Journal of Hydrology 546 (2017) 103–112

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Prediction of seasonal summer monsoon rainfall over homogenous regions of India using dynamical prediction system

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ARTICLE INFO

Article history:
Received 22 March 2016
Received in revised form 28 June 2016
Accepted 7 January 2017
Available online 9 January 2017
This manuscript was handled by K. Georgakakos, Editor-in-Chief, with the assistance of Emmanouil Anagnostou, Associate Editor

Keywords:
Seasonal prediction
Homogenous region
Regional rainfall
Teleconnections

ABSTRACT

Seasonal prediction of Indian summer monsoon rainfall is a challenging task for the modeling community and predicting seasonal mean rainfall at smaller regional scale is much more difficult than predicting all India averaged seasonal mean rainfall. The regional scale prediction of summer monsoon mean rainfall at longer lead time (e.g., predicting 3–4 months in advance) can play a vital role in planning of hydrological and agriculture aspects of the society. Previous attempts for predicting seasonal mean rainfall at regional level (over 5 Homogeneous regions) have resulted with limited success (anomaly correlation coefficient is low, ACC ≈ 0.1–0.4, even at a short lead time of one month). The high resolution Climate Forecast System, version 2 (CFSv2) model, with spectral resolution of T382 (~38 km), can predict the Indian summer monsoon rainfall (ISMR) at lead time of 3–4 months, with a reasonably good prediction skill (ACC ≈ 0.55). In the present study, we have investigated whether the seasonal mean rainfall over different homogenous regions is predictable using the same model, at 3–4 months lead time? Out of five homogeneous regions of India three regions have shown moderate prediction skill, even at 3 months lead time. Compared to lower resolution model, high resolution model has good skill for all the regions except south peninsular India. High resolution model is able to capture the extreme events and also the teleconnections associated with large scale features at four months lead time and hence shows better skill (ACC ≈ 0.45) in predicting the seasonal mean rainfall over homogeneous regions.

1. Introduction

The southwest monsoon during June to September (JJAS) is the major rainy season for Indian subcontinent contributing around 78% of the total annual rainfall. Fluctuations in monsoon rainfall affect agriculture, drinking water, energy sector and livelihood of millions of people living in the country. Thus, the seasonal prediction of Indian summer monsoon rainfall (ISMR) at a relatively long lead time (e.g., 3–4 months lead time) is very much important and it has a long history. Sir Hendry Blandford, first time released official seasonal monsoon forecast, based on Himalayan snow cover, in 1886 (Blanford, 1884). Charney and Shukla (1981) suggested a conceptual hypothesis of monsoon predictability based on the influence of boundary forcing. They proposed that dynamical prediction skill by large scale atmospheric circulation is beyond the weather limit, as they are governed by slowly varying boundary forcing, like sea surface temperature (SST), soil moisture, snow cover, etc. Indian summer monsoon is identified to be strongly influenced by slowly varying boundary forcing (Walker, 1923; Rasmusson and Carpenter, 1983; Webster et al., 1998, etc.). Among these boundary forcing, SST anomalies associated with equatorial east Pacific is of most importance and well studied (Rasmusson and Carpenter, 1983; Webster et al., 1998). The positive SST anomalies in the east Pacific (referred as El Nino) is generally associated with below normal ISMR and the negative east Pacific SST anomalies (referred as La Nina) is supposed to be associated with above normal ISMR. Indian Ocean SST anomalies in the form of Indian Ocean Dipole (IOD, Saji et al., 1999) are also supposed to influence the ISMR. Positive (negative) phase of IOD, with warming (cooling) in the western Indian Ocean and cooling (warming) in the equatorial east Indian Ocean is associated with above (below) normal ISMR. Thus Charney-Shukla hypothesis became the central paradigm of monsoon predictability studies for the last 2–3 decades. Long before the Charney-Shukla hypothesis, India

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http://dx.doi.org/10.1016/j.jhydrol.2017.01.010
0022-1694/

meteorological department (IMD) has been issuing long range forecast (LRF) of ISMR using statistical methods. The objective models were based on the regression analysis introduced by Walker (1923, 1924). These models were developed by taking into account various teleconnections of several atmospheric variables with ISMR. IMD operational forecast models had undergone many changes and modifications based on statistical methods (Rajeevan et al., 2004, 2007). At present, IMD is issuing seasonal prediction (LRF), using a statistical forecast system with 8 predictors, which have strong physical linkage with Indian summer monsoon (Rajeevan et al., 2007; Pai et al., 2011). However, all these statistical models have their own limitations due to their dependence on inter-relationship of predictors (Rajeevan, 2001). Majority of the empirical models have reasonable success in normal monsoon years, but generally fail in extreme years, e.g., in the case of the drought year 2002 (Gadgil et al., 2002).

Preethi et al. (2010), using previous generation coupled models participated in DEMETER (Development of a European Multi-model Ensemble system for seasonal to inTER-annual prediction) project (Palmer et al., 2004), found that most of the models were able to produce the large scale features of Indian monsoon however, its prediction skill is poor (Anomaly correlation coefficient, ACC $\approx$ 0.28). In a subsequent study Rajeevan et al. (2012), using present generation coupled models from ENSEMBLES project (European Commission initiated project, running multiple climate models, called "ensembles", see Weisheimer et al., 2009 for details), concluded that although the prediction skill of the ISMR in coupled models has improved (ACC $\approx$ 0.45) in recent decade, it still remains below the potential limit of predictability. Analysis of Indian summer monsoon from Climate Forecast System (CFS) retrospective forecast by Yang et al. (2008) and Pattanaik and Kumar (2010) showed that even though the major features of monsoon are predicted successfully in all forecasts initiated from March to May, the significant correlation of ISMR with observations are noticed for forecasts initiated in April only. Chattopadhyay et al. (2015) obtained a skill of 0.5 for ISMR for February hindcast runs using CFSv2. Ramu et al. (2016) showed that very high resolution version of CFSv2 (T382 $\sim$38 km horizontal resolution) has better skill for ISMR than T126 ($\sim$100 km horizontal resolution) CFS. They showed that ISMR skill is increased to 0.55 in T382, where as it was 0.5 in T126. Most importantly, the high resolution model (T382) is able to capture inter-annual variability better than low resolution model (T126), by predicting extreme years better. Ramu et al. (2016) found that the simulation of the mean state of the Asian summer monsoon, its variance and prediction skill of the ISMR is better represented in the high-resolution configuration (T382) of the CFSv2 compared to the low resolution (T126) configuration. Studies like Chattopadhyay et al. (2015) and Ramu et al. (2016) attributed the skill of ISMR to the better teleconnections of El Nino related SST and ISMR in these models. Meanwhile in recent decades, El Nino related Pacific SST anomalies are associated with two different flavors. The first one is canonical El Nino with maximum SST anomalies in the east Pacific (Rasmusson and Carpenter, 1983) and the second one is called El Nino Modoki with tripole SST anomalies in the equatorial Pacific (Ashok et al., 2007). Pillai et al. (2016) showed that the T382 resolution of CFSv2 is able to differentiate these El Nino flavors (canonical El Nino and El Nino Modoki) and their teleconnections in February IC hindcast, resulting in better ISMR skill. The high skill of ISMR in CFSv2 T382 is the major inspiration to this present study to assess the skill of the same model for regional scale monsoon rainfall. The better prediction of CFSv2 T382 is related to its ability to capture El Nino flavors and their teleconnections (Ramu et al., 2016; Pillai et al., 2016). Thus studies, like Ramu et al. (2016) and Pillai et al. (2016), indicate that higher resolution CFSv2 T382 has better skill for seasonal mean monsoon and captures its teleconnections, as compared to lower resolution model. Therefore, we believe that the high resolution models can improve the simulation and prediction skill of monsoon by adequately resolving the regional information in models. Similar view has been earlier reported by Rajendran et al. (2008).

The better prediction skill of ISMR in CFSv2 T382 and proper simulation of its teleconnections encouraged us to investigate the seasonal prediction skill of regional scale monsoon rainfall. Parthasarathy et al. (1995) have shown that there is considerable spatial variation of rainfall within the Indian land region and their relationship with large scale features (like ENSO, IOD) is also different. Earlier study by Vecchi and Harrison (2004) found that ISMR variability can be represented by two regions (Western Ghats and Ganges-Mahanadi basin) and combined rainfall in these areas account for 90% of inter-annual variability of ISMR. They also concluded that the relationship of these two regions with boundary forcing is also different indicating that interannual variability of rainfall in these regions is forced by different mechanisms. At present, based on the homogeneity of rainfall over India (Parthasarathy et al., 1995), Indian land rainfall is divided into seven homogenous regions (see Fig. 1e). Thus along with the prediction of ISMR, its regional scale distribution over different homogeneous regions are also important for planning agricultural and hydrological activities.

An accurate seasonal predication of regional rainfall will enable the country for planning the type of agriculture crop, dam water level maintenance for irrigation/drinking water, flood/drought managements, etc. Meanwhile, it is believed that large scale features averaged over large regions can only be better predicted at the seasonal scale (Preethi et al., 2010; Rajeevan et al., 2012). As a result of this belief, General circulation models (GCMs) have been relatively less tried for regional scale seasonal prediction. Acharya et al. (2011) showed that although the GCM simulated values of mean monsoon rainfall and its inter-annual variability (IAV) at the all India level are in good agreement with the observed values, the models underestimate the IAV at the homogeneous zones as compared to that of the observed IAV. Another study by Singh et al. (2012) using canonical correlation analysis on multi model ensemble hindcasts showed that regional scale monsoon rainfall correlation with observations varied from 0.1 to 0.4 for different homogenous regions for hindcasts initiated with May initial conditions. Kashid and Maity (2012), using numeric techniques like artificial intelligence, obtained skill varying from 0.03 to 0.69 for five homogenous regions over India for zero month lead forecast.

Earlier study by Xavier and Goswami (2007a,b) showed that the regional rainfall over India can be predictable only up to 4 pentads (20 days) lead time and skill over south and northeast regions of India are negligible. A recent study by Sahai et al. (2015) also showed limited prediction skill of 5 day averaged regional scale monsoon rainfall in extended range, at 4 pentads lead time. According to Charney and Shukla (1981) hypothesis, if the rainfall is closely related to boundary forcing through the large scale teleconnections, it is predictable beyond the weather scale. In CFSv2, ISMR has higher prediction skill in T382 due to simulation of better teleconnections (Ramu et al., 2016; Pillai et al., 2016). Thus our expectation is that, better simulation of teleconnections in CFSv2 may also enable better simulation of the regional scale rainfall. To the best of our knowledge, no studies were ever attempted to assess the prediction skill of rainfall over homogenous zones of India with high resolution model. The main objective of the present study is to analyze the skill of CFSv2 at two different resolutions (lower and higher resolutions) in simulating and predicting the regional scale rainfall over the homogenous regions of India. The study will further asses the role of tropical SST and circulation, in obtaining these regional scale rainfall skills. Section 2 presents the model, verification data and methodology. In Section 3, a com-