INVESTIGATIONS ON SHORT-TERM CLIMATE PREDICTION BY GCMs IN CHINA*

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ABSTRACT

Investigations on the short-term climate predictions by general circulation models (GCMs) in China have been summarized and reviewed in this paper. The research shows that GCMs have the capability to predict the seasonal and annual characteristics of atmospheric circulation in the Northern Hemisphere and the patterns of temperature and precipitation over China. It is inspiring to notice that the GCMs have the ability to predict the summer rainfall over China before two seasons. Several issues for the short-term climate prediction by the GCMs have been discussed in this paper.

Key words: short-term climate prediction, general circulation models (GCMs), summer rainfall over China

I. INTRODUCTION

Since 1990 World Climate Research Program (WCRP) has implemented a 10-year project on seasonal and annual Climate Variability and Predictability (CLIVAR). Furthermore, the experimental seasonal and annual predictions such as ENSO events have been conducted for several years in some countries.

China Meteorological Administration (CMA) started to carry on the short-term climate predictions (such as seasonal, extra-seasonal and annual predictions) since 1960s. The major means of predictions were the climate-statistic methods during the last 30 years. Chinese scientists have introduced and developed the GCMs since the end of 1980s. The GCMs' groups conducted some extra-seasonal predictions and presented the prediction results at the consultation workshops held by CMA. Chinese scientists have also taken part in the activities of CLIVAR related researches in recent years. In this paper, we summarize and review the short-term climate predictions by using the GCMs in China (on time scale of seasonal, extraseasonal and annual).

A brief description of the GCMs will be introduced in section two. In section three, evaluation of the extraseasonal predictions by the GCMs will be presented. Several issues corresponding to the short term climate predictions by the GCMs will be discussed in section four. Moreover the conclusions and discussions will be given in the last section.

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II. BRIEF DESCRIPTION OF THE GCMS

Since the second half of 1980s, Institute of Atmospheric Physics (IAP) has developed the first general circulation model (denoted as IAP AGCM) in China (Zeng 1983; Zeng et al. 1987; Zeng and Zhang 1987). After that, GCMs have been applied in climate prediction and climate change studies in China.

National Climate Center (NCC) and National Meteorological Center (NMC) of China respectively hold the annual and seasonal predictions in October and March each year since 1960s. The IAP AGCM was applied in the predictions since the end of 1980s (Zeng et al. 1990; 1994). After that, their coupled atmospheric and oceanic general circulation model was also applied in the predictions (Yuan et al. 1996). After the assessment by NCC, the improved Oregon State University's (OSU) atmospheric general circulation model coupled to the mixed-layer ocean model (OSU/NCC) has been used to do quasi-operational seasonal and annual predictions in NCC (Schlesinger and Zhao 1989; Zhao et al. 1995; Zhao et al. 1996; Gao and Zhao 1996; 1997a; 1997b; 1998). The prediction results from other three AGCMs (CCM3/NCC, T63/NCC and CCM31-LNWP.) were also presented at the consultation workshops on seasonal and annual predictions since 1997 or 1998 respectively (Yu and Dong 1997; 1998; Ye and Dang 1998; Zheng and Song 1998). The brief descriptions of these GCMs and their prediction skill will be introduced as the following.

Several general circulation models were used to predict the circulations and precipitation in the rainy season over China. The prediction results from these GCMs were presented at the consultation workshop in 1998. These models are the IAP atmospheric general circulation model (AGCM) coupled with the Pacific Ocean general circulation model (denoted as IAP/APOGCM) (Li and Yuan et al. 1998), the OSU/NCC AGCM coupled with a mixed-layer ocean model with ice (denoted as OSU/NCC AMOGCM) (Gao and Zhao 1998), the NCAR CCM3 model used by NCC (denoted as CCM3/NCC) (Yu and Dong 1998), the ECMWF T63 model used by NCC (denoted as T63/NCC) (Ye and Dang 1998), the NCAR CCM31 model used by Chinese Academy of Meteorological Sciences (CAMS) (denoted as CCM31-LNWP) (Zheng and Song 1998). Table 1 shows the brief description of these GCMs.

It is noticed in Table 1 that the vertical resolutions of the AGCMs for the IAP A/POGCM, OSU/NCC, CCM3/NCC, T63/NCC and CCM31-LNWP are 2, 2, 18, 16 and 7 respectively. The horizontal resolution for these AGCMs are 4°×5°, T63 or R15 respectively. As for the oceanic models, they are very different. The IAP AGCM was coupled to the oceanic general circulation model with the vertical resolutions of 14 or 4 layers over the Pacific Ocean. The OSU/NCC AGCM was coupled to a mixed-layer ocean and ice model with a depth of 60 m. There are no oceanic models coupled with the CCM31-LNWP, CCM3/NCC and T63/NCC models. Therefore, the sea surface temperature (SST) for each predicting month of the CCM31-LNWP, CCM3/NCC and T63/NCC was determined by the sum of SST climatology and the anomalies of the SST in February 1998 as their models' external forcing. Number of the ensemble members for the IAP A/POGCM1, IAP A/POGCM2 and OSU/NCC are 28, 9 and 5 with started date of

February 1 1998 respectively. The ensemble predictions were not applied in the prediction by CCM31-LNWP, CCM3/NCC and T63/NCC due to time limit. To obtain the models' climatology, five GCMs (IAP1, IAP2, OSU/NCC, CCM3/NCC and T63/NCC) were controlled to run 30, 20, 100, 20 and 20 years respectively.

Table 1. Brief Description of the GCMs Joined in the Extraseasonal Prediction Consultation Workshop of China in March 1998

GCMs	Authors	Resolutions	Ensembles	Initial date	Control
IAP A/POGCM1	Li et al.	4×5, L2/1×2, L14	28	Feb. 1998	30 yrs
IAP A/POGCM2	Yuan et al.	4×5, L2/4×5, L4	9	Feb. 1998	20 yrs
OSU/NCC	Gao and Zhao	4×5, L2/mixed (60 m)	5	Feb. 1998	100 yrs
CCM3/NCC	Yu and Dong	T63, L18 (NCAR)	1	15. Mar. 1998	20 yrs
T63/NCC	Ye and Dang	T63, L15 (ECMWF)	1	18. Mar. 1998	20 yrs
CCM31-LNWP	Zheng and Song	R15, L7	1	15. Mar. 1998	

III. EXTRASEASONAL PREDICTION SKILL OF PRECIPITATION BY USING THE GCMS DURING 1995 TO 1998

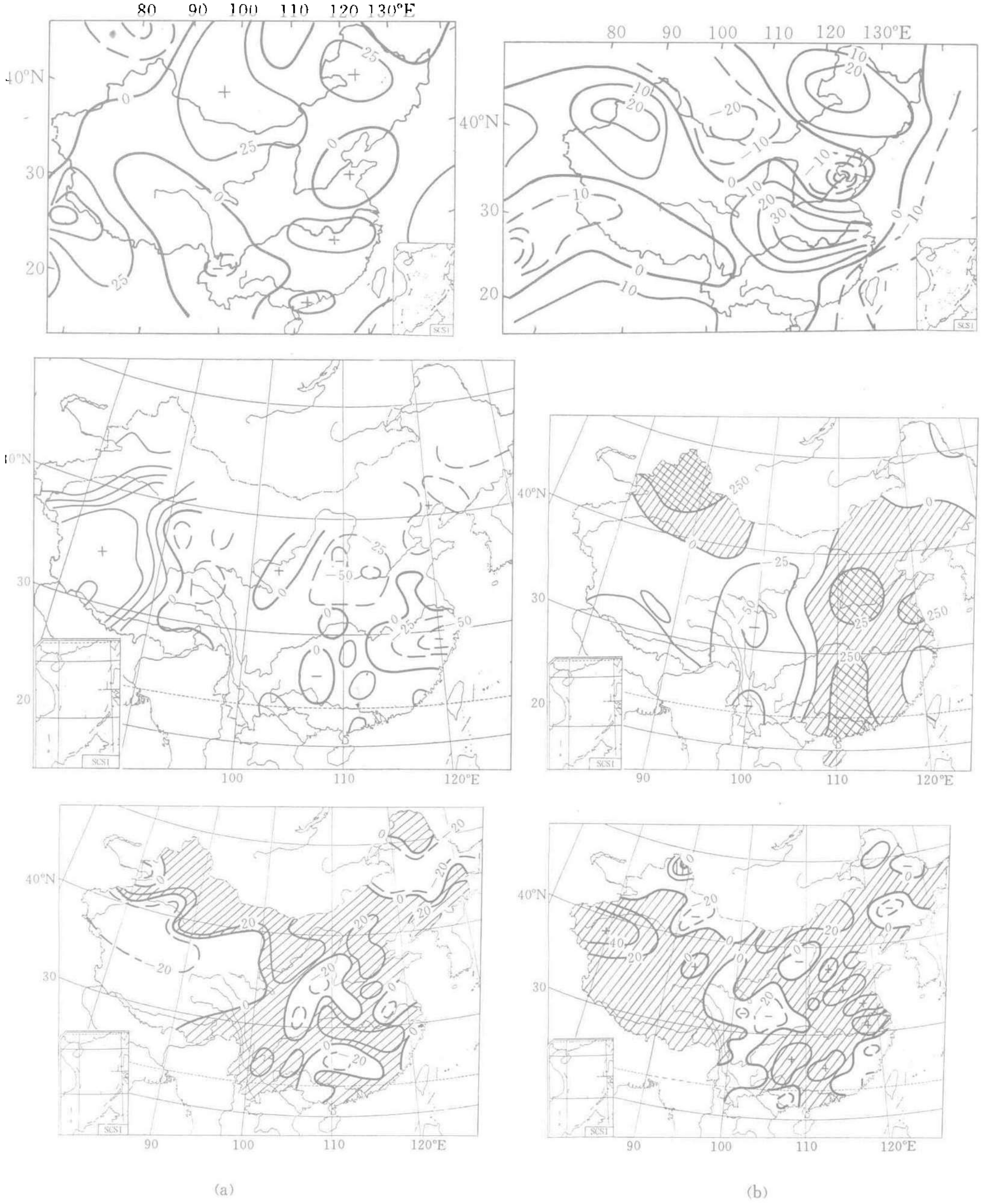
The extraseasonal prediction of summer precipitation is one of the most important issues for China. In this section, we concentrate on the evaluation of rainfall prediction skill.

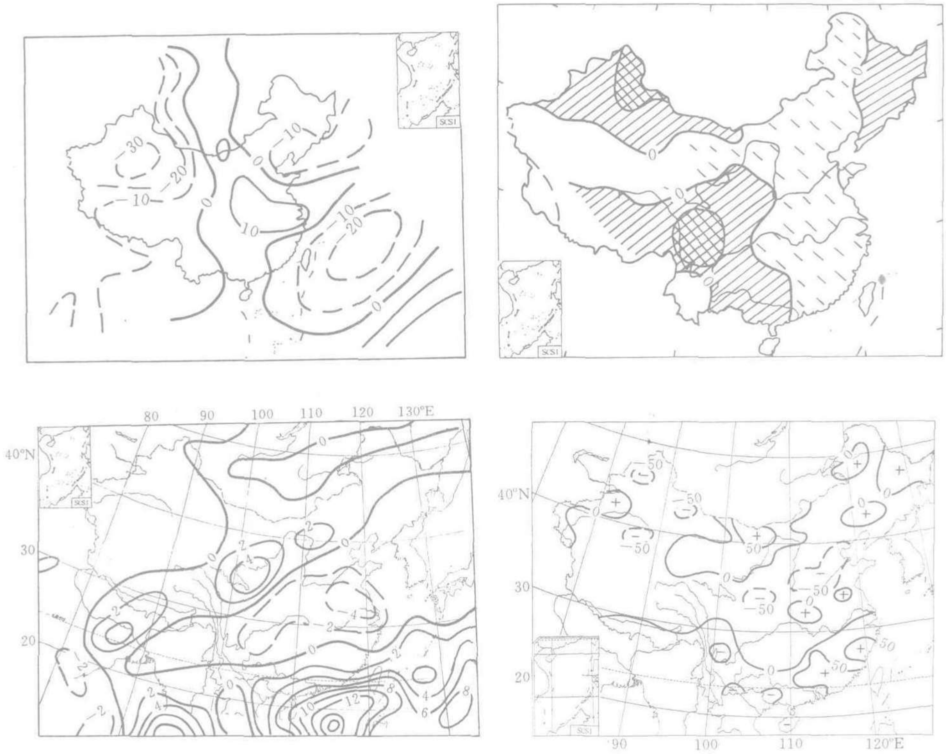
Since 1995, National Climate Center (NCC) has held the Extraseasonal Prediction Workshop once a year. Assessments and evaluations of the extraseasonal prediction of summer rainfall from each participant institute and prediction method which took part in the Workshops have been presented in the Review on Climate Prediction (RCP) published by NCC every year. Table 2 shows the accuracy rate (PP) and the anomaly correlation coefficient (CC) between the observations and the extraseasonal predictions by the IAP combined methods which included both IAP A/POGCM and statistical methods, OSU/NCC AMOGCM, and CCM3/NCC. For intercomparison of these methods, the skill (WP) of the composite prediction by the Workshop and the averaged skill (M) over all methods also presented in the last two lines of Table 2.

It is indicated in Table 2 that the PP and CC of two GCM predictions are higher than the averaged skill (M) over all methods in 1995 and 1996. It is also noticed that the predictions of GCMs were good in some years and bad in other years. For examples, the PP and CC of the OSU/NCC in 1996 were in the first position among 22 methods, but the PP of the OSU/NCC in 1997 was the last sixth of 20 methods.

Figure 1 presents the distributions of the anomalous percentage of predicted rainfall for the GCMs and observations in summer (JJA) 1995, 1996 and 1997. It is noticed in Fig. 1 that some predictions by the models are correct, such as the prediction by the OSU/NCC in summer 1996. The OSU/NCC forecasted more rainfall over East China in summer 1996 successfully. The CCM3/NCC forecasted two rain belts over China in summer 1997 well. Although the PP and CC of the OSU/NCC in summer 1997 were not good, it predicted a very dry situation located in the most part of the north of Yangtze River especially in North China successfully.

Figure 2 presents the forecasts by five GCMs for the summer of 1998. Five GCMs predicted heavy rainfall might occur in South China. The predictions by five models are different in other regions. The IAP model predicted that the rain belts might be located over South China and along the Yangtze River Valley. The OSU/NCC model forecasted the rain belt over East China. especially in South China. The CCM3/NCC model





(c)

Fig. 1. Distributions of the anomalous percentage of predicted rainfall by GCMs and observation in summer (JJA) 1995 (a), 1996 (b) and 1997 (c) in percentage. (from top to bottom: IAP A/POGCM, OSU/NCC and CCM3/NCC, but for 1995 and 1996, the third model results not shown).

forecasted the rain belt over South China and Northeast China. The T63/NCC forecasted the rain belt over South China. The CCM31-LNWP predicted the rain belts over North China and South China. The prediction results will be assessed in the 1999 Workshop.

Table 2. Evaluation of Accuracy Rate (PP) and Anomaly Correlation Coefficients (CC) between the Observations and the Extraseasonal Predictions by the GCMs

GCMs	1995		1996		1997	
	PP	CC	PP	CC	PP	CC
IAP	77	0.01	65	−0.23	59	−0.06
OSU/NCC	76	0.04	75	0.16	59	−0.28
CCM3/NCC					better	
WP	84	0.25	63	0.05	58	−0.08
M	75	0.06	65	0.00	64	0.02

Note: The composite predictions by the Workshops (denoted as WP) and average of all methods (denoted as M) are shown in the last two lines. The calculation method of PP refers to Chen (1996), Yuan (1997) and Chen (1998).

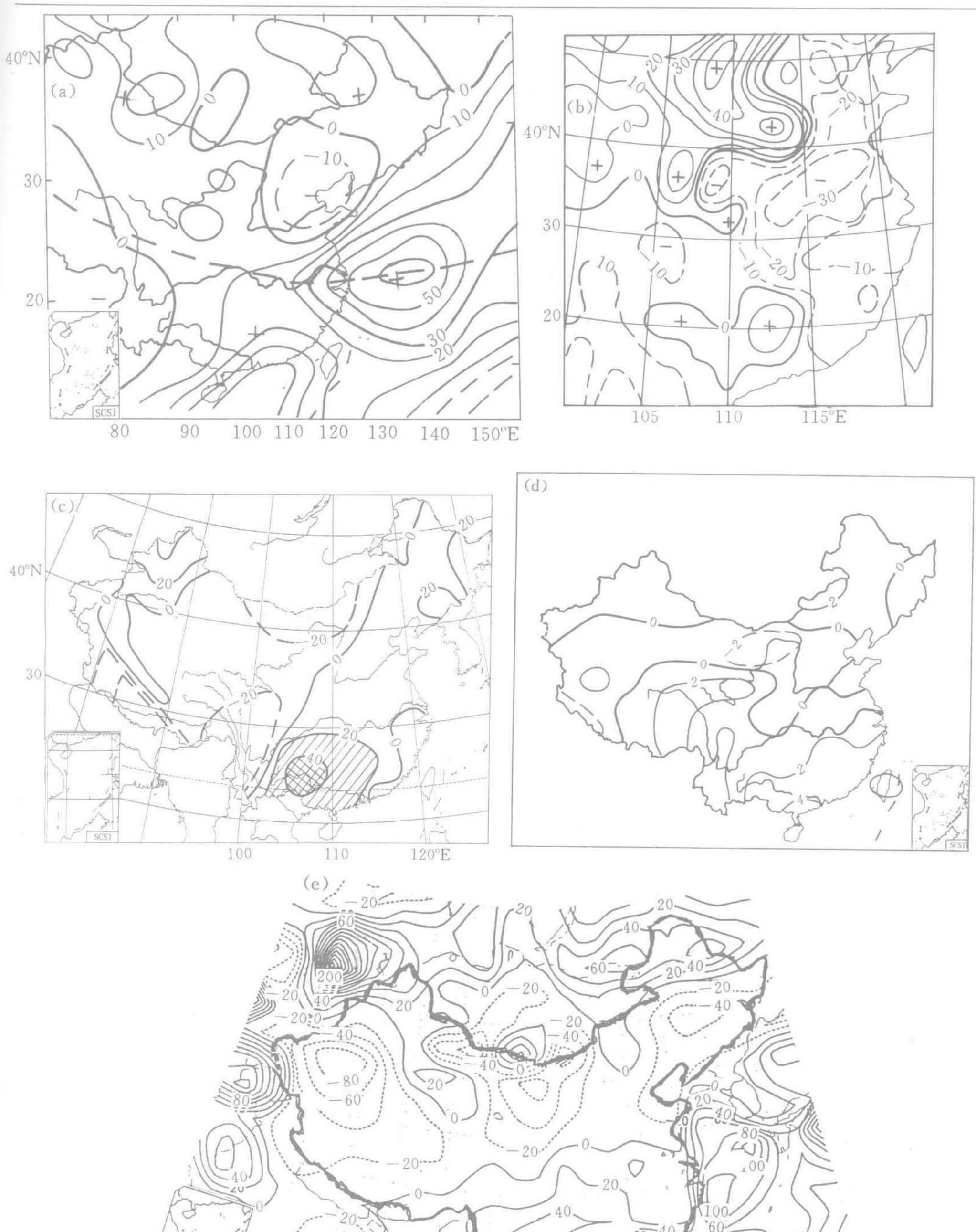


Fig. 2. Distributions of the predicted rainfall by GCMs in summer (JJA) 1998. (a) IAP A/POGCM. (b) CCM31-LNWP. (c) OSU/NCC AMOGCM. (d) CCM3/NCC and (e) T63/NCC (The models are shown in Table 1).

IV. SEVERAL ISSUES ON THE SHORT-TERM CLIMATE PREDICTIONS BY THE GCMS

1. *Reliability on the Short-Term Climate Predictions by the GCMs*

As mentioned above, it is not enough to evaluate the reliability of the GCMs due to three assessments of the extraseasonal predictions of rainfall over China for 1995, 1996 and 1997 only. One of the important issues is to evaluate the reliability and predictability of the GCMs from a longer time scale. Some GCMs' groups such as IAP and OSU/NCC have computed the reliability and predictability of their GCMs by using the hindercasts or historical predictions (Li et al. 1998; Gao and Zhao 1998).

The OSU/NCC AMOGCM have been in progress on some tests of hinder-prediction. The period of the hinder-prediction was from 1982 to 1995. Similar to the extraseasonal predictions, each hinder-prediction started in the February of each year. Five ensemble predictions were selected for each prediction. The initial date was February 1, 5, 10, 15 and 20 respectively. Table 3 shows the anomaly correlation coefficients of summer rainfall between the observations and extraseasonal hinder-prediction by the OSU/NCC AMOGCM from 1982 to 1995 (Gao and Zhao 1998). The rainfall predicted by the OSU/NCC at the grid points was interpolated into 160 stations respectively. The anomalies of rainfall for the OSU/NCC models were calculated by the mean of control runs which was run by 100 years and the last 50 year-mean was calculated as the model climate.

Table 3. Anomaly Correlation Coefficients (ACC) of Summer Rainfall (JJA) between Observations and Extraseasonal Hinder Prediction by the OSU/NCC from 1982 to 1995 (Gao and Zhao 1998)

GCMs	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	average
ACC	0.17	−0.10	−0.22	0.10	0.17	−0.17	0.08	−0.19	−0.26	0.17	−0.10	0.01	0.23	0.04	−0.01

The ACC shows in Table 3 that the average value (−0.01) of ACC between predicted anomalies and observations of rainfall for 14 years is poor. It is noted in Table 3 that ACCs are positive in seven of 14 years. The highest ACC among them is 0.23 in 1994.

Figure 3 shows the distributions of ACC of rainfall between observations and hinder-prediction in 160 stations for the period of 1982−1995 by the OSU/NCC AMOGCM in spring (MAM) and summer. The positive ACCs for spring are found in North China and Southwest China. The negative ACC are located in South China. The positive ACCs for summer are noticed along Yangtze and Huaihe River Valley, South China, west to Hetao, some part of Northeast China. It means that these regions with the positive ACC have the higher predictability and reliability. The ACCs of rainfall in one third of 160 stations in spring or summer are higher than +0.20.

The IAP scientists have also conducted some tests for their extraseasonal predictions by using the IAP AOGCM. They found that the high predictability in their model are located in South China and along Yangtze River Valley, and low predictability in North China for the extraseasonal summer prediction (Li et al. 1998).

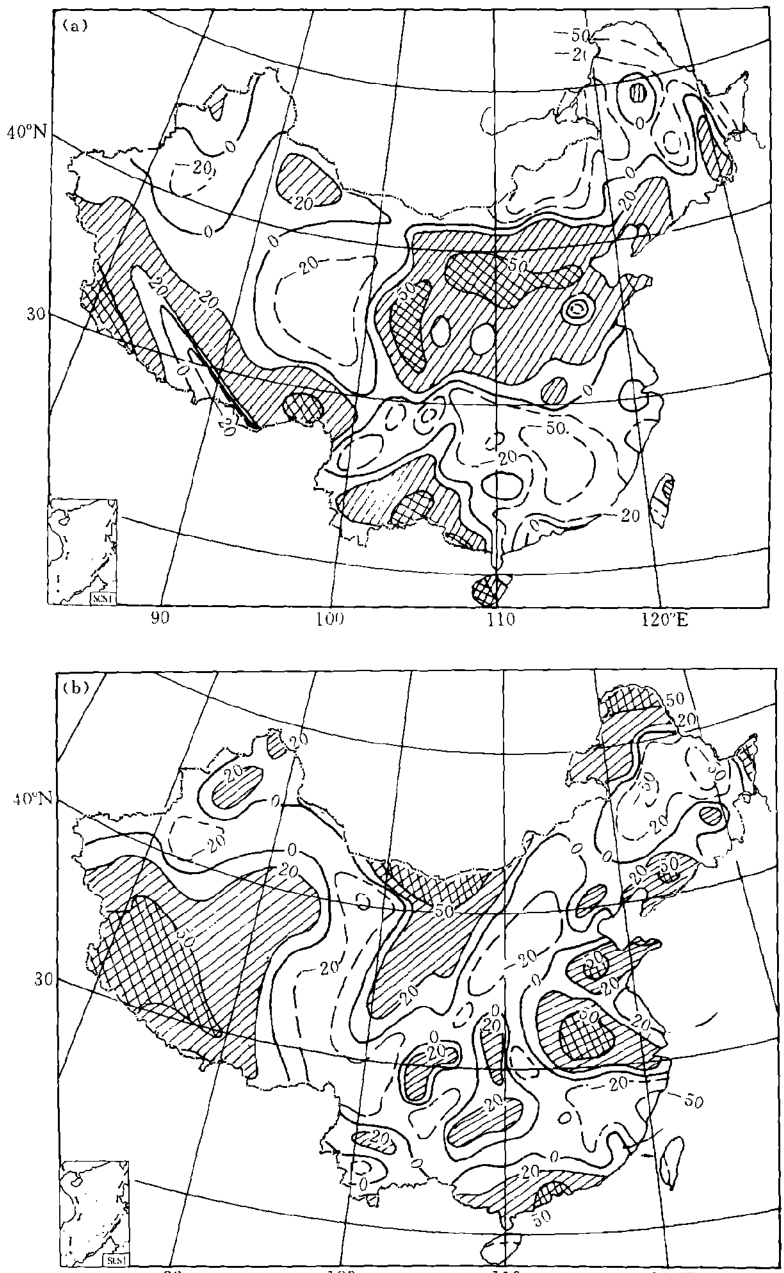


Fig. 3. Distributions of ACC of rainfall between observations and hinder prediction by the OSU/NCC AMOGCM in spring (a) and summer (b) of period 1982—1995 (Gao and Zhao 1998).

2. *Climate Drift and Anomaly Correction*

Climate drift is getting more significantly with the longer integration time. It is an important issue for the short-term climate predictions. Therefore, the GCMs' groups should consider climate drift of the models and anomaly corrections when they carry out the extraseasonal predictions.

IAP corrected the term of interactions between air and sea. They also had another correction on prediction of rainfall. They used the anomaly correction of rainfall based on deduction of the model climate from the model prediction. After the corrections of rainfall for 1991—1995, the predicted skill scores raised obviously (Zeng 1994; Yuan et al. 1996).

The OSU/NCC group made two experiments for the model climate. One of them has mentioned above. The other was that the means of 13 years (1982—1995) exclusive of the predicting year were selected as the model climate (denoted as OSU/NCC*). It means that the anomalies of rainfall for the OSU/NCC* were calculated by the mean of 1982—1995 predictions exclusive of the predict year (the 13 years-mean). Table 4 gives the ACC of summer rainfall between observations and extraseasonal hinder predictions by the OSU/NCC* from 1982 to 1995.

Table 4. Anomaly Correlation Coefficients (ACC) of Summer Rainfall (JJA) between the Observations and Extraseasonal Hinder Predictions by the OSU/NCC* from 1982 to 1995 (Gao and Zhao 1998)

GCMs	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	average
OSU/NCC*	0.10	−0.13	−0.16	0.33	0.12	−0.08	0.09	−0.02	0.06	0.04	0.12	0.09	−0.03	−0.03	0.04

It is noted in Table 4 that the mean ACC of 14 years is 0.04. The ACCs are positive in eight of 14 years. The highest ACC is 0.33 in 1985. Comparing Table 3 with Table 4, it seems that the ACC for the OSU/NCC* is better than that for OSU/NCC. The reason might be that the control run of the model for 100 years (OSU/NCC) did not correct the climate drift of the model, each prediction only runs the model for six months. Therefore, the results of 13-year predicted mean as the model climate mean which had a similar climate drift are better than 50-year control run-mean as the model climate.

3. *Resolutions of the Model*

As shown in Table 1 that the resolutions of the most Chinese GCMs are coarse. Therefore, the regional climate prediction such as rainfall over China by using the global models may result in uncertainties obviously.

One way to solve the problem is nesting a regional climate model to a GCM. Based on the NCAR RegCM2, NCC has developed a regional climate model over China (denoted as RegCM2/NCC). The seasonal prediction over Three Gorges of China for fall season (September to November) 1997 has been conducted by using the RegCM2/NCC nesting to a global atmospheric circulation model (CCM3/NCC). The domain of the RegCM2/NCC is located at about 21—41°N and 103—127°E and the horizontal resolution is 50 km with the vertical resolution of 17 layers. To compare with the observations, the RegCM2/NCC predicted the daily precipitation from September 1 to November 30, 1997 reasonably when the Yangtze River was dammed at the Three Gorges (Zhang 1997; Zhao et al. 1998). But it needs to emphasize that a good or poor prediction of a regional climate model depends on the results of the nesting GCMs. Therefore, the GCMs should be improved and developed at first.

4. *Ensemble Predictions*

The IAP GCM group has tested the numbers of ensemble members such as 5, 9 and 28. They calculated the standard deviations and scatter of ensemble predictions for precipitation by using their GCM model. It is found that the extraseasonal predictions by the GCMs should use the ensemble methods rather than single prediction. They noticed that the predictions of their GCM were different for the different initial conditions. Therefore, the predictions of the GCMs with the standard deviations and scatter should be given as the references when a model presented its prediction (Yuan et al. 1996).

Up to now only two GCMs have carried out the ensemble predictions in China and the ensemble predictions simply selected the arithmetic mean. Further tests should be conducted on the ensemble predictions.

5. *Effects of Ocean in the Short-Term Climate Predictions Using the GCMs*

As mentioned above, the IAP AGCM was coupled to the OGCM. Therefore, the sea surface temperature anomaly (SSTA) was predicted by their model. The OSU/NCC AGCM was coupled to a mixed-layer ocean model. The SSTA also was predicted by the simple model. Other models such as CCM3/NCC and T63/NCC were forced by the linear trends of the observed SSTA as boundary conditions.

The tests of predictions during 1995 to 1998 showed that the predictions of summer rainfall over China were closer to the observations when the SSTA predicted by the models or estimated by the linear trends was more correct. For example, the CCM3/NCC predicted the summer rainfall in 1997 and the OSU/NCC in 1996. Since there is a good relationship between the summer rainfall over China and the subtropical high in the Northwestern Pacific Ocean at 500 hPa, snow cover over the Tibetan Plateau as well as the SSTA over the eastern and central Equatorial Pacific Ocean, a correct prediction of SSTA plays a very important role in the prediction of a summer rainfall over China.

V. SUMMARY AND DISCUSSION

As mentioned by CLIVAR, the short-term climate prediction such as seasonal, extraseasonal and annual forecasts is an important and difficult issue, especially for the prediction of precipitation. Several Chinese groups have tried to predict precipitation in China by using the GCMs for about ten years. The seasonal, extraseasonal and annual assessments and tests of precipitation as simulated by the models indicate that the GCMs have the capability of prediction for precipitation over China. But the forecast skills show that the forecast level of the GCMs is unstable. It is good in some years, but poor in other years depending on the prediction of SSTA partly. Scientists should carry out more investigations in the future to improve the prediction skill.

There are several significant issues in the short-term climate prediction by the GCMs.

such as predictability of the short-term climate, predictability of GCMs, climate drift of GCMs and anomaly correction, the effects of SST, ensemble predictions, and resolutions of GCMs. The accuracy of the short-term climate predictions might be raised with the GCMs improved.

National Key Project of Short-term Climate Prediction System in China is going to establish and develop a climate model system which includes an AGCM coupled to an OGCM with an ice model, a regional climate model over China, a regional ocean model over both Pacific and Indian Oceans where are the important areas for the seasonal and annual predictions in China, and a simple ENSO prediction model. Among those component models, the simple ENSO prediction models have been used to predict the SSTA over the tropical Pacific Ocean on each Workshop held by NCC since January 1997. The models predicted the onset, peak and decay of the ENSO event during 1997 and 1998 successfully (Zhao et al. 1997; Li et al. 1998). After the new climate model system is established, the seasonal and annual predictions might be better than before in China.

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