Association of Sea Surface Temperature of Different Nino Regions with Summer Monsoon Rainfall over Indo-Gangetic Plains

R. Bhatla, Sandhya Singh*, B. Mandal and M. Singh
Department of Geophysics
Banaras Hindu University, Varanasi
**Department of Botany,*
Banaras Hindu University, Varanasi
Email: rbhatla@bhu.ac.in

ABSTRACT

The aim of the present study is to find out the possible association between the sea surface temperature (SST) of different Nino regions of equatorial Pacific Ocean with summer monsoon rainfall, zonal wind and convection over Indo-Gangetic Plains (IGP) during 30 years (1982-2011) period. The summer monsoon rainfall of IGP shows inverse relationship with SST anomaly for various Niño regions during May, April-May and previous spring season. On the other hand, outgoing longwave radiation (OLR) of IGP is positively associated with SST of all Nino regions. Nino-4 SST has more effect on convection of IGP during March, April-May (AM) and March-May (MAM) time period. The magnitude of correlation coefficient (CC) has been found significantly higher for the SST anomaly over Nino-4 region. SST of Nino-4 region has been used as a foreteller of monsoon over IGP.

Key words: *Indian summer monsoon rainfall, IGP, Nino regions.*

1. Introduction

About 80% of annual rainfalls in India have been supplied by Indian summer monsoon rainfall (ISMR). According to Webster et al. (1998) the annual scale fluctuation of ISMR has large consequence upon Indian agriculture as well as Indian economy. IGP is one of the extensive plain established through river system. The emerged river, Ganges has travelled 2500 km. from Himalaya towards southeast India over the northern India plain to the Bay of Bengal. The plain of Ganges has been characterized by fertile land of Indian sub-continent.

Tropical monsoon circulation of inter annual variation has been strongly affected by a major element called sea surface temperature (SST) anomaly in tropical Pacific. Numerous studied have been carried out on the variability of the ISMR over IGP by Adel (2001), (2002); Singh and Sontakke (2002); Chowdhury and Ward (2004), Bhatla, et al. (2015). It has been observed that warm SST anomaly over equatorial Pacific, known as El Nino events related to less summer monsoon rainfall over India (Sikka, 1980). Pronounce indirect relationship; exist between ISMR and eastern equatorial Pacific Ocean SST anomaly, identified by Angel (1981) and Mooley and Parthasarathy (1984) after one and two seasons. Rasmusson and Carpenter (1982, 1983), Elliot and Angel (1987) and Parthasarathy et al. (1988) had observed a link of SST anomaly over the eastern equatorial Pacific Ocean to the Indian monsoon rainfall. In the eastern equatorial Pacific an effective region closer to 2.5^{o}S, 130^{o} W recognized by Pan and Oort (1983), SST anomaly shows maximum correlation coefficient with average SST anomaly in the entire 20^{0}N-20^{0}S, 80^{0}-180^{0}W area. This area is the centre of Nino-3 region. The warming in Nino-3 region strongly affects the global atmosphere as mentioned by Cane (1991). Chattopadhyay and Bhatla (1996) try to illustrate the relation occurrence between good and bad monsoon link with ENSO/anti-ENSO prevalence. Chattopadhyay and Bhatla (2002) studied the relationship between the all India monsoon rainfall and SST anomalies (1949-1995) over different Nino regions of the equatorial Pacific Ocean.

In the last few decades, IGP is experiencing either intense excessive heat or extreme cold during summer and winter respectively, also during monsoon season it diminishes rainfall. Due to this vulnerability, monsoon pattern varies impacting agriculture, the hydrological cycle and ultimate human health. The goal of the present study is to find out possible relationship between SST anomalies of equatorial Pacific of different Nino regions (Fig.1) with Indian summer monsoon rainfall over IGP.

2. Data and Methodology

The seasonal rainfall series (June to September) have been prepared for IGP (Fig.2) using the seven meteological subdivisions IGP (Punjab, West Uttar Pradesh, Haryana, Bihar, Jharkhand, East Uttar Pradesh and Gangetic West Bengal) using the monthly rainfall data (www.tropmet.res.in) during the thirty years period (1982-2011) (Bhatla et al, 2015).

The monthly value of SST anomaly for the regions Nino(1+2), Nino3, Nino3.4 and Nino4 were obtained from the website *http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices*. The correlation coefficient (CC) of SST anomaly over different Nino regions of equatorial Pacific and IGP monsoon rainfall for each month and two successive months from January to May. The CC have also been measured for the successive three months season from the previous December to following month of May i.e. DJF (December to February), JFM (January to March), FMA (February to April) and MAM (March to May) and also calculated the CC of pre-monsoon SST anomaly between the previous spring and winter (MAM-DJF). Daily OLR data has been collected from website *http://www.esrl.noaa.gov/psd/data/olrcdr.interp.html* in order to examine the link between convection over IGP and SST of different Nino region for those cases where significant CC obtain SST of various Nino region with rainfall over IGP. Similarly, linkage of zonal wind at 850 hPa height over IGP and SST for all Nino regions have also been carried out using daily wind data obtained from European Centre for Medium-Range Weather Forecasts (ECMWF).

3. Results and Analysis

In order to investigate the interannual rainfall variability over IGP due to variation of SST at different Nino regions, the correlation approach is applied. In this section during individual months January, February, March, April and May; successive two months JF (January-February), FM (February-March) MA (March-April), and AM (April-May); successive three months DJF (-), JFM(January-February-March), FMA (February-March-April) and MAM

(March-April-MAY) compute the CC of normalize Indo-Gangetic Plains summer monsoon rainfall (IGPSMR) with SST anomaly of four different Nino regions. Further, CC has also been calculated between IGPSMR and SST anomaly at the period of previous spring to winter [MAM (-) - DJF(-)] known as tendency parameter suggested by Shukla and Paolino (1983). The significant features of this correlation coefficient have been tested by the conventional Student's t-test.

The Table-1 illustrates the magnitude of CC between IGPSMR and SST anomaly of different Nino regions. In most of the cases were obtained inverse relation, few of them were significant inverse relation, while other cases were insignificant one, whereas during this period of [MAM (-)-DJF (-)] got direct relation of them. Although, the magnitudes of CC for different period are observed diverse, some of them are found to be significant. Associated with 28 degrees of freedom, the potential magnitude of CC -0.54 (at 99.8% confidence level) out come between IGPSMR and SST anomaly for Nino4 region during the month of May, whereas comparatively moderate CC of -0.40(at 95% confidence level) and -0.32 respectively arise for both Nino3 and Nino3.4 region, while smallest magnitude of CC 0.2 has been obtained for Nino (1+2) region. Again, during individual month except May CC get analogy meaningful in case of Nino4 region than the other Nino regions. Therefore, for successive months of April-May value of CC -0.50 (at 99% confidence level) has been found with Nino-4 region, corresponding to same duration other Nino regions did not produce encouraging results. At the period of previous spring MAM (-) CC is -0.47(at 99% confidence level) of SST anomaly over Nino-4 region with IGPSMR, even rest of the Nino region SST anomaly have produce less CC than it.

The outcome of the result is significant due to fact that all four Nino regions delineate above, magnitude of CC along with remarkable significance level observed for Nino4 region. From above correlation analysis, it is come to point that alone SST anomaly over Nino4 is enormously correlated with IGPSMR during individual month May, April-May or previous spring MAM (-) and it may employ as a precursor for IGPSMR. Since variability of SST anomaly is responsible for variability of IGPSMR and not vice versa, it may treated as effective foreteller.

Fig 3(a) shows the variation of SST anomaly over Nino4 region and monsoon rainfall anomaly for 30 years during 1982 to 2011 for the month of May. From this figure it has been observed that there is inverse relation between SST anomaly and rainfall anomaly for nineteen years (1982, 1984, 1985, 1987, 1988, 1989, 1991, 1992, 1996, 1998,1999, 2000, 2002, 2004, 2005, 2008, 2009, 2010 and 2011) out of thirty years whereas during other eleven years (1983, 1986, 1990, 1993, 1994, 1995, 1997, 2001, 2003, 2006, and 2007) SST anomaly and rainfall anomaly has direct relation. For successive two month (April-May), the changing relationship between SST anomaly and monsoon rainfall anomaly for 30 years (1982-2011) has been shown in Fig. 3 (b). This figure reveals that SST anomaly and rainfall anomaly has indirect relation for nineteen years i.e. 1982, 1984, 1985, 1987, 1988, 1989, 1991, 1992, 1996, 1998, 1999, 2000, 2002, 2004, 2005, 2008, 2009, 2010 and 2011 whereas for eleven years i.e. 1983, 1986, 1990, 1993, 1994, 1995, 1997, 2001, 2003, 2006, and 2007 has direct relation in between both anomalies. An interesting feature have been observed that anomaly of two years 1998 and 2009 has direct relation for individual month whereas inverse relation for two successive months AM.

The association between SST anomaly and rainfall anomaly of previous spring seasons MAM (-) for 30 years (1982-2011) has shown in Fig. 3(c) Only twelve years i.e. 1983, 1986, 1990, 1993, 1994, 1995, 1997, 1998, 2001, 2003, 2007 and 2009 have direct relationship between SST anomaly and rainfall anomaly whereas other 18 years i.e. 1982, 1984, 1985, 1987, 1988, 1989, 1991, 1992, 1996, 1998, 1999, 2000, 2002, 2004, 2005, 2006, 2008, 2009, 2010 and 2011 have shown inverse relation between SST anomaly and rainfall anomaly. In the year 2006, both anomalies for previous spring season MAM (-) has inverse relation, whereas direct relation has been found for successive month and individual month. It has also been found that during the years 1998 and 2009, SST and rainfall anomaly has direct relation for previous spring season and inverse relation for successive two month AM in Nino4 region.

In this section, how OLR and zonal wind at 850 hPa level over IGP associated to the SST anomaly over different Nino region has been focused. The CC between SST anomaly/OLR and SST anomaly/zonal wind of 850 hPa level, for the month of May, AM and MAM (-) have been shown in Table-2. It has been observed from Table-2 that OLR over IGP is positively related to SST anomaly for all cases. During the month of May the CC between SST anomaly over Nino-4 region with OLR during summer monsoon over IGP is found to be 0.64 (at 99.9% confidence level). Whereas, Nino-3.4 region SST anomaly for May month also reflects the relationship with OLR over IGP having magnitude of CC 0.55 (at 99.8% confidence level) has been observed, while for the same time period SST anomaly over Nino3 region has also been shown the association with OLR having CC of 0.42 (at 98% confidence level). On the other hand SST over Nino (1+2) and OLR over IGP are poorly related as compared to other. When analyze impact of SST anomaly of all Nino regions for the month AM, it has been found that the strength of relationship become decreased. It has been observed that the SST over Nino-4 region, could express more control to OLR of IGP. The maximal value of CC between SST in AM and OLR over IGP has associated with SST of Nino4 region, magnitude of CC between SST of Nino4 region with OLR over IGP has the value 0.57(at 99.9% confidence level).It has also been found that CC between OLR over IGP and SST over Nino-3.4 region is 0.50(at 99% confidence level). However during AM the SST anomaly at Nino-3 region would not denied the affect of OLR over IGP having CC of 0.36 (at 95% confidence level). While Nino (1+2) region SST has fail to associate with OLR for during AM. It has been observed that for the period MAM (-) behavior of Nino4 SST represent as one of major factor to influence OLR over IGP during summer monsoon season, having of CC of them note 0.51 (at 99% confidence level). Again, it has also been observed that remarkable contribution by the SST anomaly of Nino3.4 to organized convection over IGP. SST anomaly of Nino-3.4 for previous spring season MAM (-) CC has been found to be 0.42 at 98% confidence level. While Nino3 and Nino (1+2) SST anomaly not shows any significance effect on OLR over IGP. Here, CC have been calculated between SST and OLR of IGP are 0.28 and 0.12 over Nino3 and Nino(1+2) region respectively during MAM

(-) season. This implies that increasing SST will be responsible for occurrence of less convection, conscience to occurred rainfall deficiency. Now, CC have been determined looking for the impacts on zonal wind at 850 hPa level over IGP in the period of monsoon due to SST anomaly of individual Nino-zones during May, AM and MAM(-). Table-2 shows that insignificant proportional link arises between wind and SST for May, AM and MAM(-). Therefore, over IGP easterly may be dominant during monsoon season which renders faint relationship between zonal winds of IGP to different Nino region SST.

4. Conclusions

The following conclusions may be drawn from the analysis:

- The summer monsoon rainfall of IGP is effectively inverse relationship to the SST anomaly for various Nino regions during May, April-May and previous OLR over IGP is highly influenced by the Nino4 region SST anomaly during month May at 99.9% confidence level.
- OLR of IGP is directly proportional to the SST anomaly of Nino4 region during all time scale.
- All four Nino region SST could not impact on zonal wind at 850 hPa level of IGP.
- Thus, behaviour of SST of Nino4 region can be used as precursor of monsoon rainfall.

References

Adel, M.M., 2001: Effect on water resources from upstream water diversion in the Ganges basin, J. Environ. Qual. 30, 356–368.

Adel, M.M., 2002: Man-made climatic changes in the Ganges basin, Int. J. Climatol., 22, 993–1016.

Alexander, M. A., Deser, C., and Timlin,M.S., 1999: The Re-emergence of SST Anomalies in the North Pacific Ocean, *J. Climate,* 12, 2419-2433.

Angell, J.K., 1981: Comparison of variations in atmospheric quantities with sea-surface temperature variations in the equatorial eastern Pacific, *Mon. Wea. Rev.,* 109, 230–243.

Bhatla, R., Singh, Madhu, Mall, R. K., Tripathi, A., and Raju, P. V. S., 2015: Variability of summer monsoon rainfall over Indo-Gangetic plains in relation to El-Nino/La-Nina, Nat. Hazards, 78, 837–853.

Cane, M.A., 1991: Forecasting El Nino with a geophysical model, *Teleconnections Linking World-wide Climate Anomalies*, Glantz, M.A., Katz, R.W., Nicholls, N. (eds)., Cambridge University Press, Cambridge, 345–369.

Chattopadhyay, J., and Bhatla, R., 1996: A re-examination of ENSO/anti-ENSO events and simultaneous performance of the Indian summer monsoon, Mausam, 47, 59–66.

Chattopadhyay, J., and Bhatla, R., 2002: Possible influence of QBO on teleconnections relating Indian summer monsoon rainfall and sea-surface temperature anomalies across the equatorial pacific, Int. J. Climatol., 22, 121–127.

Chowdhury, M.R., and Ward, N., 2004: Hydro-meteorological variability in the greater Ganges–Brahmaputra–Meghna basins, Int. J. Climatol., 24, 1495–1508.

Elliott, W.P., and Angell, J.K., 1987: The relation between Indian monsoon rainfall, the

Southern Oscillation and hemispheric air and sea temperature: 1884–1984, *J. Climatol. Appl. Met.,* 26, 943–948.

Keshavamurty, R.N., 1982: Response of the Atmosphere to Sea Surface Temperature anomalies over the Equatorial Pacific and the Teleconnections of the Southern Oscillation, *J. Atmos. Sci.,* 39, 1241-1259.

Mooley, D.A., and Parthasarathy, B., 1984: Indian summer monsoon and east equatorial Pacific sea-surface temperature, *Atmosphere-Ocean,* 2, 23–35.

Pan, Y.H., and Oort, A.H., 1983: Global climate variations connected with sea-surface temperature anomalies in the eastern equatorial Pacific ocean for the 1958–73 period, *Mon. Wea. Rev.* 11, 1244–1258.

Parthasarathy, B., Diaz, H.F., and Eischeid, J.K., 1988: Prediction of all India summer monsoon rainfall with regional and large-scale parameters, *J. Geop. Res.,* 93(D5), 5341–5350.

Rasmusson, E.M., and Carpenter, T.H., 1982: Variations in tropical sea-surface temperature and surface wind fields associated with the Southern Oscillation/El Nino, *Mon. Wea. Rev.* 110, 354–384.

Rasmusson, E.M., and Carpenter, T.H., 1983: The relationship between eastern equetrol Pacific sea surface temperature, *Mon. Wea. Rev.* 110, 354–384.

Shukla, J., and Paolino, D. A., 1983: The Southern Oscillation and long range forecasting of the summer monsoon rainfall over India, *Mon. Wea. Rev.,* 111, 1830-1937.

Sikka, D.R., 1980: Some aspects of large-scale fluctuation of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters. *Proc. Ind. Acad. Sci.(Earth Plan. Sci.,* 89, 179–195.

Singh, N., and Sontakke, N.A., 2002: On climate fluctuations and environmental changes of the Indo-Gangetic plains, India, Clim. Change, 52, 287–313.

Webster, P.J., Magana, V.O., Palmer, T.N., Shukla, J., Thomas, R.A., Yanai, M., and Yasunari, T., 1998: Monsoons: Process, predictability, and the prospects for prediction, *J. Geop. Res.,* 103, 14453–14510

Table1: Correlation coefficients (CC) of normalized monsoon rainfall with different Nino regions.
('***' '**' and '*'denote the confidence at 99.8%, 99% and 95% levels respectively.)

Period	Nino(1+2)	Nino3	Nino4	Nino3.4
January	-0.03	-0.2	-0.33	-0.27
Febuary	0.01	-0.2	-0.36	-0.3
March	0.00	-0.18	-0.4	-0.3
April	-0.2	-0.3	-0.46	-0.38
May	0.2	-0.32	-0.54 ***	-0.4 *
JF	-0.02	-0.2	-0.35	-0.29
FM	0.0	-0.19	-0.38	-0.3
MA	-0.12	-0.25	-0.43	-0.34
AM	-0.21	-0.32	-0.50 **	-0.4 *
JFM	-0.01	0.2	-0.37	-0.29
FMA	-0.09	-0.23	-0.41	-0.33
MAM(-)	-0.16	-0.29	-0.47 **	-0.37 *
DJF(-)	-0.06	-0.2	-0.34	-0.28
MAM(-)-DJF(-)	-0.04	0.05	0.04	0.14

Table2: Correlation coefficients (CC) of OLR and zonal wind at 850 hPa level with SST of different Nino regions.
(Superscript a, b, c, d and e indicate confidence at 99.9%, 99.8%, 99%, 98% and 95% levels respectively.)

	OLR				**Wind at 850hPa**			
	Nino(1+2)	Nino3	Nino4	Nino3.4	Nino(1+2)	Nino3	Nino4	Nino3.4
M	0.16	0.42[d]	0.64[a]	0.55[b]	0.16	0.20	0.15	0.21
AM	0.15	0.36[e]	0.57[a]	0.50[c]	0.19	0.19	0.14	0.16
MAM(-)	0.12	0.28	0.51[c]	0.42[d]	0.18	0.16	0.12	0.12

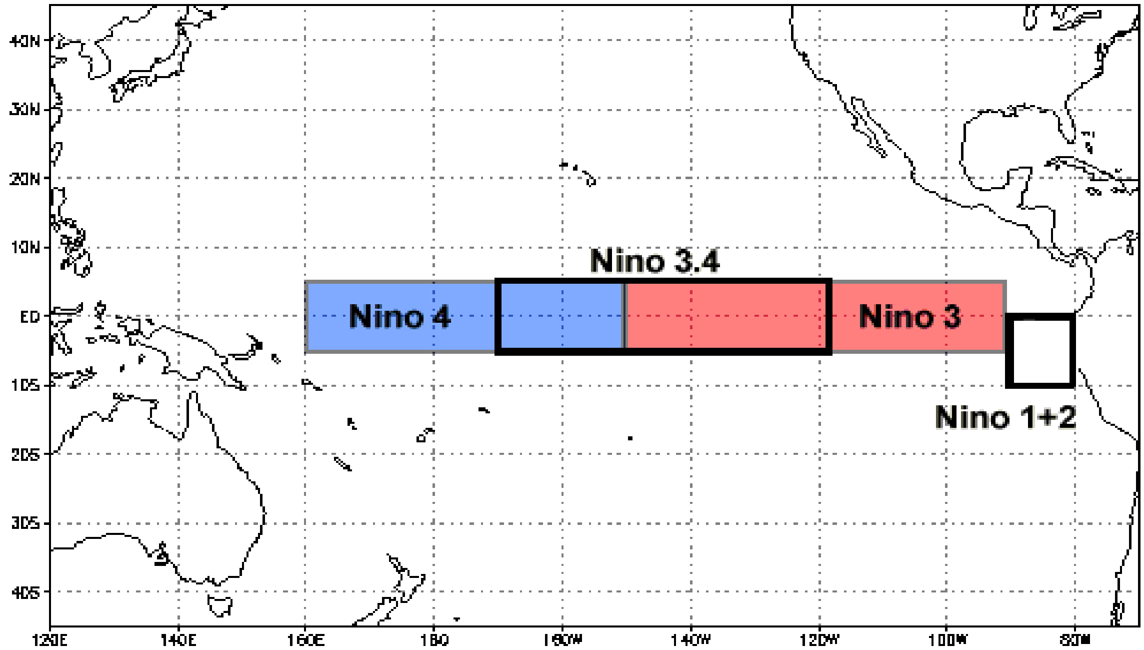

Fig.1: Location of various Nino regions of the equatorial Pacific Ocean

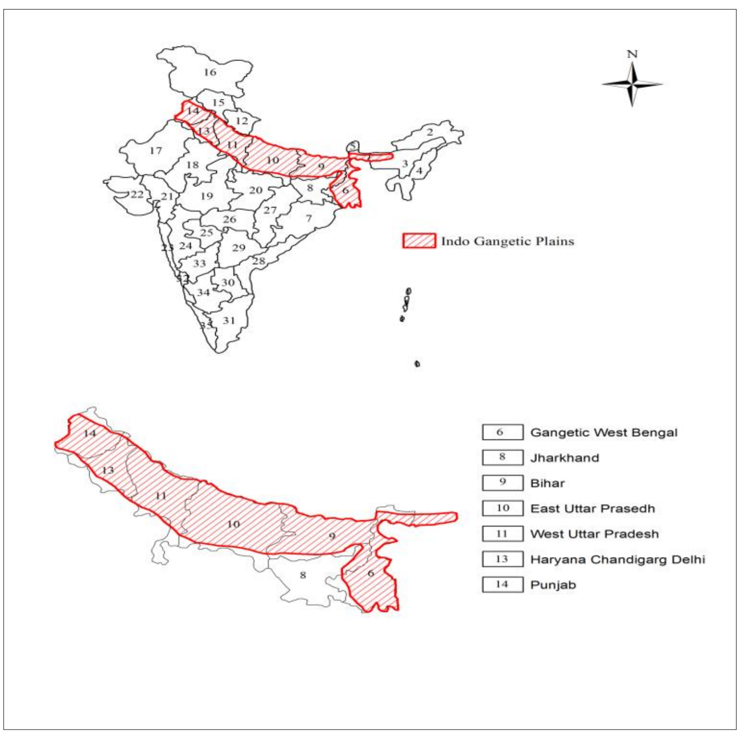

Fig.2: Location of study area Indo-Gangetic Plains

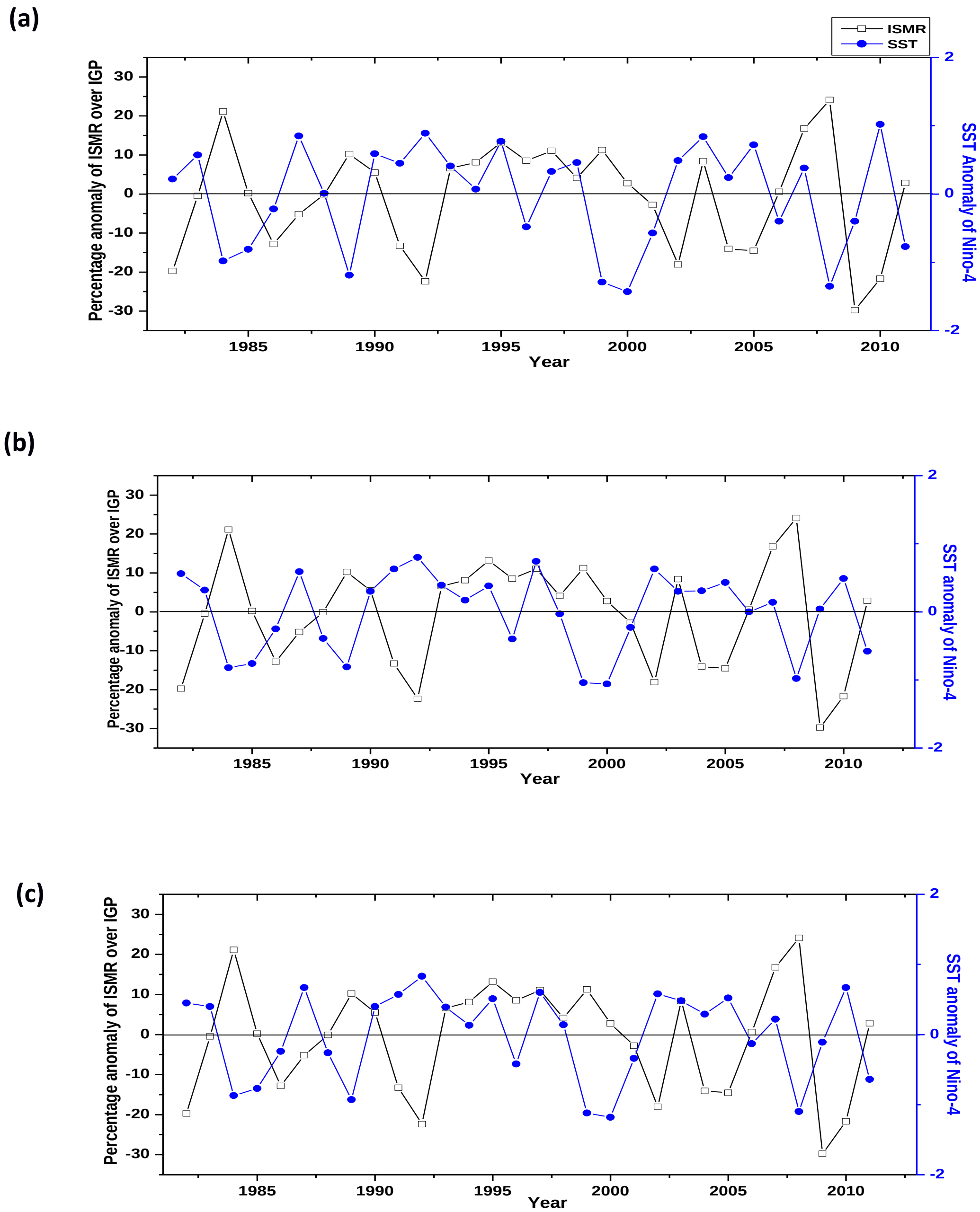

Fig. 3: Time series of IGP monsoon rainfall anomaly and SST anomaly over Nino-4 region during May: n=30, r=0.54(significant at 1% level) 1982-2011 for (a). During successive month April-May n=30, r=0.50(at 1% significant level) for (b). During previous spring season MAM (-) n=30, r=0.47 (at 1% significant level) for (c).