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A Correction Method Suitable for Dynamical Seasonal Prediction

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ABSTRACT

Based on the hindcast results of summer rainfall anomalies over China for the period 1981–2000 by the Dynamical Climate Prediction System (IAP-DCP) developed by the Institute of Atmospheric Physics, a correction method that can account for the dependence of model's systematic biases on SST anomalies is proposed. It is shown that this correction method can improve the hindcast skill of the IAP-DCP for summer rainfall anomalies over China, especially in western China and southeast China, which may imply its potential application to real-time seasonal prediction.

Key words: correction method, dynamical seasonal prediction, summer rainfall anomaly

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1. Introduction

With the rapid development of the world's economy, climate predictions have became more and more important for society. Many climate research centers have been actively engaged in the development of climate prediction systems and have conducted real-time climate predictions for a long time (e.g., Zeng et al., 1990, 1997; Bengtsson et al., 1993; Palmer and Anderson, 1994).

In 1989, the first dynamical climate prediction system based on a coupled Atmosphere-Ocean Model was built in the Institute of Atmospheric Physics/Chinese Academy of Sciences (IAP/CAS). The prediction results were encouraging (Zeng et al., 1990). Since then, great efforts have been made towards continuously improving the IAP dynamical climate prediction system (hereafter IAP-DCP) (Li, 1992; Zeng et al., 1997, 2003; Lin et al., 1998). The IAP-DCP has been applied to real-time climate predictions since 1990. Verifications show that the IAP-DCP is able to predict the large-scale patterns of summer flooding and drought over China (e.g., Zeng et al., 1997, 2003; Lin et al., 1998, 2000, 2002).

However, because of the incompleteness of climate models, such as the improper representation of the physical processes, model's systematic biases are found by computing the difference between the model and the true climate, and this may suggest the importance of applying a correction system to remove the systematic bias when conducting seasonal climate prediction (e.g., Zeng et al., 1994, 1997; Lin et al., 1998; Tennant, 1999). Many correction methods have been proposed for different climate prediction systems (e.g., Zeng et al., 1994; Feddersen et al., 1999; Zhao et al., 1999; Wang et al., 2000), and have been proven to be quite efficient for improving the prediction skill. The correction method used in the IAP-DCP is the so-called "percentage anomaly correction" (hereafter referred to as CM_OLD), which can be expressed as:

$$a' = a - \varepsilon\,, \qquad (1)$$

where a and a' are the uncorrected and corrected prediction of the percentage rainfall anomaly, respectively. a is expressed as:

$$a = [(x - x_{\mathrm{c}})/x_{\mathrm{c}}] \times 100\%\,. \qquad (2)$$

Here, x and x_{c} are the predicted and climatological rainfall, respectively. In formula (1), ε is the ensemble mean model bias averaged over the whole hindcast period. If b is the observed percentage rainfall anomaly, then

$$\varepsilon = \langle a - b \rangle_{\mathrm{h}}\,. \qquad (3)$$

Here, $\langle\cdot\rangle$ means the average over the whole hindcast period, and h corresponds to a sample set of hindcast experiments.

From the above expression, we can find that, for the CM_OLD, the correction term ε can only reflect the ensemble mean model bias averaged over the whole hindcast period. So, based on the hindcast results during 1981–2000 by the IAP-DCP, a new correction method that demonstrates the ENSO dependence of the model systematic biases is proposed in this paper, and the effectiveness of applying this correction method will be

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Table 1. Design of Hindcast Experiment for the IAP-DCP.

Prediction system	IAP-DCP
Climate model	IAP 2L AGCM (horizontal resolution: 2.0°×2.5° in latitude and longitude)
Sea surface temperature	Observed climatological SST+ Observed SSTA
Atmospheric initial conditions	Wind, geopotential height, and relative humidity, taken from NCEP real-time analysis
Ensemble size	28 members, with different initial conditions from 1 to 28 February, respectively
Duration of integration	15 February–31 August

further evaluated.

2. Data

The data used in this study are the hindcast summer rainfall data over China for the period 1981–2000 produced by the IAP-DCP. The detailed description of the hindcast experiment is shown in Table 1.

The climate model adopted by the IAP-DCP is the improved IAP 2L AGCM with a new albedo scheme and a horizontal resolution of 2.0°×2.5° in latitude and longitude (Lin et al., 1998; Zhang et al., 2004). The comparison between the observations and simulation results shows that the model can reproduce the current climate to some extent, especially for the general features of the East Asian summer monsoon and East Asian monsoon precipitation (Lin et al., 1997; Zhang et al., 2004). The good performance of the model in the rainfall simulation shows its potential to serve as a useful tool for the prediction of summer drought/flooding events over East Asia.

3. New correction method and its verification

3.1 *The method*

Sea surface temperature and its anomalies, which are the most important surface boundary conditions for Atmospheric General Circulation Models (AGCMs), can have a significant influence on the atmospheric general circulation (e.g., Lau and Nath, 1990; Fennessy and Shukla, 1991). Due to the nonlinearity of the physical processes within the climate system, the response of the atmospheric circulation and the precipitation anomalies to the SST forcing is also nonlinear (e.g., Montroy et al., 1998). This suggests that the model systematic bias may vary with different types of SST anomalies. Furthermore, as revealed by many studies (e.g., Huang and Wu, 1989; Huang and Sun, 1992), the ENSO cycle is one of the dominant factors that is closely related to the East Asian summer monsoon and its related precipitation. There are large possibilities of flooding events over the Yangtze River and Huaihe River valleys for El Niño years and of drought for La Niña years. So in this paper, we first compare the model systematic biases for three different categories of SST anomalies according to the ENSO cycle: El Niño years, La Niña years, and normal years.

In order to evaluate the model's capacity in reproducing the basic responses of precipitation to SST forcing, here we compare the correlations between rainfall and the Niño-3.4 index for both observations and GCM

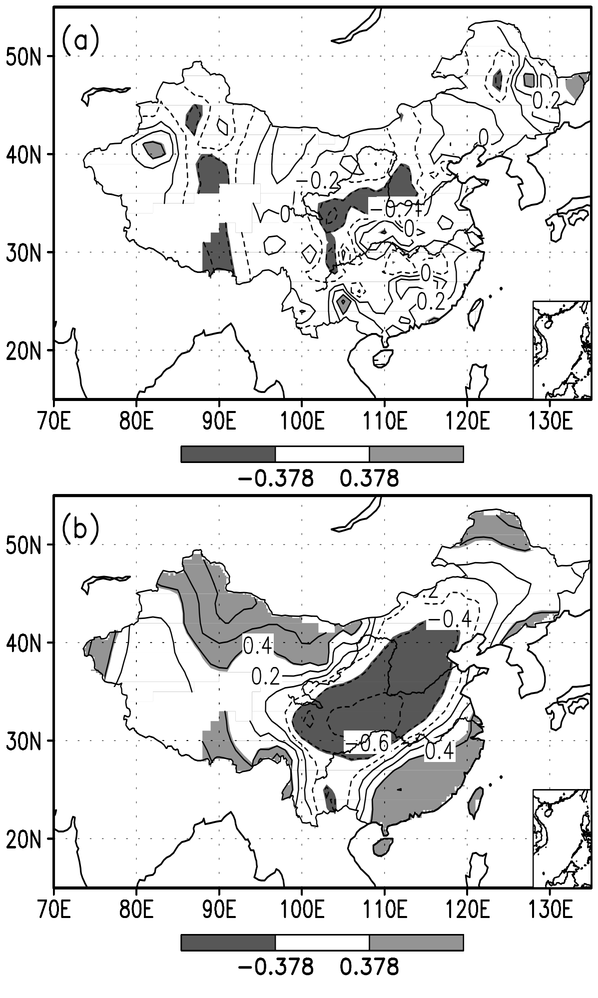

Fig. 1. Temporal correlations between the (a) Niño-3.4 index and observed rainfall; and (b) Niño-3.4 index and GCM simulated rainfall, in JJA from 1981 to 2000. Regions above the 90% significance level are shaded.

Table 2. Three categories of years according to the types of SST anomaly.

Category	Year
El Niño	1982, 1983, 1987, 1991, 1992, 1993, 1997, 1998
La Niña	1984, 1985, 1988, 1989, 1996, 1999, 2000
Normal year	1981, 1986, 1990, 1994, 1995

simulations in June, July, August (JJA). In Fig. 1a, it is found that the observed precipitation in JJA can reveal significantly negative correlation with the tropical Pacific SSTs in summer over North China, and positive correlation over South China; also the model can simulate these basic responses (Fig. 1b).

A preliminary step in our study is to categorize an ENSO year. Here we follow the definition from Trenberth (1997). It is suggested that an El Niño can be said to occur if the 5-month running means of SST anomalies in the Niño-3.4 region exceed 0.4°C for 6 months or more. With this definition, the individual years can be sorted into three categories as shown in Table 2 from the hindcast period from 1981 to 2000.

Shown in Fig. 2 are the model biases of percentage rainfall anomaly in JJA by using the IAP-DCP for El Niño, La Niña and normal years, respectively; also shown is the model bias averaged over all of the hindcast years. We find from the figure that the distributions of model biases are different for different categories of SST anomaly years. For El Niño years (Fig. 2a), the model shows a positive precipitation bias over North China and coastal areas of Southeast China, and a negative bias over the Yangtze and Huaihe River valleys, the north part of Northeast China and most areas of western China. However, for La Niña years (Fig. 2b), we find that the model bias is generally negative over most parts of China, with the maximum difference over the lower reaches of the Yangtze River Valley. As for normal years (Fig. 2c), the model bias is generally positive over western China except for the northern part of Xinjiang, and negative over eastern China. The model bias averaged over all of the hindcast years (Fig. 2d) is negative over almost the whole China, which is distinctly different from the three other types of model bias shown in Figs. 2a–c.

A new correction method suitable for the dynamical seasonal prediction is proposed, which can consider the differences of the model bias for different scenarios of SST anomalies. Differing from the current correction method as given by formula (3), the new proposed correction method is given as a stepwise function for the three different categories of SST anomalies, viz.,

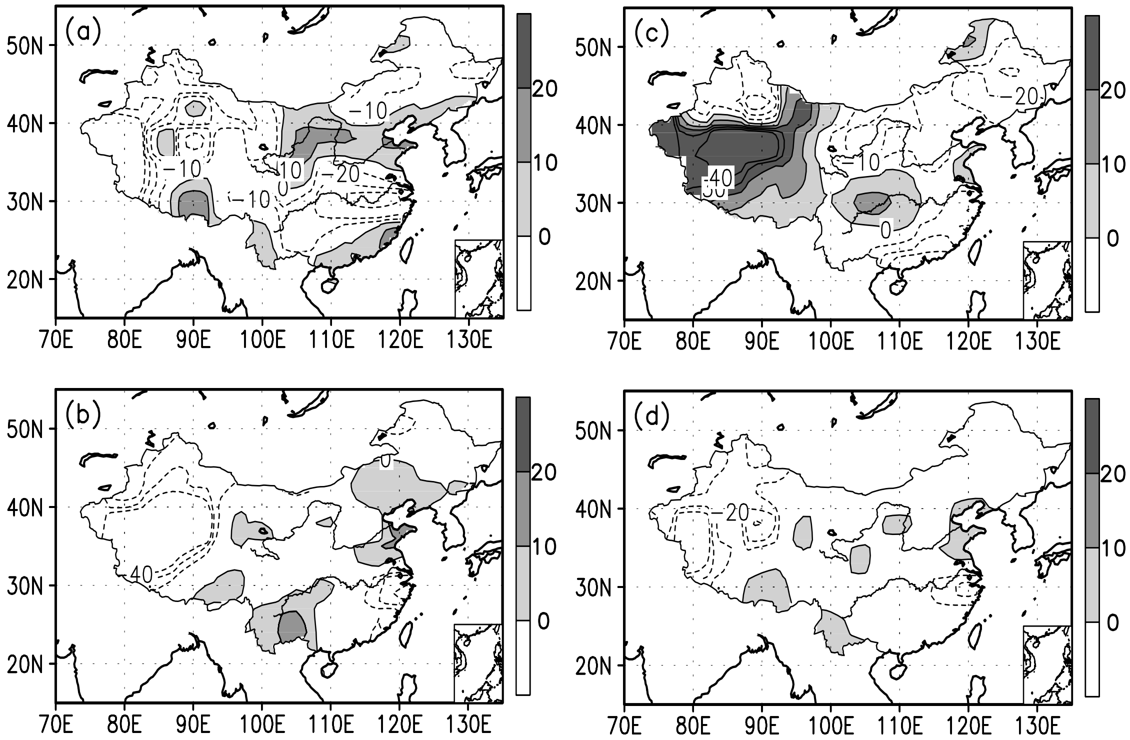

Fig. 2. Distribution of the mean model biases of percentage rainfall anomaly in JJA averaged over (a) El Niño years; (b) La Niña years; (c) Normal years; and (d) all years during the hindcast experiment period from 1981 to 2000.

$$\varepsilon_i = \langle a-b \rangle_{h_i} \begin{cases} i=1, & \text{El Niño year} \\ i=2, & \text{La Niña year} \\ i=3, & \text{Normal year} \end{cases} \quad (4)$$

Here, h_1, h_2, and h_3 are the total number of El Niño, La Niña, and normal years, respectively (see Table 2 for details). So, for El Niño years, the correction "ε" is taken as the model bias averaged over all of the El Niño years (Fig. 2a), and similarly for the other two categories. This new correction method is generated with the consideration of the ENSO cycle, so it is referred to as CM_ENSO later in this paper.

3.2 *The verification*

By using the hindcast data generated by the IAP-DCP, the new correction method (CM_ENSO) is evaluated in this section by comparing the predictive skill of the IAP-DCP with CM_ENSO and that with the CM_OLD correction method.

The parameters used for assessment of predictive skill are anomaly correlation coefficient (ACC, i.e., spatial correlation coefficient) and correctness of signs (T). T can be expressed as:

$$T = \frac{N_i}{N} \, . \quad (5)$$

Here, N is the total number of grid points for assessment, and N_i is the total number of grid points where the signs for the predicted and observed fields are the same.

In this paper, the whole China is divided as follows: western China (west of 105°E), eastern China (east of 105°E), northeast China (east of 110°E, north of 42°N), Huanghe River and Huaihe River valleys (32–42°N, east of 105°E), and southeast China (east of 105°E, south of 32°N).

The 20-year averaged ACC and T between the hindcast and observed percentage rainfall anomaly in JJA with the two correction methods are listed in Table 3. Over the whole China, the 20-year averaged ACC is only 0.09 for the IAP-DCP with CM_OLD; however it is increased to 0.27 with CM_ENSO, which exceeds the 99% significance level (i.e., ACC above 0.244). As for the T, the 20-year averaged T for the new correction method is 0.57, which is slightly higher than 0.55 for the old method. Generally, the predictive skill for the whole China increases with the new correction method.

From Table 3, we can also find that the improvement of ACC is much more remarkable over western China compared with that over eastern China. In western China, the ACC increases from 0.12 for CM_OLD to 0.32 for CM_ENSO, which exceeds the 99% significance level (i.e., ACC above 0.244), suggesting that the introduction of the new correction method is much more efficient for western China. The reason for this needs further investigation. The 20-year averaged ACC over southeast China also increases from 0.06 for CM_OLD to 0.11 for CM_ENSO, illustrating the effectiveness of applying the new correction method to a real-time prediction system. However, over northeast China, the ACC is negative for both of the two correction methods, and T is even decreased for CM_ENSO compared with CM_OLD, which may indicate that there is no skill in the prediction of the summer rainfall anomaly over this region. Over the Huanghe River and Huaihe River valleys area, ACC is increased from 0.00 for CM_OLD to 0.03 for CM_ENSO, and T is increased from 0.51 to 0.53.

Presented in Fig. 3 are time series of the ACC between the hindcast and observed percentage rainfall anomaly for CM_OLD and CM_ENSO of the IAP-DCP over the whole China, western China, and eastern China. From the figure, we can find that, over the whole China, for the new correction method, the ACC are all improved compared with the old method except for the years of 1982, 1992, 1996, 1997 and 1999, and the correlation coefficients exceed 0.50 for many years. So the predictive skill for the whole China increases with the use of the CM_ENSO. Over western China, the predictive skill is also increased greatly for most years. Over eastern China, ACC is increased for all years except for 1982, 1985, 1989, 1990, 1992, 1997 and 1999; however for 1990, 1992 and 1997, it is decreased greatly, so the 20-year average ACC shows no improvement.

The above comparisons show that, generally, the

Table 3. 20-year averaged Anomaly Correlation Coefficient (ACC) and correctness of signs (T) for the hindcast and observed percentage rainfall anomalies in JJA over China for the IAP-DCP with the CM_OLD and CM_ENSO correction methods.

		The whole China	Western China	Eastern China	Northeast China	Huanghe River and Huaihe River valleys	Southeast China
ACC	CM_OLD	0.09	0.12	0.02	−0.17	0.00	0.06
	CM_ENSO	0.27	0.32	0.02	−0.04	0.03	0.11
T	CM_OLD	0.55	0.55	0.54	0.57	0.51	0.55
	CM_ENSO	0.57	0.59	0.54	0.53	0.53	0.56

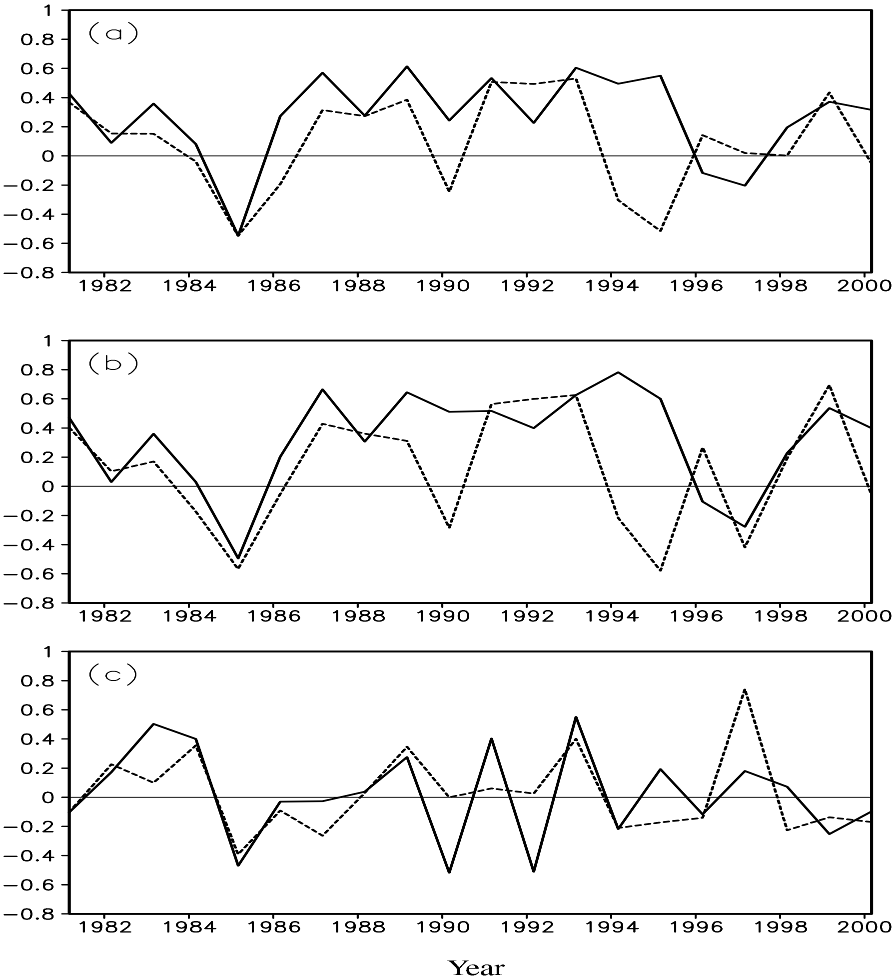

Fig. 3. ACC of the hindcast and observed percentage rainfall anomalies in JJA for the old (dotted line) and new (solid line) correction methods over (a) the whole China; (b) western China; (c) eastern China.

predictive skill of the IAP-DCP with CM_ENSO is higher than that with CM_OLD over western China, the Huanghe River and Huaihe River valleys, and southeast China; however, over northeast China the predictive skill is poor for both correction methods.

4. Conclusion

In this paper, we have proposed a correction method (CM_ENSO) according to the SST anomaly and evaluated its performance based on the extraseasonal hindcast results of summer rainfall anomalies over China by the IAP-DCP. Results indicate that CM_ENSO does show some skill in the simulation of the summer rainfall anomaly in China, especially in western China and southeast China. So, this method has the potential to be used for improving the skill of dynamical seasonal prediction.

However, this correction method still has some deficiencies. For example, over Northeast China, the new correction method failed to improve the hindcast skill and plays little role in that area; the new correction method does not consider decadal variation, etc. So, further efforts are needed to improve the correction method and to establish a more sophisticated correction system in the near future. Maybe the combination of the old and new correction methods in the operational model prediction would be more successful.

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