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INFLUENCE OF EQUATORIAL PACIFIC SST ANOMALIES OF NINO 3.0 AND 3.4 ON INDIAN SUB-DIVISIONAL RAINFALLS

1. In the last 31 years period (1970- 2000), India has seen five flood years (1970, 1975, 1983, 1988 and 1994) and seven drought years (1972, 1974, 1979, 1982, 1985, 1986, 1987 and more recently the year 2002). This country witnessed 12th successive normal monsoon till the year 1999. Many studies on Indian summer monsoon indicated intra-seasonal and inter-annual variations in the monsoon due to various external and internal dynamics of the monsoon and our scientific understanding of monsoons have been greatly improved by such scientific studies. The sea surface temperatures in the Pacific oceanic region and Tahiti (18° S / 150° W) and Darwin

TABLE 1

Showing correlation coefficients between Equatorial Pacific Nino 3.0 and 3.4 SST anomalies and Indian sub-divisional rainfalls

Sub-division	Winter	Nino 3.0 Pre-monsoon	Monsoon	Post-monsoon	Winter	Pre-monsoon	Nino 3.4 Monsoon	Post-monsoon
North Assam	0.14	0.15	0.07	-0.05	0.08	0.09	0.02	-0.07
South Assam	-0.13	-0.14	-0.03	-0.04	-0.14	-0.15	-0.07	-0.07
Sub-Himalayan West Bengal	0.17	-0.02	-0.20	-0.31*	0.09	-0.07	-0.27	-0.35*
Gangetic West Bengal	-0.27	-0.21	-0.17	-0.16	-0.26	-0.24	-0.13	-0.14
Orissa	-0.20	-0.12	-0.04	0.03	-0.15	-0.07	0.06	0.11
Bihar Plateau	-0.09	-0.06	-0.06	-0.05	-0.12	-0.12	-0.07	-0.05
Bihar Plains	-0.09	-0.07	-0.04	-0.09	-0.17	-0.19	-0.09	-0.13
East Uttar Pradesh	-0.04	-0.20	-0.33	. -0.35*	-0.10	-0.25	-0.40+	-0.40+
West Uttar Pradesh	0.17	-0.08	-0.33*	-0.41+	0.14	-0.09	-0.39*	-0.41+
Haryana	0.21	-0.12	-0.34*	-0.37*	0.24	-0.03	-0.37*	-0.38*
Punjab	-0.03	-0.36*	-0.50+	-0.48+	-0.01	-0.29*	-0.51+	-0.50+
West Rajasthan	0.15	0.04	-0.20	-0.26	0.16	0.06	-0.25	-0.30*
East Rajasthan	0.11	-0.15	-0.42+	-0.41+	0.14	0.06	-0.40+	-0.40+
West Madhya Pradesh	0.09	-0.11	-0.34*	-0.33*	0.11	-0.05	-0.33*	-0.34*
East Madhya Pradesh	-0.04	-0.10	-0.25	-0.23	-0.02	-0.04	-0.16	-0.18
Gujarat	0.24	0.00	-0.29*	-0.27	0.24	0.07	-0.31*	-0.31*
Saurashtra & Kutch	0.16	-0.02	-0.25	-0.22	0.19	0.05	-0.26	-0.24
Konkan & Goa	0.25	0.12	-0.21	-0.30*	0.22	0.11	-0.28*	-0.35*
Madhya Maharashtra	0.18	0.03	-0.25	-0.29*	0.19	0.02	-0.35*	-0.34*
Marathwada	0.30*	0.02	-0.36*	-0.42+	0.25	0.01	-0.47+	-0.49+
Vidarbha	0.27	-0.06	-0.41*	-0.37*	0.32*	0.08	-0.38*	-0.37*
Coastal Andhra Pradesh	0.11	-0.08	-0.28*	-0.32*	0.07	-0.11	-0.38*	-0.36*
Telangana	0.16	-0.09	-0.36*	-0.37*	0.15	-0.09	-0.45+	-0.43+
Rayalaseema	0.29*	0.09	-0.19	-0.26	0.24	0.07	-0.29*	-0.33*
Tamil Nadu	0.00	-0.15	-0.27	-0.33*	-0.03	-0.17	-0.32*	-0.34*
Coastal Karnataka	0.16	0.02	-0.21	-0.22	0.14	0.01	-0.28*	-0.30*
North interior Karnataka	0.22	0.02	-0.25	-0.28	0.17	-0.03	-0.37*	-0.35*
South interior Karnataka	0.24	0.01	-0.29*	-0.31*	. 0.25	0.04	-0.34*	-0.35*
Kerala	0.00	-0.07	-0.17	-0.13	0.05	-0.02	-0.18	-0.15

'*' indicates CCs significant at 95% confidence level and '+' indicates CCs significant at 99% confidence level

(12° S / 131° E) pressure difference (Southern Oscillation) in the mid-Pacific oceanic region together constitute ENSO and whenever the SO is negative, it is an El-nino year. Further, the equatorial Pacific oceanic region is divided into four sub-regions Nino 1+2 region (0° - 10° S / 90° W - 80° W), Nino 3 region (5° N -5° S / 150° W - 90° W), Nino 3.4 region (5° N - 5° S / 170° W - 120° W), Nino 4 region (5° N - 5° S / 160° E - 150° W) and influence regional scale SST- anomalies of equatorial Pacific ocean on summer monsoon are investigated by many to explain the inter-annual variability of summer monsoons. Many studies established influence of other than ENSO parameters on the summer monsoon1Bamzai and Shukla, 1999; Clark *et al.*, 2000; Liu and Yanai, 2001). Loschnigg *et al.*, (2003) found that the observed tropical biennial oscillations in the Asian monsoon are influenced by the large scale forcing from tropical Pacific and regional forcing associated with meridional temperature gradient between Asian continent and the Indian Ocean SST anomalies. Nicholos (1995) studied relationship between Indian summer monsoon (June - September) and sea surface temperatures around Northern Australia-Indonesia using data from 1949-91. He found that warmer sea surface temperatures are generally associated with a good monsoon and a poor monsoon is preceded or accompanied by low sea surface temperatures and the two predictors (April SSTs and change in Darwin pressure from January-April) together account for 50% of the variance in Indian summer monsoon rainfall Nitta and Yamada (1989) found significant SST increases in the tropics of the central and eastern pacific and Indian Ocean were linked to enhanced convective activity. A GCM study in which solar forcing of the land and ocean incorporated separately showed that the annual cycle of SST in the Indian Ocean is crucially important in establishing monsoon circulation and rainfall (Shukla and Fennessy, 1994). A cool Arabian-Sea surface temperature leads to a reduced Indian rainfall and *vice versa* (Shukla, 1975). Soman and Slingo (1997) suggested through the sensitivity experiments with the GCM model that equatorial wards shift of the sub-tropical jet is a remote response to the warm SST anomalies in the central and east Pacific associated with El-Nino. Furthermore, relationship between SOI in September and Nino 3.4 region SST in August, September months with coastal Andhra Pradesh winter monsoon rainfall has been investigated and results showed that the SOI (September) has significant negative correlation and Nino 3.4 SST (August, September) have significant positive correlation with coastal Andhra Pradesh winter summer monsoon rainfall (Bhanukumar *et al*., 2004). Kane (1998) studied summer monsoon rainfall departures of all India and also of 29 meteorological sub-divisions by characterizing each year as El-Nino, Southern Oscillation, ENSO warm or cold or none events for the period 1871-1990 and concluded that drought years were associated with unambiguous ENSO warm events and floods with cold events. The study also indicated that in normal monsoon years during ENSO warm or cold events, sub-divisional rainfalls were normal or mixed. In this paper, an attempt has been made to study the influence of equatorial Pacific SST anomalies of Nino 3.0 and Nino 3.4 regions on the Sub-divisional Summer Monsoon Rainfalls of India (SSMR) and also the relationships among 29 sub-divisional rainfalls considered in this study.

2. *Data and methodology* - The homogeneous Centre for Ocean-Land-Atmosphere studies (COLA) area weighted sub-divisional rainfall data, widely considered as reliable, of 29 meteorological sub-divisions, contributed by the Indian Institute of Tropical Meteorology (IITM), Pune for the period 1951-1999 were used and Nino 3.0 and Nino 3.4 region SST anomalies in degree Celsius for the same period were taken from Climate Analysis Section (CAS) which were discussed and appeared as figures in Trenberth (1997) and threshold of such values was within ± 0.5°C. The raw date source is Climate Prediction Centre (CPC), National Oceanic & Atmospheric Administration (NOAA) data files for these SST anomalies based on 1950-1979. The influence of equatorial SSTs on the Sub-divisional Summer Monsoon Rainfall (SSMR) was studied by finding out correlations between SSMRs and Season-wise Equatorial Pacific SSTs. The spatial distribution of the summer monsoon was also found by finding out correlation between each of sub-divisional summer monsoon rainfalls of the 29 sub-divisions considered for the study. Only standard correlation formula was employed for the study.

3. *Results and discussion* - It was found that correlations (0.28) that are significant at 95% confidence level and correlations (0.40) that are significant at 99% confidence level exist between seasonal anomalies of equatorial Pacific Nino 3.0 and 3.4 SSTs and SSMRs. From the figures given in Table 1, it is clear that the winter (DJF) (1950/51 -1998/99) Nino 3.0 region SST anomalies correlates positively with Sub-divisional Summer Monsoon Rainfall (SSMR) of Marathwada and Rayalaseema with remaining sub-divisions showing no significant correlations. The Nino 3.4 SST anomalies correlates positively with SSMR of Vidarbha only. Similarly, the pre-monsoon (MAM) Nino 3.0, Nino 3.4 region SST anomalies correlates negatively only in case of SSMR of Punjab. The monsoon (JJAS) Nino 3.0 region SST anomalies correlates negatively with SSMRs of east UP, west UP, Haryana, Punjab, east Rajasthan, west MP, Gujarat, Marathwada, Vidarbha, coastal Andhra, Telengana, south interior Karnataka and Nino 3.4 region SST anomalies correlates negatively with SSMRs east UP, west UP, Haryana, Punjab, east Rajasthan, west MP, Gujarat, Konkan & Goa, Madhya Maharastra, Marathwada, Vidarbha, coastal Andhra, Telengana, Rayalaseema, Tamilnadu, coastal Karnataka, north interior Karnataka and south interior Karnataka. The post-monsoon (ON) Nino 3.0 region SST anomalies correlates negatively with SSMRs Gangetic West Bengal, east UP, west UP, Haryana, Punjab, east Rajasthan, west MP , Konkan & Goa, Madhya Maharastra, Marathwada, Vidarbha, coastal Andhra, Telengana, Tamilnadu, north interior Karnataka, south interior Karnataka. The Nino 3.4 region SST correlates negatively with SSMRs Sub-Himalayan West Bengal, east UP, west UP, Haryana, Punjab, west Rajasthan, east Rajasthan, west MP, Gujarat, Konkan & Goa, Madhya Maharastra, Marathwada, Vidarbha, coastal Andhra, Telengana, Rayalaseema, Tamilnadu, coastal Karnataka, north interior Karnataka,

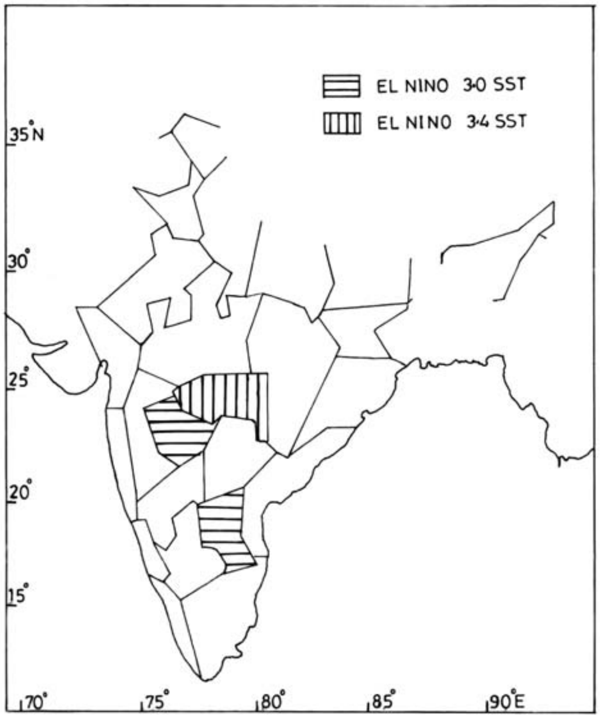

Fig. 1. Showing sub-divisions having positive correlations between Indian summer monsoon rainfall (June-September) and winter (DJF) El-Nino 3.0, 3.4 SST anomalies (1951-1999)

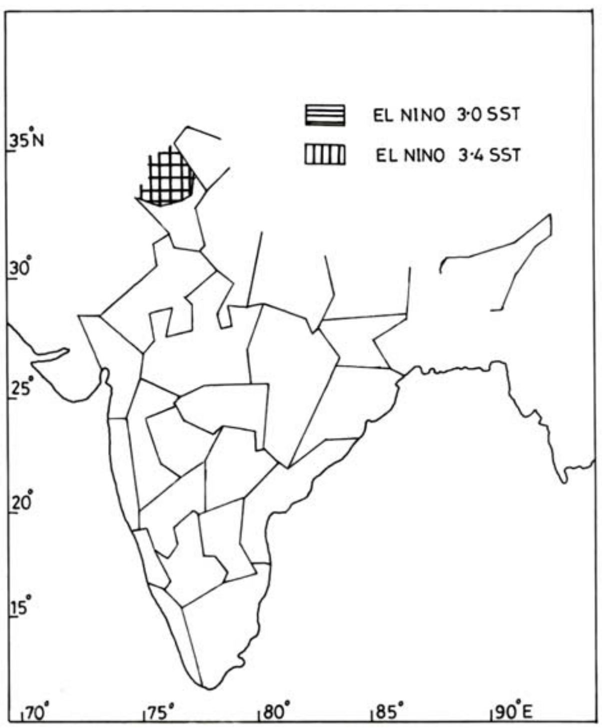

Fig. 2. Showing sub-divisions having negative correlations between Indian summer monsoon rainfall (June-September) and per-monsoon (MAM) El-Nino 3.0, 3.4 SST anomalies (1951-1999)

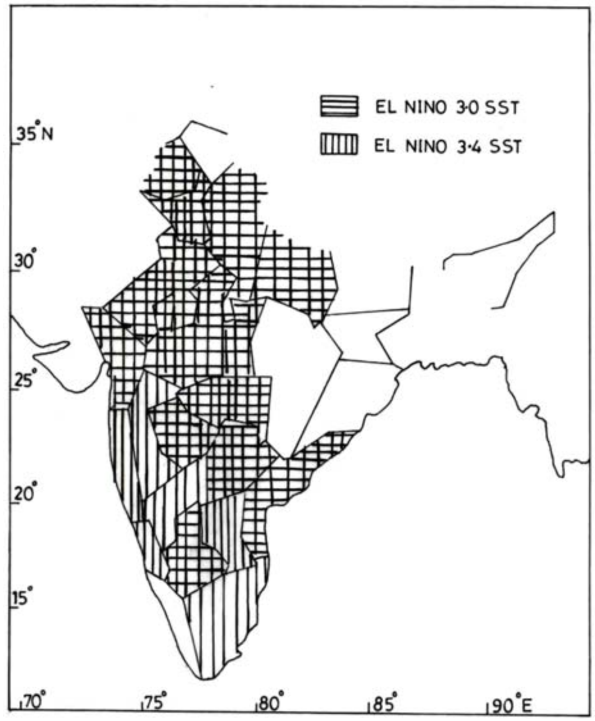

Fig. 3. Showing sub-divisions having negative correlations between Indian summer monsoon rainfall (June-September) and monsoon (JJAS) El-Nino 3.0, 3.4 SST anomalies (1951-1999)

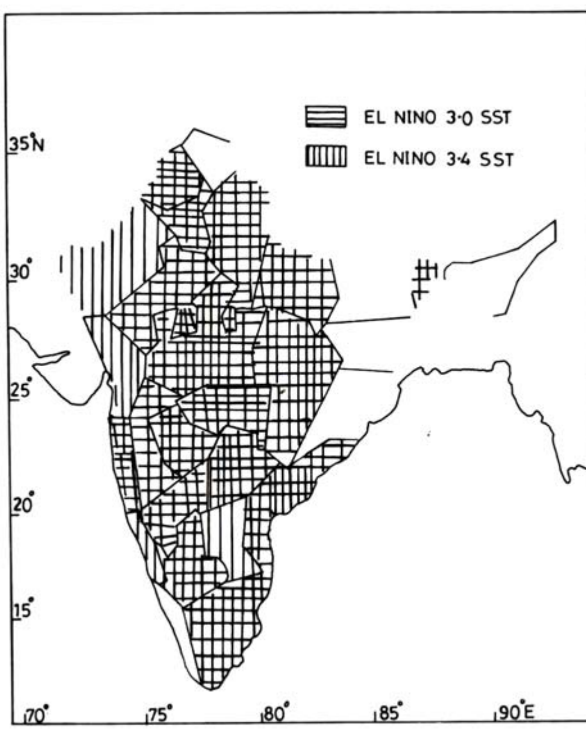

Fig. 4. Showing sub-divisions having positive correlations between Indian summer monsoon rainfall (June-September) and post monsoon (ON) El-Nino 3.0, 3.4 SST anomalies (1951-1999)

TABLE 2

Showing statistically significant correlations among rainfalls of meteorological sub-divisions

Sub-division	Positive CCs	Negative CCs
North Assam	South Assam*/ Sub-Himalayan West Bengal */Bihar plains*	Saurastra & Kutch/Kerala
South Assam	-	East Rajasthan/West MP/East MP
Sub-Himalayan West Bengal	Bihar plains*/ Rayalaseema	East Rajasthan/Saurastra & Kutch
Gangetic West Bengal	Bihar plateau*/Bihar plains*/West MP/East MP	-
Orissa	West MP/East MP*/Gujarat	-
Bihar Plateau	Bihar plains*/Punjab/West Rajasthan/East Rajasthan/West MP*/East MP*/ Gujarat	-
Bihar Plains	East UP	Vidarbha
East Uttar Pradesh	West UP*/Haryana/Punjab*/East Rajasthan/ West MP*/East MP/Gujarat/ Konkan & Goa/Marathwada/Telangana/Coastal Karnataka	-
West Uttar Pradesh	Haryana*/Punjab*/East Rajasthan*/West M.P*/ East MP*/Gujarat/Konkan & Goa*/Marathwada/Coastal Andhra/Telengana*/Rayalaseema/Tamil Nadu/ Coastal Karnataka/North Interior Karnataka	-
Haryana	Punjab*/West Rajasthan*/East Rajasthan*/West MP/East MP/Gujarat/Madhya Maharastra/Coastal Andhra/Rayalaseema/TamilNadu/North Interior Karnataka	-
Punjab	West Rajasthan/East Rajasthan*/West MP*/East MP/Gujarat/Vidarbha/Coastal Karnataka	-
West Rajasthan	East Rajasthan*/West MP*/East MP/Gujarat*/Saurastra & Kutch*/Coastal Andhra/Telengana/Rayalaseema/Coastal Karnataka*	-
East Rajasthan	West MP*/East MP*/Gujarat*/Saurastra & Kutch/ Konkan & Goa/ Madhya Maharastra/Vidarbha*/Coastal Karnataka	-
West Madhya Pradesh	East MP*/Gujarat*/Konkan & Goa*/Madhya Maharastra/ Vidarbha*/Coastal Karnataka.	-
East Madhya Pradesh	Gujarat*/Saurastra & Kutch/Vidarbha*/Coastal Karnataka	-
Gujarat	Saurastra & Kutch*/Konkan & Goa/Madhya Maharastra*/ Marathwada*/ Vidarbha*/Coastal Andhra/Telengana*/Coastal Karnataka/North Interior Karnataka*	-
Saurastra & Kutch	Konkan & Goa/Madhya Maharastra*/Marathwada*/Vidarbha*/Coastal Andhra/ Telengana*/Coastal Karnataka*/North Interior Karnataka*/South Interior Karnataka*/Kerala	-
Konkan & Goa	Madhya Maharastra*/Marathwada*/Vidarbha*/Coastal Andhra*/Telengana*/ Rayalaseema/Coastal Karnataka*/North Interior Karnataka/South Interior Karnataka/	-
Madhya Maharastra	Marathwada*/Vidarbha*/Coastal Andhra*/Telengana*/Rayalaseema*/Coastal Karnataka*/North Interior Karnataka/South Interior/Karnataka/Kerala	-
Marathwada	Vidarbha*/Coastal Andhra*/Telengana*/Coastal Karnataka*/North Interior Karnataka*/South Interior Karnataka/Kerala	-
Vidarbha	Coastal Andhra/Telengana*/Tamilnadu*/Coastal Karnataka/North Interior Karnataka*/South Interior/ Karnataka/Kerala	-
Coastal Andhra	Telengana*/Rayalaseema*/Tamilnadu*/Coastal Karnataka/North Interior Karnataka*/South Interior Karnataka	-
Telengana	Rayalaseema*/Tamilnadu/Coastal Karnataka*/North Interior Karnataka/South Interior Karnataka	-
Rayalaseema	Tamilnadu*/North Interior Karnataka*/South Interior Karnataka*	-
Tamil Nadu	North Interior Karnataka/South Interior Karnataka*	-
Coastal Karnataka	North Interior Karnataka/South Interior Karnataka*/Kerala*	-
North Interior Karnataka	South Interior Karnataka*	-
South Interior Karantaka	Kerala*	-
Kerala	-	-

'*' are significant at p = 0.01 and rest are significant at p = 0.05.

Interior Karnataka, south interior Karnataka when correlation coefficients significant at 95% and 99% are considered. The Nine sub- divisional rainfalls *viz*., north Assam, south Assam, Gangetic west Bengal, Orissa, Bihar Plateau, Bihar Plains, east Madhya Pradesh, Saurastra & Kutch and Kerala showed no significant correlations with Nino 3.0 and 3.4 SST anomalies during the period of study. The above results show that the preceding winter and pre-monsoon season, equatorial Pacific SSTs of the regions Nino 3.0 and Nino 3.4 has an meager influence on the SSMRs. Only the concurrent, monsoon season and succeeding post-monsoon season equatorial Pacific SSTs of Nino 3.0 have considerable influence over SSMR with 41% of the sub-divisions studied and 55% of the sub-divisions studied respectively. The influence of concurrent monsoon season and succeeding post-monsoon season equatorial Pacific SSTs of Nino 3.4 on SSMR was found to be more with 62% of the sub-divisions and 69% of the sub-divisions having inverse relationship. The significant correlations found between SSMR and concurrent equatorial Pacific SSTs of Nino 3.0 and Nino 3.4 indicate their modifying effect on the Hadley/Walker circulation and, in turn, on the monsoon circulation pattern. The significant correlations between SSMRs and equatorial Pacific SSTs of Nino 3.0 and Nino 3.4 indicate the cooling effect of the summer monsoon over the equatorial Pacific SSTs as a result of dry cold northwesterly winds blowing from the cooled continent. The sub-divisions whose rainfall was having significant correlation with equatorial Pacific SST of region 3.0 and 3.4 were presented in Figs. 1 to 4 season wise. The significant correlations found between SSMRs of the 29 sub-divisions were presented in Table 2. From Table 2, it can be seen that north Assam SSMR has got negative correlations with the Kerala and Saurastra & Kutch SSMRs, south Assam SSMR has got negative correlations with east Rajasthan, west MP and east MP SSMRs, Sub-Himalayan West Bengal has got negative correlations with east Rajasthan and Saurastra & Kutch and Bihar plains SSMR has negative correlation with Vidarbha SSMR. The rest of the significant correlations between SSMRs were all positive out of 29 sub-divisions considered for the study.

4. *Conclusions* - (*i*) Study in this paper, establishes a regional scale influence of concurrent monsoon season equatorial Pacific Nino 3.0 and Nino 3.4 SST anomalies on the monsoon circulation over the sub-continent. It is also noticed that no statistically significant relationship exists between Nino 3.0 SST anomalies of concurrent monsoon season and sub-divisional rainfalls of north Assam, south Assam, Sub-Himalayan West Bengal, Gangetic West Bengal, Orissa, Bihar plains, Bihar plateau and east MP in the eastern parts of the country. In the western parts of the country sub-divisions like west Rajathan, Saurashtra & Kutch, Konkan & Goa and Madhya Maharashtra have shown no statistical significant relationship with Nino 3.0 SST anomalies and only west Rajasthan, Saurashtra & Kutch with Nino 3.4 SST anomalies. In the southern parts of the country Rayalaseema, Tamilnadu, coastal Karnataka, north interior Karnataka and Kerala have shown no statistically significant relationship with Nino 3.0 SST anomalies and only Kerala with Nino 3.4 SST anomalies. The inverse relationship between sub-divisional rainfalls and Nino 3.0, 3.4 region SST anomalies of concurrent monsoon season establish the influence Karnataka and Kerala have shown no statistically significant relationship with nino 3.0 SST anomalies and only Kerala with Nino 3.4 SST anomalies. The inverse relationship between sub-divisional rainfalls and Nino 3.0, 3.4 region SST anomalies of concurrent monsoon season establish the influence of ENSO on summer monsoon and the noticed inverse relationship between sub-divisional rainfalls and succeeding post monsoon SST anomalies of both Nino 3.0, 3.4 indicate cooling effect.

(*ii*) The study also indicated statistically significant at 95% confidence level inverse relationship between sub-divisional rainfalls of the following.

(a) North Assam and Sausrashtra & Kutch, Kerala.

(b) South Assam and east Rajasthan, west MP, east MP.

(c) Sub-Himalayan West Bengal and east Rajasthan, Saurastra & Kutch.

(d) Bihar plains and Vidarbha.

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References

Bamzai, A. S. and Shukla, J., 1999, “Relation between Eurasian snow cover, snow depth, and the Indian summer monsoon : An observational study”, *Journal of Climate*, **12**, 3117-3132.

Bhanukumar, O. S. R. V., Naidu, C. V. and Rao, S. R. L., 2004, “Influence of Southern oscillation and SST over Nino-3.4 region on the winter monsoon rainfall over Coastal Andhra Pradesh”, Proceedings of Indian Academy of Science, *Earth and Planetary Science*, **113**, 3, 313-319.

Clark, C. O., Cole, J. E. and Webster, P. J., 2000, "Indian Ocean SST and Indian summer rainfall: Predictive relationships and their decadal variability", *Journal of Climate*, **13**, 2503-2519.

Kane, R. P., 1998, "Extremes of the ENSO phenomenon and Indian Summer Monsoon rainfalls", *International Journal of Climatology*, **18**, 7, 775-791.

Liu, X. and Yanai, M., 2001, "Relationship between the Indian monsoon rainfall and the tropospheric temperatures over the Eurasian continent", *Quarterly Journal of Royal Meteorological Society*, **127**, 909-937.

Loschnigg, J., Meehl, G. A., Webster, P. J., Arblaster, J. A. and Compo, G. P., 2003, "The Asian monsoon, the tropospheric biennial Oscillation and the Indian Ocean Zonal mode in the NCAR CSM", *Journal of climate*, **16**, 1617-1642.

Nicholls, Neville, 1995, "All India Summer Monsoon rainfall and Sea Surface temperatures around Northern Australia and Indonesia", *Journal of climate*, **8**, 5, 1463-1472.

Nitta, T. and Yamada, S., 1989, "Recent warming of tropical Sea Surface Temperature and its relationship to the Northern Hemispheric Circulation", *Journal of Meteorological Society,* Japan, **67**, 375-383.

Shukla, J., 1975, "Effect of Arabian Sea surface temperature anomaly on the Indian summer monsoon: A numerical experiment in the GFDL model", *Journal of atmospheric Science*, **32**, 503-511.

Shukla, J. and Fennessy, M. J., 1994, "Simulation and predictability of monsoons", Proceedings of International Conference on Monsoon variability and prediction", Technical report WCRP-84, Geneva, Switzerland, World Climate Research Programme, 567-575.

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", *Quarterly Journal of Royal Meteorological Society*, **123**, 309-336.

Trenberth, K. E., 1997, "The definition of El-Nino", *Bulletin of the American Meteorological Society* , **78**, 2771-2777.

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