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Prediction model for spring dust weather frequency in North China

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It is of great social and scientific importance and also very difficult to make reliable prediction for dust weather frequency (DWF) in North China. In this paper, the correlation between spring DWF in Beijing and Tianjin observation stations, taken as examples in North China, and seasonally averaged surface air temperature, precipitation, Arctic Oscillation, Antarctic Oscillation, South Oscillation, near surface meridional wind and Eurasian westerly index is respectively calculated so as to construct a prediction model for spring DWF in North China by using these climatic factors. Two prediction models, i.e. model-I and model-II, are then set up respectively based on observed climate data and the 32-year (1970—2001) extra-seasonal hindcast experiment data as reproduced by the nine-level Atmospheric General Circulation Model developed at the Institute of Atmospheric Physics (IAP9L-AGCM). It is indicated that the correlation coefficient between the observed and predicted DWF reaches 0.933 in the model-I, suggesting a high prediction skill one season ahead. The corresponding value is high up to 0.948 for the subsequent model-II, which involves synchronous spring climate data reproduced by the IAP9L-AGCM relative to the model-I. The model-II can not only make more precise prediction but also can bring forward the lead time of real-time prediction from the model-I's one season to half year. At last, the real-time predictability of the two models is evaluated. It follows that both the models display high prediction skill for both the interannual variation and linear trend of spring DWF in North China, and each is also featured by different advantages. As for the model-II, the prediction skill is much higher than that of original approach by use of the IAP9L-AGCM alone. Therefore, the prediction idea put forward here should be popularized in other regions in China where dust weather occurs frequently.

spring dust weather frequency, prediction model, iap9l-agcm, hindcast experiment, real-time prediction

Under the background of climate change characterized mainly by global warming, meteorological disasters in China enhance notably, and its influences on social development intensify steadily. Therein, frequent spring dust weather in recent years has been paid more attention to and has become an important focus of the consulting meeting on interannual climate prediction. However, dust weather frequency (hereinafter as DWF) alters dramatically on seasonal, interannual and decadal timescales[1−3]. Moreover, dust weather event is jointly decided by many factors. These give rise to the fact that DWF prediction still lies in a preliminary phase in China.

In the prior literature on DWF prediction, scientist usually emphasizes atmospheric general circulation and then Figures out statistically significant predictors for DWF so as to perform eventual prediction. It is found that dust weather in North China is closely related to surface wind velocity, humidity and surface air temperature, and the former is generally seen as the most important factor. On seasonal and interannual timescales, surface wind and precipitation are regarded to act the

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most important roles in dust weather event[4−9]. In addition, the leading sea surface temperature (SST) in Pacific, ENSO cycle and climatic factors in the northern mid-high latitudes (e.g., geopotential height at 500 hPa, polar vortex intensity, Arctic Oscillation and westerly in the northern high latitudes) are also documented to impact dust weather event in China significantly[10−15]. Recently, atmospheric general circulation in the Southern Hemisphere was also involved, and a significant negative correlation relationship between Antarctic Oscillation and spring DWF in North China was reported[16], which provides a new scope for DWF prediction.

According to previous studies, it can be judged that spring DWF in China can be predicted to a certain extent, although dust weather event is jointly dominated by many factors. In this field, some preliminary investigations have been carried out so far. Most researchers usually attempt to establish relationship function between DWF and potential climatic factors by use of statistical analysis and then generate prediction result. For example, Yu et al.[17] constructed an index to describe DWF variation in North China except for the Uygur autonomous region of Xinjiang via the relationship between DWF and surface air temperatures as well as disturbance vortex. Li et al.[18], Zhao et al.[19] and Mao et al.[20] set up prediction models for frequency and change trend of dust storm in China by taking into account the leading atmospheric general circulation. More recently, Wang et al.[21] utilized an atmospheric general circulation model to perform real-time extra-annual prediction experiment for spring DWF in China and obtained encouraging results. After that, numerical model prediction is paid more attention to in the real-time climate prediction of DWF in China. Nevertheless, it still remains very difficult to make accurate prediction for spring DWF in China at present because key climatic factors responsible for dust weather event are not fully taken into account or DWF-related climate background is partly included in the previous studies, together with inadequacy of climate model. As such, one question should be asked that if key climatic factors that have been revealed to impact dust weather in China notably are taken into consideration as comprehensively as possible, especially including the effect of Antarctic Oscillation found most recently, whether the prediction skill of spring DWF in North China can be further enhanced. Moreover, it also remains unsolved that whether the prediction skill derived from either observation or numerical model alone can be further improved if statistical method and numerical model prediction are combined together.

Bearing these two issues in mind, the relationship between spring DWF in North China and surface air temperature (SAT), precipitation (PRE), Eurasian westerly, Antarctic Oscillation (AAO), Arctic Oscillation (AO), ENSO cycle and surface meridional wind (V_g, the north orientation is positive.) is examined here, and two prediction models for spring DWF in North China are then constructed. At last, the feasibility of the prediction method in the real-time extra-annual prediction is evaluated.

1 Data and method

The observational PRE and SAT are derived from monthly dataset over 160 stations in China Meteorological Administration. Eurasian westerly index (EUI) is defined as the normalized difference of zonally averaged geopotential height at 500 hPa along with 40°N and 65°N within 60°—120°E. Both the AO and AAO follow the definition by Thompson and Wallace[22,23]. The former is time coefficient series of the first mode of empirical orthogonal function (EOF) analysis of sea level pressure within 20°—90°N, and the latter is the time coefficient series of the first mode of EOF analysis of geopotential height at 850 hPa within 20°—90°S. The Southern Oscillation index (SOI) is obtained from the U.S. Climate Prediction Center, and it is expressed as the mean sea level pressure difference between Tahiti in South Pacific and Darwin in northern Australia. The geopotential height data used to calculate the SOI and the V_g data are from the U.S. National Centers for Environmental Prediction and National Center for Atmospheric Research.

Seasonal mean of climatic factors is delineated as the following throughout this article. Winter denotes the average of December and subsequent January and February (DJF), spring denotes the average of March, April and May (MAM), summer denotes the average of June, July and August (JJA), and autumn denotes the average of September, October and November (SON). DWF refers to the sum of the days with blown sand, floating dust and dust storm, and the corresponding observation is obtained from the National Climate Center of China Meteorological Administration. Previously, it has been indicated that the observational interannual variation of monthly DWF either in Beijing or in Tianjin station is almost the same as that in North China as a whole, and dust weather occurs mainly in spring[14,24−26]. Therefore, the sum of spring DWF in Beijing and Tianjin stations is taken together as an approximation of the whole North China in this study, in lieu of the sum of DWF in more stations in North China, aiming to avoid the influence of target area expansion on prediction accuracy.

Regression analysis method is applied here to construct prediction model for spring DWF in North China, and all of the data are firstly normalized. Then, the correlation between spring DWF in North China and seasonal mean of the aforementioned seven climatic factors is respectively calculated in order to take synergistic role of these factors into account much better. After that, an observation-based prediction model for spring DWF in North China, namely model-I, is established. In an attempt to combine statistical method with numerical model prediction, another prediction model, namely model-II, is subsequently constructed on the basis of the methodology to constitute the model-I and the 32-year hindcast experiment performed by the 9-level Atmospheric General Circulation Model developed at the Institute of Atmospheric Physics (IAP9L-AGCM)[27]. It should be emphasized that in the model-II the seven climatic factors are respectively recalculated according to their original definition by use of the IAP9L-AGCM output. At last, based on observation data and the real-time numerical model prediction result for spring climate during 2002—2006 (refer to ref. [21] for prediction method), the real-time predictability of these two models is examined.

2 Construction of the prediction model for spring DWF in North China

2.1 Relationship between spring DWF in North China and climatic factors

The geographical distribution of the correlation coefficient between spring DWF in North China and SAT, PRE and surface meridional wind are firstly calculated in order to obtain these three climatic factors' time series included in the prediction model. As for SAT and PRE, the spatial pattern of the correlation coefficient varies greatly with seasons and regions, with the largest values in North and Northeast China (Figures 1 and 2). The correlation coefficient is the largest in winter than other seasons for PRE, and it remains relatively large in winter, spring and summer for SAT. Therefore, PRE in northern Northeast China, expressed by the average value of Bo Ketu, Qi Qihaer, Hailun and Jia Musi stations, is included when constructing regression equation. Meanwhile, winter SAT in North China represented by Beijing and Tianjin stations, spring SAT in northern Northeast China represented by Hailaer, Qi Qihaer, Hailun and Fujin stations, and summer SAT in the eastern Uygur autonomous region of Xinjiang represented by Kuche and Hami stations are taken into account. In addition, it is noted that the significant positive correlation coefficients between spring DWF in North China and seasonally averaged surface meridional wind in the last year distribute from northeast to southwest in the western part of Mongolia plateau (Figure 3), which exactly suggests that the preceding intensified cold air in Mongolia is in favor of spring dust weather event in China. Therefore, area-averaged surface meridional wind within the range of 95°—102.5°E and 40°—47.5°N is utilized here.

The correlation coefficients between spring DWF in North China and the seven leading climatic factors mentioned above are listed in Table 1. It can be found that increased winter PRE in northern Northeast China, warmed summer SAT in the eastern Uygur autonomous region of Xinjiang, La Niña event and intensified cold air in Mongolia are favorable for subsequent spring dust weather in China. On the contrary, warmed SAT in North China in winter or in northern Northeast China in spring, strengthened preceding AO, AAO and EUI are unfavorable for subsequent spring dust weather in China. Meantime, the influence of SAT, V_g, Eurasian westerly and AAO on spring dust weather in North China is generally larger and lasts much longer compared to that of AO and SOI. Incidentally, the effect of AO is most prominent in winter, which is probably attributed to the fact that AO reaches its maximum in this season[28].

2.2 Observation-based prediction model for spring DWF in North China

In order to emphasize the synergistic effect of 7 leading climatic factors on subsequent spring DWF in North China, the number of the factors is gradually enlarged from 1 to 7 when constructing regression equation. Meantime, each of 7 climatic factors listed in Table 1 owns different seasonally aver aged values, and each value can be regarded as an individual fitting factor. As an attempt to reduce calculation amount to some extent,

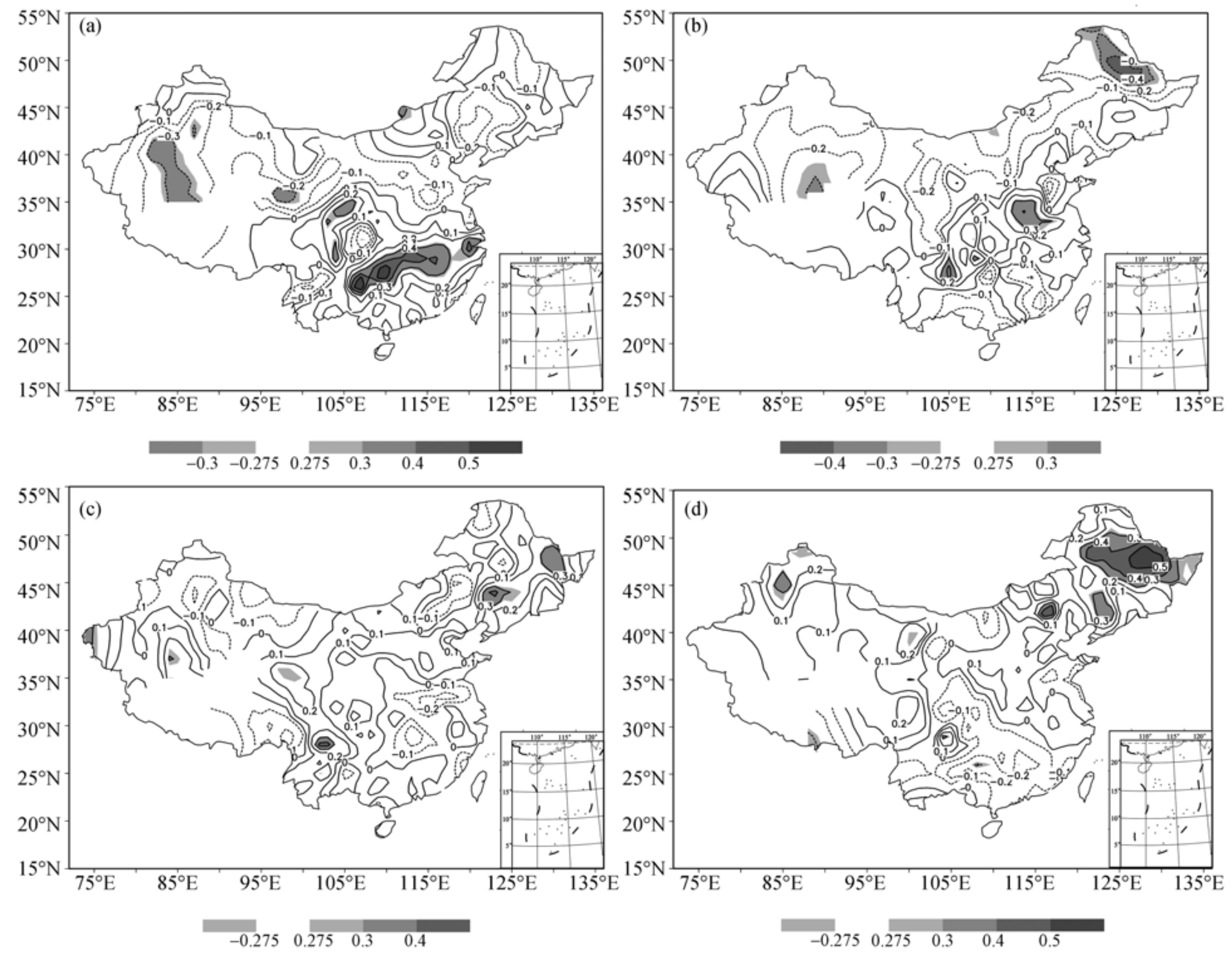

Figure 1 The geographical distribution of the correlation coefficient between spring DWF in North China and seasonally averaged precipitation in last year. (a) Spring; (b) summer; (c) autumn; (d) winter. The areas with confidence level exceeding 95% are shaded.

each of the seven factors is added into regression equation one by one according to their sequence in Table 1, and the climatic factors included in the last regression equation is remained when a new climatic factor is additionally involved. As a consequence, seven regression equations are constructed here, and the corresponding regression curves are shown in Figure 4(a)—(g). It can be found that when parts of the seven climatic factors are introduced into the regression equation, the amplitude of the regressed interannual variation of spring DWF in North China is generally weaker than observation, although the inter-decadal variation and linear trend of the regressed series agrees well with observation. On the whole, the prediction skill enlarges steadily when the involved climatic factors are gradually increased. The linear correlation coefficient enhances from initial 0.760 to final 0.933. The final regression curve (Figure 4(g)) not only accords well with observation but also overcomes the prior drawback through the late 1960s to the mid 1970s embedded in Figure 4(a)—(f). Therefore, it is of great promise to make reliable prediction for spring DWF in North China when the effects of the seven climatic factors are fully taken into consideration. This prediction model, namely model-I, can be expressed as follows:

$$Y = X_{-1} + X_{-2} + 0.151, \tag{1}$$

$$\begin{aligned} X_{-1} = &-0.024x_{1\mathrm{MAM}} + 0.382x_{1\mathrm{JJA}} - 0.124x_{1\mathrm{DIF}} \\ &+ 0.368x_{2\mathrm{DIF}} + 0.110x_{3\mathrm{MAM}} - 0.123x_{3\mathrm{DIF}} \\ &- 0.009x_{4\mathrm{MAM}} - 0.383x_{4\mathrm{DIF}} - 0.338x_{6\mathrm{SON}} \\ &+ 0.528x_{6\mathrm{DIF}} - 0.515x_{7\mathrm{JJA}} + 0.253x_{7\mathrm{SON}}, \end{aligned} \tag{2}$$

$$\begin{aligned} X_{-2} = &-0.138x_{1\mathrm{JJA}} + 0.031x_{1\mathrm{DIF}} - 0.177x_{3\mathrm{JJA}} \\ &- 0.302x_{4\mathrm{DIF}} + 0.291x_{5\mathrm{DIF}} + 0.336x_{6\mathrm{MAM}} \\ &+ 0.678x_{7\mathrm{SON}} - 0.171x_{7\mathrm{DIF}}, \end{aligned} \tag{3}$$

where the subscripts of 'X_{-1}' and 'X_{-2}' denote 'last year'

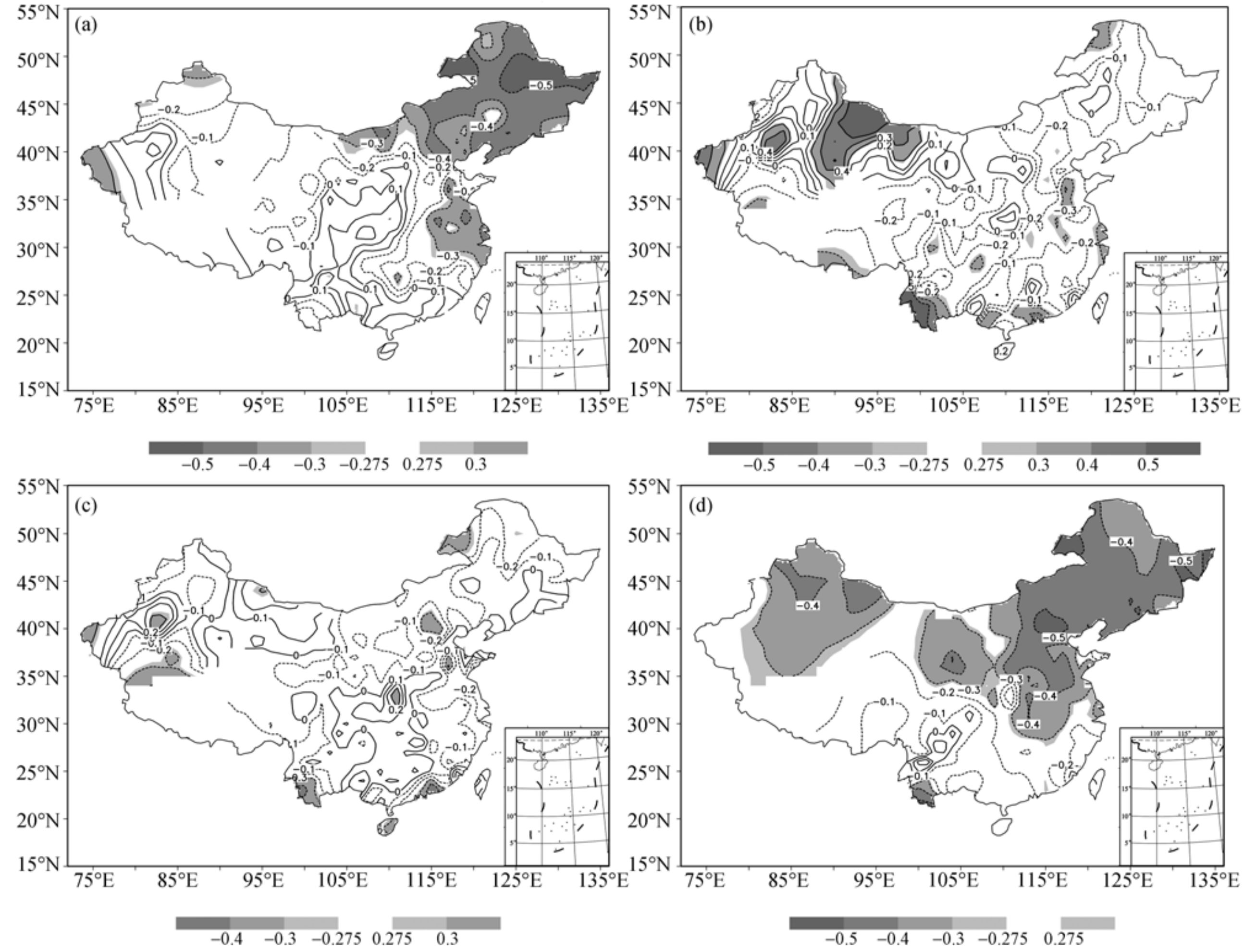

Figure 2 The geographical distribution of the correlation coefficient between spring DWF in North China and seasonally averaged surface air temperature in last year. (a) Spring; (b) summer; (c) autumn; (d) winter. The areas with confidence level exceeding 95% are shaded.

Table 1 The correlation coefficients between spring DWF in North China and the leading climatic factors[a)]

Time		Climatic factors						
		SAT	PRE	EUI	AAO	AO	SOI	V_g
Last year (Y_{-1})	MAM	−0.53	–	−0.38	−0.49	−0.13	0.16	0.36
	JJA	0.64	–	−0.07	−0.48	−0.12	0.12	0.46
	SON	–	–	−0.23	−0.39	−0.05	0.12	0.50
	DJF	−0.57	0.55	−0.11	−0.43	−0.26	0.12	0.46
The year before last year (Y_{-2})	MAM	−0.39	–	−0.47	−0.39	−0.02	0.28	0.30
	JJA	0.60	–	0.01	−0.43	−0.00	0.24	0.34
	SON	–	–	−0.36	−0.40	−0.07	0.20	0.51
	DJF	−0.51	0.29	−0.25	−0.58	−0.11	0.15	0.43

a) '–' denotes that the corresponding factor is neglected.

and 'the year before last year', respectively. x_1 to x_7 correspond to the seven climatic factors listed in Table 1, namely SAT, PRE, ⋯, and V_g. According to the above regression equation, it can be found that these climatic factors in every preceding season can influence subsequent spring dust weather event in North China. Moreover, winter and spring climatic factors are dominant. This corroborates the reasonability of the essential idea of real-time extra-annual numerical prediction in China, namely forecasting spring DWF based on the preceding winter and synchronous climate prediction results. However, it should be reminded that as far as prediction practice is concerned, two key limitations are embedded in the model-I. Firstly, the real-time prediction for spring

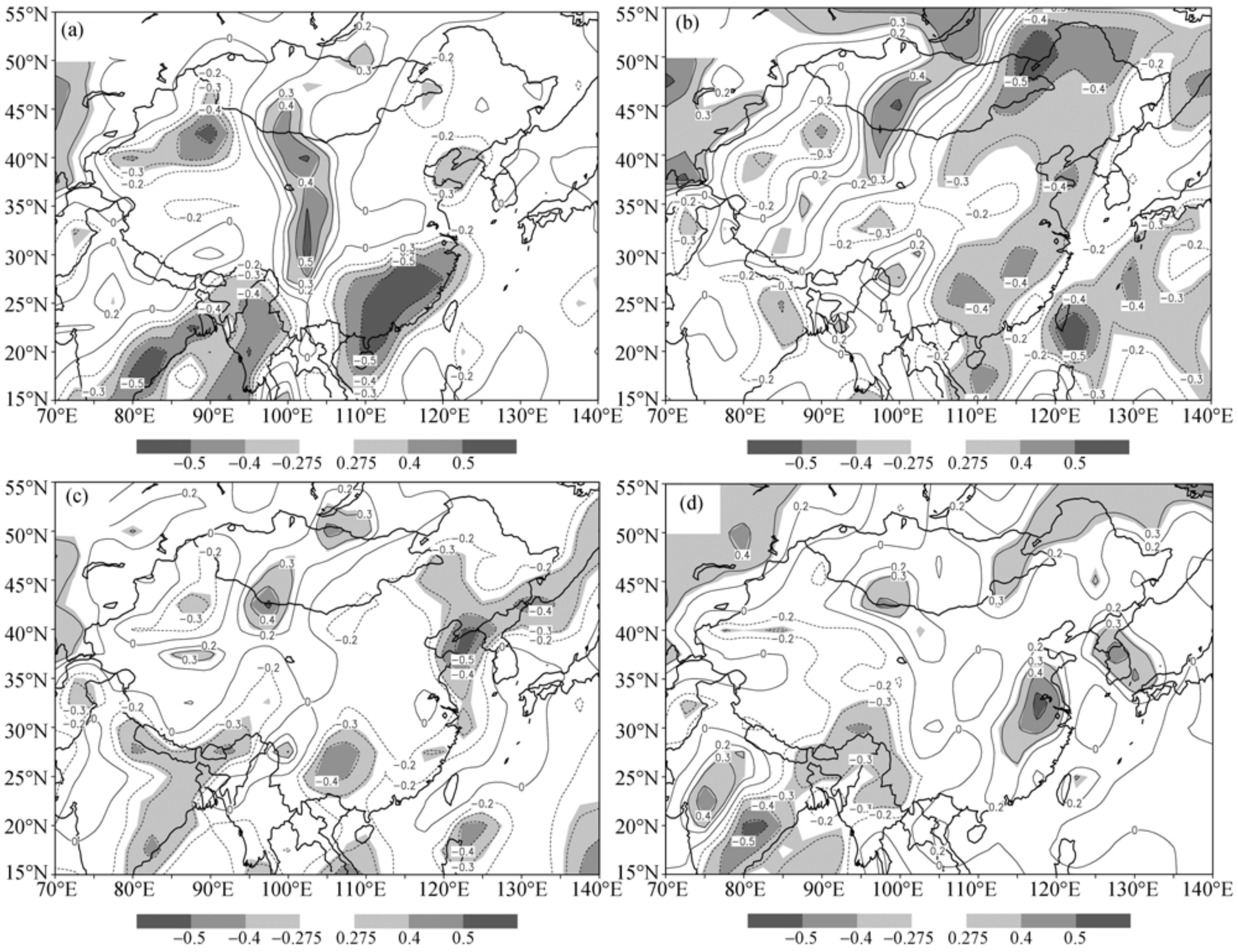

Figure 3 The geographical distribution of the correlation coefficient between spring DWF in North China and seasonally averaged surface meridional wind in last year. (a) Spring; (b) summer; (c) autumn; (d) winter. The areas with confidence level exceeding 95% are shaded.

DWF in China is usually carried out in the end of winter or in the beginning of spring. However, winter observation data, which are necessary for the model-I, cannot be attained at that time. Secondly, synchronous spring messages of these seven climatic factors are not included in the model-I, although they have been documented to be closely related to spring dust weather occurrence[2,6,15,17,29]. The importance of synchronous spring climatic factors can be corroborated here in Table 2, especially for SAT, AAO and V_g. Therefore, constructing a prediction model that can not only provide accurate spring DWF prediction as early as possible but also can make the best of related climate data will undoubtedly improve the prediction skill of spring DWF in North China. As such, an operational approach is to make use of available real-time prediction results of climate model.

Table 2 The correlation coefficients between spring DWF in North China and synchronous observed climatic factors during 1955−2001

Climatic factors	SAT	EUI	AO	AAO	SOI	V_g
Correlation coefficient	−0.58	0.13	−0.28	−0.48	0.26	0.52

2.3 Prediction model for spring DWF in North China based on hindcast data reproduced by the IAP9L-AGCM

Some advances in the prediction of DWF in China has been made by use of the IAP9L-AGCM since related investigation is initiated at the Institute of Atmospheric Physics, Chinese Academy of Sciences[21,30]. Originally, the predicted cold air intensity, PRE and SAT in current winter and forthcoming spring, which are reproduced by the real-time extra-annual climate prediction performed by the IAP9L-AGCM, are generally used as predictors of forthcoming spring DWF in North China. This ap-

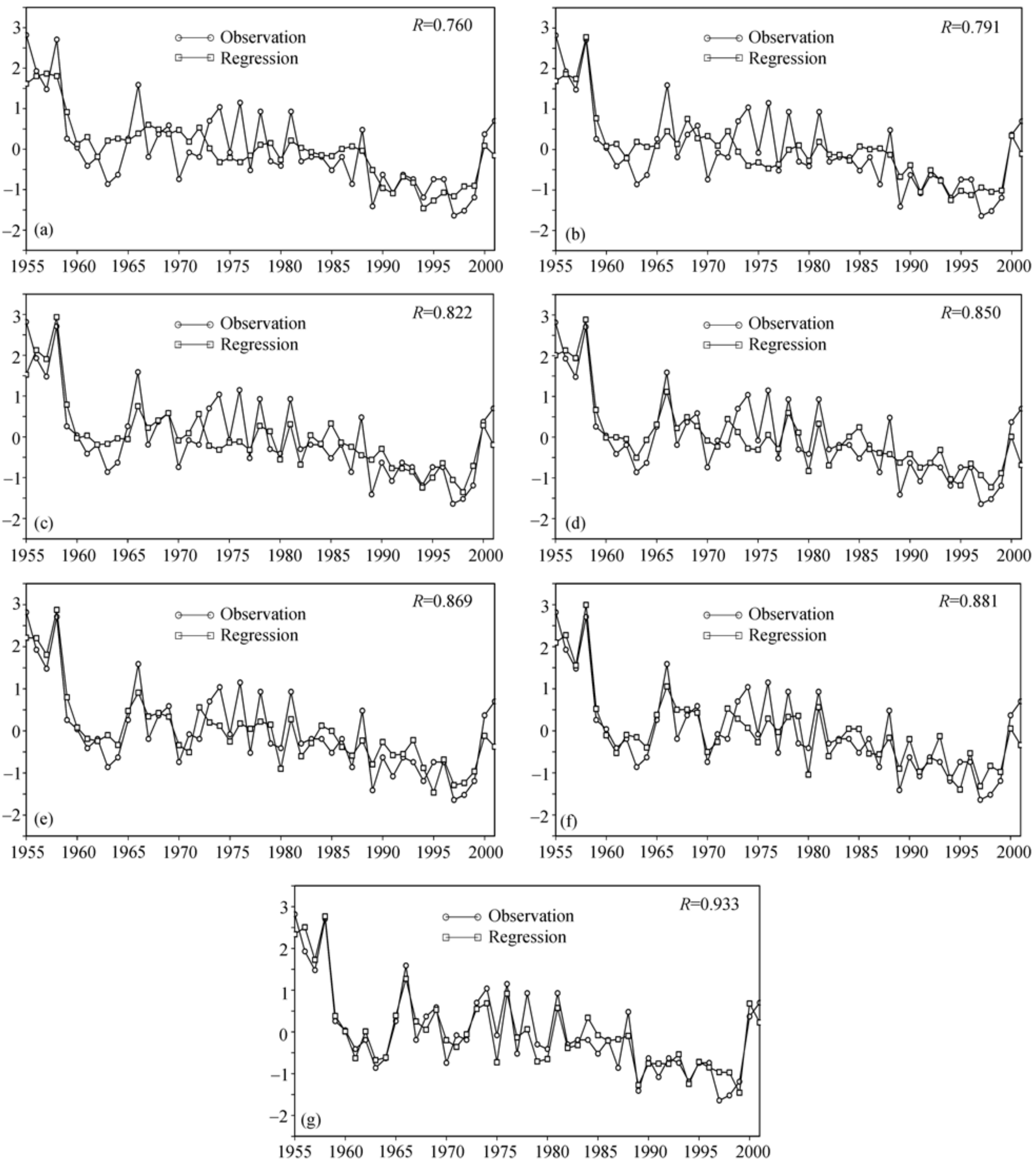

Figure 4 The normalized interannual variation of spring DWF in North China as derived from observation and the model-I regression based on observational climate data. The involved climatic factors are (a) SAT; (b) SAT and PRE; (c) SAT, PRE and EUI; (d) SAT, PRE, EUI and AAO; (e) SAT, PRE, EUI, AAO and AO; (f) SAT, PRE, EUI, AAO, AO and SOI; (g) SAT, PRE, EUI, AAO, AO, SOI and V_g.

proach is relatively simple compared to the model-I, although it is physically reasonable to some extent. Therefore, we expect to construct a prediction model for spring DWF in North China on the basis of both the idea to set up the model-I and the real-time climate prediction result reproduced by the IAP9L-AGCM, aiming to further improve the real-time prediction skill of spring DWF in North China and its interannual variation.

Accordingly, the values of 6 climatic factors listed in Table 2 are firstly calculated in accordance with their original definition by use of the 32-year (1970—2001) ensemble hindcast data reproduced by the IAP9L-AGCM. Another prediction model for spring DWF in North China, namely model-II, is then set up in terms of the idea to generate the model-I. Evaluation of the potential predictability of the model-II indicates that the correlation coefficient between prediction and observation can reach up to 0.948. As shown in Figure 5, the prediction agrees well with observation both in interannual variation throughout the period and detailed values in some years. It should be mentioned that DWF prediction can be made half year in advance when the model-II is applied. On the whole, the prediction derived from the model-II is much more accurate and operational than the original approach that makes the corresponding prediction on the basis of the DWF related climate background alone as predicted by the IAP9L-AGCM, and the model-II consequently exhibits higher potential predictability. The regression equation of the model-II is as follows:

$$Y = X_0 + X_{-1} + X_{-2} + 0.314, \tag{4}$$

$$X_0 = -0.803\,x_{1\mathrm{MAM}} + 1.167\,x_{2\mathrm{MAM}} - 0.623\,x_{3\mathrm{MAM}} + 0.528\,x_{4\mathrm{MAM}} - 0.107\,x_{5\mathrm{MAM}}, \tag{5}$$

$$X_{-1} = 0.348\,x_{1\mathrm{DIF}} + 0.840x_{2\mathrm{MAM}} + 0.216\,x_{3\mathrm{DIF}} - 0.525\,x_{4\mathrm{DIF}} - 0.474\,x_{5\mathrm{DIF}} - 0.277\,x_{6\mathrm{DIF}} + 0.333x_{6\mathrm{MAM}}, \tag{6}$$

$$X_{-2} = -0.256\,x_{1\mathrm{DIF}} - 0.539\,x_{2\mathrm{DIF}} + 0.164x_{3\mathrm{DIF}} + 0.567x_{3\mathrm{MAM}} - 0.580x_{5\mathrm{DIF}}, \tag{7}$$

where the subscripts of ‘X_0’, ‘X_{-1}’ and ‘X_{-2}’ denote ‘current year’, ‘last year’ and ‘the year before last year’, respectively. x_1 to x_6 correspond to 6 climatic factors listed in Table 2, namely SAT, EUI, ···, and V_g. In contrast with the model-I, the model-II is significantly improved in the following two aspects. One is inclusion of synchronous climatic information of spring dust weather event, and the other is that the lead time of real-time prediction is brought forward from the model-I’s one season to half year. Additionally, PRE is not involved in the model-II. At present, the common drawback to predict precipitation in the middle and high latitudes by current atmospheric general circulation models is also embedded in the IAP9L-AGCM, and the reasonable prediction result cannot be obtained over there even if correction method is applied[31]. Actually, how to improve the prediction skill of precipitation itself still remains unsolved so far.

2.4 Real-time prediction for spring DWF in North China using the prediction models

Now that the two prediction models constructed above display large potential predictability for the past changes in spring DWF in North China, the final question concerned here is how about their real-time prediction skills in practice. Accordingly, the real-time prediction for spring DWF in North China during 2002—2006 are taken as examples to perform below by use of these two models. The observation data used in the model-I have been described above, and the ensemble hindcast data used in the model-II are replaced by the real-time climate prediction data reproduced by the IAP9L-AGCM.

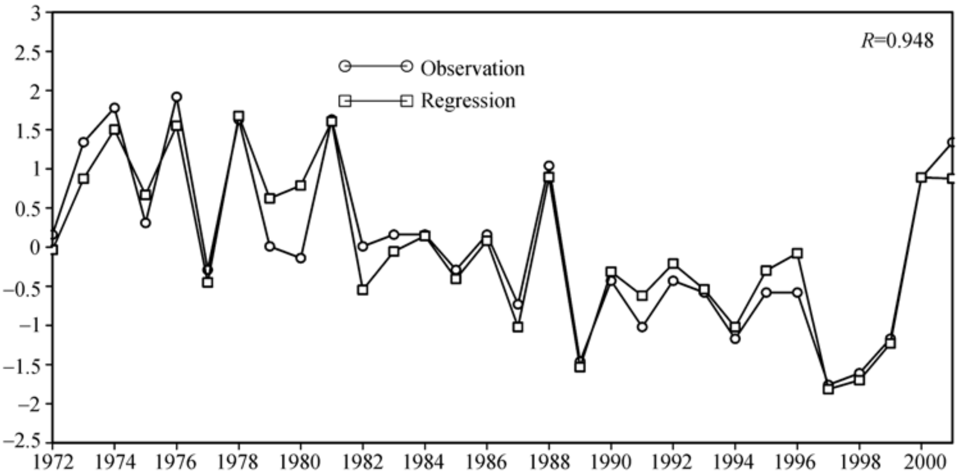

Figure 5 The normalized interannual variation of spring DWF in North China during 1972—2001 as derived from observation and the model-II regression based on the hindcast data reproduced by the IAP9L-AGCM.

As indicated in Figure 6, both the values during 2002—2004 and enhanced trend throughout the period of spring DWF in North China are successfully predicted by the model-I. In contrast, the prediction result for 2005 is unreasonable, which may be partially due to that the effect of spring climate signals in 2005 is much larger than that in the other years. When the model-II is used, both the interannual variation and linear trend (figure omitted) of spring DWF in North China during 2002—2005 are well predicted half year ahead. However, the prediction result for 2006 is unreasonable, which bears closely on the IAP9L-AGCM capacity to predict synchronous climate background of spring dust weather event. As a whole, as far as the current prediction skill of spring DWF in China is concerned, the performances of these two models are satisfactory. The pertinent studies, of course, are called for to further enhance the prediction skill in the future.

As for the model-II, the ensemble hindcast data reproduced by the IAP9L-AGCM with prescribed SST are utilized, and the corresponding prediction skill consequently depends on SST accuracy to a large extent. Then,

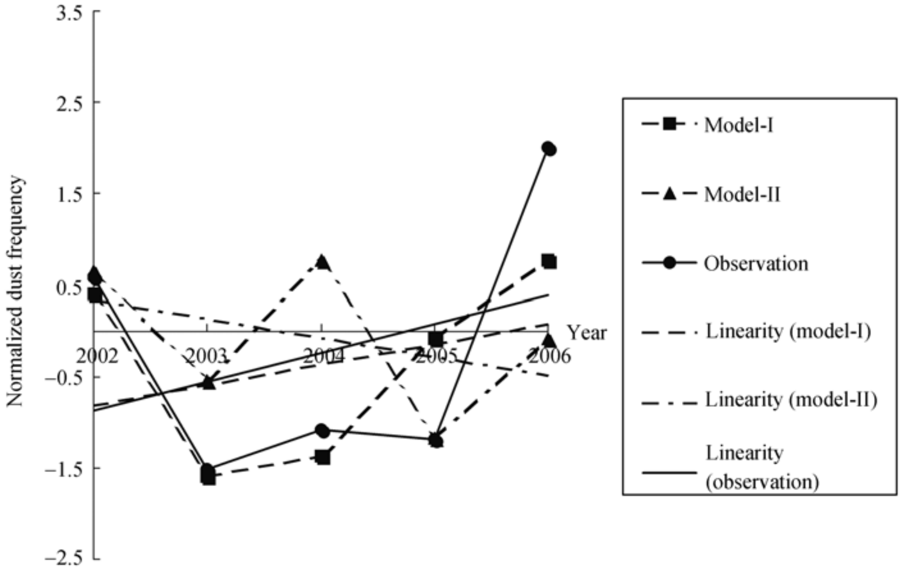

Figure 6 The normalized interannual variation and linear trend of spring DWF in North China during 2002—2006 as respectively derived from observation and the real-time predictions of the model-I and model-II base on predicted SST.

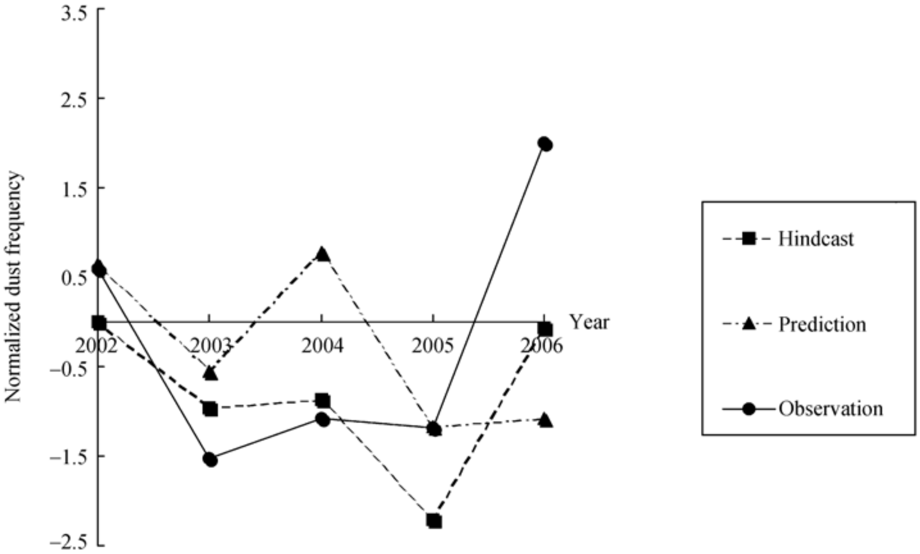

Figure 7 The normalized interannual variation of spring DWF in North China during 2002—2006 as respectively derived from observation, the real-time prediction of the Model-II based on predicted SST, and the hindcast prediction of the model-II based on observed SST.

does the prediction skill become larger if fully accurate SST is taken? Comparing the model-II results as respectively derived from the IAP9L-AGCM real-time prediction data and hindcast data indicates that the prediction skill of the latter is much better than that of the former either in individual years, e.g. 2003, 2004 and 2006, or as a whole. However, discrepancies between observation and prediction still cannot be fully reconciled even if the hindcast data is applied (Figure 7). This should be intrinsically related to the sensitivity of the climate prediction skill of the IAP9L-AGCM to SST signals in key ocean regions, which needs to be further examined.

3 Conclusions and discussions

In this paper, the feasibility to construct prediction models for spring DWF in North China using either observation or climate model data is explored, and the prediction models' reliability in practice is then examined. Firstly, the statistically significant relationship between spring DWF in North China and SAT, PRE, Eurasian westerly, AO, AAO, South Oscillation and V_g are confirmed by use of correlation analysis. After that, a prediction model, named model-I here, for spring DWF in North China is established by constituting a regression equation of the above seven climatic factors. The correlation coefficient between observation and the model-I prediction during 1955—2001 reaches 0.933, suggesting a large potential predictability. However, two deficiencies are embedded in the model-I when it is applied in practice. One is time limitation, and the other is that synchronous climate signal of spring dust weather event is not taken into account.

As an attempt to overcome these two deficiencies, another prediction model, namely model-II, is subsequently set up on the basis of both the idea to set up the model-I and the extra-annual ensemble hindcast data reproduced by the IAP9L-AGCM. The correlation coefficient between observation and the model-II prediction during 1972—2001 is high up to 0.948. Therefore, the model-II can not only make more precise prediction than the original approach based on the IAP9L-AGCM alone, but also can bring forward the lead time of real-time prediction from the model-I's one season to half year. At last, the real-time predictability of these two models for spring DWF in North China during 2002—2006 is examined. It follows that both models exhibit high prediction skill for both interannual variation and linear trend of spring DWF in North China, and each is also featured by different advantages. Therefore, the prediction skill of spring DWF in North China can be enhanced to a certain extent if these two models, especially the model-II, are applied in practice.

Throughout this research, it is noted that winter and spring signals of the seven climatic factors play dominant roles in spring dust weather event, and some summer and autumn climate signals are also important and hence should be given much attention to in further studies. In addition, when only the factors correlating best with spring DWF in North China are utilized to construct regression equation, the corresponding fitting result is not necessarily good. On the contrary, some climatic factors act important roles in the prediction model, although the correlation coefficients between them and spring DWF in North China are not so large as others. Based on the above, it can be judged that the climate background responsible for the occurrence of spring dust weather event in North China is highly complicated, and the concerned DWF prediction needs to be further investigated.

Furthermore, many pertinent questions should be addressed in future studies. For example, the prediction models set up here only focus on spring DWF in North China, and the methodology should be widely applied to other regions where dust weather also occurs frequently. As for different regions, these two models' regression equations need to be reconstructed, and new climatic factors maybe need to be additionally involved, such as vegetation condition[32] and Arctic sea ice[33]. Meanwhile, the accuracy of the model-II prediction is largely confined by the following two aspects. One is that the horizontal resolution of the IAP9L-AGCM is too coarse to reliably capture regional changes of the climatic factors, especially for PRE, SAT and V_g, and the other is that the reliability of the climate model data included in the model-II is essentially restricted by the prediction skill of the IAP9L-AGCM itself. In addition, coupled ocean-atmosphere process has been documented to act a crucial role in monsoon region[34]. However, the reproducibility of current models to simulate East Asian monsoon climate is weak as a whole. Therefore, when climate model is continually developed, climate characteristic and corresponding physical mechanism in monsoon region should be further investigated so as to improve coupled climate model system. At last, it should be mentioned that climate conditions are highly complicated in China, and radiation forcing change due to local dust weather maybe influence regional climate largely. Therefore, using regional climate model to predict dust weather event should be promising. In recent years, several advances have been made in this aspect, in which dust related processes are introduced into regional climate model to make prediction of dust weather event[35,36]. This topic will be emphasized in our future researches.

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