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Short communication

Predictor-based error correction method in short-term climate prediction

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Abstract

In terms of the basic idea of combining dynamical and statistical methods in short-term climate prediction, a new prediction method of predictor-based error correction (PREC) is put forward in order to effectively use statistical experiences in dynamical prediction. Analyses show that the PREC can reasonably utilize the significant correlations between predictors and model prediction errors and correct prediction errors by establishing statistical prediction model. Besides, the PREC is further applied to the cross-validation experiments of dynamical seasonal prediction on the operational atmosphere-ocean coupled general circulation model of China Meteorological Administration/National Climate Center by selecting the sea surface temperature index in Niño3 region as the physical predictor that represents the prevailing ENSO-cycle mode of interannual variability in climate system. It is shown from the prediction results of summer mean circulation and total precipitation that the PREC can improve predictive skills to some extent. Thus the PREC provides a new approach for improving short-term climate prediction.

Keywords: Short-term climate prediction; Seasonal prediction; Predictor; Error correction

1. Introduction

In the past decades, short-term climate prediction has gradually become an important issue concerned internationally as various climate disasters occur frequently [1]. Especially since the 1990s, many research and operation organizations in the world have established short-term climate prediction systems. But practical prediction levels based on these systems are not yet high. Generally speaking, seasonal prediction skills mostly distribute over tropics and oceans, whereas skills in middle- and high-latitude areas are very low, which is the main difficulty existing in international researches [2]. At present, both the physical statistical method and the dynamical method based on numerical model have been widely used in operational short-term climate prediction [3]. As a current preferred approach, the dynamical seasonal prediction is relatively unsatisfactory, but the physical statistical method can still give considerable or better prediction skill [4]. Actually, it is a perspective approach for improving predictive effect to combine the two methods and exert the superiority of each other [5–13]. Here, the key problem is how to effectively combine them [14], which needs further investigation.

As we have known, prediction errors vary with the state of climate system because model errors vary with state. Therefore, in previous researches, many statistical experiences have been acquired for the calibration of model prediction by identifying principal correlation patterns based on techniques such as canonical correlation analysis (CCA), empirical orthogonal function (EOF) analysis, and singular value decomposition (SVD) [15–17]. But these schemes are inclined to technical problems and the related works are short of understanding the features of model

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prediction errors and exploring their formulated physical processes, which is very important for the evaluation and development of models. In fact, the variability of climate system directly or indirectly influences the configuration and evolution of model errors, and such influences will further be reflected in the distribution and change of prediction errors. In other words, prediction errors could be manifested by some statistical characteristics as are influenced by the variability of climate system state. For instance, the analogy between initial states may be corresponding to the analogy between model prediction errors, which has been applied to error correction [13,18]. Moreover, different prediction errors could appear in the ENSO warm year, cold year and normal year, respectively [19].

Thus it is very necessary to examine the relationship and impact between model prediction errors and the state of climate system. This will not only help to evaluate the performance of model and provide reference for improving model, but also benefit to develop the new prediction strategy and methodology for correcting prediction errors. In the present paper, the relationship between a predictor and seasonal prediction errors of model will be examined by considering the characteristic representing the prevailing mode of interannual variability in climate system as the physical predictor. Further, a new method of error correction will be developed based on such a relationship and also verified by conducting prediction experiments.

2. Data

At present, an operational system for short-term climate prediction has been established in China Meteorological Administration/National Climate Center (NCC) [20,21], which covers a 23-year hindcast dataset of 1983–2005 produced by NCC atmosphere-ocean coupled general circulation model (CGCM). Here, we use annual June–August ensemble-mean data predicted at the end of February and the initial values of atmospheric model generated at 00Z UTC on the last 8 days of February from the NCEP/NCAR reanalysis dataset (NNRA). The initial values of oceanic model are from the global ocean data assimilation system of NCC. All of these initial values are perturbed and combined into 48 ensemble members of dynamical seasonal prediction.

Further, seasonal prediction errors are generated by utilizing the 23-year summer mean 500 hPa geopotential height and total precipitation fields from the hindcast data, the NNRA and the CMAP analysis data. As we have known, there are many characteristics that can reflect the principal modes of climate system from different sides. Without losing generality, the sea surface temperature index in Niño3 region (denoted as NINO3I here), that is the characteristic standing for the prevailing mode of interannual variability in climate system, is regarded as the physical predictor, and the time dataset of the NINO3I can be downloaded from the NOAA/CPC website.

3. Correlation analysis based on the NINO3I

First of all, correlation analyses are conducted by calculating time correlation coefficient (TCC) between the early autumn, winter, spring and simultaneous summer NINO3Is, and prediction errors of summer mean 500 hPa geopotential height and total precipitation, respectively.

3.1. Relationship between the NINO3I and the prediction errors of summer mean circulation

In the following, Fig. 1 gives the correlation map between the NINO3I and the prediction errors of summer mean 500 hPa geopotential height.

It can be seen from Fig. 1 that the significant positive correlations between the NINO3I and the prediction errors of summer mean 500 hPa geopotential height distribute over the whole tropics, which is related with the physical sense represented by the NINO3I because the ENSO variability primarily influences low-latitude areas. Simultaneous correlations are slightly weaker than the early ones and are characterized by clearly weaker correlation over the equatorial Pacific areas where significant ranges appreciably decrease. In contrast, the early-winter correlations are the strongest in the low latitude where there are some significant areas beyond the 99.9% confidence level over the Asian-Australian monsoon and western Pacific areas. Such situations are very evident on the correlation maps corresponding to the early autumn and spring, which indicates the predominent impacts of the ENSO variability on the prediction errors of summer circulation over the areas. As a whole, seldom of correlations are significant over extratropics and there is similar situation between the early and simultaneous maps. Thus, the relationship between the prediction errors of summer circulation over extratropics and the low-latitude ENSO cycle is not significant. Moreover, the large-range significant positive correlations in the low-latitude areas show that the prediction errors of summer circulation will become larger when the NINO3I gets big, which reflects that the simulation capability of the present CGCM to the ENSO event is unsatisfactory.

3.2. Relationship between the NINO3I and the prediction errors of summer total precipitation

Fig. 2 further gives the correlation map between the NINO3I and the prediction errors of summer total precipitation.

In Fig. 2, most of significant correlations lie on oceans and the early correlation map is featured by significant positive and negative correlations over the tropical Pacific, which indicates that the ENSO cycle has evident impact on the model prediction errors of precipitation over this area. Besides, the significant correlations corresponding to the early autumn and winter distribute over the tropical Indian Ocean, the northwestern Pacific and a part of southern

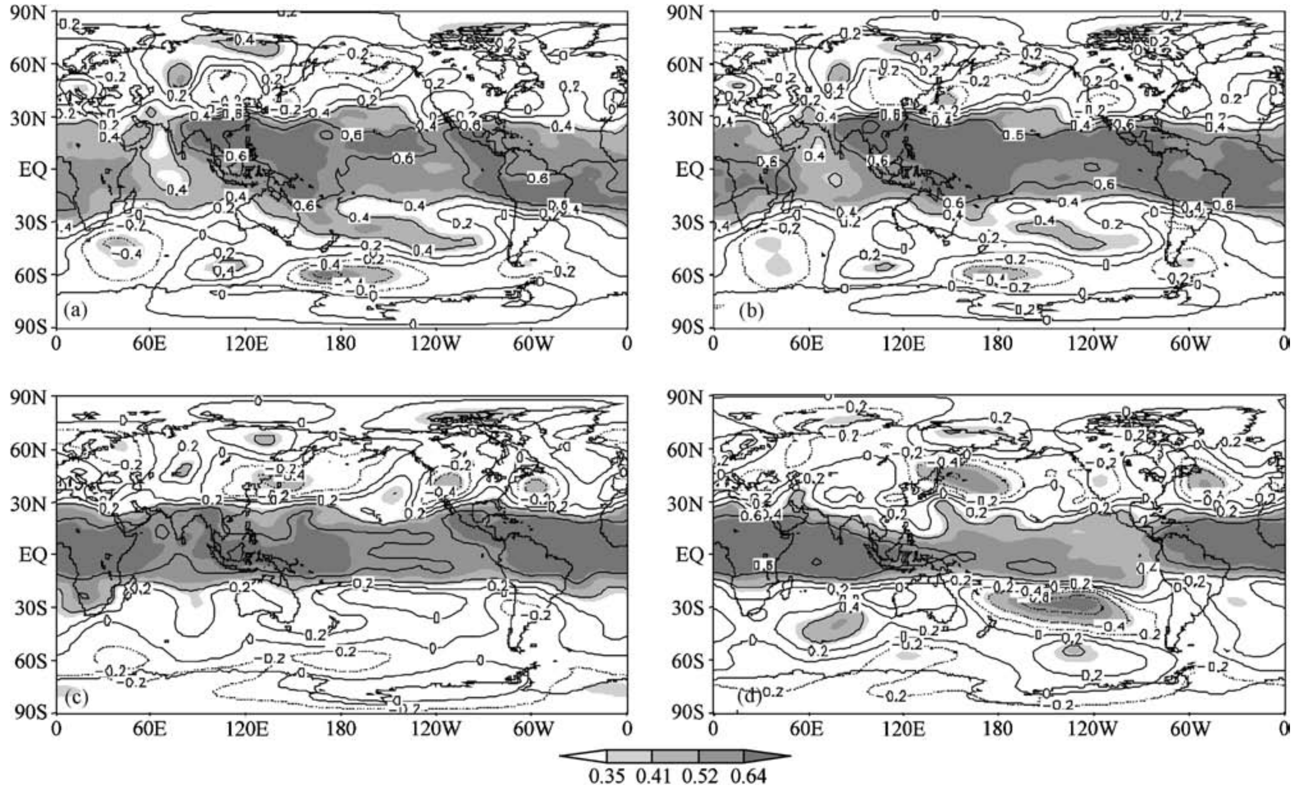

Fig. 1. The distribution of TCCs between the prediction errors of summer mean 500 hPa geopotential height and the early autumn (a), winter (b), spring (c) and simultaneous summer (d) NINO3Is, respectively, where the interval of contours is 0.2, and numbers 0.35, 0.41, 0.52 and 0.64 stand for 90%, 95%, 99% and 99.9% confidence levels, respectively, based on Student's *t*-test.

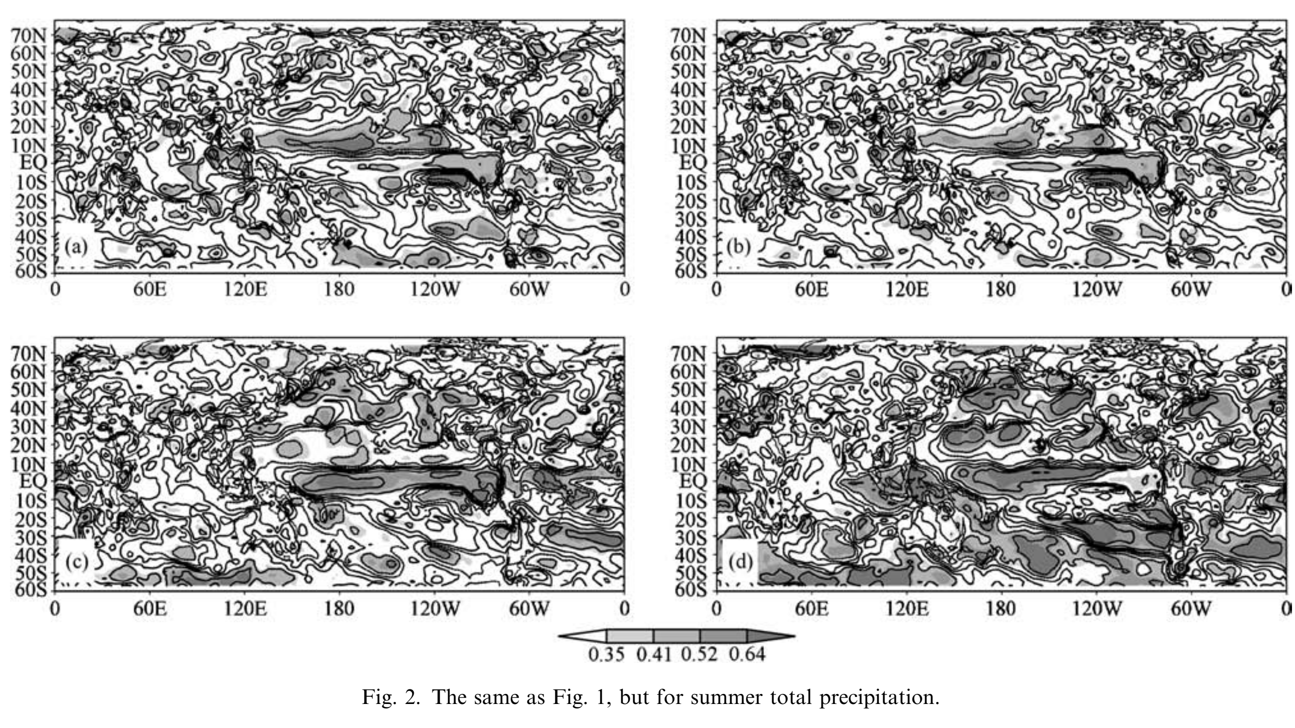

Fig. 2. The same as Fig. 1, but for summer total precipitation.

Pacific area, and those to the early spring mostly lie in the northern Pacific, the Atlantic, and the southern Indian Ocean, and so on. As a comparison, the simultaneous correlations are much more evident than the early ones and there are zonal significant correlation areas over the Pacific, the Atlantic and the eastern Indian Ocean except the western tropical Indian Ocean. As a whole, the distribution of correlations on land is very scattered and disordered with a few significant areas. For simultaneous correlations, significant areas are very small and only distribute in the western North America and southeastern South America, which is even smaller when compared with correlation situations of the early spring.

4. A new predictor-based error correction method

The results of above correlation analyses show that the NINO3I has significant impacts on the prediction errors of summer 500 hPa height and precipitation to different extents. Indeed, there are many physical factors reflecting the principal modes of climate system, so it is necessary to select more factors and conduct more detailed diagnoses. For the convenience of investigation, only the representative results of correlation analyses based on the NINO3I are given here. Anyway, the certain significant correlations between the physical factor regarded as the characteristic of the variability of climate system state and model prediction errors should vary with different physical factors and model output variables.

According to the fore-mentioned correlationship, one may infer the physical processes that the physical factors influence the distribution of model prediction errors. Namely, the variability of climate system characterized by the change of physical factors will directly or indirectly influence the configuration and evolution of model errors, and further reflect the distribution and change of prediction errors. As we know, in those conventional methods for statistical prediction, the basic procedure is to search predictors with physical significance for some predictand, and further to establish statistical prediction model on the basis of the significant correlationship between the predictors and predictand [3,22]. Consequently, based on the above-mentioned correlationship, in terms of the same procedure as conventional statistical prediction, one can establish the statistical prediction model (e.g. regression equation) between predictor and prediction errors, and estimate unknown prediction errors from the known predictor, and entirely carry out the calibration of model prediction. So the prediction errors of model may be effectively corrected by using the above significantly predictive correlationship between the early predictor and prediction errors.

In terms of such an essential idea, a new method of PredictoR-based Error Correction (predictor error correction or predictor correction for short, denoted as PREC) is put forward here. In the new prediction method, the calibration of model prediction can be carried out on the basis of model prediction results by selecting the predictor correlated significantly with prediction errors and establishing the statistical prediction model between the predictor and prediction errors. Evidently, the PREC follows the idea of predicting the prediction errors of dynamical model [18] and the above results of correlation analyses provide physical basis for the PREC. Furthermore, the advantage and feature of the PREC is to make full use of a good many achievements in researches of physical statistics on the basis of model prediction. On one hand, many physical predictors have been developed in previous works to represent the characteristics of spatial modes with different scales in the climate system, and many of them have been applied to statistical prediction. Thus one can select some representative predictors with physical meanings from them for the PREC. On the other hand, in the spatio-temporal range affected by predictors, since there are close linkages between predictors and simulation biases resulted from model errors, it will be very hopeful for reducing the impacts of model errors on prediction results and improving dynamical prediction that the significant correlationship between predictors and prediction errors is used to calibrate model prediction.

5. Results of prediction experiment

In the following, the cross-validation is used for prediction experiments, in which any year from the 23 years is randomly selected as the objective year and the known information in residual years is used to predict summer circulation and precipitation in objective year. Time correlation coefficient (TCC) is employed as verification score for prediction results.

5.1. Prediction results based on the SPEC

As a comparison, Fig. 3 gives the CGCM predictions of summer mean 500 hPa geopotential height based on systematic prediction error correction (SPEC). Here, the SPEC has removed the bias between real climatology and

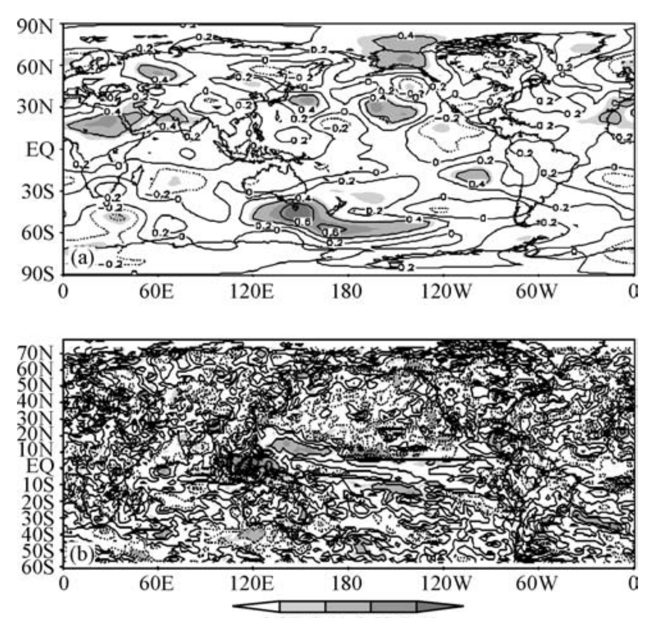

Fig. 3. The distribution of TCCs between predictions and verifications of summer mean 500 hPa geopotential height (a) and total precipitation (b) based on the SPEC. Other notes are the same as in Fig. 1.

model climatology (excluding the objective prediction year) from prediction.

It can be seen from Fig. 3(a) that the predictive effect based on the SPEC only is unsatisfactory over the most of globe especially in the low-latitude areas with high predictability, where TCCs between prediction and verification are relatively small and those in only a few areas are significant (beyond a 90% confidence level). Furthermore, in Fig. 3(b), the contours of TCCs corresponding to summer precipitation look very scattered with only a few areas beyond a 90% confidence level, and the model prediction skill based on systematic error correction only is very significant over tropical oceans, which also is the main difficulty in current short-term climate prediction [2].

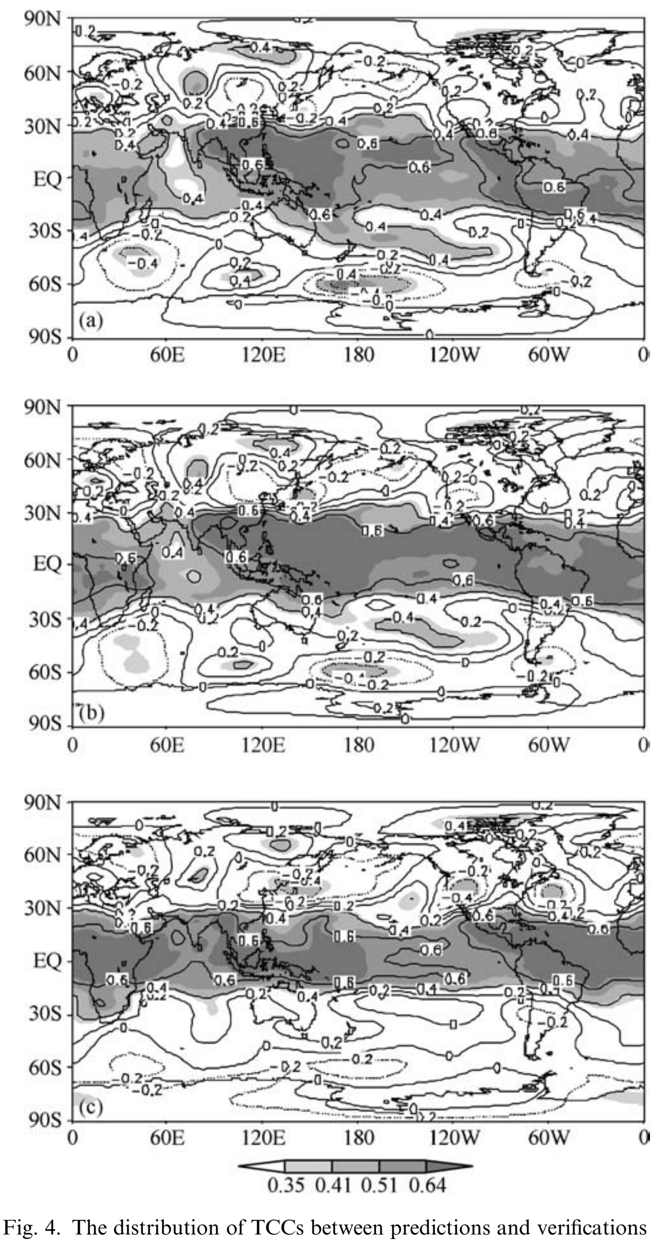

Fig. 4. The distribution of TCCs between predictions and verifications of summer mean 500 hPa geopotential height based on the PREC by using the early autumn (a), winter (b) and spring (c) NINO3Is, respectively. Other notes are the same as in Fig. 1.

5.2. Prediction results based on the PREC

The essential difference between the PREC and the SPEC lies in the fact that the former's error correction varies with the climate system state, which helps to improve predictive effect. Here, the simple-linear regression method is applied to statistical prediction of prediction errors for the PREC. As the NINO3Is in early seasons have different correlationships with prediction errors, so the predictive effects based on the predictors used for different early seasons have been investigated. Figs. 4 and 5 give the prediction results of summer mean 500 hPa geopotential height and total precipitation based on the PREC, respectively.

Compared to Fig. 3(a), the middle- and low-latitude areas in Fig. 4 are almost covered by significant positive correlations, which exhibits that the predictions of summer circulation based on the PREC become obviously better than those based on the SPEC. Especially in the correlation maps corresponding to the early autumn and winter predictors, there are quite a few extremal centers of significant high correlations at the 99.9% confidence level over the Asian, African and South American monsoon areas, which may provide some valuable references for seasonal prediction in these monsoon areas.

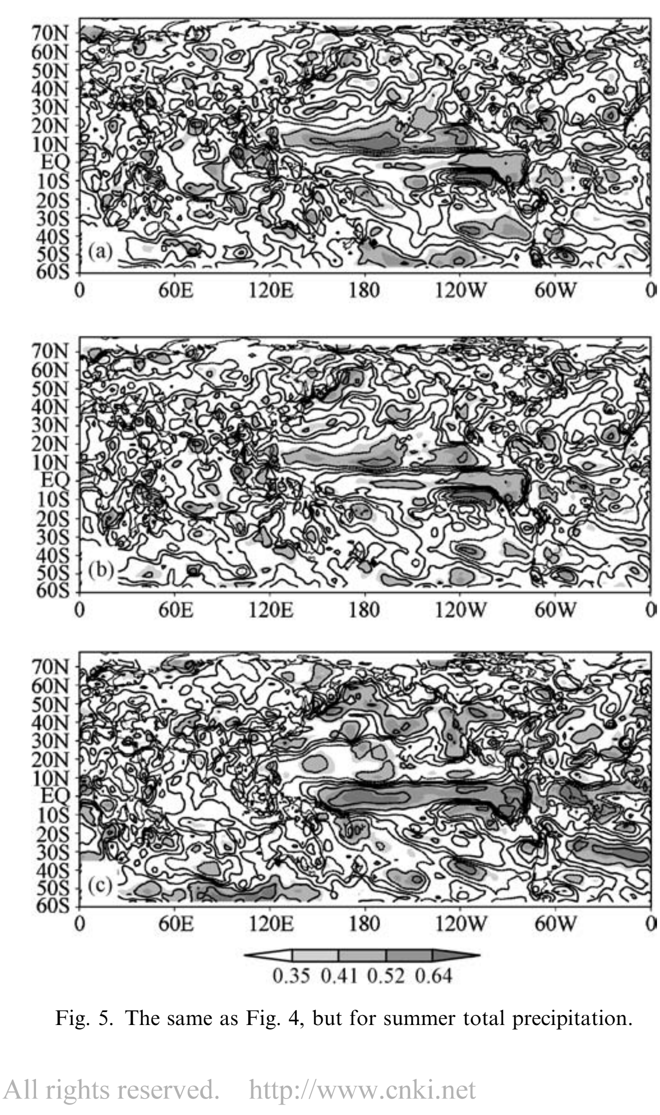

Fig. 5. The same as Fig. 4, but for summer total precipitation.

It can be seen from Fig. 5 that the contours of TCCs are still very disordered and most significant correlations exist over tropical oceans with a larger range and better confidence than those in Fig. 3(b). Especially, in the correlation maps corresponding to the early autumn and spring predictors, there are significant correlations over some middle-latitude areas in southern hemisphere. Moreover, it can be also found that the significant positive correlation areas in Fig. 4 are very accordant with the significant positive and negative correlation areas in Fig. 1, and so as in Figs. 5 and 2, which show a slightly decreased accordance. All of this show that the variances of prediction errors over the low-latitude area are primarily from the NINO3I. Thus prediction skill in this area can be evidently improved in terms of the predictor-based error correlation.

In conclusion, the PREC has clearly better performance for improving dynamical prediction than the SPEC by effectively utilizing the significant correlationship between the early autumn, winter and spring NINO3Is and prediction errors, and estimating and correcting prediction errors based on the early predictors. However, it can also be seen that except for the low-latitude areas, the NINO3I is unsuitable for being an early predictor according to the PREC for the most areas of extratropics. Thus it will be validated by using other physical predictors in future studies. Indeed, all of the above conclusions originate from current CGCM and more experiments still need to be conducted on other models for validating the PREC.

6. Summary and discussion

Development of prediction strategy and methodology for short-term climate prediction is now a very important issue and has attracted a lot of attentions. In this paper, in terms of the characteristic that model prediction errors vary with climate system state, the sea surface temperature index in Niño3 region is selected as the physical predictor and is used to examine the correlationship between it and the prediction errors of summer mean circulation and total precipitation. Analyses show the physical processes that the physical factor influences the distribution of model prediction errors. Namely, the variability of climate system state characterized by the change of physical factor will directly or indirectly influence the configuration and evolution of model errors, and further influence the distribution and change of prediction errors. Thus, a new prediction method of predictor-based error correction (PREC) is put forward by utilizing the significant correlationship between the early predictor and model prediction errors. In the PREC, the prediction results of dynamical model may be calibrated to some extent by establishing the statistical prediction model between the predictor and prediction errors.

Furthermore, the PREC has been applied to the cross-validation of dynamical seasonal prediction. Results of prediction experiments show that compared with the conventional systematic error correction, the PREC can improve the dynamical predictions of summer circulation and precipitation to different extents. Thus the PREC presents a new approach for improving short-term climate prediction by utilizing statistical experiences. Although the PREC is originated from seasonal scale, its essential idea should be suitable for solving prediction problems on various spatio-temporal scales. Therefore, the PREC has a wide range of applications and development perspective. At the moment, the predictive effect for extratropics is still unsatisfactory based on the NINO3I only, so it will be quite necessary to adopt other physical predictors in the future work. Moreover, the PREC needs establishing statistical prediction model, which could introduce new errors into prediction results, thus how to solve such a problem will be the next step in the future studies.

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