Coupled Predictability of Seasonal Tropical Precipitation

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Introduction

Prediction of seasonal-to-interannual climate variations and the associated uncertainties using multiple coupled models has become operational. However, how to determine the practical predictability of the tropical seasonal precipitation in coupled climate models remains an unresolved issue. We propose and compare two methods. The first relies on identification of the "predictable" leading modes of the interannual variations in observations and multi-model ensemble (MME) hindcast results. The predictability is quantified by the fractional variance accounted for by the "predictable" leading modes. The second approach is based on the signal to noise ratio, which extends the method used for assessing the predictability in atmospheric general circulation models for given lower boundary forcing (e.g., Kang and Shukla 2006). Here the signal is measured by the MME mean, while the noise is measured by the "spread" among individual model's ensemble means. We demonstrate the conceptual consistency and differences between the two measures of predictability using 10 coupled climate prediction models.

Data and analysis procedure

The models that are examined in this study are 10 fully coupled atmosphere-ocean-land seasonal prediction systems that come from the following two international projects: the Development of a European Multi-model Ensemble system for seasonal to inTERannual prediction (DEMETER) (Palmer et al. 2004) and the Asia-Pacific Economic Cooperation Climate Center/Climate Prediction and Its Application to Society (APCC/CliPAS) (Wang et al. 2007).

The selected models have retrospective forecasts (hindcasts) for the common 21-year period of 1981-2001 with 6- to 9-month integrations for 6 to 15 different initial conditions for four seasons. The hindcasts are initialized in February 1, May 1, August 1, and November 1. We use one-month lead seasonal forecasts of precipitation for four seasons. Suppose the forecast was initialized on February 1, the one-month lead seasonal prediction means the average of predicted March, April, and May means. The Climate Prediction Center Merged Analysis of Precipitation (CMAP) data set (Xie and Arkin 1997) is used as the verification dataset.

Season-reliant Empirical Orthogonal Function (S-EOF) analysis (Wang and An 2005; Wang et al 2007) was applied to seasonal precipitation over the Tropics from 30°S to 30°N in order to identify the "predictable" leading modes of interannual variations of tropical precipitation. The purpose of the S-EOF is to depict seasonally evolving anomalies throughout a full monsoon calendar year. A covariance matrix was constructed using four consecutive seasonal mean anomalies for JJA(0), SON(0), DJF(0/1), and MAM(1) that were treated as a "yearly block". Here Year 0 refers to the year in which the sequence of anomalies commences.

Results

Figure 1 (page 20) shows the performance of the coupled MME system on one-month lead seasonal prediction in terms of temporal correlation skill over the entire Tropics for 21 years from 1981 to 2001. The correlation coefficients that are higher than 0.5 are generally observed over the tropical Pacific and Atlantic between 10°S and 20°N all year around. Prediction in DJF, SON and MAM is evidently better than JJA due to the model's capacity in capturing the ENSO teleconnections around the mature phases of ENSO. In JJA, while the skill increases over the North Pacific and North Atlantic due to northward migration of the thermal equator, the skill over the Indian Ocean and the continental summer monsoon regions are very low. The correlation skill in the Asian-Australian monsoon (A-AM) region remains moderate, varying from 0.3 to 0.5 depending on season.

We found that the MME prediction skill of the seasonal tropical precipitation basically comes from the first four leading modes of S-EOF. The fractional variance is obtained from the ratio of the variance associated with a single S-EOF mode to the total variance (Wang and An 2005). The first four leading modes of precipitation in observations account for about 60% of the total variances. The first two S-EOF modes are very well predicted in terms of both the spatial structure and temporal evolution (Figure 2). The third and even the fourth modes are also reasonably well predicted. But all other higher modes are not predictable as shown by the insignificant correlation skills in the spatial structures (Figure 2). Thus, we consider the first four major modes as the predictable part of the interannual variations.

Figure 3a and b (page 20) show the fractional variance explained by the predictable leading modes for all seasons in observations and MME prediction, respectively. In observations, the fractional variance exhibits large spatial variations. Those predictable modes are significantly related to ENSO variability with different lead-lag relationships, especially the 1st and 2nd modes (not shown). The MME prediction exaggerates the

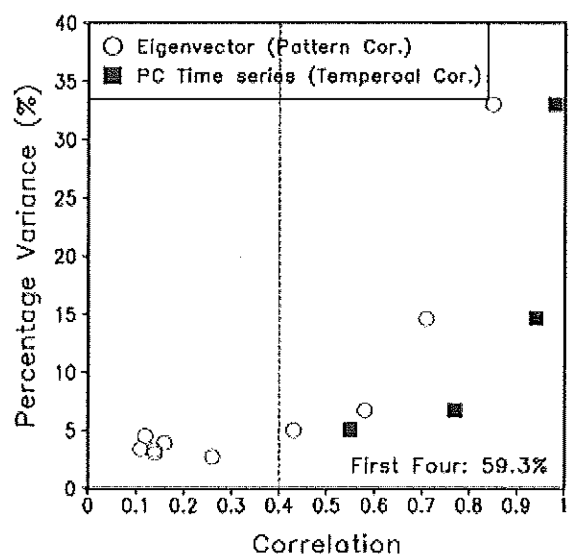

Figure 2: The spatial pattern correlation (circle) of eigen vector and temporal correlation (filled square) of principal component time series between the observed and predicted S-EOF modes for precipitation over the globe [0-360E, 30S-40N]. The first four major modes of observed seasonal precipitation over the tropics capture total 60% of the variability.

fractional variance of predictable modes (Figure 3), suggesting that the MME does not capture the higher modes.

How good is the prediction skill of the MME in terms of the predictable part? Figure 3d shows correlation skill for reconstructed precipitation by only using the four predictable modes. The similarity between Figures. 3c and 3d indicates that the MME prediction skill basically comes from the first four leading modes of seasonal precipitation.

Conclusion

How to measure the predictability of the coupled climate system, where no atmospheric lower boundary forcing is given, is an open issue. We have shown that the prediction skill of the coupled model MME basically comes from the skill in prediction of the first four major modes of interannual variations in the global tropical precipitation (Figures 3c and d). The four modes together account for about 60% of the total interannual variance averaged over the Tropics in observations (Figure 2). This portion of the variation may be considered as the practically predictable part of the precipitation variability, because the MME can capture these four major modes reasonably well but cannot capture the rest of the higher modes (Figure 2). This result leads to a new approach to estimate the practical predictability of the tropical seasonal precipitation in coupled climate models; i.e., we can quantify the "predictability" by the fractional variance that is accounted for by the "predictable" leading modes in the observations (the left panels of Figure 4, page 21)). Such "predictable" modes can be determined by examining models' hindcast results such as the performance shown in Figure 2.

The second possible approach is to extend the idea of signal-to-noise ratio used for assessing the atmospheric predictability for a given lower boundary forcing. In coupled models, the signal may be measured by the interannual variation of the MME, while the noise is measured by the "spread" (variance) among individual model's ensemble mean. In this measure the region in which the spreading exceeds the interannual variation of MME is considered as unpredictable. It is found that the signal-to-noise ratio defined as above may underestimate the models' predictability over the Western North Pacific in JJA and SON and over Maritime Continent in DJF and MAM (right panel in Figure 4). While the models' predictions have a large spread compared to the interannual variations in MME in the aforementioned regions, the hindcast results indicate that the MME does have practically useful skills there (Figure 1). In contrast, there is spatial consistency between the fractional variance of observed "predictable" modes and MME hindcast skill. The concept and approach proposed here is preliminary and more in-depth research is underway.

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Asian Monsoon Predictability in JMA/MRI Seasonal Forecast System

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1. Introduction

The Japan Meteorological Agency (JMA) has been running a forecast system for ENSO using a coupled atmosphere-ocean model since 1999. The JMA also operates the TL95L40 atmosphere general circulation model (AGCM) in a two-tiered mode for seasonal forecasts. The persistent SST anomalies at initial time are prescribed for one-month-lead 3-month forecasts.

One reason for the use of the two-tiered forecast system is that the JMA one-month-lead forecast system shows relatively good skill over Japan after statistical downscaling is applied: correlations of 0.6 (0.47) in the boreal summer (winter) are obtained in hindcast mode. Good reliability is also found in the real time operational forecast (not shown here). The good forecast skill may be partially due to relatively high seasonal predictability over East Asia.

The East Asian climate is influenced by western tropical Pacific convection activity through atmospheric teleconnections. For instance, Nitta (1987) showed the Pacific-Japan (PJ) teleconnection pattern propagating from active convection over the subtropical western Pacific near 20°N. The regions of convection over the western tropical Pacific were positively correlated with geopotential height at 500hPa around Japan in boreal summer. The relationship in boreal winter between the geopotential height at 500 hPa around Japan and the western tropical Pacific convection is also pointed out e.g., in Ose, 2000. Therefore, predictability of convective activity over the western tropical Pacific is the key for seasonal prediction over East Asia.

Although the two-tiered seasonal forecast system can give us useful seasonal forecast skill in practice, the real air-sea interaction in the western tropical Pacific is not simple. This suggests that atmosphere-ocean coupled models or one-tiered seasonal forecast systems are necessary for predicting precipitation over the western tropical Pacific through physically correct model simulations (Kobayashi et al., 2005).

A new version of the ENSO and seasonal forecast system has been developed at JMA/MRI. Here we show the seasonal hindcast skill related to the western tropical Pacific precipitation and the Asian Monsoon in comparison with that of the operationally adapted two-tiered seasonal forecast system.

2. Why is HINDCAST (persistent SST) better than SMIP (real SST)?

Two sets of simulations have been carried out with the JMA operational AGCM (JMA, 2002). One is the set of integrations