	3	3	3	5	3	4	8	20	3	13	3	4				
	2	3	1	1	2	1	1	1	4	4	4	3	3	3	3	3	7	4	3	2	8	4	3	2	4	4				
2	2	4	0	0	3	1	0	1	5	5	4	5	5	5	3	2	2	1	2	2	6	4	4	2	8	7	7			
2	4	4	1	1	1	1	0	4	4	3	4	4	4	3	2	4	2	2	5	5	6	2	2	1	9	7	2			
			4	4	5	1	0	0	4	2	2	5	4	6	5	3	3	2	2	2	2	2	2	2	9	2	2	2		
				3	4	1	3	3	1	3	2	5	4	8	8	3	2	1	1	1	1	2	4	5	4	2	2	5		
				2	2	1	3	3	2	1	3	1	1	8	4	4	2	1	1	1	5	5	2	5	5	4	6	6	6	14
				3	2	1	0	0	1	0	3	2	1	1	4	8	7	4	1	1	5	4	4	6	4	6	6	6	14	14
				3	2	1	1	1	1	1	3	3	1	1	6	8	1	1	1											
					3	2	1	6	2	2	4	4	2	2	9	6	3													
						1	1	6	6	9	6	12	9	8	9															
								7	7	13	11	12	23	18																
											10	19	36	37																
													36	37																

Fig.4. Distribution of the simulated runoff in the Huaihe River Basin in October 1953 with the inputs of the downscaled precipitation data

Fig.4 shows the distribution of the simulated runoff with the inputs of the downscaled precipitation data (exponential distribution downscaling method) in the Huaihe River Basin in October 1953 corresponding to Fig.1. It can be seen that the runoff is calculated in the most grid cells while running the daily hydrological model by the use of the downscaling method.

5 Conclusion and Discussion

The Xin'anjiang Model is used as the basic model to develop a monthly grid-based macroscale hydrological model for the assessment of the effects of climate change on water resources. The monthly discharge from 1953 through 1985 in the Huaihe River Basin is simulated and sensitivity analysis on runoff is made under assumed climatic scenarios. There is a good agreement between the observed and simulated values.

Due to the increase of time interval and decrease of precipitation intensity within a month, no monthly runoff appears in some girdded cells as the monthly hydrological model is applied to the Huaihe River Basin. Two methods of downscaling monthly precipitation to daily resolution are validated by running the Xin'anjiang model at a daily time step from the monthly data, and the model outputs are more accurate than the monthly hydrological model. The methods of downscaling of monthly precipitation to daily resolution may provide an idea in solving the problem of the shortage of daily data. In the research of the climate change on water resources, the daily hydrological model can be used instead of the monthly one.

Some primary work has been done in this study in order to answer question concerning the effects of possible climate change on water resources. In spite of the relative success of conceptual macroscale hydrological modeling in use for climate impact studies, its final value in coupled continental scale land-atmosphere modeling is still unclear, due to the lack of energy balance components and without further considerations in vegetation in the conceptual model. Full coupling of hydrological models and climate models requires that both the water balance and the