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Teleconnections of monsoon with ENSO, IOD and IMI from ECMWF model with reference to climate change: a statistical approach

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ABSTRACT
The European Centre for Medium-Range Weather Forecasts (ECMWF) System 3 coupled data for the time domain 1961-2007 is used in this study. We tried to investigate the observed teleconnections of ISMR with ENSO, IOD and IMI and its predictability from the ECMWF System 3 coupled model. It is observed that the model is better in predicting the observed teleconnections pattern of ISMR with ENSO and IOD for the time domain 1997-07 as compared to 1961-1996. The anomaly correlation skill of model produced JJAS precipitation with respect to IMD observation was found to be 0.37 and 0.51 for the time domain 1961-1996 and 1997-2007 respectively. This improvement in the prediction skill of ISMR can be attributed to the better prediction of teleconnections patterns of ISMR with ENSO and IOD for the time domain 1997-07 by the coupled model. Indian Monsoon Index (IMI) is also supposed to represent the dominant mode of interannual variability of ISMR. Thus in order to understand the effects of various factors on ISMR and the change of predictability of ISMR by the coupled model, we applied multiple linear regression model considering Nino3.4, IOD and IMI indices as explanatory variables and the ISMR index as dependent variable. We found that the Nino3.4 Index alone is unable to produce the ISMR index. Moreover, reproduction of ISMR index through linear models not only stabilizes the

teleconnections patterns of ISMR with Nino3.4 and IOD for almost the entire domain of our study but also anomaly correlation skill for ISMR is improved during the time domain 1961-1996 although the anomaly correlation skill remains the same during the time domain 1997-2007.

Keywords: ISMR, ENSO, IOD, IMI, Multiple Linear Regression Model.

1. INTRODUCTION

Study of Indian summer monsoon variability is an important socially relevant scientific theme that receives much attention (Webster *et al*. 1998; Biswas Roy *et al*. 2015; Alok Kumar Mishra *et al.* 2015; Atul Srivastava *et al.* 2015; Lokesh Kumar Pandey *et al.* 2015), because of its complexity and its effect on about 20% of world population. India's agriculture mainly depends on summer monsoon and about 70% of the annual rainfall over India received during June–July-August-September (JJAS) season. The accurate and timely prediction of seasonal forecasts of the Indian summer monsoon rainfall (ISMR) is of societal and economical importance. The understanding of modulation of Indian monsoon rainfall through the external forcing and the changes in its behaviour with respect to Climate Change is useful to achieve this goal. The El Nino–Southern Oscillation (ENSO), one of the major external forcing, is beleive to influence the interannual variability and interdecadal variability of the Indian monsoon.

The relationship between the Indian summer monsoon and ENSO has been a subject of numerous studies. Empirical studies have demonstrated that the Indian monsoon rainfall tends to be below normal in the developing phase of ENSO (Kawamura 1998; Wang *et al*. 2001; Annamalai *et al.* 2007, Boschat *et al*. 2011; Rishma *et al*. 2015). However, the relationship between the ISMR and ENSO is susceptible to decadal changes; it weakened from the late 1970s to the end of the century (Kumar *et al*., 1999). Xavier *et al*. (2007) also discussed the uncertainty in the monsoon–ENSO relationship in previous decades. Indian Ocean dipole mode (Saji *et al*. 1999) is another modulator of Indian monsoon rainfall as well as ENSO-monsoon relationship (Ashok *et al*., 2001, 2004; Krishnamurthy, 2003; Pokhrel *et. al*. 2012). IOD, ENSO, the monsoon and their mutual connections form an important and complex aspect of the tropical climate worth of further attention (Achuthavarier *et al*. 2012). Indian Monsoon Index (IMI) defined by Wang *et al*. (2001), is a circulation index and is supposed to represent dominant modes of interannual variability of ISMR.

In the present study we tried to explore to what extent European Centre for Medium-Range Weather Forecasts (ECMWF) System 3 is capable of explaining the relationship of ISMR with ENSO, IOD and IMI with respect to Climate Change by applying correlation analysis for the time domain of our study, 1961-2007. We also investigated the influence of ENSO, IOD and IMI over ISMR and its prediction through the coupled model using multiple linear regression models considering ISMR index as dependent (regressed) variable and Nino3.4, IOD and IMI indices as independent (regressor) variables.

2. MODEL & DATA

The ECMWF adopted System 3 model as its operational seasonal forecasts since March 2007. The System 3 forecast includes a coupled atmosphere–ocean model, a data assimilation scheme to create initial conditions for the ocean, and a strategy for ensemble generation. The resolution of the atmosphere model is T159 with 62 vertical levels and a horizontal zonal resolution of 1.125° (Stockdale et al. 2011). The ocean model used in system 3 is HOPE. The resolution remains effectively 1° X 1° in mid-latitudes and smoothly varying to meridional resolution of 0.3° in the tropics and has 29 vertical levels with the highest resolution of 10 m near the surface (Stockdale et al. 2011). The re-forecasts have 11 members and initialized in the months of February, May, August and November and the length of the each forecast is seven months. We have used model output from ECMWF System 3 on daily time scale and initialized in the month of May for 47 years (1961-2007) in the present work. The daily gridded precipitation data over the land points of India from India Meteorological Department (IMD) has been used for the period 1961-2007 (Pai *et al*., 2014). The IMD data set are based on rain gauge observation at more than 2000 stations distributed across Indian subcontinent. The wind circulation reanalysis data from National Centers for Environmental Prediction (NCEP) on monthly time scale is used for the period 1961-2007.

3. RESULTS & DISCUSSION

In order to study the teleconnections between ISMR-Nino3.4 and ISMR-IOD, we first quantified them through various indices. The ISMR index is defined as rainfall anomaly averaged over the land points of the region bounded by 65˚E to 110˚E and 0˚ to 40˚N. The Nino3.4 index is computed as sea surface temperature (SST) anomaly of JJAS season averaged over the region 120˚W to 170˚W and 5˚N to 5˚S (Wu *et al*. 2004). The Dipole mode Index (DMI) is computed as the difference between SST anomaly in the western (50˚E to 70˚E and 10˚S to 10˚N) and eastern (90˚E to 110˚E and 10˚S to 0˚) region of Indian Ocean (Saji *et al.*,1999). We have computed Indian Monsoon Index (IMI) as the difference between 850 hPa zonal winds anomalies between (5°N to15°N and 40°E 80°E) and (20°N to 30°N and 70°E to 90°E) for JJAS season (Wang *et al.*,2001).

We have constructed twenty four year running correlation time series between ISMR- Nino3.4 and ISMR-DMI for the time domain 1961-2007 for JJAS (Fig. 1(a,b)). The correlation time series clearly indicates enhanced prediction skill of the model for the period 1997-2007 as compared to the time period 1961-1996 in both the ISMR-Nino3.4 and ISMR-IOD.Although, the temporal correlation between ISMR-Nino3.4 for model and observation are -0.52 and -0.45 respectively but the temporal correlation for the period 1961-1996 is -0.34 and -0.54 and for the period 1997-2007 is -0.88 and -0.14 respectively. Thus we can say that the prediction of teleconnection between ISMR-Nino3.4 of ECMWF System 3 is better during the period 1961-1996. Similar results are obtained for ISMR-IOD relationship.

The Anomaly Correlation Skill (ACS) also shows better correlation skill of the model for the ISMR during the time period 1997-2007 (0.51) than the time period 1961-1996 (0.37) (Fig. 2). Since the model predicts SST with a greater skill as the temporal correlations for Nino3.4 between model and observation are 0.74, 0.78 and 0.66 for the periods 1961-2007, 1961-1996 and 1997-2007 respectively, we can say that the results obtained above can be attributed to the model inability to predict Indian Ocean SST anomalies and wind circulation as prediction skill of the model is poor for the IOD and IMI.

Besides Nino3.4 and IOD, wind circulation index also plays significant role in the regulation of the ISMR. The temporal correlations between the ISMR and IMI for observation and model are 0.87 and 0.39 respectively during 1961-2007(Fig. 3(b;c)). The temporal correlation between observed and predicted IMI is 0.41 (Fig. 3 a). Thus the model is unable to predict both the IMI and the relationship between ISMR and IMI precisely.

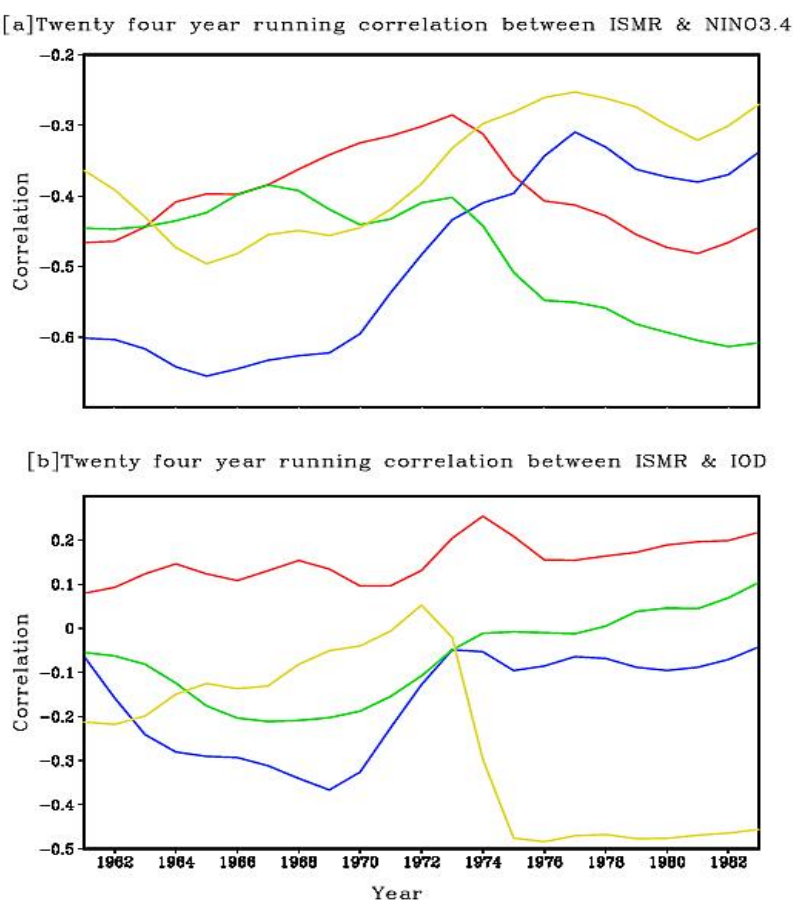

Figure 1-(a) Twenty four year running correlation between ISMR and NINO3.4 indices .(ISMR & Nino3.4 for model shown in red,ISMR & Nino3.4 for observation shown in blue, ISMR (observation) & Nino3.4 (model) shown in green and ISMR (model) & Nino3.4(observation) shown in yellow)**;** (b) Twenty four year running correlation between ISMR and IOD indices. (ISMR & IOD for model shown in red, ISMR & IOD for observation shown in blue, ISMR (observation) & IOD (model) shown in green and ISMR (model) & IOD (observation) shown in yellow).

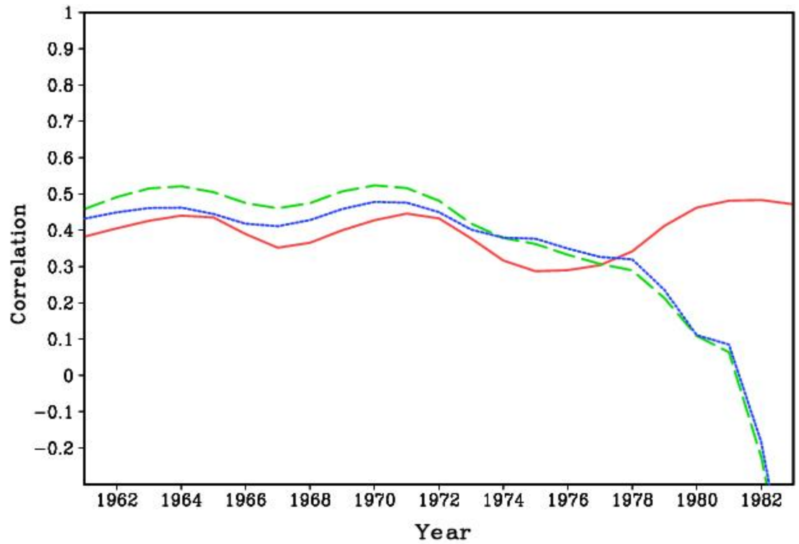

Figure 2 Anomaly correlation skill of ISMR index.(ACS for ECMWF System 3, model 4 and model 2 are shown in red,green and blue respectively).

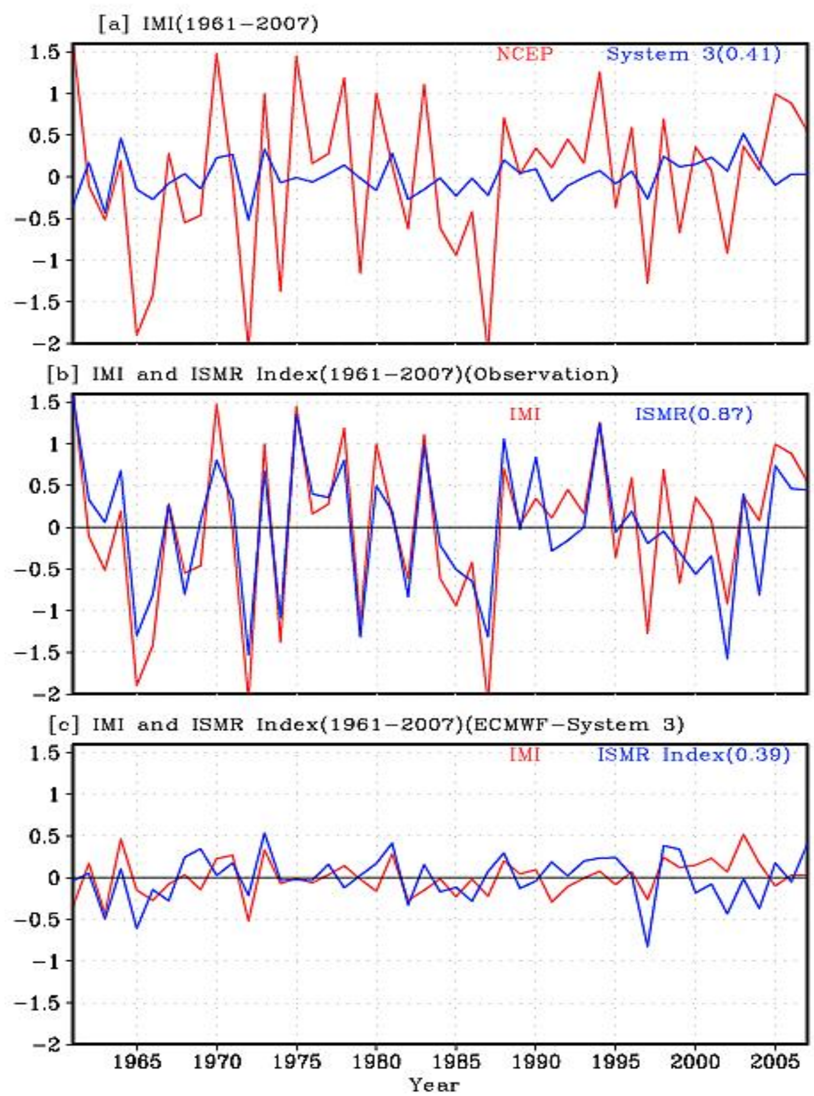

Figure 3 (a) Indian Monsoon index (IMI); (b) IMI and ISMR indices for observation; (c) IMI and ISMR indices for model. (*Numbers in parentheses show corresponding correlation*).

In order to assess the combined effect of ENSO, IOD and IMI on the ISMR; we reconstructed ISMR index using various linear models using NINO3.4 index, IOD index and IMI as explanatory (independent) variables and ISMR index as explained (dependent) variable. The results obtained are summarized in the table below:

Table 1 The results from the four ISMR Index reconstruction model obtained by multiple linear regression for Observations-

Model no.	Explanatory variables	Adjusted Multiple Correlation Coefficient (R^2)	Model Equation
1	NINO3.4	0.19	ISMR=-0.34×NINO3.4
2	NINO3.4, IOD	0.31	ISMR=-0.54×NINO3.4+1.23×IOD
3	NINO3.4, IMI	0.75	ISMR=-0.05×NINO3.4+0.69×IMI
4	NINO3.4, IOD, IMI	0.80	ISMR=-0.20×NINO3.4+0.78×IOD+0.65×IMI

The adjusted multiple correlation coefficient (0< R^2 < 1) is known as 'goodness of fit' of a linear model. A linear model with higher value of R^2 is preferred.The linear reconstruction of ISMR on the basis model 3 and model 4 has a stronger correlation with the observed ISMR than the model 1 and 2. The overall correlations between the observed (true) ISMR and the reconstructed ISMR by model 3 and model 4 are 0.87 and 0.90 respectively. Thus we can conclude that Indian Ocean SST anomalies and zonal wind circulation, together, play significant role in regulating ISMR. In order to verify whether the model output giving the same results obtained above, we applied the same regression models on the model output data. The results obtained are summarized below:

Table 2 The results from the four ISMR index reconstruction model obtained by multiple linear regression for ECMWF System 3

Model no.	Explanatory variables	Adjusted Multiple Correlation Coefficient (R^2)	Model Equation
1	NINO3.4	0.25	ISMR=-0.26×NINO3.4
2	NINO3.4, IOD	0.43	ISMR=-0.35×NINO3.4+0.26×IOD
3	NINO3.4, IMI	0.24	ISMR=-0.23×NINO3.4+0.11×IMI
4	NINO3.4, IOD, IMI	0.46	ISMR=-0.28×NINO3.4+0.30×IOD+0.35×IMI

Table 2 clearly indicates that the model can only reproduce the results obtained from the observation for model 1, and for model 2 to some extent. This is due to ability of the model to predict NINO3.4 for the entire period of study (1961-2007). Since the model is unable to predict the relationship between ISMR and IMI as well as IMI itself, this leads to poor reproduction of model 3 and model 4 by model output. Since, the adjusted multiple correlation coefficient (R^2) for model 4 are 0.46 and it also includes a circulation index (IMI); we consider it as a model output for ISMR index (Fig. 4(a;b)).

Thus, we have reconstructed the ISMR index using the model 4.Using this reconstructed ISMR index, we again constructed the twenty four year running correlation time series between ISMR-NINO3.4 and ISMR-IOD and compared the results obtained with the previous analysis. We observed that the ACS is slightly improved for most of the period of the study except for last five or six years (Fig. 3). The correlation patterns between ISMR-Nino3.4 and ISMR-IOD (Fig. 5(a,b)) also shows better correlation between the observed and predicted variables.

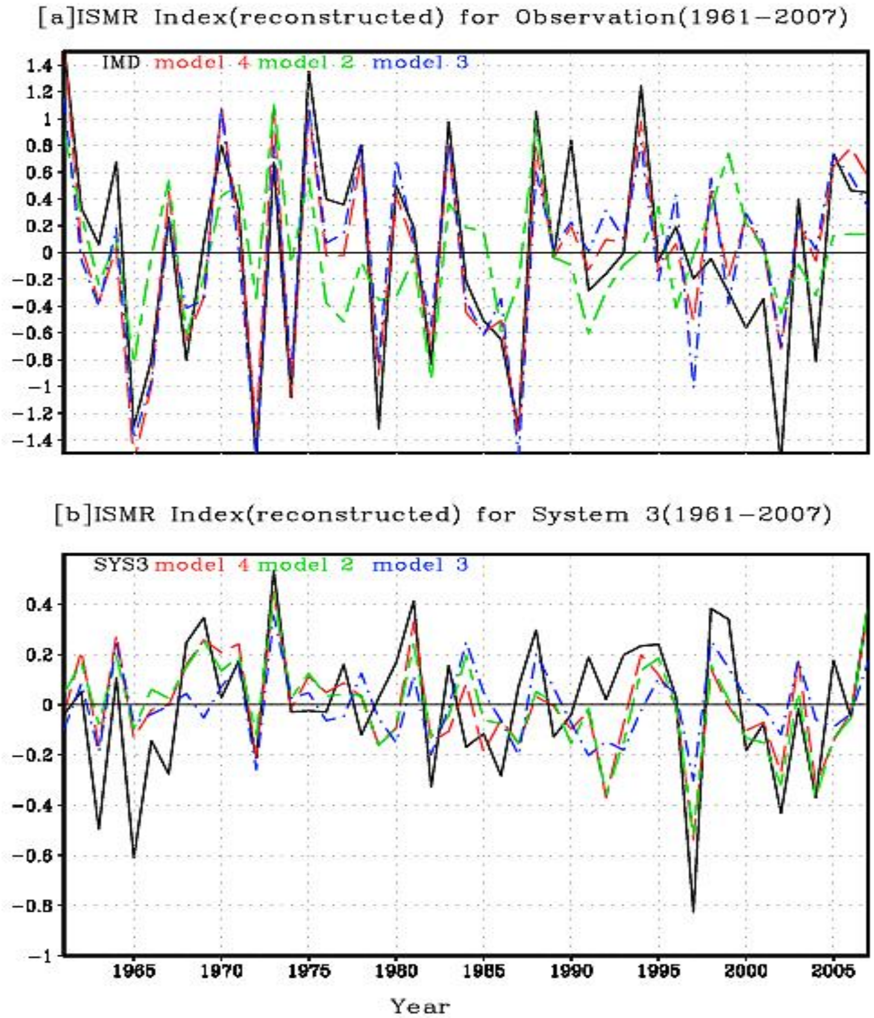

Figure 4 (a) ISMR index reconstructed for observation;(b) ISMR index reconstructed for model

4 CONCLUSIONS

The possible teleconnections among ISMR, ENSO, IOD and IMI have been analyzed for the period 1961-2007.The twenty four year running correlation between IMR-NINO3.4 and IMR-IOD shows lower prediction skill of teleconnection patterns during the 1961-1996 but an improved skill during 1997-2007. The skill of the model is higher during 1997-2007 than during 1961-1996. In order to understand these results we have tried to assess effects of various factors on the ISMR by applying multiple linear regression models. We observed that NINO3.4 is unable to explain the variability of ISMR alone as the value of R^2 is very low (0.19) for model 1. We also found that among the above indices, Indian Monsoon Index (IMI) also plays a significant role in the regulation of ISMR as model 3 and model 4 explain ISMR better than the rest of the regression models. It has been found that model 3 is unable to explain ISMR for model output. This can be attributed to poor prediction skill of the model for the circulation index (IMI).It is found that using the ISMR index reconstructed by model 4 as a model output explained the results obtained from the twenty four year running correlation and the ACS for the entire period of study except few recent years. Thus in order to improve the prediction skill of the model, the prediction of IOD and circulation index must be improved. This study is at preliminary stage and we shall further explore the possible factors responsible for regulating ISMR and their inter-relationships. These type of studies will enable us to understand the complex phenomenon of Indian summer monsoon and the factors regulating it.

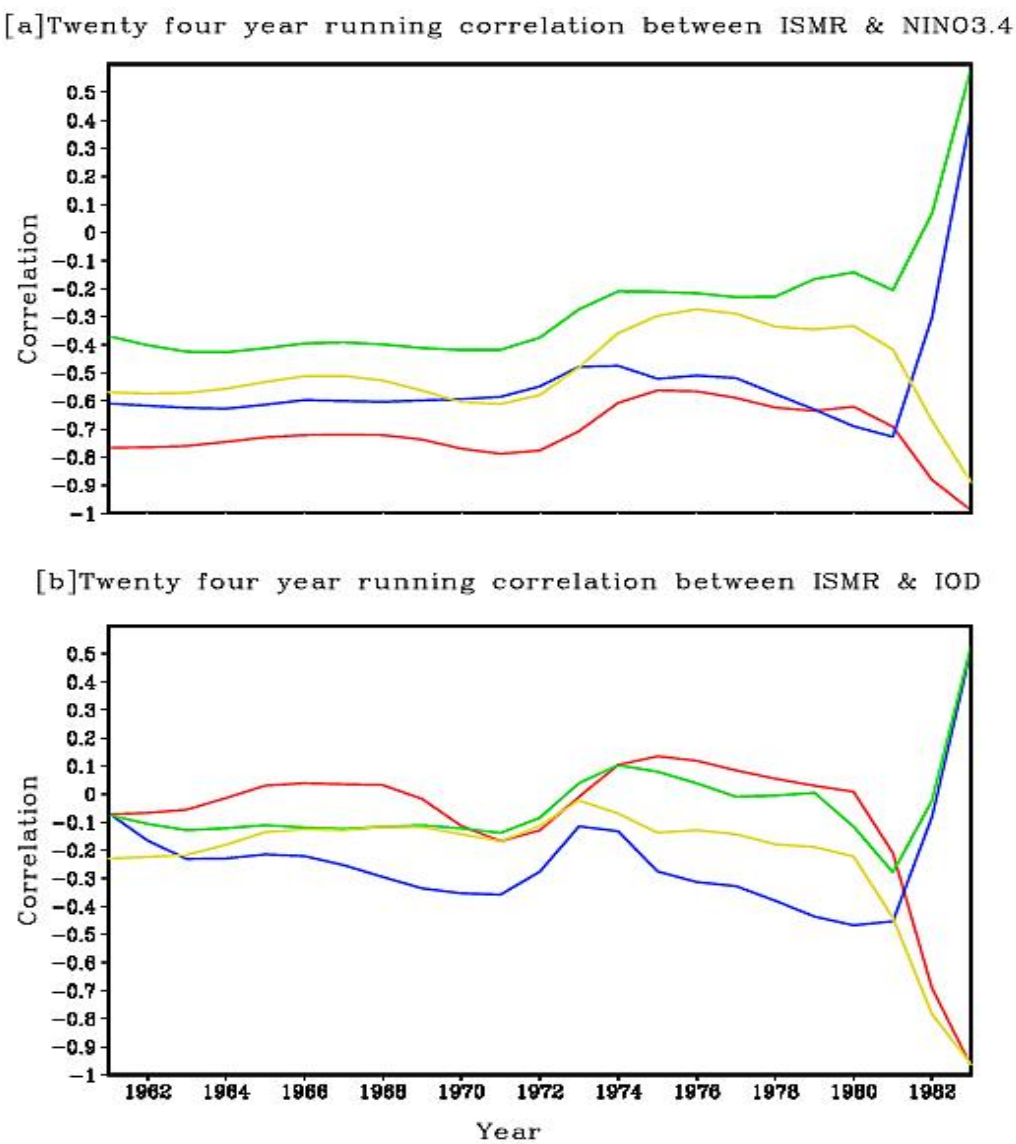

Figure 5 (a) Same as the figure 1(a) except the ISMR index (model) as it is reconstructed according to model 4; (b) Same as the figure 1(b) except the ISMR index (model) as it is reconstructed according to model 4.

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