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Forecasting of Indian Monsoon Pattern with Empirical and Dynamic Models

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Abstract—*A strong monsoon usually produces abundant crops, although too much rainfall may produce devastating floods. Unlike irrigated agriculture, rainfed farming is usually diverse and risk prone. The India Meteorological Department (IMD) has long been issuing seasonal forecasts of rainfall using statistical prediction schemes that took firm root with the discovery of significant correlation between the seasonal rainfall and various regional and global climate phenomena. The prospect for monsoon forecast skill based on dynamical models in which ocean conditions are perfectly known, and are specified. Some of the monsoon predictors used is linked to the El Niño-Southern oscillation (ENSO), along with atmospheric and coupled models for additional input for better results.*

CFS (Climate forecast system) model simulated a weaker monsoon circulation due to a cold bias at the surface over the Asian continent. In India, the dynamical seasonal prediction (DSP) method, introduced a few years ago, integrates the GCM (General Circulation Model) with an ensemble of initial conditions for each season in order to provide probabilistic seasonal forecasts. Atmospheric and Coupled General Circulation Models (AGCM and CGCM) are the main tools for dynamical seasonal prediction. Dynamical Higher resolution using AGCMs with perfectly known Ocean conditions specified, as well as coupled models are reported to have insignificant forecast skill over ASM. The simulation of the link between EQUINOO and the Indian monsoon rainfall could be improved by investigations of the processes suggested to be important, such as the modulation of the interplay between the local Hadley circulation in the Indian longitudes and the Walker circulation associated with the El Niño events. In addition, GOALS (Global coupled ocean atmosphere-land model) or statistical based models, such as: ANN, GA-ANN models etc. may be used to predict the Indian Monsoon correctly.

Keywords*: Indian Monsoon, IMD, El Nino, CFS, GCM, EQUINOO, RCMs.*

1. INTRODUCTION

Prediction of Indian Monsoon on monthly and seasonal time scales is not only scientifically challenging but also important for planning and devising agricultural strategies. The skilful and timely forecasts of intra-seasonal monsoon rainfall possess a greater potential utility for agriculture and water resource management compared to seasonal rainfall forecast and should be given the highest priority for prediction within the monsoon regions (Webster and Hoyos, 2004). Year-to-year variability in the onset date of the monsoon has large impacts on agriculture in monsoonal developing countries. From the climate dynamics perspective, the monsoons of India are influenced by ENSO on seasonal timescales. The Indian monsoon is characterized by winter–summer reversals in various aspects of the atmospheric circulation over the South Asian subcontinent (Pant and Kumar, 1997). According to Drbohlav and Krishnamurthy (2007) forecasting the monsoon on time scales of weeks to seasons, is a major sci-scientific issue in the field of monsoon meteorology. Systematic errors in the forecasts consist of deficient rainfall over India, excess rainfall over the Arabian Sea and a dipole structure over the equatorial Indian Ocean. On inter-annual time scale, two types of the monsoon are recognized. One is the monsoon that is regionally controlled (regional mode) and the other is the monsoon that has a strong relation with El Niño and Southern Oscillation (ENSO-related mode). A popular question is the prospect for monsoon forecast skill based on dynamical models in which ocean conditions are perfectly known, and are specified (Kang *et al.,* 2002). The extended range forecast of southwest monsoon rainfall from monthly to seasonal scale is vital for the policy planning and national economy for the agro-economic country like India. The long-range forecasting of Indian summer monsoon rainfall was initiated more than a century ago, and since then, various empirical and dynamical methods (Saha, *et al.,* 2016) for predicting the summer monsoon rainfall have been developed. The India Meteorological Department (IMD) has been issuing long-range forecasts of seasonal mean rainfall over India using statistical models for over a hundred years with varying degree of success (Rajeevan, 2001). A better approach through dynamical prediction has been followed by several investigations since the mid-1980s by simulating the Indian monsoon by GCMs, some with organized international efforts. In a very recent study, Gadgil *et al.,* (2005) addressed the major problems of the statistical and dynamical methods for long range prediction of monsoon rainfall.

2. EL-NINO EFFECT

Webster *et al.* (1998) provide an extensive discussion of the link between Indian monsoon rainfall and the Southern Oscillation (SO). All El Nino years (solid triangles) fall in the negative quadrant while all La Nina years (solid squares) lie in the positive quadrant. Soman and Slingo (1997) stressed the importance of the local Hadley circulation in monsoon variability and demonstrated that SST anomalies in the west Pacific can influence the tropical convective maximum in that region and, hence, the strength of the local Hadley circulation and the behavior of the monsoon. The actual ISMR prediction skill of CFSv2 is maximum at lead-3 (correlation 0.58), which is almost equal to the model's potential prediction skill. ISMR variability is known to be linked with SST (Saji *et al.,* 1999), Eurasian snow (Saha *et al.,* 2013), soil moisture (Saha *et al.,* 2012), which act as lower boundary forcing of the atmosphere.

3. MONSOON PREDICTION MODELS

The reliability of any empirical and statistical prediction model depends largely on the stability of the relationship between the predictant and the predictor. At present, the new statistical models developed by Rajeevan *et al*., (2007) based on the ensemble multiple linear regression and projection pursuit regression techniques are used for generation of the seasonal forecasts of ISMR. Some of the predictors used are linked to the El Niño-Southern oscillation (ENSO), predictions from atmospheric and coupled models are an additional input to the operational forecasts issued by IMD (Delsole and Shukla, 2012).

4. ECMWF GENERAL CIRCULATION MODEL

Slingo *et al.,* (1988) noted that the Asian summer monsoon and onset dates are most sensitive to the radiation and convective parameterization schemes in the European Center for Medium Range Weather Forecasts (ECMWF) general circulation model. Systematic errors in the ECMWF model from short range to extended range forecast time scale perspectives and development of a large anticyclonic bias over the central North Pacific, underestimation of the kinetic energy of transient eddies, and underestimation of synoptic systems at higher latitudes and underestimation of atmospheric blockings in medium and extended range forecast time scales for monsoon.

5. GEOPHYSICAL FLUID DYNAMICS LABORATORY (GFDL)

The R30 version of the GFDL model is capable of simulating the observed tropical 30–50-day intra-seasonal oscillations (Hayashi and Golder, 1993), the low-resolution model does not simulate them. Rowell (1995) personal communication) recently carried out an ensemble of six runs with the Hadley Centre model using observed SST for the recent 45 yr between 1948 and 1993.

6. CLIMATE FORECAST SYSTEM (CFS)

Prediction of the Asian/Indian summer monsoon by CFS has been assessed by analysis of these retrospective forecast (Rai and Krishnamurthy, 2011). Achuthavarier and Krishnamurthy (2010) have analysed long simulations of the CFS-coupled model with two different horizontal resolutions and of the one atmospheric component of CFS, viz. the GFS model and found that the relation between intraseasonal and interannual variation was well simulated by the CFS model. Pattnaik *et al.* (2013) attempt to characterize and evaluate systematic forecast biases of the CFS-1 coupled model comprised of the GFS atmospheric model at T62 (210 km) resolution with 64 vertical sigma levels and the Geophysical Fluid Dynamical Laboratory (GFDL)'s Modular Ocean Model Version 3 (MOM3) as ocean model with SAS and RAS cumulus parameterization over the Indian monsoon region from an extended range time scale perspective (up to 45 days forecast). Stratiform rainfall has a profound impact on dynamical modulations of various monsoon processes over the Indian region (Choudhury and Krishnan, 2011). The JJAS climatology of stratiform component of the total precipitation simulated from these two versions of CFS-1 model clearly suggested that RAS (SAS) is overestimating (underestimating) stratiform rain throughout the region compared to TRMM (Fig.1). Krishnamurthy and Rai (2010) examined the climatology and the seasonal forecasts (1981-2005) of the Indian monsoon, showing that there is variation in the skill of the CFS (Drbohlav and Krishnamurthy 2010).

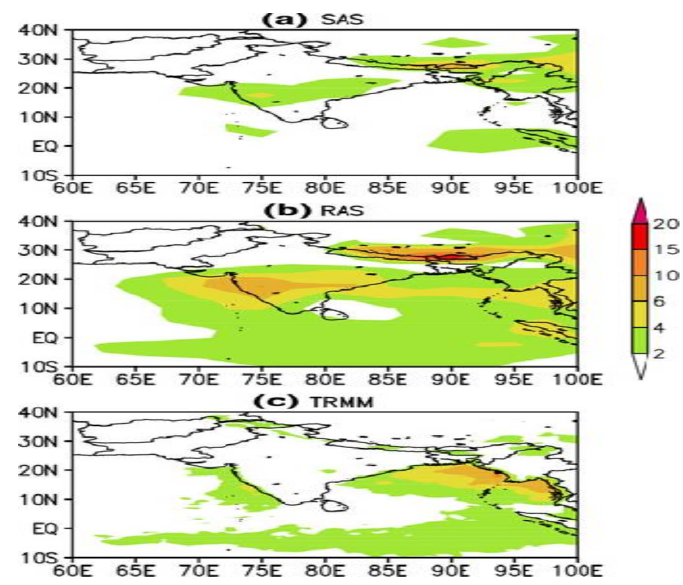

Figure 1: JJAS (2001–2007) stratiform rainfall (mm day-1) a SAS, b RAS, and c TRMM Pattnaik *et al.,* 2013.

The results indicate that the predictability of the monsoon circulation at the upper level (200 hPa) involves two time scales with the errors growing faster at the initial stage followed by slower growth. The errors of the circulation at the lower level (850 hPa), grow mainly at the faster scale. An assessment of the forecast skill for the El Nino, Indian Ocean Dipole (IOD), monsoon circulation indices is also made. The skill of simulation of broad scale monsoon circulation index (Webster and Yang, 1992; WY index) is quite good in the CFS with highly significant (above 99.9% level) CC between the observed and predicted by the CFS from the March, April and May forecasts (Fig. 2). Pattanaik and Kumar, (2009) analysis of the JJAS seasonal mean and inter-annual variability of Indian summer monsoon rainfall in the CFS based on a 15 member ensemble for 25 years (1981–2005) with initial conditions of March (lag-3), April (lag-2) and May (lag-1), the positive values significant at 95% level is shaded, (Fig. 2).

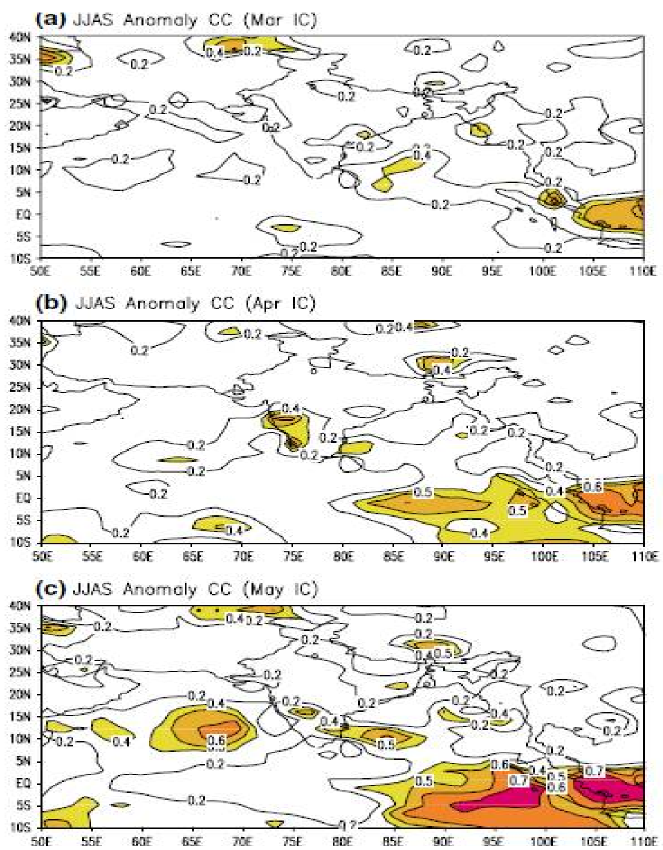

Figure 2: Anomaly correlation coefficient (ACC) between JJAS rainfall from verification analysis and CFS forecast during the period from 1981 to 2005 with (a) March, (b) April, and (c) May initial conditions Pattanaik and Kumar, (2009)

7. DYNAMICAL MODEL

GCM model

Statistical forecasting of the monsoon rainfall and the usage of atmospheric general circulation models (GCMs) forced with sea surface temperature (SST) have not been quite successful (Krishnamurthy and Shukla, 2001). Coupled GCMs are suggested to be more appropriate for better simulation of the monsoon because of the crucial role played by the ocean-atmosphere interaction (Wang *et al.,* 2005). General circulation model (GCM) experiments which showed that the tropical atmospheric variability is largely determined by slowly-varying boundary forcings such as sea surface temperature (SST), soil moisture and snow cover in the Monsoon GCM Intercomparison Project of the Climate Variability and Predictability (CLIVAR) program (Kang *et al.*, 2002). The General Circulation Model (GCM) from Hadley centre for climate prediction and Research (2004-2007), U.K., named as 'Portable Unified Model' (PUM), version 4.5, is installed on ORIGIN-350, HadCM3(Sahai *et al.,* 2007). Krishnamurthy and Shukla, (2011) discuss the predictability of coupled GCMs in simulating the Indian monsoon for the period 1981-2005, forecasts of seven coupled models from the DEMETER, a project to test the concept of multimodel ensemble prediction, were analyzed for the period 1980-2001. Large errors in the seasonal anomalies of the rainfall occur in the Bay of Bengal, the Arabian Sea along the west coast of the Indian Peninsula and the equatorial Indian Ocean.

8. AGCM MODEL

Atmospheric and Coupled General Circulation Models (AGCM and CGCM) are the main tools for dynamical seasonal prediction. Dynamical Higher resolution using AGCMs with perfectly known ocean conditions specified, as well as coupled models are reported to have insignificant forecast skill over ASM (Gadgil *et al.,* 2005). Singh *et al.,* (2012) have used lead-0 to lead-2 ISMR forecasts by several AGCMs and CGCMs (including CFSv1) to calculate climatology, inter-annual variability, root mean square error, correlation, signal-to-noise ratio, potential predictability, and index of agreement. Observed anomalous rainfall-SST relationship derived from CMAP and Optimal Interpretation SST (Reynolds, *et al.,* 2002, Fig. 3) for summer seasons (June through August) of 1982-2001.

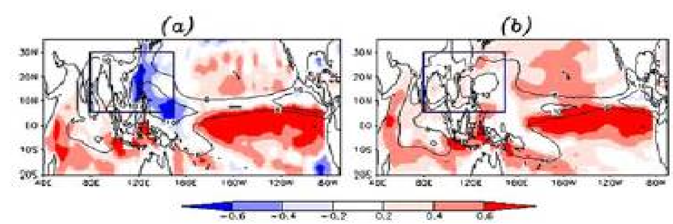

Figure 3: Correlation coefficients (a) Observed and (b) simulated, between the June–August SST and precipitation anomalies (the color shadings).

9. EQUINOO

EQUINOO has been considered to be the atmospheric component of the Indian Ocean Dipole/Zonal Mode (IOD/IOZM). (Surendran *et al.,* 2015) explains 54% of ISMR variance, suggesting a strong dependence of the skill of monsoon prediction on the skill of prediction of ENSO and EQUINOO. The simulation of the link between EQUINOO and the Indian monsoon rainfall could be improved by investigations of the processes suggested to be important such as the modulation of the interplay between the local Hadley circulation in the Indian longitudes and the Walker circulation associated with the El Niño events, such as that of 1997 and the interaction between equatorial waves and physical processes which determines the rainfall anomalies over the eastern equatorial Indian Ocean and the Indian region (Annamalai, 2010). Physically ENSO and IOD are dynamically linked through the planetary-scale Walker and regional-scale Hadley circulation, respectively (Pokhrel *et al.*, 2012). ISMR has the negative (positive) correlation with ENSO (IOD) (Saha, *et al.*, 2016). Rajeevan and Nanjundiah (2009) have shown that in most of the coupled models of IPCC-AR4, ISMR is poorly correlated with EQUINOO. A negative phase of EQUINOO made a significant contribution to the deficit rainfall in 2002 (Gadgil *et al.*, 2005). Gadgil *et al.*, (2004) have shown that every drought (excess monsoon season) during 1958–2003 is associated with an unfavourable (favourable) phase of either ENSO or EQUINOO, or both. Thus, there is a strong relationship between extremes of ISMR and ENSO index and EQWIN. This relationship is also found to be valid for the subsequent droughts of 2004 and 2009 (Francis *et al.*, 2010).

10. GOALS (GLOBAL OCEAN-ATMOSPHERE-LAND SYSTEM)

An important tool for GOALS is the global coupled ocean atmosphere-land model. The GOALS endeavour will be a coupled ocean-atmosphere enterprise but with the addition of land surface and ice process all considered on a global domain. In TOGA project use this model to extend Asian monsoon prediction from the pacific basin to the global domain (Webster, *et al.*, 1998). This degree of spread is surprising given the relative success of empirical forecast techniques under the auspices of the international climate variability and predictability program (CLIVAR), (WCRP, 1995).

11. ARTIFICIAL NEURAL NETWORK (ANN)

The ANN is also used as a powerful technique for pattern recognition and prediction (Haykin, 1999). ANNs have been used successfully to ISMR prediction (Kumar *et al.*, 2007). Sahai *et al.*, (2000) describes the artificial neural network (ANN) technique with error- back-propagation algorithm to provide prediction (hindcast) of ISMR on monthly and seasonal time scales to the five time series of June, July, August, September monthly means and seasonal mean (June + July + August + September) rainfall from 1871 to 1994. The previous five years values from all the five time-series were used to train the ANN to predict for the next year. Dwivedi and Pandey (2011), develop a 5 years forecasting strategy for prediction of the monsoon ISO using a two-layer feed-forward input-time delay back propagation neural network (‘GA-ANN) and The forecasted ISO indices are near perfect (94%) correlated..

12. CONCLUSION

The prediction of Indian Monsoon on monthly and seasonal time scales is not only scientifically challenging but is also important for planning and devising agricultural strategies. The long-range prediction of average rainfall could be of immense value for water management and agricultural planning. The degree of predictability of monsoons is a matter of considerable social and economic importance. From the climate dynamics perspective, the monsoons of India are influenced by ENSO on seasonal timescales.

REFERENCE

[1] Achuthavarier, D. and Krishnamurthy, V. (2010), Relation between intra-seasonal and inter-annual variability of the South Asian monsoon in the National Centres for Environmental Predictions forecast systems. J Geophys Res 115:D08104. doi:10.1029/2009JD0v12865.

[2] Annamalai,H.(2010), Moist dynamical linkage between the equatorial Indian Ocean and the south Asian monsoon trough J. Atmos. Sci. 67:589–610.

[3] Cannon, A. J. and Mckendry, I. G. (1999), Forecasting all-india summer monsoon rainfall using regional circulation principal components: a comparison between neural network and multiple Regression models, Int. J. Climatol. 19: 1561–1578 (1999).

[4] Choudhury, A.D. and Krishnan, R. (2011), Dynamical response of the South Asian monsoon trough to latent heating from stratiform and convective precipitation. J Atmos Sci 68:1347–1363.

[5] Delsole, T. and Shukla, J. (2012), Climate models produce skilful predictions of Indian summer monsoon rainfall Geophys. Res. Lett. 39 L09703.

[6] Drbohlav, H.K.L. and Krishnamurthy, V. (2007), Spatial Structure, Forecast Errors and Predictability of South Asian Monsoon in CFS Monthly Retrospective Forecasts: 2-28.

[7] Dwivedi, S. and Pandey, A. C. (2011), Forecasting the Indian summer monsoon intraseasonal oscillations using genetic algorithm and neural network, Geophys. Res. Lett., 38, L15801, doi:10.1029/2011GL048314.

[8] Francis, P. A. and Gadgil, Sulochana, (2010), Towards understanding the unusual Indian monsoon in 2009. J. Earth Syst. Sci., 119(4): 397–415.

[9] Gadgil, S., Rajeevan, M. and Nanjundiah, R. S. (2005), Monsoon prediction-why yet another failure?, Curr. Sci. 88:1389–1400.

[10] Gadgil, S., Vinaychandran, P. N., Francis, P. A. and Gadgil, S. (2004), Extremes of Indian summer monsoon rainfall, ENSO, equatorial Indian Ocean Oscillation. Geophys. Res. Lett.: 31, doi: 10.1029/2004GL019733.

[11] Hayashi, Y. and Golder, D. G. (1993), Tropical 40–50 and 20–30 day oscillations appearing in realistic and idealized GFDL climate models. J. Atmos. Sci., 50:464–494.

[12] Haykin, S. (1999), Neural Networks, MacMillan, New York.Jung, A., Tompkins, M. and

[13] Krishnamurthy, V. and Rai, S. (2010), Predictability of South Asian Monsoon circulation in the NCEP Climate Forecast System, COLA Technical Report 301: 1-19.

[14] Krishnamurthy, V. and Shukla, J. (2001), Observed and model simulated interannual variability of the Indian monsoon. Mausam, 52: 133-150.

[15] Krishnamurthy, V. and Shukla, J. (2011), Predictability of the Indian monsoon in coupled general circulation models, COLA Technical Report 313: 1-46.

[16] Kumar, D. N., Reddy, M. J. and Maity, R. (2007), Regional rainfall forecasting using large scale climate teleconnections and artificial intelligence techniques, J. Intell. Syst., 16:307–322, doi:10.1515/JISYS.2007. 16.4.307.

[17] Pant, G.B. and Kumar, K.R. (1997), Climates of South Asia, Wiley, West Sussex: 344.

[18] Pattanaik D. R. and Kumar, A. (2009), Prediction of summer monsoon rainfall over India using the NCEP climate forecast system, Clim Dyn, ,DOI 10.1007/s00382-009-0648-y:1-17.

[19] Pattnaik, S., Abhilash, S., De, S., Sahai, A. K., Phani, R. and Goswami, B. N.(2013), Influence of convective parameterization on the systematic errors of Climate Forecast System (CFS) model over the Indian monsoon region from an extended range forecast perspective, Climate Forecast System ,Clim Dyn:1-25,DOI 10.1007/s00382-013-1662-7.

[20] Rai, S. and Krishnamurthy, V. (2011), Error growth in climate forecast system daily retrospective forecasts of South Asian monsoon. J Geophys Res 116 D03108. doi:10.1029/2010JD014840.

[21] Rajeevan, M. (2001), Prediction of Indian summer monsoon: Status, problems and prospects. Curr. Sci., 81:1451-1457.

[22] Rajeevan, M., Pai, D.S., Kumar, A. R. and Lal, B .(2007), New statistical models for long-range forecasting of southwest monsoon rainfall over India Clim. Dyn. 28 (8): 13–28.

[23] Rajeevan, M. and Nanjundiah, R. S. (2009), Coupled model simulations of twentieth century climate of the Indian summer monsoon. In Platinum Jubilee Special Volume of the Indian Academy of Sciences, Indian Academy of Sciences, Bangalore: 537–568.

[24] Reynolds, R. W., Rayner, N. A., Smith, T. M., Stokes, D. C. and Wang, W. (2002), An improved in situ and satellite SST analysis for climate, J. Clim., 15: 1609– 1625.

[25] Rodwell, R.J. (2005), Some aspects of systematic errors in the ECMWF model. Atmos Sci Lett 6:133–139.

[26] Rowell, D., Folland, C. K. Maskell, K. and

[27] Saha, S. K., Pokhrel, S. and Chaudhari, H. S. (2013), Influence of Eurasian snow on Indian summer monsoon in NCEP CFSv2 freerun, Clim. Dyn., 41: 1801–1815.

[28] Sahai. A. K., Soman, M. K. and Satyan, V. (2000), All India summer monsoon rainfall prediction using an artificial neural network, Climate Dynamics,16: 291-302. doi:10.1007/s003820050328.

[29] Sahai, A. K., Sujata, K., Mandke, M. A., Shinde, R., Chattopadhyay, S.J. and Goswami, B. N. (2007), Experimental Seasonal Forecast of Indian Summer Monsoon 2007: Statistical and Dynamical Models, ISSN 0252-1075, Contribution from IITM Research Report No. RR-120: 1-25.

[30] Saji, N. H. Goswami, B. N., Vinayachandran, P. N. and Yamagata, T. (1999), A dipole mode in the tropical Indian Ocean, Nature, 401: 360–363.

[31] Singh, A., Acharya, N., Mohanty, U. C., Robertson, A. W. and Mishra, G. (2012), On the predictability of Indian summer monsoon rainfall in general circulation model at different lead time, Dyn. Atmos. Oceans, 58: 108–127.

[32] Soman, M. K. and Slingo, J. M. (1997), Sensitivity of the Asian summer monsoon to aspects of the sea surface temperature anomalies in the tropical Pacific Ocean. Quart. J. Roy. Meteor. Soc., 123: 309–339.

[33] Stern, W. and Miyakoda, K. (1995), The feasibility of seasonal forecasts inferred from multiple GCM simulation. J. Climate, 8: 1071–1085.

[34] Surendran, S., Gadgil, S., Francis, P.A. and Ajeevan, M.R.(2015), Prediction of Indian rainfall during the summer monsoon season on the basis of links with equatorial Pacific and Indian Ocean climate indices, Environ. Res. Lett. 10: 094004, doi:10.1088/1748-9326/10/9/094004

[35] Webster, P. J. and Hoyos, C. (2004), Prediction of monsoon rainfall and river discharge on 15-30day time scales, Bull. Am. Meteorol. Soc., 85: 1745–1765, doi:10.1175/BAMS-85-11-1745.

[36] Wang, B., Ding, Q., Fu, X., Kang, I.S., Jin, K., Shukla, J. and Doblas Reyes, F. (2005), Fundamental challenge in simulation and prediction of summer monsoon rainfall Geophys. Res. Lett. :32, L15711. doi:10.1029/2005GL022734.

[37] Webster, P. J. and Yang, S. (1992),Monsoon and ENSO: Selectively interactive systems. Q. J. R. Meteorol. Soc., 118: 877-926.

[38] Webster, P. J., Magana, V. O., Palmer, T. N., Shukla, J., Tomas, R. A., Yanai, M. and Yasunari T. (1998), Monsoons: Processes, predictability, and the prospects for prediction, J. Geophys. Res., 103(14): 451–510.

[39] World Climate Research Programme (WCRP), CLIVAR: A study of Climate variability and predictability, WMO/TD 690:157, Geneva, Switzerland, 1995.