Evaluation of IPCC AR4 global climate model simulation over the Yangtze River Basin

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Abstract The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) presents 22 global climate models. This paper discusses the accuracy of the models in different temporal and spatial scales and evaluates their performances in simulating the temperature and precipitation over the Yangtze River Basin in China. The results indicate that the models are capable of simulating past climate. However, several climate models underestimate surface air temperatures and overestimate precipitation. Performances vary greatly among the models. Most models need to be improved since only a few produce correct seasonal cycles of climate. The results of scenarios analysis show differences among the models. The predicted tendencies of climate change, indicating the increase of temperature and precipitation in some regions, are consistent among the models. The results also show that the temperature and precipitation increase under different scenarios. The increase in temperature for the A2 scenario is the highest while the increase for the B1 scenario is the lowest. Eight models, that is: BCCR_BCM2.0, CCCMA_CGCM3.1, CNRM_CM3, GFDL_CM2.1, UKMO_HadCM3, MRI_CGCM2.3.2, NCAR_CCSM3 and NCAR_PCM, are able to precisely represent the characteristics of annual temperature and precipitation variations over the Yangtze River Basin. They have been selected to aid forecasting trends in water resources under future climate changes.

Key words IPCC AR4; simulation evaluation; Yangtze River Basin; temperature; precipitation

1 INTRODUCTION

According to the predictions of the *Fourth Assessment Report* by the Intergovernmental Panel on Climate Change (IPCC), average global temperatures could rise by 1.1–6.4°C by the end of the 21st century (IPCC, 2007). Climate change will affect the global and regional hydrological cycle, altering the spatial and temporal distribution of water cycle elements, such as precipitation, evaporation, runoff and soil moisture, causing re-allocation of water resources over time and space, thus increasing the probability of a variety of hydrological extremes.

At present, two methods are generally adopted to evaluate the impact of climate change on hydrology and water resources (Zhang & Wang, 2007). First are incremental scenarios, that is, to make use of different combinations of the assumed temperature and precipitation changes to form hypothetical scenarios of the future climate change. For example, Nash & Gleick (1991) adopt a conceptual hydrological model to study the influence on basin annual runoff for a temperature increase by 2°C and precipitation increase or decrease by 10–20%. Hao & Su (2000) used the improved distributed Xin'anjiang hydrological model assuming various temperature and precipitation changes to analyse the sensitivity of the Huaihe Basin runoff to climate changes. Nemec & Schaake (1982), Wang *et al.* (2000), Jia *et al.* (2008), Feng *et al.* (2006) and Zhu & Zhang (2005) also used similar methods for their research in different basins and regions.

The second method is the coupling of GCM predictions and the hydrological model. A good example is the work of Ozkul (2009), who combined the climate change scenarios of the IPCC AR4 report, with a water balance model, and forecast that surface water resources under future climate changes will reduce by 20% in 2030, and by 35% and 50% by 2050 and 2100, respectively. Nijssen *et al.* (2001) adopted scenarios of four climate models coupled with the VIC model to predict hydrological cycle changes in 2025 and 2045 for nine river basins. Hao *et al.* (2006) constructed a large-scale distributed hydrological model, considering the impact of melting snow and frozen soil, coupled with climate model predictions to evaluate water cycle and water resource changes due to climate change over the Yellow River source region. Chiew & McMahon (2002), Wetherald & Manabe (2002), Ellis *et al.* (2008), Edwin (2007) and Christensen & Lettenmaier (2007) have also done similar research. Most of the future water resources evaluation by coupling GCMs and hydrological models are based on a single or a few GCM outputs. Because different models have different simulation abilities, a single GCM has greater uncertainty in the output. There is no sufficient reason for selecting multiple GCMs, even though differences between GCMs have been considered and their statistical characteristics also have a certain stability and reliability. Therefore the principles and methods of selecting GCMs become extremely important.

The Yangtze River Basin, having large water resources, is the most important region in China. Its drainage area is 180 × 10^4 km^2 and it plays a significant role in the water security, energy security, the South-to-North Water Transfer Project implementation and future economic development of China. Therefore, understanding the evolution and future changes in water resources in the Yangtze River Basin under climate changes will provide a basis for water resources management and planning. In this paper, simulations by the 22 GCMs, released in the Fourth Assessment of IPCC Data Distribution Center, are evaluated. GCMs covering the Yangtze River have been selected for this work. Temperature and precipitation forecasts of these GCMs during 2010–2099 under three typical emission scenarios: A1B, A2 and B1, combined with one hydrological model, have been used to forecast future water resources changes.

2 SELECTION OF THE GLOBAL CIRCULATION MODELS

2.1 Data selection

Monthly temperature and precipitation data of the 22 global climate models in the contemporary climate (20C3M) conditions of the reference period 1961–1990 (IPCC AR4, 2007) have been selected for this study. We compare them with observations of 118 major meteorological stations in the Yangtze River Basin for the same period. Models with relatively better simulations of precipitation and temperature have been selected. Hao *et al.* (2010) introduced the global climate models in the Yangtze River in detail and their performance. Figure 1 is the distribution of the 118 weather stations (dots) and the two hydrological stations (small triangles) at Yichang and Datong. Table 1 presents the basic information of the 22 GCM models, and the grid boundary and numbers in the Yangtze River. More detailed information of the models can be found at http://www.pcmdi.llnl.gov/ipcc/about-ipcc.

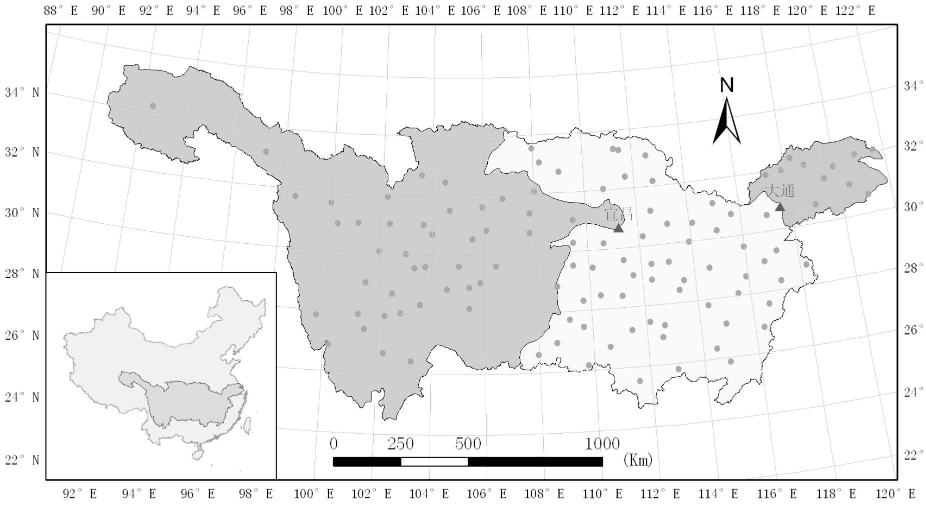

Fig. 1 The Yangtze River Basin and distribution the weather and hydrological stations. The dots represent 118 weather stations and the two triangles represent the two hydrological stations.

Table 1 Information of the 22 climate models of IPCC AR4 and boundary configuration for the Yangtze River Basin.

Number	Model	Country	Grid resolution /°	Longitude range /°	Latitude range /°	Grid number
1	BCCR_BCM2.0	Norway	2.81×2.79	87.18–118.12	20.93–37.67	35
2	CCCMA_CGCM3.1 T47(med-res)	Canada	3.75×3.71	86.25–120	20.41–38.96	22
3	CNRM_CM3	France	2.81×2.79	87.18–118.12	20.93–37.67	35
4	CSIRO_Mk3.0	Australia	1.88×1.87	88.12–120	23.31–38.23	60
5	MIUB_ECHO-G	Germany	3.75×3.71	86.25–120	20.41–38.96	22
6	LASG_FGOALS-g1.0	China	2.81×2.79	87.18–118.12	20.93–37.67	35
7	GFDL_CM2.0	USA	2.50×2.00	88.75–118.75	23–37	46
8	GFDL_CM2.1	USA	2.50×2.00	88.75–118.75	23–37	46
9	GISS_AOM	USA	4.00×3.00	86–118	22.5–37.5	21
10	GISS_E-H	USA	5.00×4.00	87.5–117.5	22–38	18
11	GISS_E-R	USA	5.00×4.00	87.5–117.5	22–38	18
12	UKMO_HadCM3	UK	3.75×2.50	86.25–120	22.5–37.5	26
13	UKMO_HadGEM1	UK	1.88×1.25	88.125–120	23.75–37.5	83
14	INM_CM3.0	Russia	5.00×4.00	85–115	20–40	18
15	INGV_SXG 2005	Italy	1.13×1.12	88.87–120.37	22.99–36.44	146
16	IPSL_CM4	France	3.75×2.54	86.25–120	21.55–39.29	29
17	NIES_MIROC3.2 hires	Japan	1.13×1.12	88.87–120.37	22.99–36.44	139
18	NIES_MIROC3.2 medres	Japan	2.81×2.79	87.18–118.12	20.93–37.67	35
19	MPI-M_ECHAM5-OM	Germany	1.88×1.87	88.12–120	23.31–38.23	60
20	MRI_CGCM2.3.2	Japan	2.81×2.79	87.18–118.12	20.93–37.67	35
21	NCAR_CCSM3	USA	1.41×1.40	88.59–120.93	23.11–37.12	99
22	NCAR_PCM	USA	2.81×2.79	87.18–118.12	20.92–37.67	35

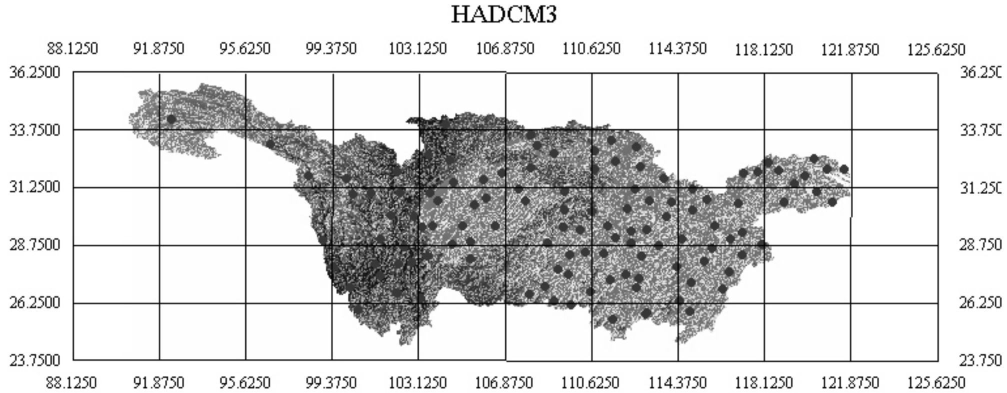

Fig. 2 Grid patterns of the UKMO_HadCM3 Model on Yangtze River Basin, dots present the 118 weather stations.

2.2 Evaluation of the model performance

According to the original mesh, monthly temperature and precipitation data of the GCMs has been calculated, using the geometric average method for the reference period 1961–1990. Relative error, absolute error, correlation coefficient, and coefficient of determination (Ju, 2009) have been chosen as the performance evaluation index. The average temperature of the Yangtze River Basin in the reference period is 15°C, and the average precipitation is 1186.2 mm. The simulated temperature and precipitation are compared with the observation values at the 118 weather stations. The results show that all model simulations underestimate temperature (Table 2). Each model's correlation coefficients are above 0.9 and their deterministic coefficients are low.

Table 2 Comparison between simulated temperature and precipitation with station observations: temp = temperature, Ppt = precipitation (after Wetherald & Manabe, 2002).

No.	Model	Analogue value		Absolute error of Temp	Relative error of Ppt	Correlation coefficient		Coefficient of determination	
		Temp (°C)	Ppt (mm)			Temp	Ppt	Temp	Ppt
1	BCCR_BCM2.0	8.5	1324.8	−6.5	11.7	0.986	0.836	0.256	0.609
2	CCCMA_CGCM3.1 T47 (med-res)	10.2	1135.3	−4.8	−4.3	0.979	0.813	0.559	0.591
3	CNRM_CM3	9.2	1289.5	−5.7	8.7	0.978	0.823	0.387	0.534
4	CSIRO_Mk3.0	7.4	850.6	−7.5	−28.3	0.976	0.836	−0.041	0.468
5	MIUB_ECHO-G	−8.0	463.4	−22.9	−60.9	0.983	0.799	−8.926	−0.671
6	LASG_FGOALS-g1.0	−6.0	585.8	−21.0	−50.6	0.975	0.557	−8.002	−0.544
7	GFDL_CM2.0	6.9	1048.7	−8.0	−11.6	0.975	0.854	−0.159	0.675
8	GFDL_CM2.1	8.3	1089.9	−6.7	−8.1	0.972	0.852	0.176	0.627
9	GISS_AOM	−6.6	591.5	−21.6	−50.1	0.978	0.827	−7.857	−0.205
10	GISS_E-H	−7.4	315.9	−22.3	−73.4	0.975	0.695	−9.051	−1.312
11	GISS_E-R	−8.0	286.1	−23.0	−75.9	0.968	0.645	−9.38	−1.462
12	UKMO_HadCM3	10.0	1241.2	−5.0	4.6	0.981	0.873	0.54	0.714
13	UKMO_HadGEM1	7.9	1443.8	−7.1	21.7	0.986	0.827	0.076	0.29
14	INM_CM3.0	−4.7	558.5	−19.7	−52.9	0.967	0.75	−6.57	−0.396
15	INGV_SXG 2005	−3.6	583.0	−18.6	−50.9	0.977	0.734	−6.001	−0.367
16	IPSL_CM4	−10.1	476.8	−25.1	−59.8	0.975	0.808	−11.214	−0.601
17	NIES_MIROC3.2 hires	−5.9	475.1	−20.9	−59.9	0.978	0.751	−7.705	−0.613
18	NIES_MIROC3.2 medres	−6.8	525.1	−21.8	−55.7	0.980	0.788	−8.354	−0.395
19	MPI-M_ECHAM5-OM	−6.5	598.9	−21.4	−49.5	0.979	0.814	−7.708	−0.146
20	MRI_CGCM2.3.2	10.9	1106.6	−4.0	−6.7	0.981	0.853	0.676	0.712
21	NCAR_CCSM3	9.4	961.0	−5.6	−19.0	0.986	0.847	0.432	0.605
22	NCAR_PCM	9.5	1233.8	−5.5	4.0	0.980	0.867	0.436	0.735

Comparisons of simulations of average temperature changes (1961–1990) in the Yangtze River basin with the observed temperature (Fig. 3(a)) indicate that the annual cycle or seasonal cycle of all models can be divided into two groups. One group with positive coefficients of determination is consistent with the measured data (Table 2). The other group with negative coefficients of determination are greatly different (with a large variation). Comparisons between simulated precipitation and the observations also show larger coefficients of determination.

The coefficients of determination of both temperature and precipitation greater than 0 are selected as the standard in choosing the model. Nine models, such as BCCR_BCM2.0, have been chosen. From Table 1, it can be seen that in these nine models, only UKMO_HadGEM1 model's relative error of precipitation simulation is higher than 20%. The relative errors of the other models are all less than 20%. The correlation coefficients are all above 0.8. Therefore, the UKMO_HadGEM1 model will be excluded. The temperature and precipitation forecasts for 2010–2099 of the following 8 climate models, i.e. BCCR_BCM2.0, CCCMA_CGCM3.1 T47(med-res), CNRM_CM3, GFDL_CM2.1, UKMO_HadCM3, MRI_CGCM2.3.2, NCAR_CCSM3 and NCAR_PCM, under three typical emission scenarios are chosen, in order to evaluate streamflow changes at the Yichang and Datong gauges in the Yangtze River Basin.

3 PREDICTION OF TEMPERATURE AND PRECIPITATION

Assessment of the eight models for annual precipitation and temperature of the Yangtze River Basin in the 21st century are shown in Table 3. Most models indicate increases, except the GFDL_CM2.1. The GFDL_CM2.1 predicts precipitation decreases in for A1B and B2 scenarios. In the A2 scenario, the proportion of increase is highest, followed by the A1B, while the B1 scenario has the smallest increase, and the UKMO_HadCM3 has the maximum increase. All the models show increase in temperature under the three scenarios. In the A1B scenario, the average temperature will increase by 3.2°C/100 year, which is slightly below the A2. The B1 scenario has

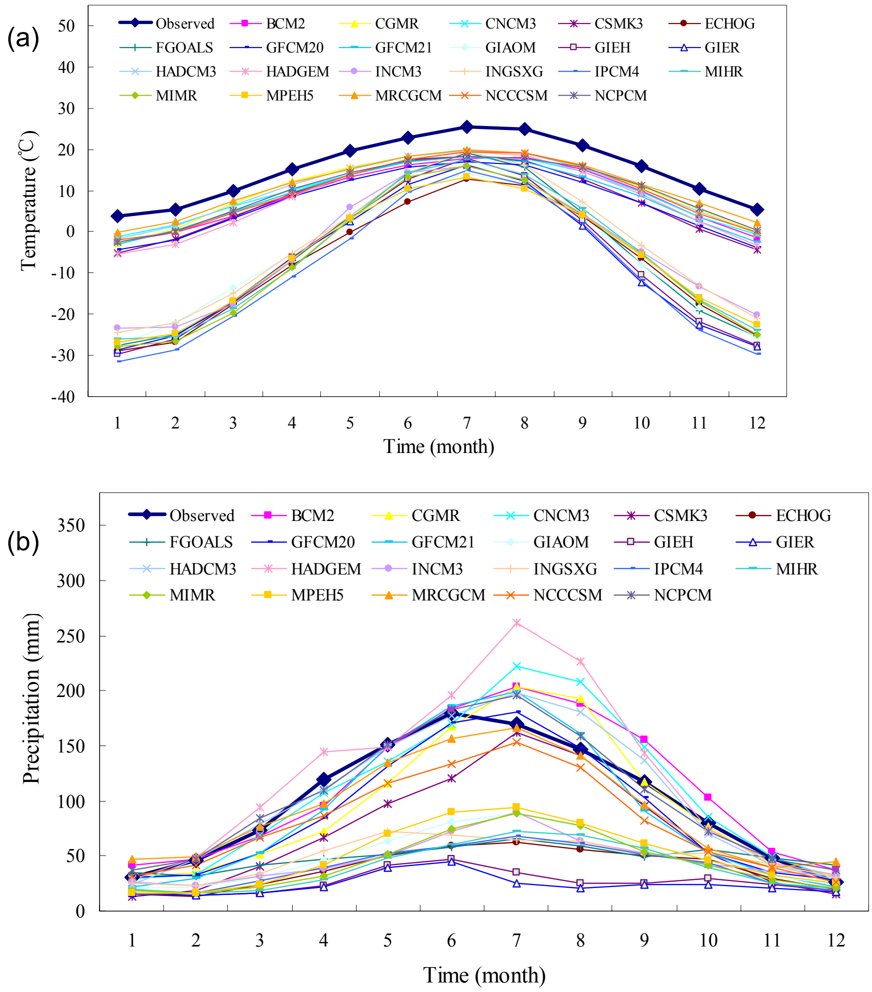

Fig. 3 Comparison between simulation and observation for temperatures (a), and precipitation (b) of the Yangtze River Basin during 1961–1990.

Table 3 Linear trend of temperature and precipitation from GCM (2000–2099).

Scenario	Precipitation (mm/100 year)			Temperature (°C/100 year)		
Model	A2	A1B	B1	A2	A1B	B1
BCCR_BCM2.0	/	181.3	79.9	3.1	2.8	1.4
CCCMA_CGCM3.1 T47(med-res)	/	106.9	/	/	2.6	/
CNRM_CM3	2.5	38.5	/	3.9	3.1	1.5
GFDL_CM2.1	198.9	–18.5	–19.9	3.3	3.7	2.2
UKMO_HadCM3	269.9	214.9	154.1	5.1	4.	3.0
MRI_CGCM2.3.2	154.8	142.6	95.9	3.7	3.9	2.3
NCAR_CCSM3	152.9	150.7	65.9	4.3	3.0	1.3
NCAR_PCM	34.3	73.9	/	2.6	2.4	/
Average	135.6	111.3	75.2	3.7	3.2	2.0

the smallest warming rate (2.0°C/100-years). Except for five scenarios with no information or incomplete information, the future 19 climate changes scenarios of the Yangtze River Basin are listed in Table 3.

4 CONCLUSION

This paper compares precipitation and temperature simulations for the Yangtze River Basin among 22 global climate models used in the Fourth Assessment of the IPCC. GCM simulations have been assessed by three evaluation indexes: error, correlation coefficient and coefficient of determination. Comparions between the simulated and measured values of the 22 climate models during 1961–1999 suggest that eight models, such as BCCR_BCM2.0, have certain advantages in reproducing temperature and precipitation over the Yangtze River Basin. Model prediction of the future climate indicates that both precipitation and temperature will increase. Based on this analysis, GCM simulations suitable for the Yangtze River have been selected. We will use the GCM temperature and precipitation forecasts for 2010–2099 under the three typical emission scenarios to combine with a hydrological model. This will allow us to forecast basin water resources changes in the future.

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