Science in China Series D: Earth Sciences

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Forecasting the summer rainfall in North China using the year-to-year increment approach

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A new approach to forecasting the year-to-year increment of rainfall in North China in July-August (JA) is proposed. DY is defined as the difference of a variable between the current year and the preceding year (year-to-year increment). NR denotes the seasonal mean precipitation rate over North China in JA. After analyzing the atmospheric circulation anomalies associated with the DY of NR, five key predictors for the DY of NR have been identified. The prediction model for the DY of NR is established by using multi-linear regression method and the NR is obtained (the current forecasted DY of NR added to the preceding observed NR). The prediction model shows a high correlation coefficient (0.8) between the simulated and the observed DY of NR throughout period 1965—1999, with an average relative root mean square error of 19% for the percentage of precipitation rate anomaly over North China. The prediction model makes a hindcast for 2000—2007, with an average relative root mean square error of 21% for the percentage of precipitation rate anomaly over North China. The model reproduces the downward trend of the percentage of precipitation rate anomaly over North China during 1965—2006. Because the current operational prediction models of the summer precipitation have average forecast scores of 60%—70%, it has been more difficult to forecast the summer rainfall over North China. Thus this new approach for predicting the year-to-year increment of the summer precipitation (and hence the summer precipitation itself) has the potential to significantly improve operational forecasting skill for summer precipitation.

annual increment, North China precipitation prediction, prediction skill

There are complex challenges concerning the accurate prediction of summer rainfall over North China. As North China is located at the northern boundary of the activity of the East Asian summer monsoon, the summer rainfall over North China is influenced by the summer monsoon, extratropical circulation and other systems. Summer rainfall over North China possesses variations on time scales of interannual, Tropospheric Biennial Oscillation (TBO) and decadal variation[1−4], which are associated with processes including the Asia summer monsoon, the sea surface over the tropical Pacific, the North Pacific oscillation, the subtropical High over the west Pacific, the South Asian High, the block circulation over East Asia as well as the Antarctic Oscillation[5−18]. Studies on the reliability of short-term climate prediction have been carried out[19−30]. This research has provided a substantial basis for the seasonal forecasting summer rainfall in China. However, it is still difficult to deal with the inconsistency between interannual and decadal variation of precipitation for seasonal forecasting of precipitation in North China by the statistical or climate models.

Fan et al.[31] proposed a new approach to predicting summer rainfall over the Yangtze River valley, by predicting the year-to-year increment of summer precipita-

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Received April 24, 2008; accepted July 10, 2008; published online February 26, 2009
doi: 10.1007/s11430-009-0040-0

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Supported by National Basic Research Program of China (Grant No. 2009CB421406), National Natural Science Foundation of China (Grant Nos. 40631005, 40775049) and Excellent Ph. D Dissertation in Chinese Academy of Sciences

tion with the average relative root mean square error being 20% (18%) for the simulated (hindcast) period. The model expresses the interannual variability of the percentage of precipitation rate anomaly and reproduces its increase (decrease) trend during 1984—1998 (1998—2006), suggesting the new approach may improve the forecasting accuracy for rainfall in the Yangtze River valley. Our intention is to investigate the feasibility of the new approach being applied to the forecasting of summer rainfall in North China.

The new approach provides the following improvements: (1) defines DY as the difference of a variable between the current year and the preceding year and defines NR as the seasonal mean precipitation rate in July-August (JA) over North China, e.g. the DY of NR in 1998 is the NR of 1998 minus that of 1997; (2) establishes a prediction model for the DY of NR to predict the DY of NR; (3) NR is obtained from the DY of NR in the current year being added to the observed NR in the preceding year. This new approach has additional benefits: (1) it amplifies the forecasting signal of the predictand. The DY of NR represents the high frequency variability of NR to be predicted, with its standard variation much greater than NR itself (i.e. DY of seasonal mean precipitation rate in JA over North China during 1965—1999 is 1.59 mm/day and the seasonal mean precipitation rate is 1.0 mm/day); (2) the annual increment may represent climate anomalies with clear definition. In general, as precipitation anomalies refers to abnormal precipitations that relative to a certain climatological period involving the decadal variability, the precipitation anomaly in a year might vary with climatological period selected. In a sense, the precipitation anomalies lack a clear definition. If the predicted model for the precipitation anomaly is established, the decadal variation of the forecast signal could result in misleading forecasting of summer precipitation. In addition, forecasting the annual increment of summer precipitation may capture not only the interannual variability of precipitation but also that of the decadal variability, because the accumulation of the predicted DY of NR reflects the linear trend, which is reflected by the accumulation of the annual increments.

1 Data

Monthly rainfall data at 160 stations in China was obtained from the China Meteorological Administration (CMA). The 17 stations represent the area of North China (i.e. Chengde, Beijing, Tianjin, Shijiazhuang, Dezhou, Xintai, Anyang, Yantai, Qingdao, Weifang. Jinan, Linyi, Heze, Zhenzhou, Changye, Taiyuan, Linfen)[32]. Seasonal mean precipitation rate over North China in JA denotes the summer rainfall over North China. Atmospheric circulation and predictors refers to the annual increment variables (e. g. the variable of the current year minus that of the preceding year). The National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) monthly atmospheric reanalysis with a resolution of 2.5º×2.5º is employed. The Niño3 index is defined as the sea surface temperature anomaly averaged over (5ºS—5ºN) and (150º—90ºW). The period of the datasets above covers 1965—2007.

2 DY of summer rainfall over North China and its circulation

A connection between atmospheric circulation in winter and that in spring exists, for which the changes of sea surface temperature over the eastern tropical Pacific and the westerly drift over north Pacific are responsible[1−4]. The East Asian winter monsoon and the summer monsoon as well as ENSO have a quasi biennial oscillation (TBO) feature, suggesting a stronger (weaker) winter monsoon correspondence to weaker (stronger) summer monsoon next year. The interaction between anomalous East Asian winter monsoon and the ENSO cycle might be a fundamental cause of the TBO[1−4]. Accordingly, we analyze the DY of circulations in winter (December-January-February, DJF) related to the DY of NR. Significant positive sea level pressure anomalies are located north of 40°N and negative anomalies are located over North China and its southern areas (Figure 1(a)). The negative temperature anomalies at 1000 hPa dominate the north of 40°N and the positive temperature anomalies at North China and its southern areas (Figure not shown). The DY of anticyclonic anomaly at 850 hPa influences Northeast China. The cyclonic anomaly occurs over North China and its southern areas where the southern flow anomaly prevails (Figure 1(b)). The changes of circulation above show that the negative anomalies of DY for the winter monsoon tend to the positive anomalies of DY of NR, which is consistent with previous findings. Therefore, NEI is selected as a predictor, which is defined as the area of mean DY of sea level pressure over the region (40°—55°N, 120°—

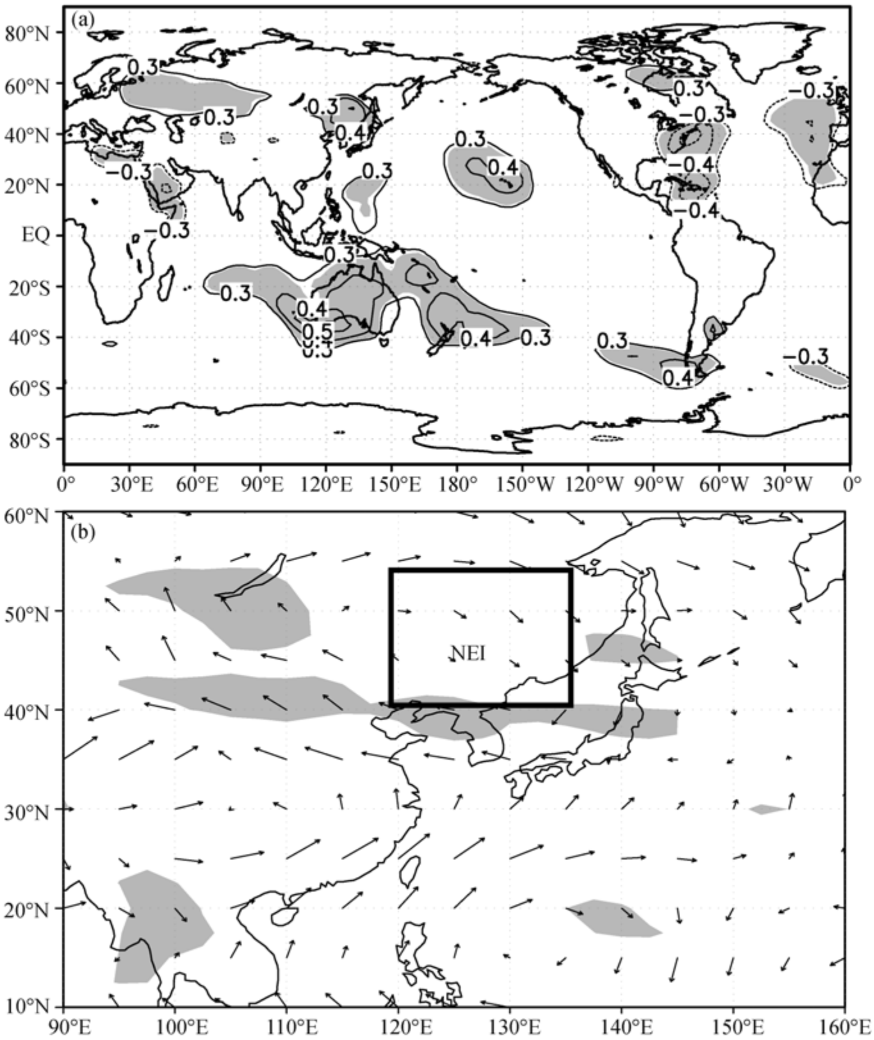

Figure 1 The correlation coefficients between the DY of NR and the DY of circulations in DJF. (a) Sea level pressure during 1965－1999; (b) wind at 850 hPa. Shaded areas indicate significant correlation coefficients at a 0.05 significance level, estimated by a local students'-t test; the box indicates the selected area-mean for computing the NEI.

135°E)(see Figure 1(b)). The correlation coefficient between the NEI and the DY of NR is 0.39 during 1965－1999, with a 0.01 significance level.

The DY of circulation in spring (March-April-May, MAM) related to the DY of NR are also investigated. The DY of the Southern Oscillation is pronounced. Early studies pointed out that less summer rainfall occurred over North China during ENSO episode. This suggested that ENSO could impact summer rainfall over North China via the subtropical high over the west Pacific, the East Asia jet and the Indian monsoon[6,7,13]. The DY of Niño3 in June is therefore selected as a predictor for the DY of NR. The correlation coefficient between the DY of Niño3 in June and the DY of NC was −0.64 during 1965－1999, with a 0.01 significance level.

Another significant positive correlation is located in the central part of the North Pacific which is associated with the activity of the west Pacific subtropical High, which determines the pattern of the East China summer rainband. Consequently, NPI is defined as the area of mean DY of the geopotential height over the region (20°－35°N, 180°－150°W) at 500 hPa in MAM representing circulation over North Pacific (see Figure 2(a)). The change of sea surface temperature over the tropical west Pacific throughout spring and summer may induce the East Asian Pacific wave train which modulate the location of the west Pacific subtropical high and the transportation of water vapor over North China in JA as well (see Figure 2(b)).

The circulation in June may also affect forecasting rainfall in JA over North China. As the South Asia high

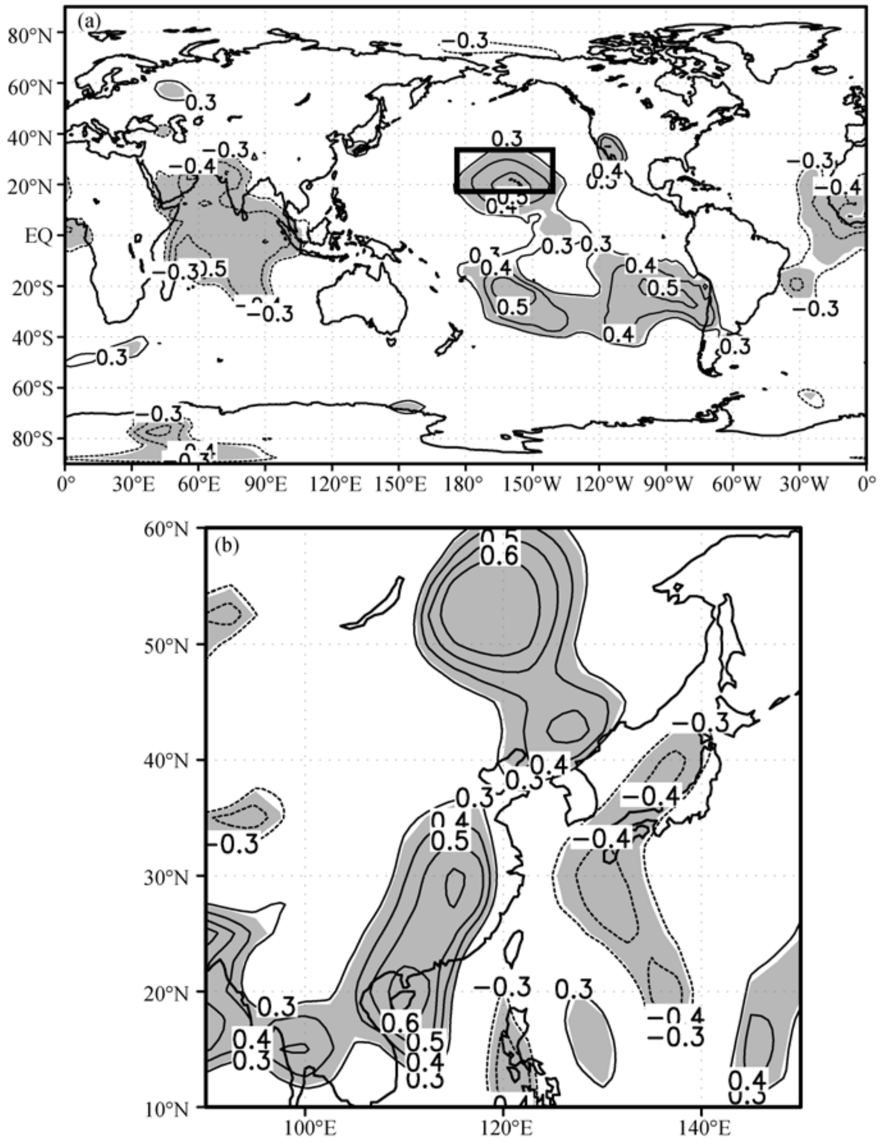

Figure 2 (a) The correlation coefficients between the DY of NR and the DY of sea level pressure in MAM during 1965—1999; (b) the correlation coefficients between NPI and the DY of wind at 850 hPa in JA. Shaded areas are the same as Figure 1, with the box indicating the selected area-mean for computing the NPI.

is an important component of the Asia monsoon, its seasonal movements from south to north as well as the oscillation from west to east may impact the outbreak of the Asia monsoon influencing the summer rainfall over China[5]. When the South Asia high moves northward into the Tibet Plateau, the summer circulation has been established. The circulation over South Asia (SAI) in June is therefore defined as an area of mean DY of geopotential height over the region (45°—90°N, 20°—35°N) at 200 hPa (see Figure 3(a)). The correlation coefficient between the ASI and the DY of NR was 0.57 during 1965—1999, with above a 0.01 significance level. Webster[33] defined the south Asia monsoon index as the zonal wind anomaly vertical shear between 850 and 200 hPa over the region (0°—20°N, 40°—110°N). Figure 3(b) illustrates that both the DY of SAI in June and in JA have correlated well with the South Asia monsoon index (see Figure 3(b)). It suggests that the South Asia monsoon not only is involved with the interaction of the DY of SAI and the DY of NR but also transports the water vapor into North China[6,7].

Another index of circulation at high latitudes (NHI) is defined as the area mean DY of sea level pressure over the region (70°—80°N, 60°—120°N), which may be associated with the activity of the polar vortex in the Northern Hemisphere (see Figure 3(a)).

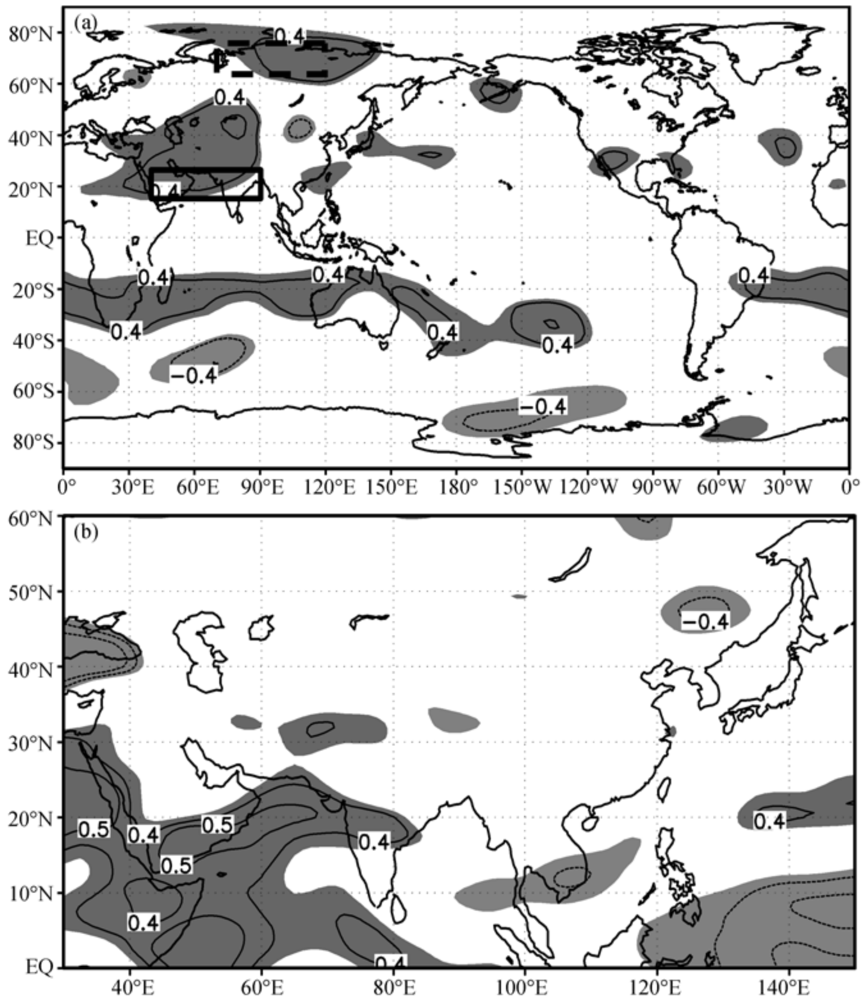

Figure 3 (a) The correlation coefficients between the DY of NR and DY of geopotential height at 200 hPa, with the box indicating the selected area-mean to compute the SAI; (b) the correlation coefficients between SAI and zonal wind shear between 850 and 200 hPa in JA during 1965－1999. Shaded areas are the same as Figure 1, with the box indicating the selected area-mean for computing the SAI and the dashed box indicating the selected area-mean for computing the NHI.

Five predictors for the DY of NR are identified based on the analysis above. x_1, DY of NEI in DJF representing the circulation over North East Asia; x_2, DY of NPI representing the circulation over the North Pacific in MAM; x_3, DY of SAI in June; x_4, DY of NHI in June representing circulation at high latitudes in the northern hemisphere; x_5, the DY of the Niño3 index in June.

3 Establishment of a predictive model and its validation

The following physically-based statistical prediction model for the DY of NR was derived through multi-linear regression analysis,

$$y = 0.23x_1 + 0.15x_2 + 0.34x_3 + 0.17x_4 - 0.43x_5. \tag{1}$$

To validate the prediction model, the following formulas were utilized:

(i) The percentage of precipitation rate anomaly of the observation

$$\frac{y_0 - \overline{y_0}}{\overline{y_0}} \times 100\%. \tag{2}$$

(ii) The percentage of precipitation rate anomaly of the simulation (prediction)

$$\frac{y - \overline{y_0}}{\overline{y_0}} \times 100\%. \tag{3}$$

(iii) The percentage of relative error of the simulation (prediction)

$$\frac{y - y_0}{\overline{y_0}} \times 100\%. \tag{4}$$

The average relative root mean square error of the simulation (prediction)

$$\frac{\sqrt{\left(\sum_{i}^{n}(y-y_0)^2\right)/N}}{\overline{y_0}}, \tag{5}$$

where y_0 is the observed NR, y is the simulated (predicted) NR, $\overline{y_0}$ is the average of the observed NR during 1965－1999. N is the length of the sample. The simulated period is 35 years (1965－1999) and the hindcast period is 8 years (2000－2007).

Figure 4 shows the interannual variability of the DY of NR exhibiting quasi biennial oscillation feature, suggesting that a positive (negative) anomalies of the DY of YR this year corresponds to be followed by a negative (positive) anomalies of the DY of NR next year. The correlation of coefficient is 0.8 between the modeled and the observed DY of NR for the period of 1965－1999. The simulated values are close to the observed values for these years 1981, 1984, 1985, 1986, 1988, 1989, 1990, 1993, 1995, 1996, 1997, 1998. The modeled NR is obtained by adding the preceding year's observed precipitation to the modeled DY of NR. Figure 5 shows that the simulated and the observed percentage of precipitation rate anomaly exhibits close agreement both qualitatively and quantitatively, with the simulated values being close to the observed values in 1984, 1985, 1986, 1987, 1988, 1995, 1996, 1997, 1998. The average relative root mean square error was 19% during the simulated period 1965－1999.

In order to make a validation of the model, we make the hindcast of the DY of NR for the years 2000－2007. The predicted and observed DY of NR had a coherent variation for the five years 2000, 2002, 2003, 2005, 2007, with a rate of coherence of 5/8. For the three years 2000, 2002, 2003, with a larger variability of the DY of NR, the predicted values were very close to the observed values. The DY of NR is reasonably predicted for 2001, 2004, 2006, respectively, because both the predicted and the observed values are less than a standard variation (1.5 mm/day). As far as the prediction of the percentage of precipitation rate anomaly is concerned, the rate of coherence is 3/8. It is noted that the model predicts an anomalous drought in 2002, with the predicted value (−43.7%) consisting of the observed value (−52.6%), as well as the predicted percentage of relative error of 10%. In other years, the predicted values and observed values are between negative 25% and positive 25% suggesting normal precipitation, with the average relative root mean square error of 21% during the hindcast period 2000－2007. The forecast model reproduced the down trend of the percentage of precipitation rate anomaly during 1965－2006. Because the current operational forecast scores is only at 60%－70% and it is more difficult to predict the summer rainfall over North China[34], the new ap-

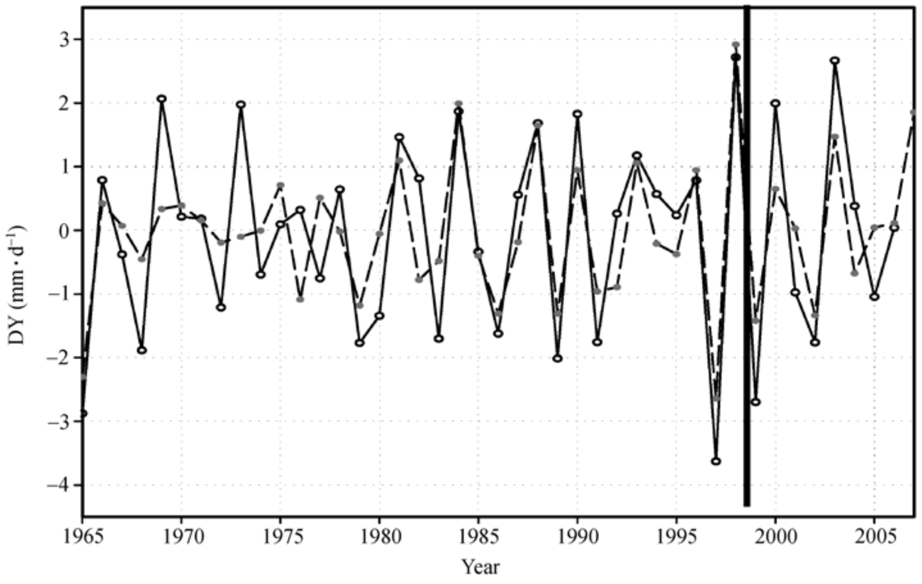

Figure 4 The time series for the actual DY of NR (solid line) and the model simulated (dashed line) and hindcast DY of NR (dashed line). The model simulated DY of NR is for the period 1965－1999, and the forecasted DY of NR is for the period 2000－2007. The black solid line represents the divided line between the simulated period and the hindcast period.

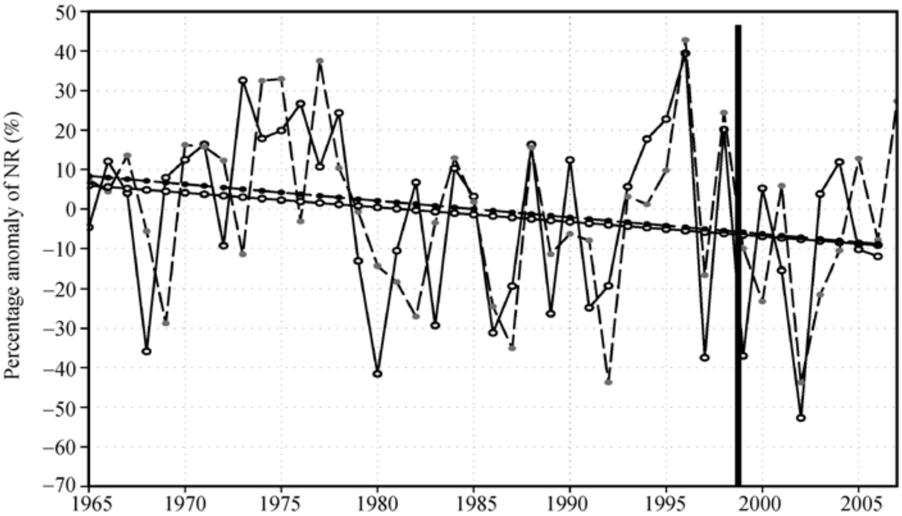

Figure 5 The time series for the actual (solid line) and the model simulated (dashed line) and the hindcast (dashed line) percentage anomalies of NR. The model simulation is for the period 1965—1999, and the hindcast is for the period 2000—2007. The observed and the modeled trend are plotted with the solid line with the circle and the dashed line with a dot during 1965—2006. The black solid line represents the divided line between the simulated period and the hindcast period.

proach (year-to-year increment of precipitation and hence precipitation itself) is feasible and has the potential to significantly improve the operational forecast skill of summer precipitation over North China.

To further validate the new approach and the prediction model, the second forecast model is established based on 1972—2006, to be made a hindcast for 1965—1971. It is found that the predictors and the coefficients of each item are the same in two prediction models. The correlation coefficients between the simulated values and the observed values of the DY of NR are 0.8 during 1972—2006 in the second prediction model. For the hindcast years 1965—1971, the rate of coherence of the DY of NR and that of the percentage of precipitation rate anomaly are respectively 6/7, with the average relative root mean square error of 21% for the percentage of precipitation rate anomaly. The two forecast models indicate that the approach to predicting the annual increment of precipitation and its predictors are steady. However, the forecasting skill of prediction model need to be further validated using the signal to noise obtained from climate models. Forecasting skill for the annual increment of precipitation might be further investigated in terms of signal rate and noise from climate models.

Predictors in June in our forecast model are selected based on the following considerations. Because the peak season of rainfall over North China occurs between late July and early August, predictions in June supply ample lead time. An effective forecasting method combining the statistical model and climate model will be used in the future, and the predictor in June in climate model will be used to forecast rainfall in JA.

4 Conclusions

Based on the TBO feature existing in summer rainfall and in the tropospheric atmospheric, a new approach is proposed to predict the annual increment of precipitation and hence to predict the precipitation itself. Five predictors are identified and a prediction model is established by multi-liner regression. The high correlation coefficient between the simulated and observed DY of NR was 0.8 during 1965—1999. During the hindcast years 2000—2007, the predicted and observed percentage of precipitation rate anomaly has substantial agreement. The prediction model successfully predict the anomalous drought year in 2002, with a predicted percentage of relative error of 10%. The forecast model reproduced the downward trend of the percentage of precipitation rate anomaly during 1965—2006. Our research suggested that the statistical model is an effective tool for forecasting summer rainfall in China. A highly effective future prediction method may combine statistical with a climate dynamical model. The physical processes behind the relationships between the predictors and the summer precipitation over North China need to be further investigated. The predictability of annual increment of precipitation requires further investigation. The annual increment of a variable might to be applied in the validation or correction forthe statistical or the dynamic climate models.

The revision of the manuscript has been assisted by helpful comments from three reviewers.

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