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Intra-seasonal oscillation of north east monsoon over southern peninsular India-an investigation

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Abstract- When illustratively went through the NE rainfall pattern of southern peninsular India enclosed within latitudes of 8˚N and 13˚N, longitudes 75˚E and 82˚E for last 5 decades demonstrated no long term trend in it. At the same time there is a prominent inter-annual variation in the seasonal mean rainfall as well as its sub seasonal distribution, which cannot be correlated to anything in a simple style. Effort is done to decode the length of different spells of precipitation found within the season and attention is given to individual years that displayed similar sub seasonal distribution. Thus it became necessary to consider various forcing factors of inter-annual variability such as ENSO, IOD which drive the variability of Boreal Fall Monsoon precipitation over southern peninsular India to unravel the mystery behind different oscillations**.** The evolution of MISOs in the equatorial region of Boreal Summer Season and its passage across the SP towards north and its potential to modify the intra-seasonal variability of Boreal Summer Monsoon is widely discussed in many of the earlier studies. The capacity of the Madden Julian Oscillation to drive Ocean Atmosphere coupled dynamic processes in tropics during Boreal Winter is also well documented. The Boreal fall season lies in annual cycle during the transition from Boreal Summer to Boreal Winter and where the synoptic activities are as strong as the low frequency Intra Seasonal Oscillations (ISO). Southern Peninsular India and Sri Lanka, which get benefited by Boreal Fall Monsoon are positioned in between the two poles of Indian Ocean Dipole mode can give its own impact to the year to year variation of the rain fall pattern and that is also considered. The part of ocean that can impart more sensible changes and can modulate the intra-seasonal rain variation of SP is located and the possibility as well as the potential of that particular area is kept under special scrutiny throughout the study. To get a clear picture of the frequently found paces of rain, FFT analysis is carried out for strong and weak NE monsoon, positive and negative IOD years, El Nino and La Nina years and their composites. Paper agrees to an earlier approved fact like IOD can affect intra-seasonal modes of variability whereas ENSO can modify long term inter-annual changes. Obviously the proximity of IOD to the experimental region and the probable lag in executing the effect of ENSO on the concerned area can be the reason for it. It invariably points out the local and remote effect of the ocean to modify the climate outweighing the role of atmosphere in doing the same. 1-5 days Synoptic changes, 10-20 days mode oscillations, as well as 20-60 days low frequent intra seasonal oscillations are found to be equally prominent within the season. SST, SLP and wind parameters found in and around equatorial Indian Ocean region are examined to get a better understanding. Identifying the part of ocean that can more creatively and directly influence the rainfall pattern is located. The SST of Bay of Bengal and South China Sea as well as SLP gradient from Philippines Sea to Arabian Sea are nominated as the most important parameters in modifying the Boreal Fall Monsoon (BFM) Season of Southern Peninsular India (George et al 2011).

Index Terms- North east monsoon, intra-seasonal, oscillation, South Asian winter monsoon, long term cycle, ENSO, equatorial Indian Ocean, FFT analysis, Indian Ocean Dipole, SST, Sea Level Pressure.

I. INTRODUCTION

The enchanting lush green tip of India is very famous for the opulence of rain it enjoy during both the phases of Asian monsoon the summer south west as well as the winter north east phase. The paper concentrate in the retrieving winter phase of Indian monsoon occurring during October – December in the southern peninsular India enclosed within latitudes of 75°E: 82°E and 6°N: 13°N. South Asian Monsoon is really complex and versatile. It is Bay of Bengal just adjacent to SP receives maximum amount of rain in this planet. Among the countries that enjoy South Asian Monsoon the west part of Western Ghats is a region that get local maximum amount of monsoon is also included in the experimental area. Since the eastern part of Western Ghats remain as a rain shadow region during south west summer monsoon season it receives rain only during the winter phase the north east monsoon time. So in short southern peninsular India, as it include places that enjoy both the phases of Asian monsoon, the peculiarity of its shape and position, exposition to the seas around along with its major oscillations altogether, demands key attention in understanding the rainfall pattern all over the country even though it remain as a less explored area today. So the very motive of this study is to try to decode the types of intra-seasonal variations of boreal season rainfall (October-December) occurring in this region and to justify the probable reasons leading to it.

During boreal winter in NH north easterly wind dominates zonal wise between west Pacific and Indian Ocean. The heat source region of boreal winter is a combination of near equatorial zone as well as extra tropical region (Boyle and Chen 1978, Chan and Li 2004). Hence the temperature and density stratification of higher latitudes imbibe more control on winter monsoon than in the summer monsoon. The region between 10°S- 10°N undergo maximum wind reversal and the rainfall happen in pace with this wind change in this area. The latent heat release from this area can be considered as the major planetary heat source that runs the global circulation during boreal winter. The convective

organization of this region like land ocean stratification weighs very important in winter monsoon study of the region.

In East Asian monsoon 6-8 day oscillation associated with cold air break, 5-8 days peaks in west of north Pacific region, 10-20 days quasi weekly oscillation are commonly found. This happens mainly due to the blocking of atmospheric circulations in the mid latitude by the Ural Mountains where the northerly surges originate (Chen 1999). The 30-60 day oscillation of East Asian winter monsoon is more related to mid troposphere dynamics. Zonal wind of lower troposphere in East Asia and west of north Pacific can give good indication to this long term oscillation. 2 years, 4-7 years, 7-10 years and 20-30 years are the commonly found annual cycles of East Asian winter monsoon out of it. 2year cycle can be due to biennial oscillation and 4-7 year cycle is likely to be related to ENSO.

In Asian monsoon the locality of mean precipitation is predetermined by the MISO s and biweekly signals from South China Sea coupled with local effect and land atmosphere feedback. But of course long term inter-decadal variability is well connected to ENSO. The cumulative of frequently seen intra-seasonal oscillation of Asian monsoon with 20-80 days scale modulate inter annual variation of rain. MISO s encompasses all major synoptic activity. The northward propagation of MISOs from Indian Ocean carries with it tremendous amount of moisture within and give good precipitation along Burma mountain range and NE Bay. The geographical pattern of the land doesn't play any crucial role in deciding the evolution of MISOs even though it has decisive role in seasonal rainfall structure

The variability of monsoon is mainly associated with the northward propagation of ITCZ or cloudy zone along with it carry pressure, wind, OLR and SST shifting (Lawrence and Webster 2002). MISOs take its shape in the equatorial Indian Ocean move eastward along the equator reaches the ocean and gets modulated depending on the regional features modifying the spectral peaks of variation accordingly. The nature of ocean atmosphere coupling and the land atmosphere feedback of the locality can imbibe grave modification to intra seasonal mode that can imprint its own signature even in the annual variability of monsoon. The cumulative activity of MISO can be regarded as the main donor of specific characteristic to the annual and intra-seasonal oscillation of Asian monsoon.

Movement of MJO (Madden-Julian oscillation) can enhance the tropical convection along with upper level divergence and simultaneous sub tropical upper level convergence. Exactly opposite effect can be expected in the opposing phase of MJO. Normally the MISOs formed at the equatorial region moves eastwards pushing off the diverging circulation between the tropics and subtropics further east until it reach at exit region of Asian–Pacific jet. When the ISO convection is going on in Indian Ocean it gives a north south dipole in flux in the upper troposphere above north western Pacific. (Kim et al 2008) and it influence the mid latitude low frequency variability through zonal wind. Thus MJO can be considered as coupling mode between the tropics and extra- tropics via convective processes and associated density differences. Anyhow it is genuine to believe that ISO and MJO are interactive dynamic processes.

II. DATA AND METHODOLOGY

High resolution (1° X 1°) gridded daily rainfall data set for the period 1951-2008 available over Indian continent has been used for the present study. IMD prepared this data set based on a weighted average of rain gauge measurements. The study area is Southern Peninsular India (75°E: 82°E, 6°N: 13°N) and the Study period is Boreal Fall Season / NE Monsoon Season (1st October to 31st December) from 1951 to 2008. For meteorological parameters like SST and SLP are taken from NCEP and NCAR data. (Collins1996). Ferret Data Visualization and Analysis software developed by PMEL (Pacific Marine Environmental Laboratory) of United States National Oceanic and Atmospheric Administration (NOAA) is used for analysis of the data.

The daily gridded data over SPI has been averaged over the SPI region and a time series data of daily rainfall for the NE monsoon season has been prepared from the IMD daily gridded data set using ferret. For the present work, analysis has been carried out for the NE monsoon season of 92 days starting from October 1 to December 31 for the years 1951 to 2008. The daily climatology was computed as the mean of the areal average for each calendar day. This daily climatology data was subtracted from the daily area average data to obtain the daily anomalies for the entire study years.

FFT analysis of the time series for the NE Monsoon season for each year from 1951 to 2008 was done and the amplitude spectrum is plotted against time period. The time series of NE monsoon rainfall data for strong NE Monsoon years (1966, 1972, 1977, 1993 and 1997) are plotted and FFT is done for individual years and amplitude of FFT is computed and plotted against time period for the years. The mean of the FFT amplitudes of strong NE Monsoon years is computed and the composite plot for the strong NE Monsoon years is plotted. Similarly, FFT analysis is done for weak NE monsoon years (1968, 1974, 1988 and 1995) and amplitude of FFT is computed and plotted against time period for the years. Composite plot for the weak NE monsoon years is also done using the mean values of the FFT amplitudes of weak NE Monsoon years. The same procedure is followed for positive IOD years, negative IOD years, El Nino years, La Nina years and for the individual composites.

III. OBJECTIVE

The main objective of the study is to chase out and study the main types of oscillations found in the north east monsoon season of southern peninsular India. Identifying various types of oscillation in excess as well as week north east monsoon period of southern peninsular India is meticulously carried out. An attempt is done to trace out the SST, SLP and wind parameters found in and around equatorial Indian Ocean region responsible for this change. We have also tried to correlate different type of oceanic oscillations with different mode of intra-seasonal rainfall patterns found in NEMR. Any way anomalous SST fields, SLP and associated wind are assumed to have direct influence in creating abnormal rainy days throughout the study. Importance is given to Indian Ocean Dipole frequently occurring closer to the peninsula and highlights its influence on the frequency of rainfall. It was a matter of interest to know whether ENSO can impose comparatively more effect or long term effect on the

rhythm of winter rainfall of this region. Climatology of NEMR is also considered to get a genuine approach in the deal. The study is carried out exclusively for some individual years which showed some abnormal nature. The SST of Bay of Bengal and Sea Level Pressure of Arabian Sea are assumed to be the salient components influencing the intra-season rainfall oscillation and have checked it to know how far the assumptions hold true scientifically. To locate the exact dimension of the ocean that can give maximum impact in the game was another matter of interest. The lag or lead of the event with its corresponding influence on rain pattern was another interesting feature. MJO, IOD, EQUINOO, ENSO and what not frequent cyclonic events of Indian Ocean everything play its own role in modifying the mode of rain indeed. An overall attempt is done to distinguish as far as possible to alienate the different disturbances and to study its due effect in aloof.

IV. RESULT AND DISCUSSION

Southern Indian Ocean is a major moisture source for Asian Monsoons during boreal summer and winter. Any way the major factors that modify the moisture source by SST are evaporation, near surface wind, near surface atmospheric humidity and turbulent exchange coefficient.

The role of SST anomalies of Indian Ocean in modifying regional climate variability was under observation of many scientists. When tried to understand distinctly the importance of local and remote forcing of SST anomalies, using AGCM model, It was interestingly noticed that 50% of the precipitation anomaly of maritime continent (the region consist of Malaysia, Indonesia, and the surrounding land and oceanic areas of the equatorial western Pacific between 10°S- 10°N) is just due to Indian Ocean SST anomaly. Changes of Indian Ocean affect the Walker circulation and decrease the precipitation amount occurring over tropical west Pacific maritime continent encouraging the formation of a low level anticyclone above Philippine and south China sea. But this anticyclone can give additional rainfall to East Asia during winter from December to May. (Ping **Liu**, Shang-Ping 2005) The continuing SST and precipitation over Indian Ocean can lead to anomalous subsidence over maritime continent during spring and prevent the north westward propagation of ITCZ. The delay in the migration of ITCZ can lead to say 6-7days procrastination of Indian summer monsoon onset(Ping **Liu**, Shang-Ping 2005) This study emphasizes the ultimate relevance of inclusion of Indian Ocean SST variability from December to May in the overall regional climate variability study of any place around the Indian Ocean rim.

When we consider South Asian Monsoon in general the vertically integrated moisture transport across 100 E is responsible for the net moisture convergence variability in the north Indian Ocean region. Naturally it depends on the trade wind regime existing in this area at that time. The rest of the moisture variability is found to be associated with Arabian Sea and the net outcome of the sea level pressure difference between the north and western part of the Indian Ocean basin. EIO display barest minimum intra-seasonal oscillation in Asian monsoon and is considered to be the source of wide variability, like active and break periods of monsoon. It is a proved fact that south and western Indian Ocean are the most integral part of monsoon variability. The SST gradient between eastern equatorial and central subtropical Pacific Ocean and accompanied moisture transport prior to the monsoon onset can connect monsoon and ENSO. (Webster, P.J 1999) The prevailing Indian Ocean circulation in the mean time decides further ENSO monsoon coupling. In Asian Australian monsoon system the moisture from East and South China Seas are significant for precipitation in the eastern and southeastern coastal areas while Arabian Sea and Bay of Bengal are important moisture sources for southern and central region of China. The moisture source for some regions in Asian monsoon domain is from NH. ENSO related SST anomalies account for 30% and regional SST variation leads to 20% of AAM anomalies. Tropical central Pacific SST can exert good variation in AAM only during boreal winter and transition seasons (Webster, P.J 2002).

Climatologically the study of monsoon rainfall of southern peninsular India shows that SP experience two phases of monsoon both summer SW and winter NE monsoon. SW monsoon is quantitatively bigger for the peninsular India even though the rain shadow region of Tamil Nadu don't experience s any rain in this season. SP experience NE during Oct, Nov and Dec. Out of it rainfall maximum is observed during October gradually diminishes and virtually ends by the end of December.(Fig: 1). Even though in the diminishing order six distinguishable peaks are vividly noticeable in whole NE monsoon season with a minimum of two individual peaks in each months. However each peak sustains ten to fifteen days in general where as the October rainfall is more intense and is at more prolonging pace. A sudden downfall in rainfall amount associated with the end of each month is also a noticeable feature in the fifty year climatology figure. As regards rainfall amount during boreal fall of October SP receives an average of 9cms of rain and it gradually crashes down to 6cms in November and further in December even lesser than 4cms. The rain is not simply cut off until the mid of January. In order to get good insight into the Pattern of raining it is better to look into the FFT figures of boreal fall.

From (Fig 2) the north east monsoon of SP during 1951, the weekly swinging of the rain as well as a very dominant peak of 20 to 60s day oscillation in rainfall pattern is the striking characteristic. Unlike a normal boreal fall the break period is noticeably short in this year. No doubt it was a flooding year. The very important characteristic of very short pulse rain of a dry boreal fall is really unseen throughout the season. Continuous rainy days 8, 15 and 20 might have flooded the place which is not really accustomed to this much amount of pouring. The diverging pattern of the FFT curve make one believe that rainy days were not even confined with the end of the year. To check this year with the occurrence of IOD, major ENSO oscillations, occurrence of EQUINOO or the association with cyclonic depression of Bay of Bengal can give some positive results towards the cause of the same. (Fig.3) Daily rainfall anomaly of 1951 also confirms the excess rain occurred in the year. The weekly swinging of the rain as well as two dominant 15 to 20 day oscillation in rainfall pattern is the striking scenario of 1951 boreal fall of SP. Unlike a normal boreal fall the break period is noticeably short in this year. The very important characteristic of very short pulse rain of a dry boreal fall is really unseen throughout the season. The FFT analysis of the 1951 rainfall underlines once again the above mentioned observation. The

FFT of the rainfall pattern showed a marginal difference from the climatology pattern. As regards the number of rainy days it was much ahead the normal. The breaks were unusually short too. The greater anomaly to the higher side point towards the possibility of a flooding year again. The boreal fall was getting extended beyond December unlike a normal year. Weekly oscillations and fifteen to twenty days oscillation of rain is only found in this year and the absolute absence of short pulses evidently confirms the flooding nature of 1951.

(Fig: 4) The FFT analysis of north east monsoon of southern peninsular India for last 58 years all put together reveals the below given observations. Compared to long mode of raining pattern short rain events are generally observed in the boreal fall season of Southern Peninsular India. The FFT picture for last 58 years strengthen the idea that if at all the boreal season of SP display long continuous rainfall it can be flooding years because the same area is subjected to rain of more intensity for far more days. Rather lesser occurrence of longer pace during the observational period indirectly implicit the above fact. Very short lived rain just for one or two days is the most common sight during the boreal fall of the area. Two to four days short pulses of rain takes the second position among the observed period. Makes one conclude southern peninsular India generally experience comparatively short lived rainfall during boreal winter than the boreal summer rain. A periodicity of one to two days shower, three to five days rain, ten to twelve days rain and oscillations of duration twenty to sixty days are the frequent mode of raining observed in boreal fall. Out of it first two types display dry and normal boreal fall and the final two shows flooding rain respectively

FFT analysis of strong and weak north east monsoon years of SPI and its composite analysis derived certain conclusions as follows. Strong NE monsoon FFT analysis (Fig: 5) emphasize the probability of boreal fall having dominance in week long and more than twenty days continuous rainfall in spite of short one to two days spins of rain. Anomaly composite of the strong years (Fig: 7) confirm the above disparity of oscillation in an excess NE monsoon year from a normal boreal fall year. Week NE monsoon rainfall anomaly (Fig: 8) pattern is also a combination of different type of oscillations one to two, three to four, eight days and fifteen days. But the striking difference lies in the domination of only the first two types of rain but never extending to the third type anyway. Composite picture agrees to the same. Strong year anomaly tells us that even though the frequently found oscillation in these years are in long modes maximum variation happens in the two three days rain format or week long shower. Two three days rain as well as weeklong rain is significantly varied much more than any other swing in an excess boreal fall year confirms the composite anomaly. However fifteen to twenty days oscillation will be undoubtedly present in an excess boreal fall of SPI. FFT analysis of week boreal fall anomaly help (Fig: 6) us to say that only first three types of oscillations are found there in a week NE monsoon season. Maximum number of spin is found in one to five days shower whereas maximum variation happens in weak long rain pattern in all week NE monsoon season. Absence of 20 to 60 days rain is the most noticeable feature of the week boreal fall of SPI.

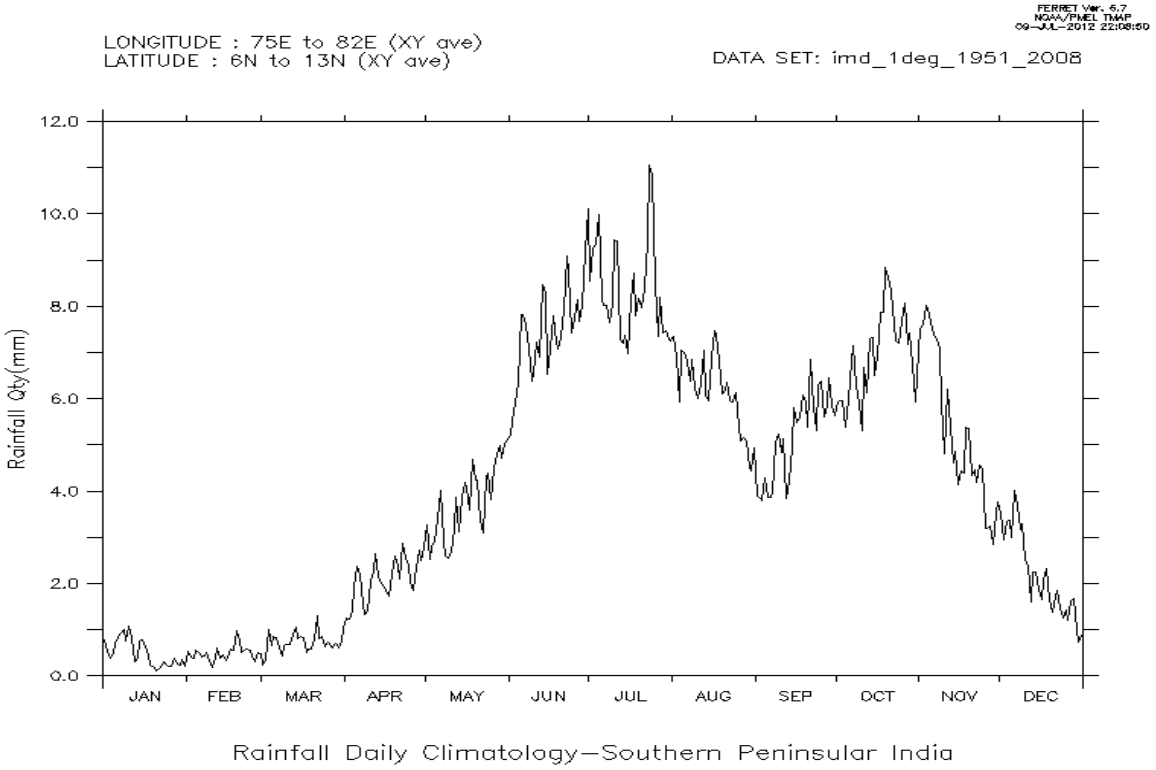


Fig: 1

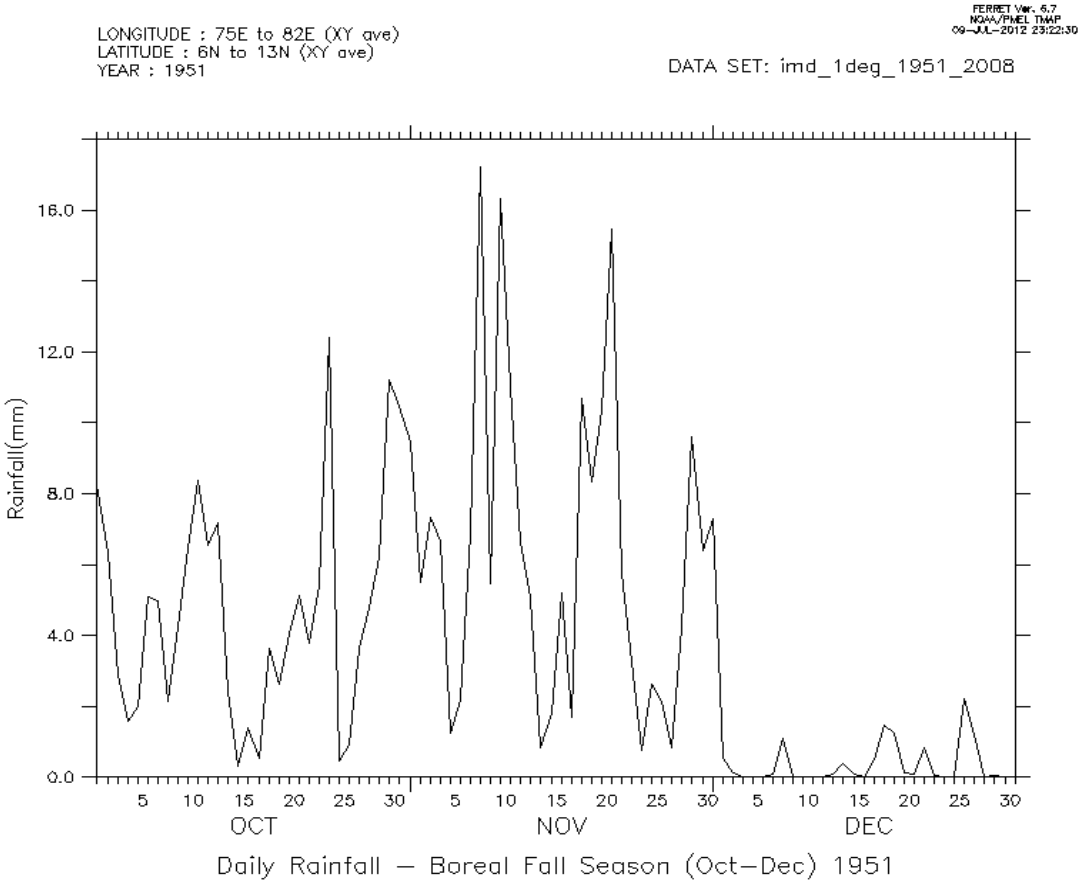

LONGITUDE : 75E to 82E (XY ave)
LATITUDE : 6N to 13N (XY ave)
YEAR : 1951
DATA SET: imd_1deg_1951_2008
Rainfall(mm)
16.0
12.0
8.0
4.0
0.0
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30
OCT
NOV
DEC
Daily Rainfall — Boreal Fall Season (Oct—Dec) 1951

Fig: 2

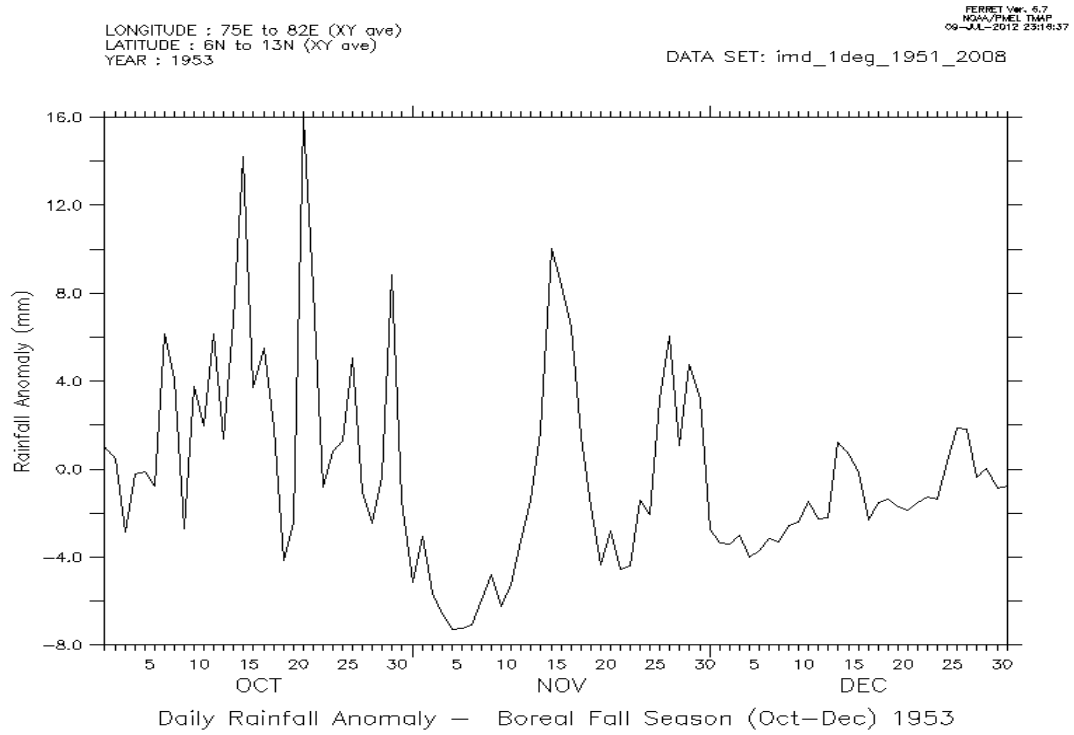

LONGITUDE : 75E to 82E (XY ave)
LATITUDE : 6N to 13N (XY ave)
YEAR : 1953
DATA SET: imd_1deg_1951_2008
Rainfall Anomaly (mm)
16.0
12.0
8.0
4.0
0.0
-4.0
-8.0
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30
OCT
NOV
DEC
Daily Rainfall Anomaly — Boreal Fall Season (Oct—Dec) 1953

Fig: 3

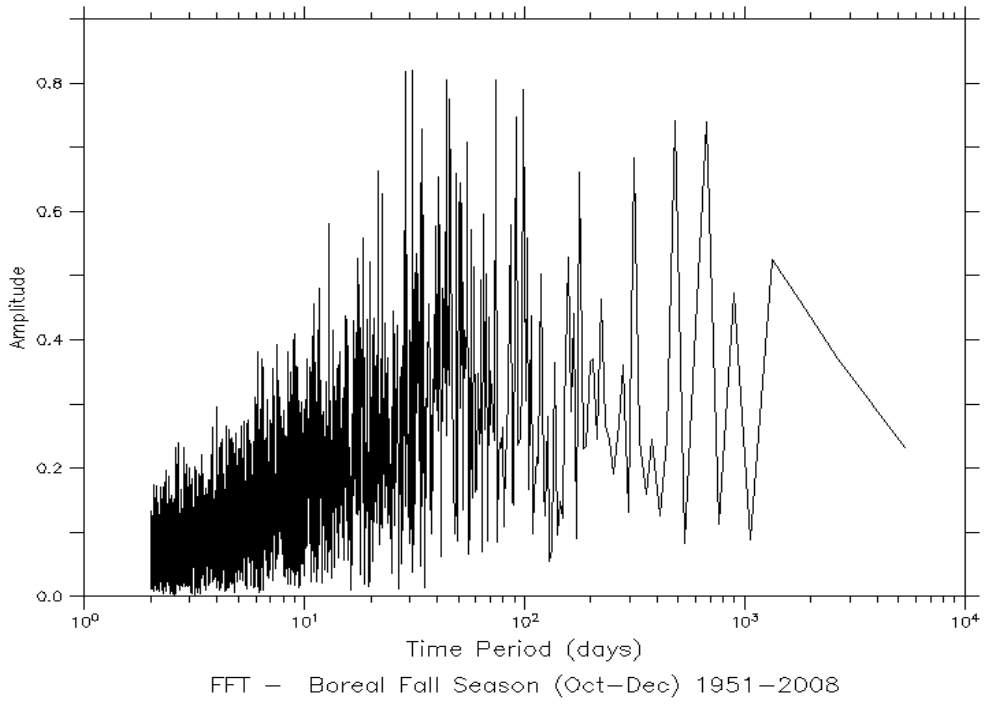
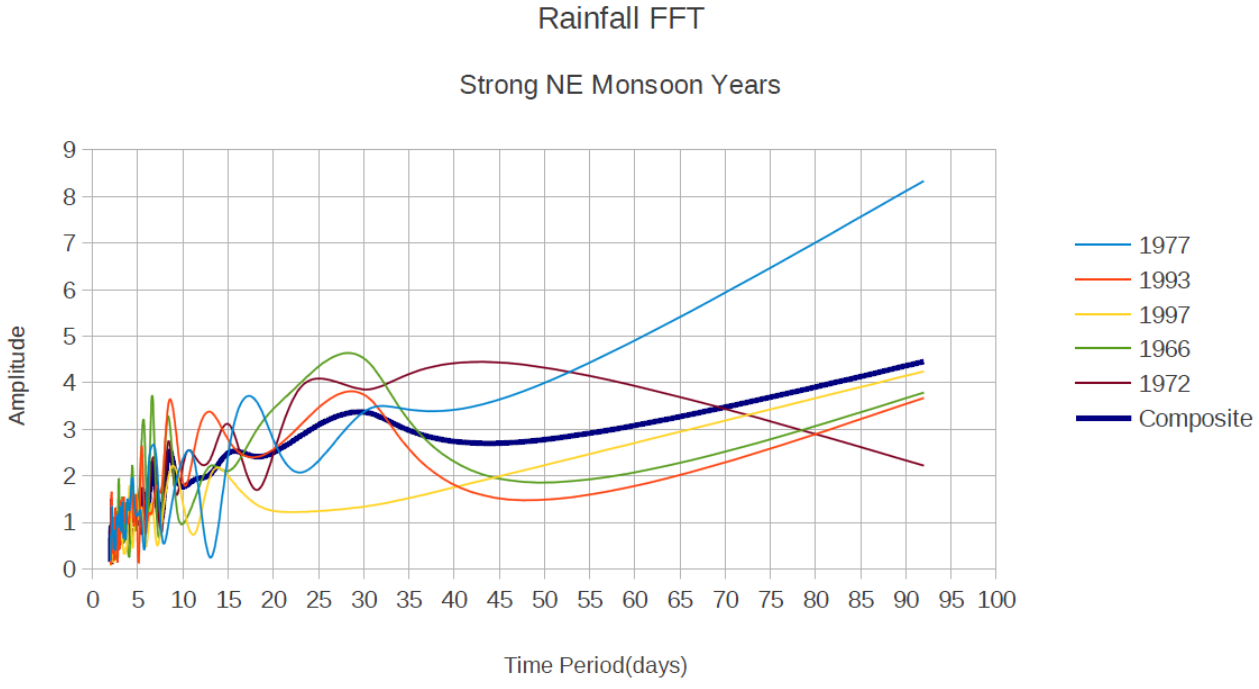

Amplitude
0.0
0.2
0.4
0.6
0.8
10^0
10^1
10^2
10^3
10^4
Time Period (days)
FFT – Boreal Fall Season (Oct–Dec) 1951–2008

Fig: 4


Rainfall FFT
Strong NE Monsoon Years
Amplitude
0
1
2
3
4
5
6
7
8
9
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Time Period(days)
1977
1993
1997
1966
1972
Composite

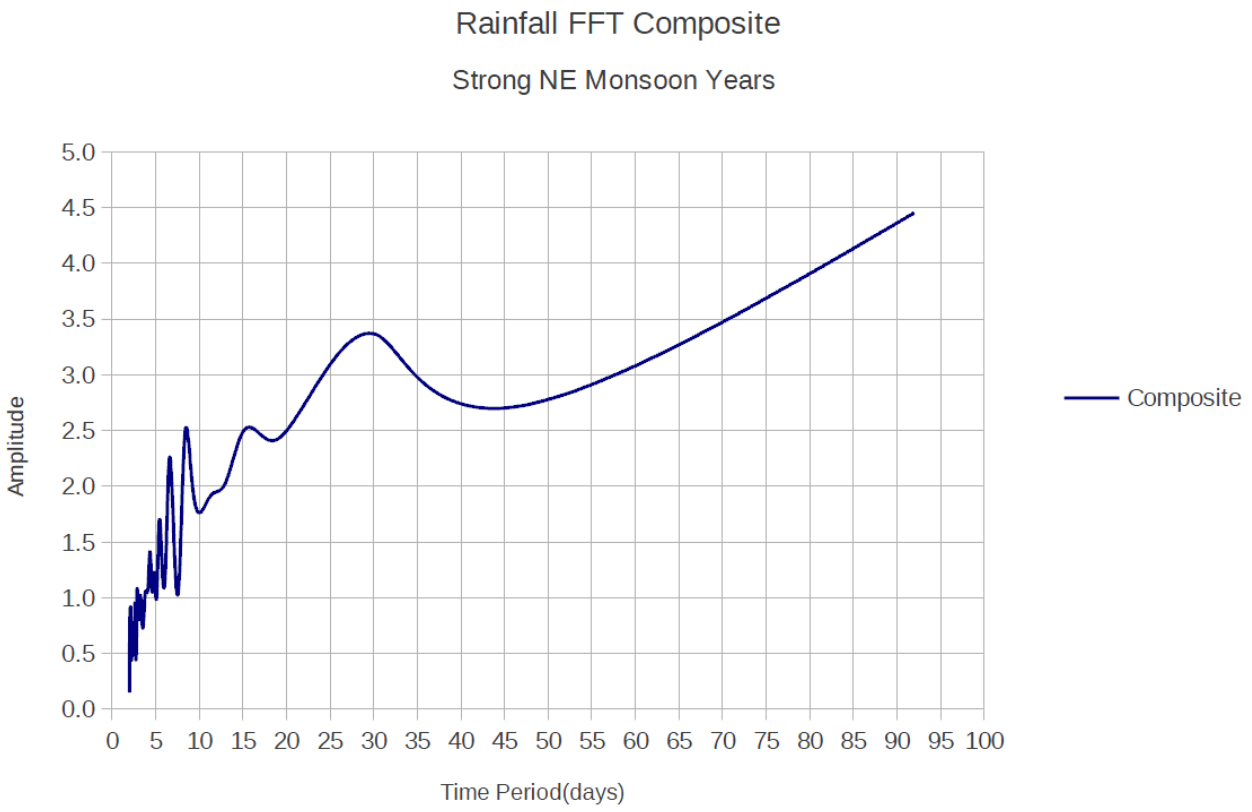
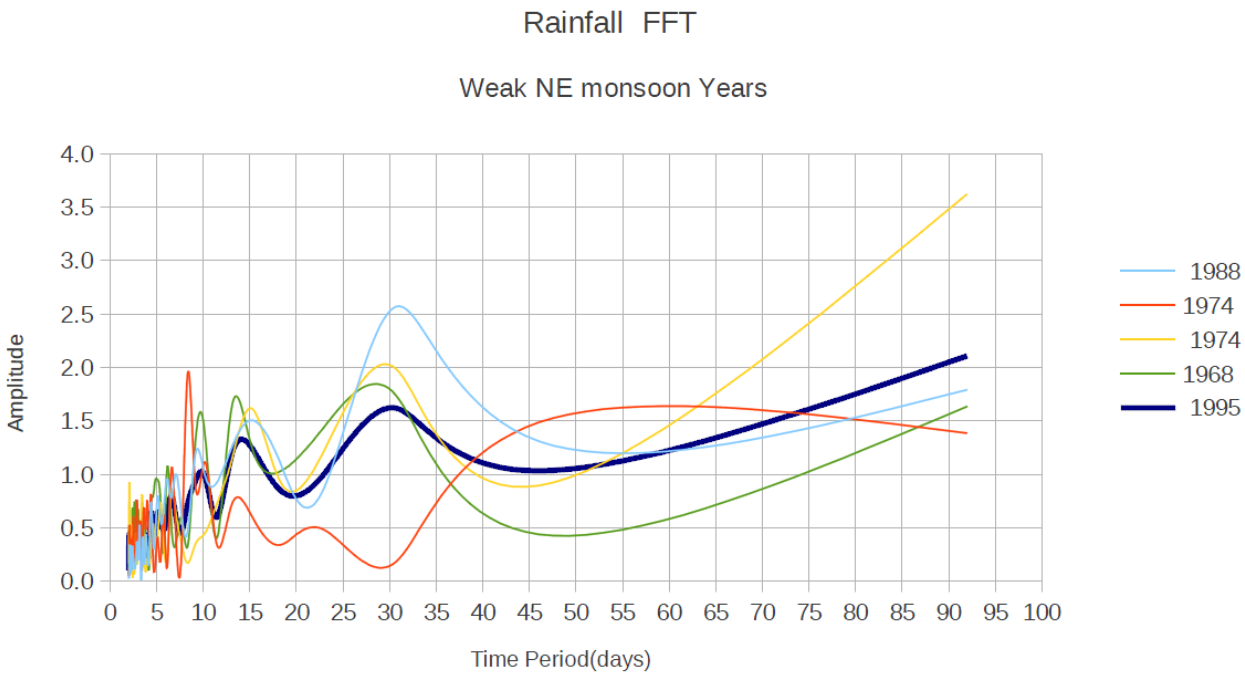

Rainfall FFT Composite
Strong NE Monsoon Years
Amplitude
Time Period(days)
Composite

Fig: 5


Rainfall FFT
Weak NE monsoon Years
Amplitude
Time Period(days)
1988
1974
1974
1968
1995

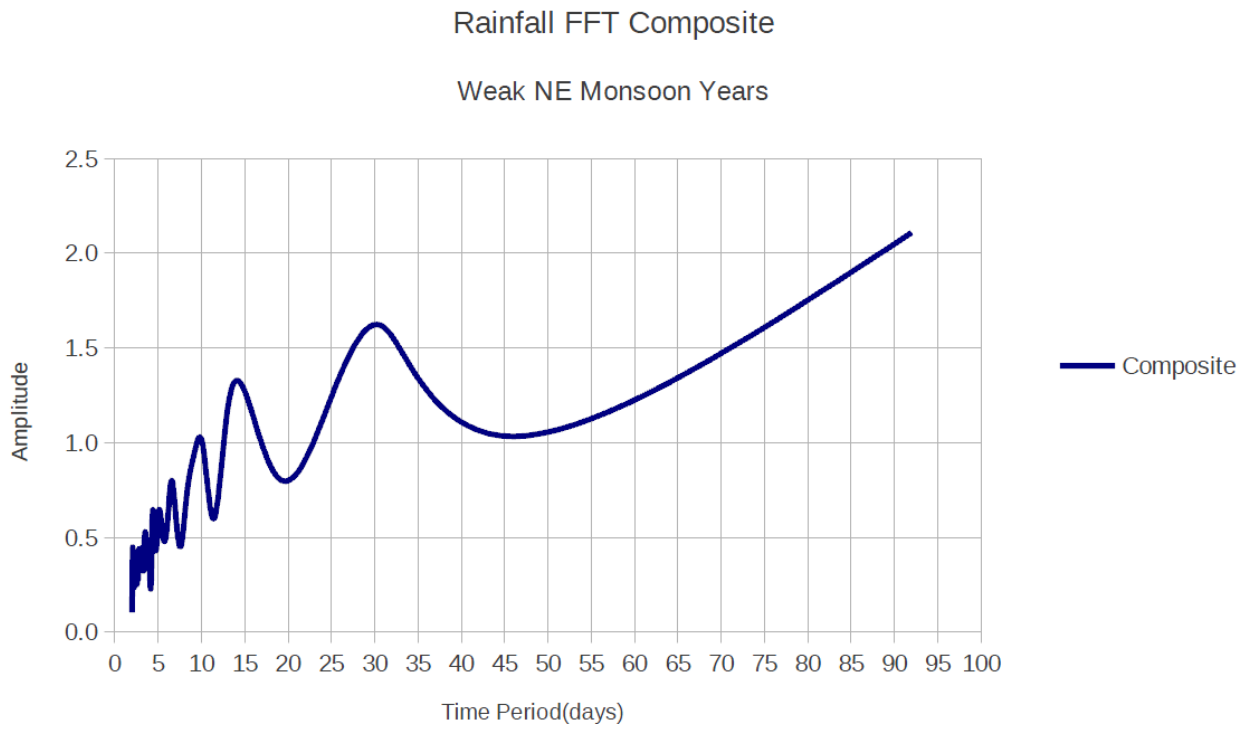
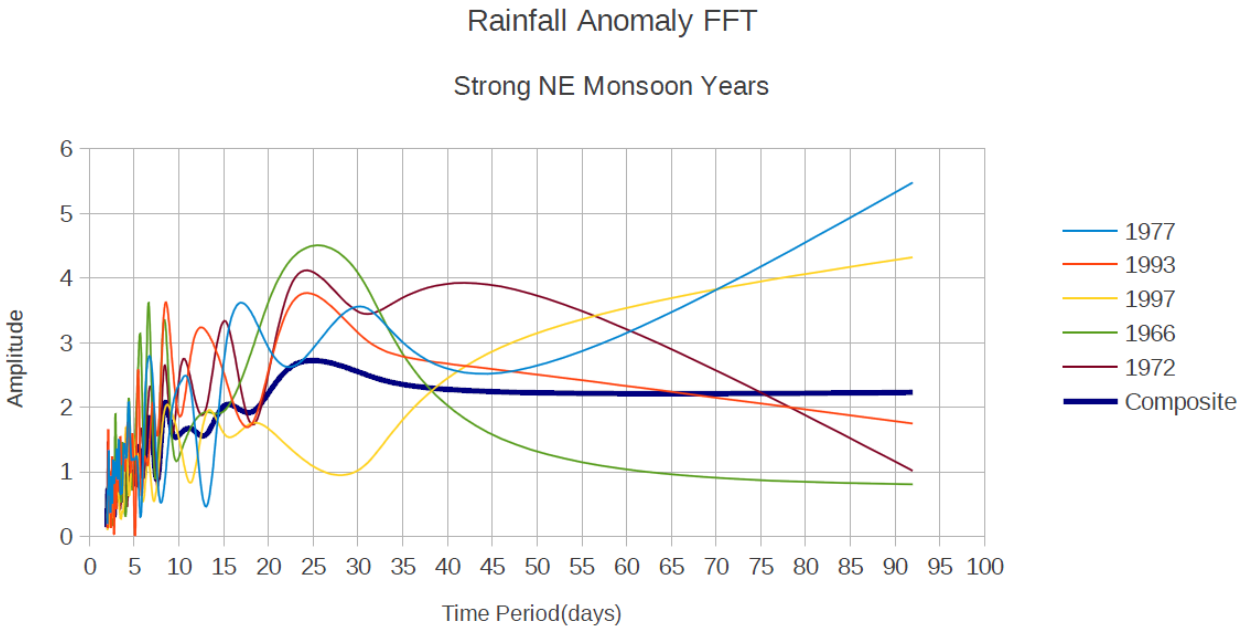

Rainfall FFT Composite
Weak NE Monsoon Years
Amplitude
Time Period(days)
Composite

Fig: 6


Rainfall Anomaly FFT
Strong NE Monsoon Years
Amplitude
Time Period(days)
1977
1993
1997
1966
1972
Composite

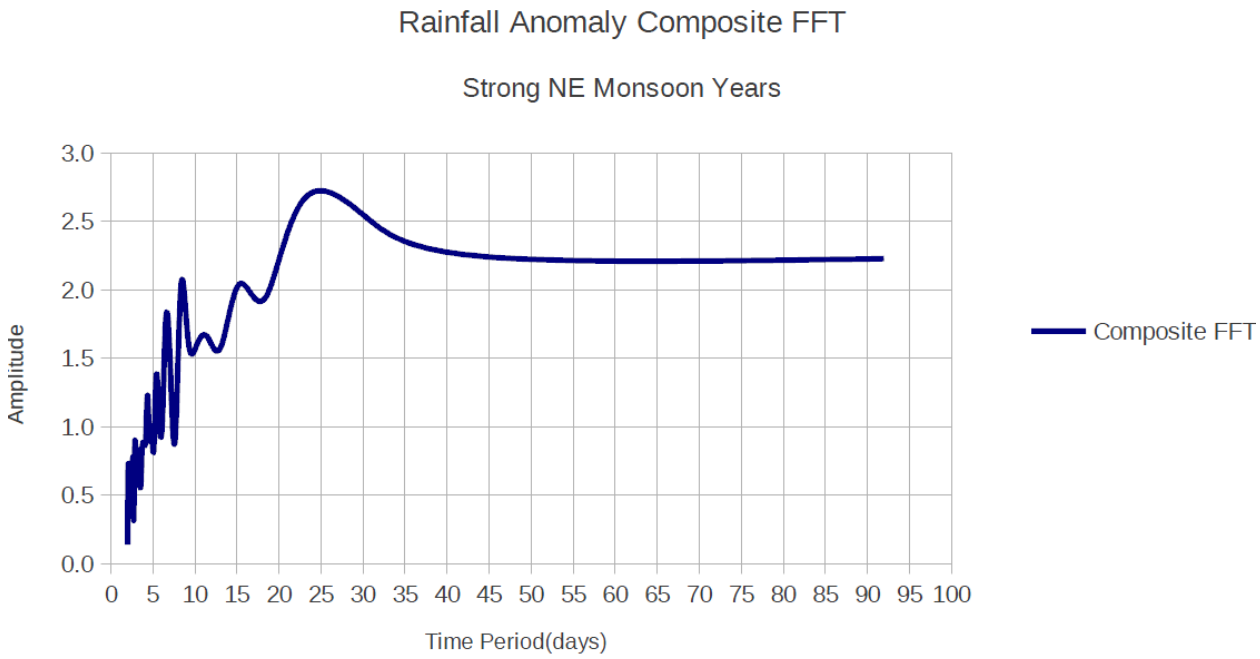
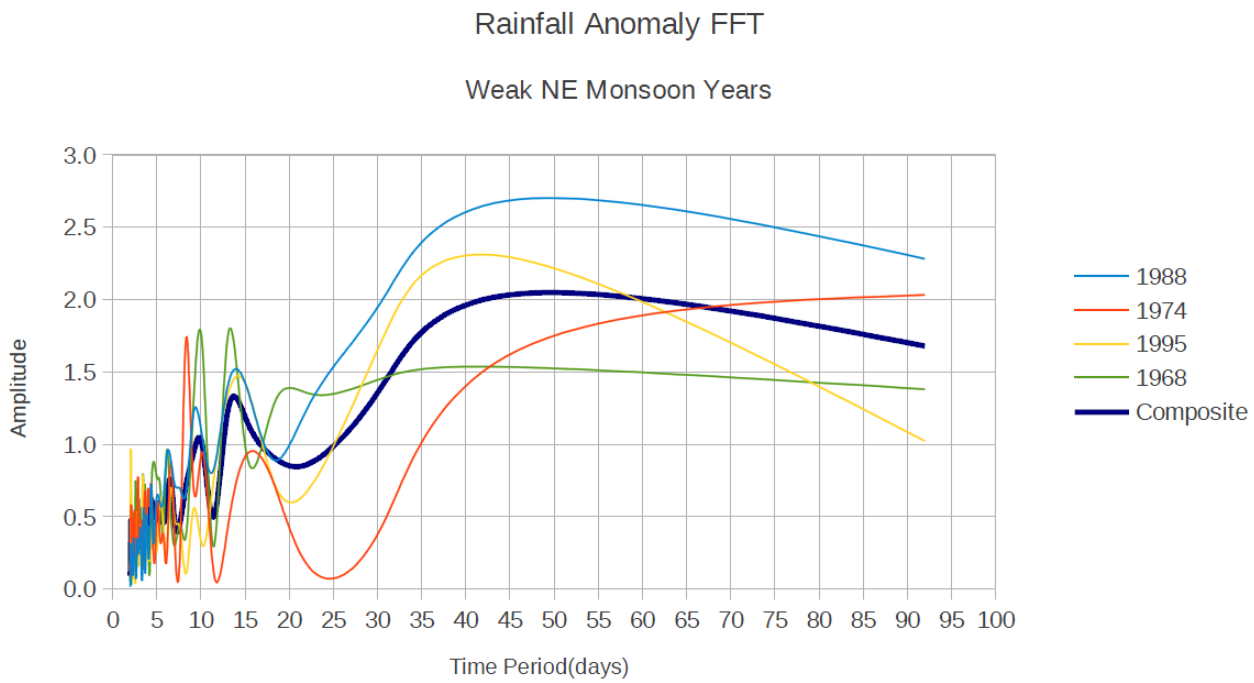

Rainfall Anomaly Composite FFT
Strong NE Monsoon Years
Amplitude
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Time Period(days)
Composite FFT

Fig: 7


Rainfall Anomaly FFT
Weak NE Monsoon Years
Amplitude
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Time Period(days)
1988
1974
1995
1968
Composite

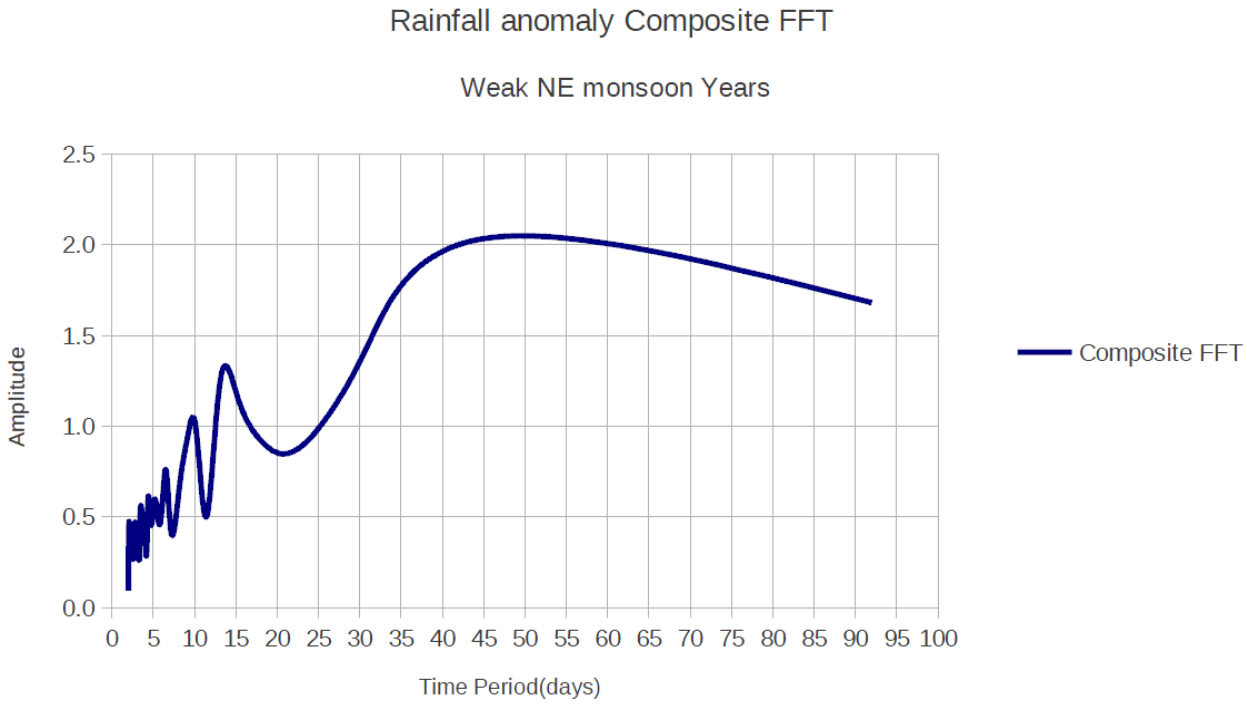


Fig: 8

V. POSITIVE AND NEGATIVE IOD YEARS

NEMR is positive when IODM is active and NEMR is suppressed when IODM is inactive. Moistened air flowing down from south Indian Ocean and Bay of Bengal converges over SP during positive phase of IOD whereas a diverging air flow dominates in the negative phase. The abnormality in SST and associated circulation accompanied with positive IOD/excess rainfall as well as negative IOD/deficit rainfall underlines the ocean atmosphere coupled process involved in NEMR and IODM. By October the retreating SW monsoon and reversing pressure and wind distribution springs up a trough region along the south of Bay of Bengal. The passage of westward moving low pressure waves create depressions and cyclonic storms on and off in this region. Modern studies of (Yamagata 2003a) reveals that IODM formed in IO during October to November period influence the rainfall of Sri Lanka and SP because of its position in between the dipole. Mode peaks in September-November and boreal fall peaks in October- December with one month lag. Mean NEMR of SP is 312mm with a SD of 83mm. Year to year random fluctuations are not in symmetry with climate change. The time series analysis of NEMR show an obvious decadal epochs of above normal or below normal rainfall whereas for SW monsoon it is an epoch lasting for nearly three decades. The presence of cooler water on the eastern side of IO generate easterly wind in the equatorial region of IO enhancing the warming on the west IO leading to positive IODM which rear out in summer but blooms only in boreal Autumn. Certainly the reverse situation is marked as a negative IODM.

During the last 40 year period the correlation coefficient between NEMR and IOD index is +.3 and +.2 (Kumar P, 2004). The positive correlation value implies that positive phase of IOD is conducive for NEMR. The proximity of protruded SP with the warmer west pole and cold pole allow it to enjoy the modulated circulation and the pumping of moistened wind inland. IODM is also connected with extreme rainfall events of NEMR. South westerly in the summer and westerly flow in the equatorial IO leads to cold water along Sumatra coast. Easterly/northeasterly along Bay of Bengal along south east peninsular India implies warming of the west IO and hence a positive phase of IOD. The positive phase of IOD is noticed with a transfer of moisture from the IO towards S India and the formation of an anomalous circulation over Bay of Bengal around 12.5^0 N, 87.5^0 E. The easterly observed at this edge support moisture convergence and the negative phase display moisture transport away from south part of India.

(Fig: 9) Just at one sight the picture says the rain was abundant in almost all positive IOD years. 10-12 days epochs of rain are frequently seen in all positive IOD years. Long term break of rain is rarely observed throughout the season. Very strong IOD year display 20 to 25 and at times even 20 to 60 days rainfall cycle is possible. IOD peaks are generally seen in November and hence the moisture availability and peak raining is mainly confined to these period and intense rain wanes out in December as the converging curves testify. The land in SP that is really vulnerable to continuous raining for more than a week might have undergone a mild flooding. One to two day spin of rain is almost absent in all positive IOD years. Still two to three days cycles are plenty and 10-12 epochs are even more in a mildly positive IOD year. Very strong IOD is distinguishable by the presence of

20-25 day rain and that may extend to 20 to 60 days continuous pouring. The composite of all positive IOD years approve the above observations.

(Fig: 10) At the outset raining was meager in all negative IOD years. 1-2 days, 2-3 days like short intense spin of rain were absent. Very long breaks are noticeable in the season. Week long rain is possible but very rare. In 1998 a week long good amount of rain is seen unlike any other negative IOD years. This is slightly misleading the whole picture and hence the reliability of the composite is skeptical**.**

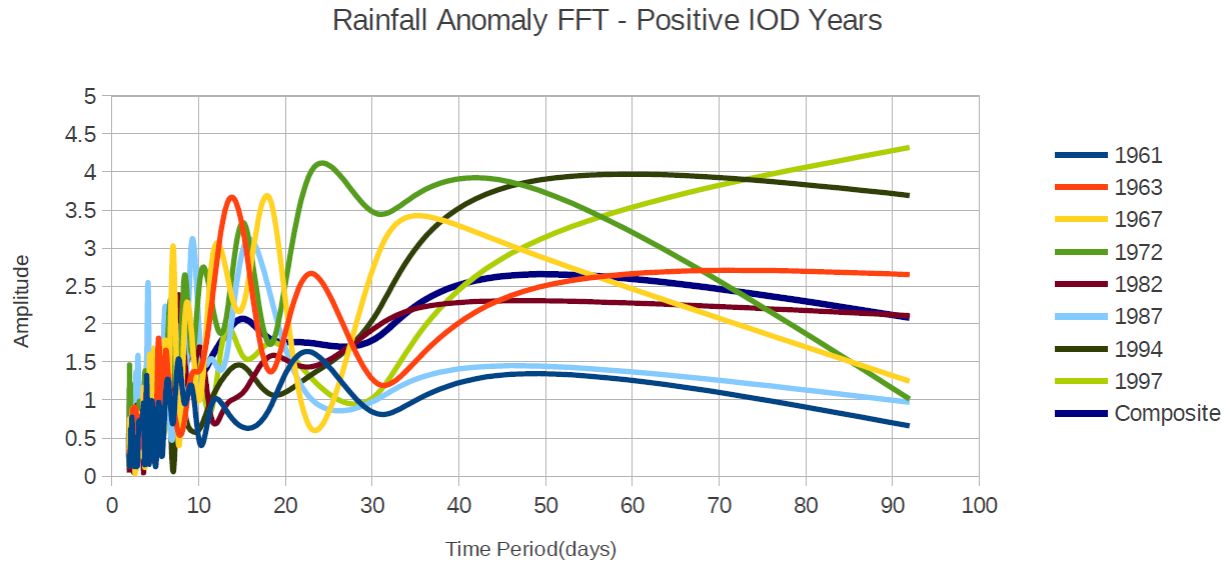


Fig1. Boreal Fall Season Rainfall (Oct-Dec) Analysis – Positive IOD Years

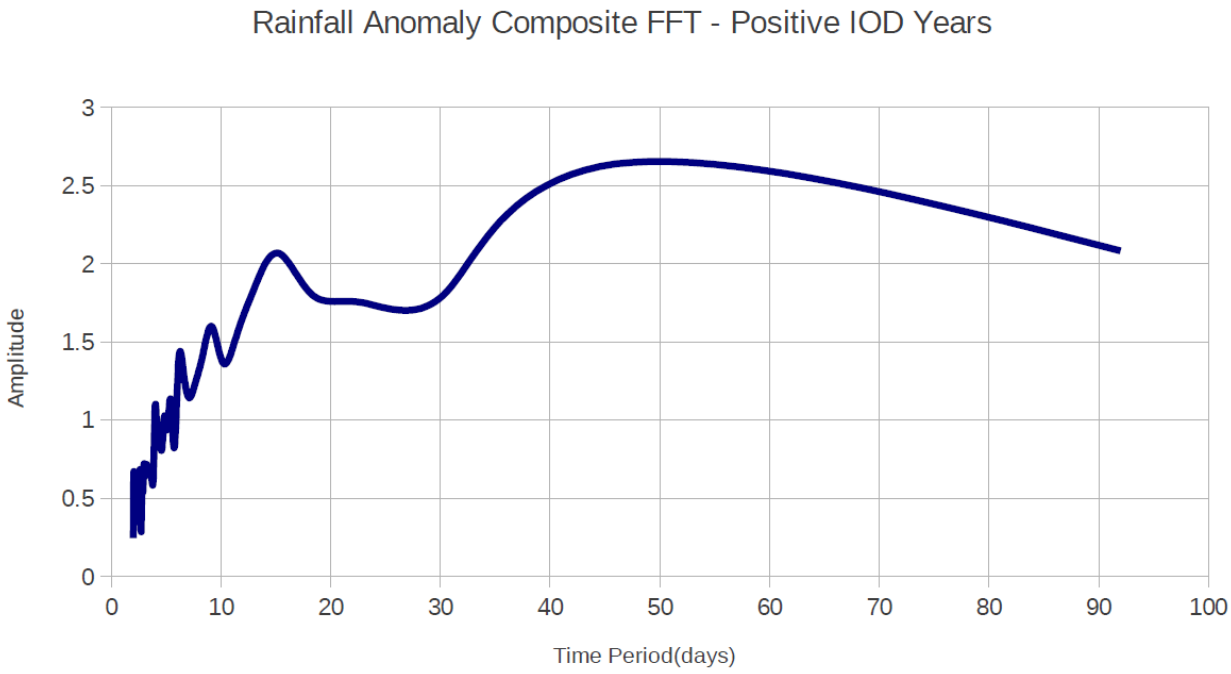


Fig2. Boreal Fall Season Rainfall (Oct-Dec) Analysis – Positive IOD Years

Fig: 9

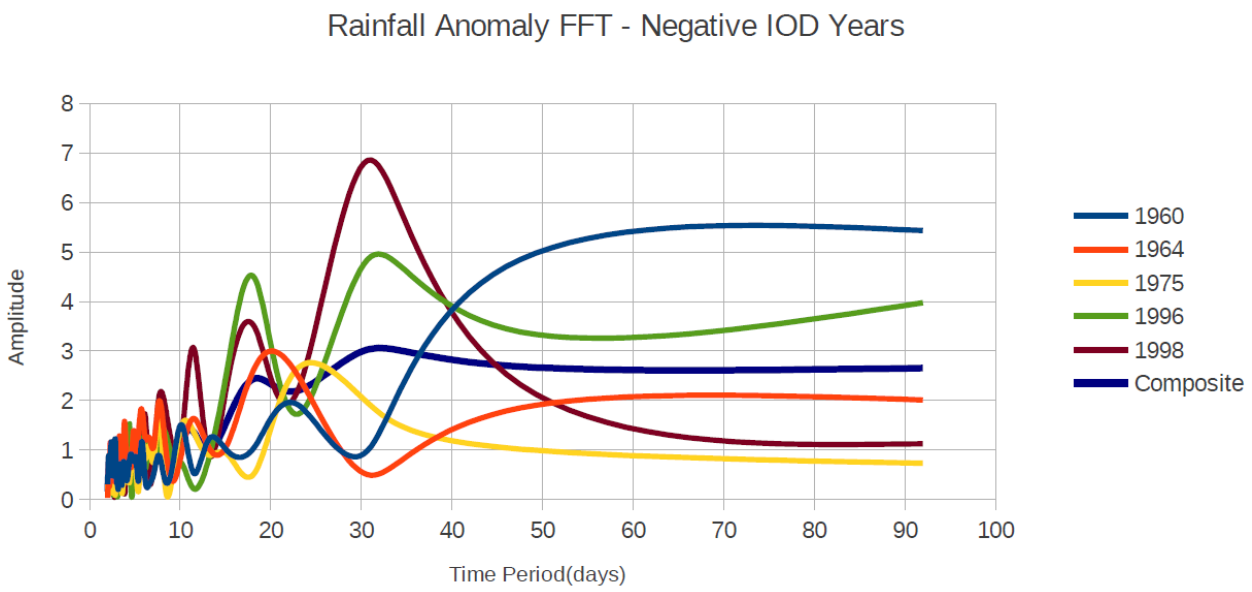


Fig3. Boreal Fall Season Rainfall (Oct-Dec) Analysis – Negative IOD Years

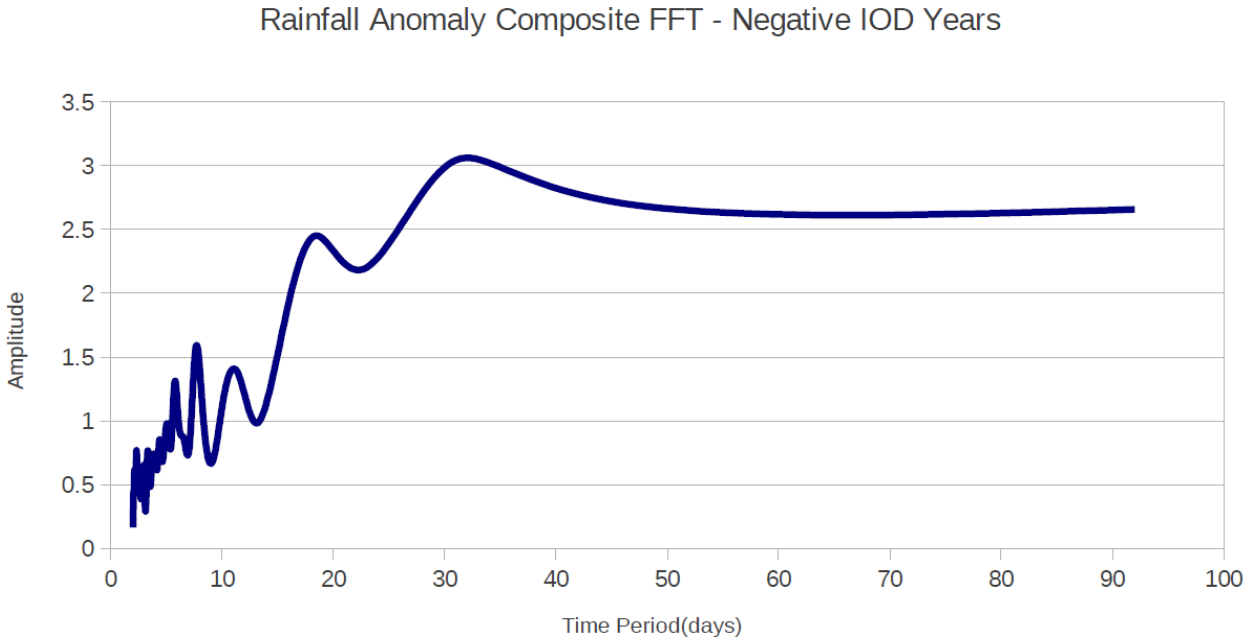


Fig4. Boreal Fall Season Rainfall (Oct-Dec) Analysis – Negative IOD Years

Fig: 10

VI. Positive and Negative El Nino

(Fig: 11) Duringmany El Nino years SP suffer severe drought. If at all it rained it was short living intermittent rain with long breaks. Severe El Nino can pose good threat to the winter rainfall of SP. 1969,1987 and 1992 are exceptional with adequate rain probably these years may be coinciding with positive IOD or EQUINOO or it can be due to some cyclonic disturbance, or depressions formed in Bay of Bengal. During those years 20-30 days rainfall is seen unlike the rest of El Nino years. 2-3 days short spells of rain is the remarkable feature of all El Nino years. Rarely if El Nino is followed by good boreal rainfall in SP it can be traced to the combined effect of other oceanic events. El Nino can contribute only drought to SP unless it is complemented with some opposing force that can pamper the region with adequate moisture necessary for good rain. (Fig: 12) La Nina years are good north east monsoon years too. Ten days epochs of rain and 20-25 days are the main features observed. Short intense rain pattern are also present. Each peak is often followed with an equivalent dry period. Maximum variation in rainfall pattern happens in 20-25 days mode of oscillation. Composite well agree with above observation.

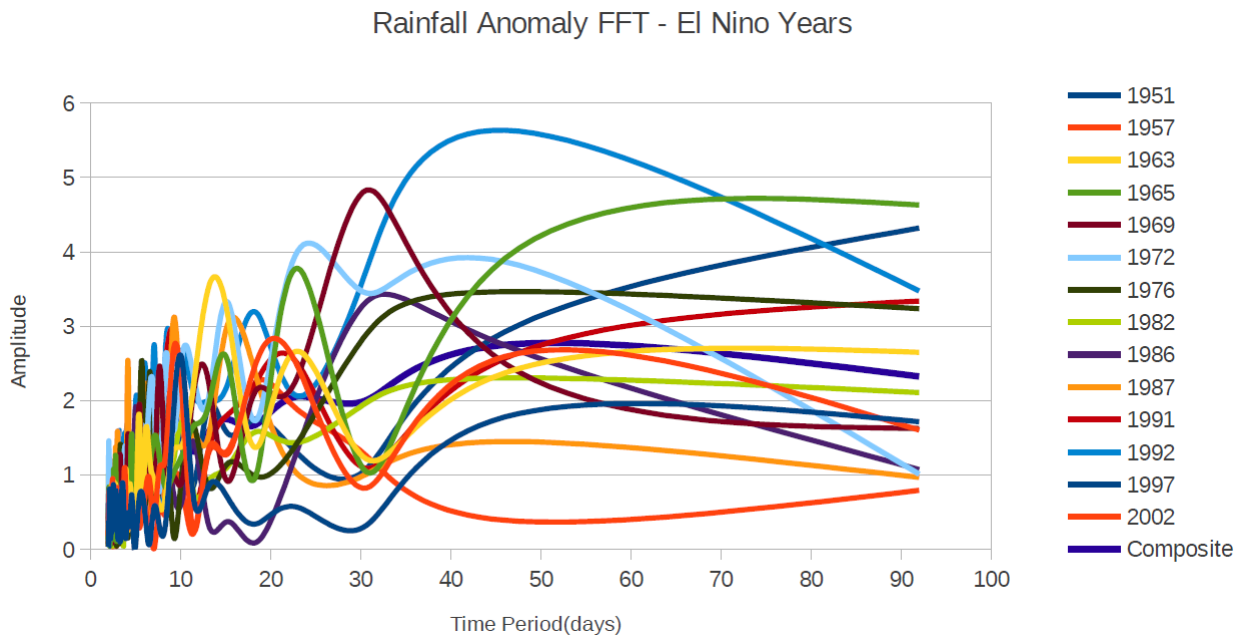


Fig5. Boreal Fall Season Rainfall (Oct-Dec) Analysis – El Nino Years

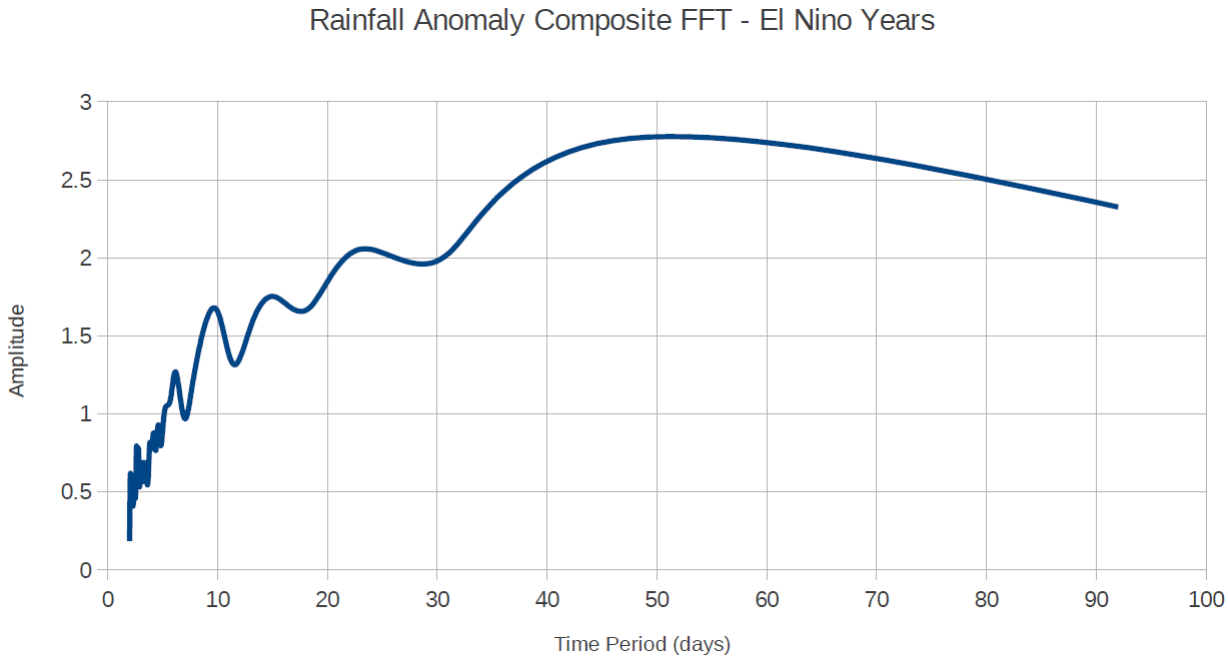


Fig6. Boreal Fall Season Rainfall (Oct-Dec) Analysis – El Nino Years

Fig: 11

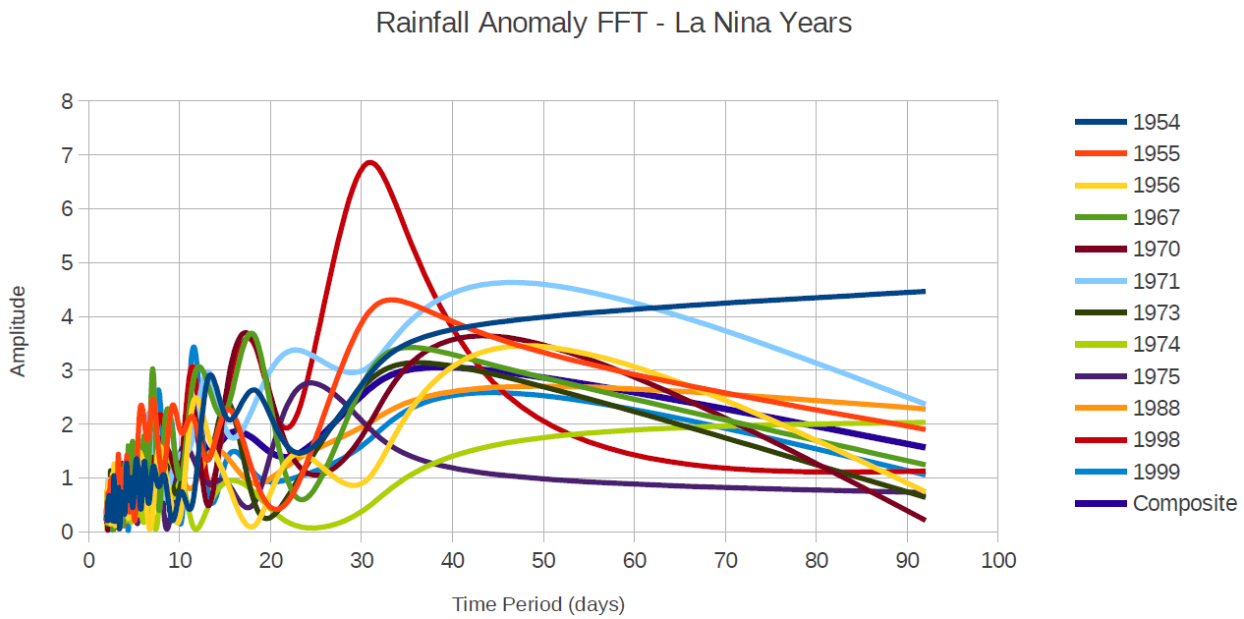


Fig7. Boreal Fall Season Rainfall (Oct-Dec) Analysis – La Nina Year

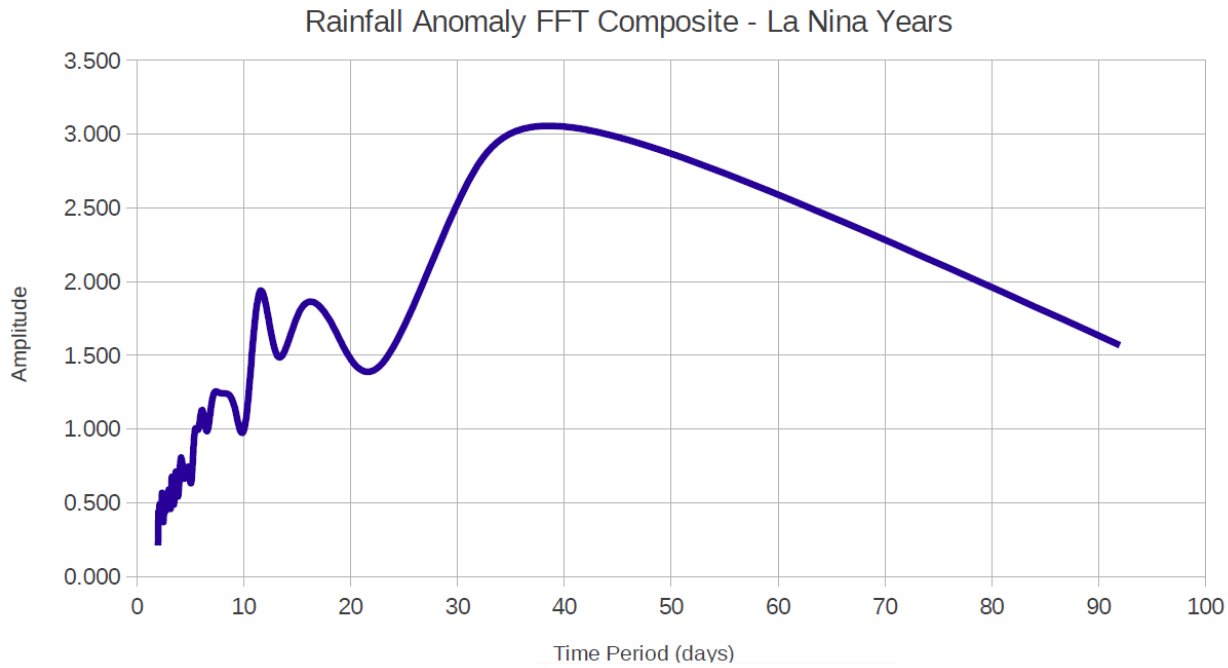


Fig8. Boreal Fall Season Rainfall (Oct-Dec) Analysis – La Nina Years

Fig: 12

VII. The local effect of SST, SLP and wind on the intra-seasonal oscillation of NE monsoon of SP

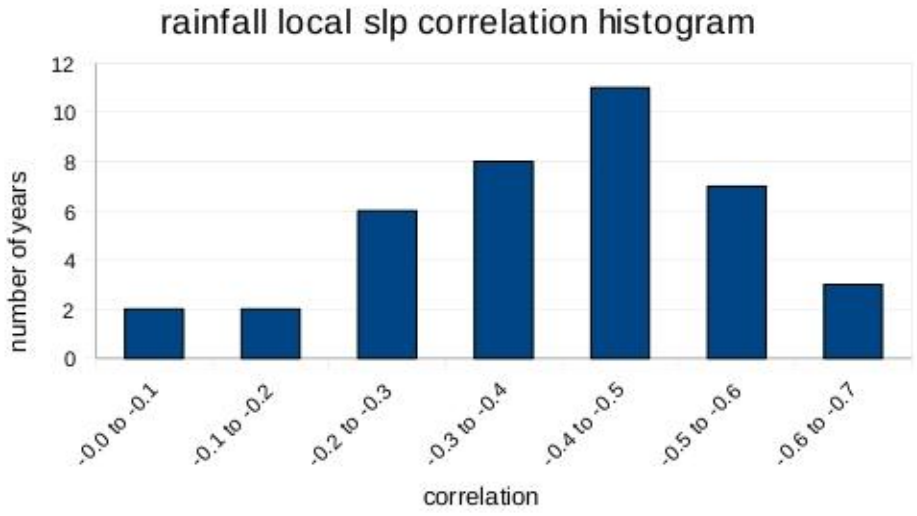
The histogram showing correlation analysis (Fig: 13) suggest that sixteen years have very strong positive (>99%) intra seasonal correlation (0.4 to 0.7) of daily rainfall with Bay of Bengal temperature and those years are 1960, 1961, 1962, 1964, 1966, 1970, 1975, 1977, 1981, 1989, 1990, 1991, 1992, 1993, 1994 and 1995 respectively. Composite analysis of these years shows that these years display remarkable strong anomalies in northwest Pacific. The SLP anomaly in Northwest Pacific is negative whereas strong positive anomaly of SST exists in the same region with persisting westerly zonal wind anomaly Among these sixteen selected years three years of extremely high correlation value (> 0.6) are 1962, 1977 and 1994. Years showing very low correlation (<90% significant) of daily rainfall with Bay of Bengal temperature are 1965, 1969, 1971, 1978 and 1996.

The variability of North East monsoon is mainly controlled by ENSO. Years with strong Bay of Bengal temperature influence (fig:15) have high pressure anomaly over head Bay of Bengal

and low pressure anomaly over equatorial West Indian Ocean. These years with strong influence of Bay of Bengal temperature have positive DMI. There exists a strong negative anomaly of SST at the equatorial east pacific Nino T and Bay of Bengal temperature. The anomaly of Nino Temperature is found to be negative 0.45^0K and this implies that La Nina years can also display very good positive correlation of Bay of Bengal temperature with rainfall. Those years of strong influence of rainfall on Bay of Bengal temperature often associated with easterly anomaly in equatorial central Indian Ocean. 1962, 1977 and 1944 are years that display strong influence of Bay of Bengal temperature on rainfall and their correlation coefficients are 0.678, 0.629 and 0.621 respectively.

The histogram (fig: 13) reveals strong negative intra-seasonal correlation (-0.4 to -0.7) of daily rainfall mean of NE monsoon with Arabian Sea Pressure for twenty one years. They are 1962, 1963, 1965, 1970, 1971, 1973, 1976, 1977, 1978, 1979, 1980, 1981, 1985, 1986, 1990, 1991, 1992, 1993, 1995, 1996 and 1998. The climatology of SST and SLP during north east monsoon season of southern peninsular India is shown in (Fig: 14). The composite analysis of these years confirms that there exist a strong positive anomaly in the Siberian high pressure, strong positive anomaly in Indonesian SST and strong westerly component of zonal wind in equatorial Indian Ocean in all these years. Three of the selected years showing extremely strong correlation value (beyond 99.9% significant) are 1965, 1992 and 1995 and the four years with least correlation (< 90% significant) are 1961, 1968, 1988, and 1997 respectively. Compared to years of weak influence of Arabian Sea Pressure the years with strong influence of Arabian Sea Pressure are marked by a positive anomaly of 1hPa in Siberian high and over northeast Africa (Fig: 15). Southeast Indian Ocean is having negative anomaly of 0. 05hPa.This may be due to the negative DMI. The composite picture of strong influence of local SLP on rainfall show the presence of a warm pool formation near to Indonesian coast. This also is an indication of negative Dipole Mode Index. The Indonesian warm pool has an anomaly of 0.15^0K. The westerly anomaly in the zonal wind is helpful for the persistence of negative DMI. The persistence of negative anomaly of SST in Nino temperature suggests that the strong intra-seasonal correlation of daily north east rainfall mean with local SLP is usually observed during El Nino years. The Nino temperature has an anomaly of -0.15^0K and zonal wind is found to be weak westerly anomaly over equatorial Indian Ocean. Years of strong influence of Arabian Sea Pressure on rainfall show westerly anomaly over equatorial Indian Ocean. 1965, 1992 and 1995 show very good correlation between mean value of rainfall and Arabian Sea Pressure and their correlation coefficients are -0.612, 0.600 and 0.612 respectively.(Table: 3)

The variation in sea surface temperature of a specific box (usually a SST difference of 1^0c can be noticed during El Nino years in this region) in Bay of Bengal if found to be very slow with strong annual cycle it seems to be acting as a guiding factor for the long pulse oscillation mode of rainfall (Fig: 16). In other words slow and steady nature of SST at that specific box in Bay of Bengal leads to excess north east monsoon over SPI. Similarly increased variation of sea level pressure of a specific box of Arabian Sea leads to multiple pulse oscillations or abrupt changes in north east monsoon of India whenever the Bay of Bengal temperature runs high. An year in which Arabian Sea SLP puts forth more control on NE monsoon of SP is shown in (Fig: 17). If the Bay of Bengal SST is not subjected to wide variations the normal synoptic pattern sustains in rainfall. Any marginal difference to it due to IOD, EQUINOO, cyclonic disturbances or El Nino reflects immediately in the rainfall pattern of boreal winter of SP. Obviously the years with warm Bay of Bengal with high SST in South China Sea results in good amount of north least monsoon rainfall due to strong moisture supply. Strong La Nina years show very good correlation of Bay of Bengal temperature and rainfall. Better to say Bay of Bengal Temperature puts forth a control on the intra-seasonal variability of NE monsoon rainfall for years of positive DMI and El Nino years whereas Arabian Sea SLP dictate the same whenever negative DMI sustains as well as in La Nina years. The study reveals 90% statistically significant correlation between Bay of Bengal temperature and rainfall for 34 years, in which nearly 20 years displayed 99% correlation. In the case of Arabian Sea Pressure rainfall showed 90% significant correlation for 35 years studied and half of them with 99% correlation.



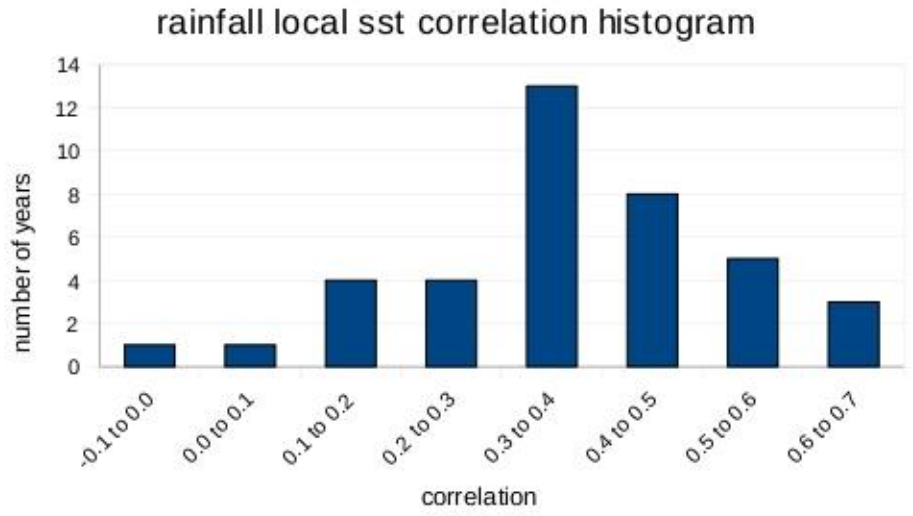
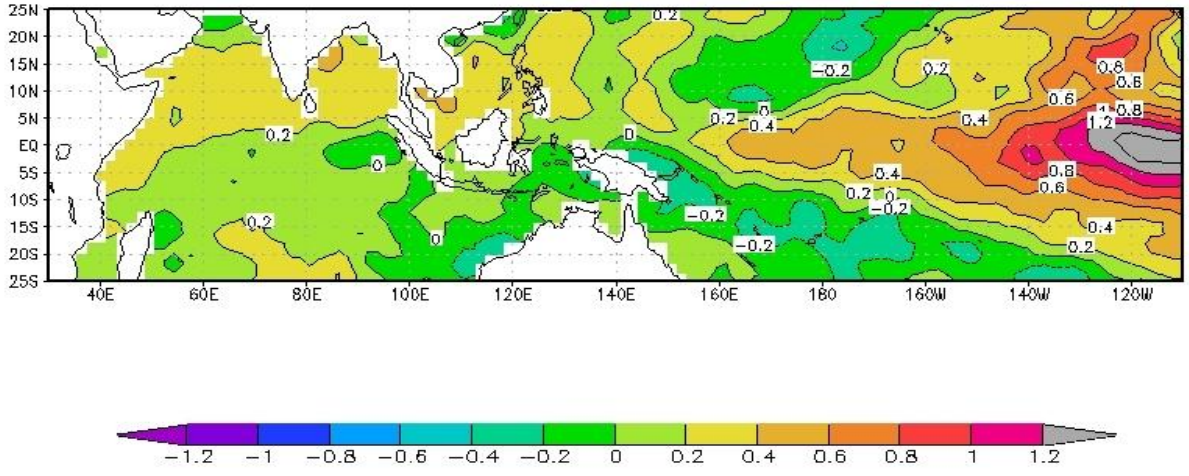
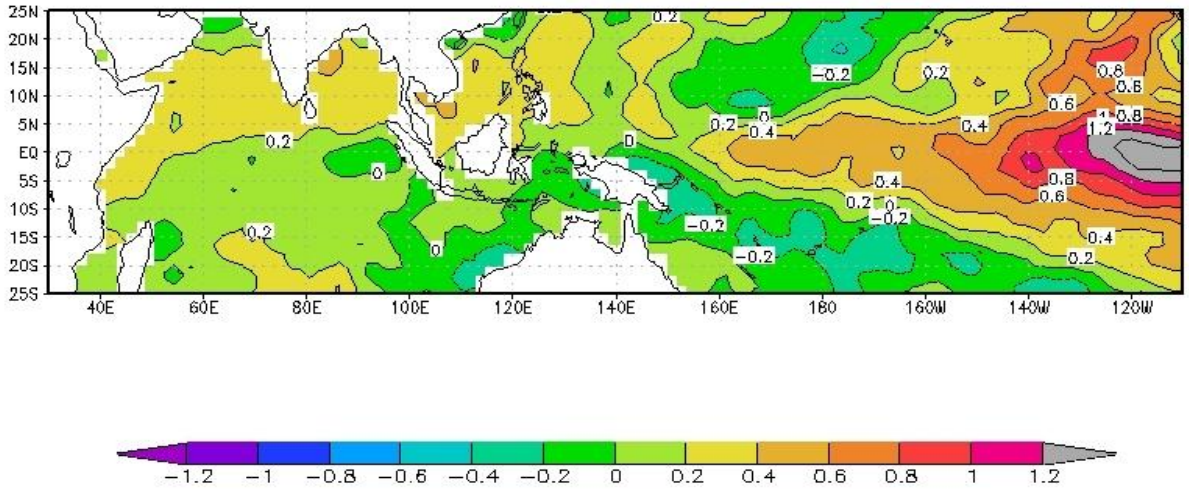


Fig: 13

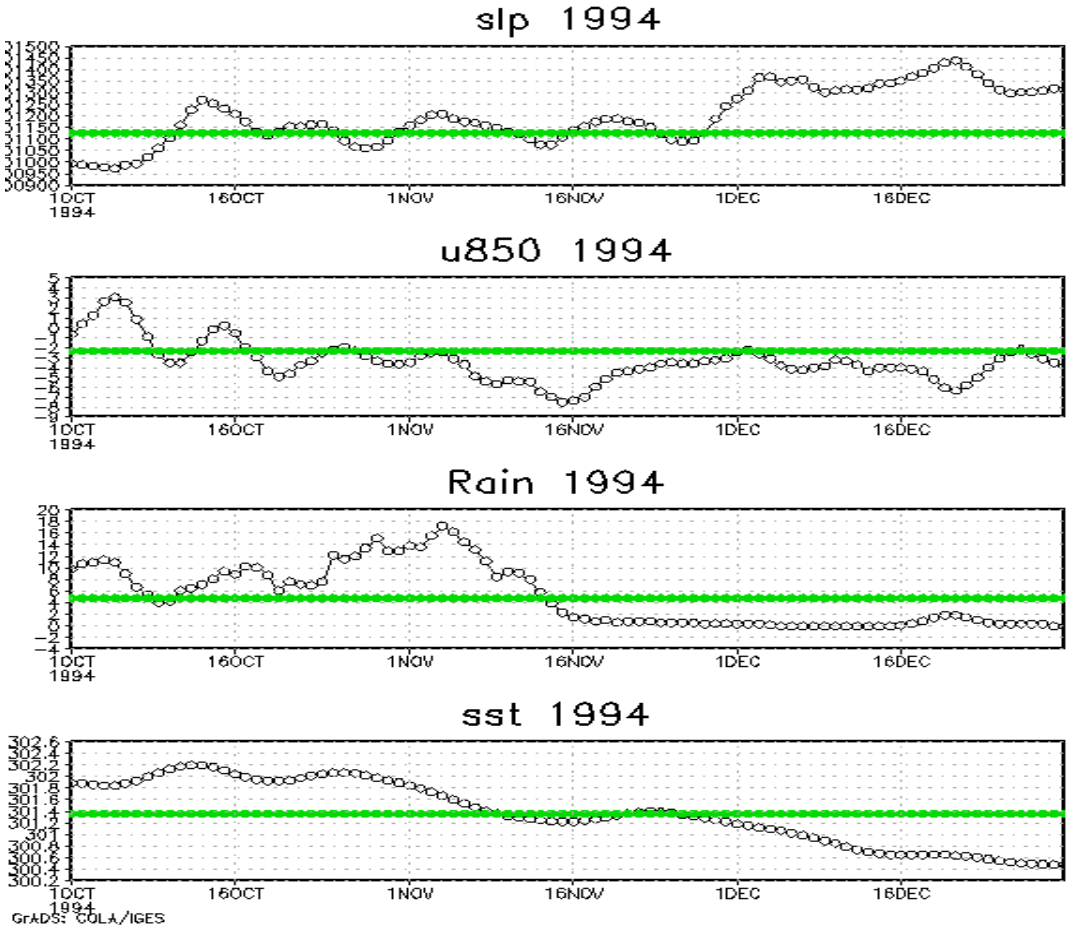


The Climatology of SST during NE monsoon of southern Peninsular India



The Climatology of SLP during NE monsoon of southern Peninsular India

Fig: 14



1994: A year SST of Bay of Bengal showed more influence on the NE monsoon rainfall of southern Peninsular India.

Fig: 15

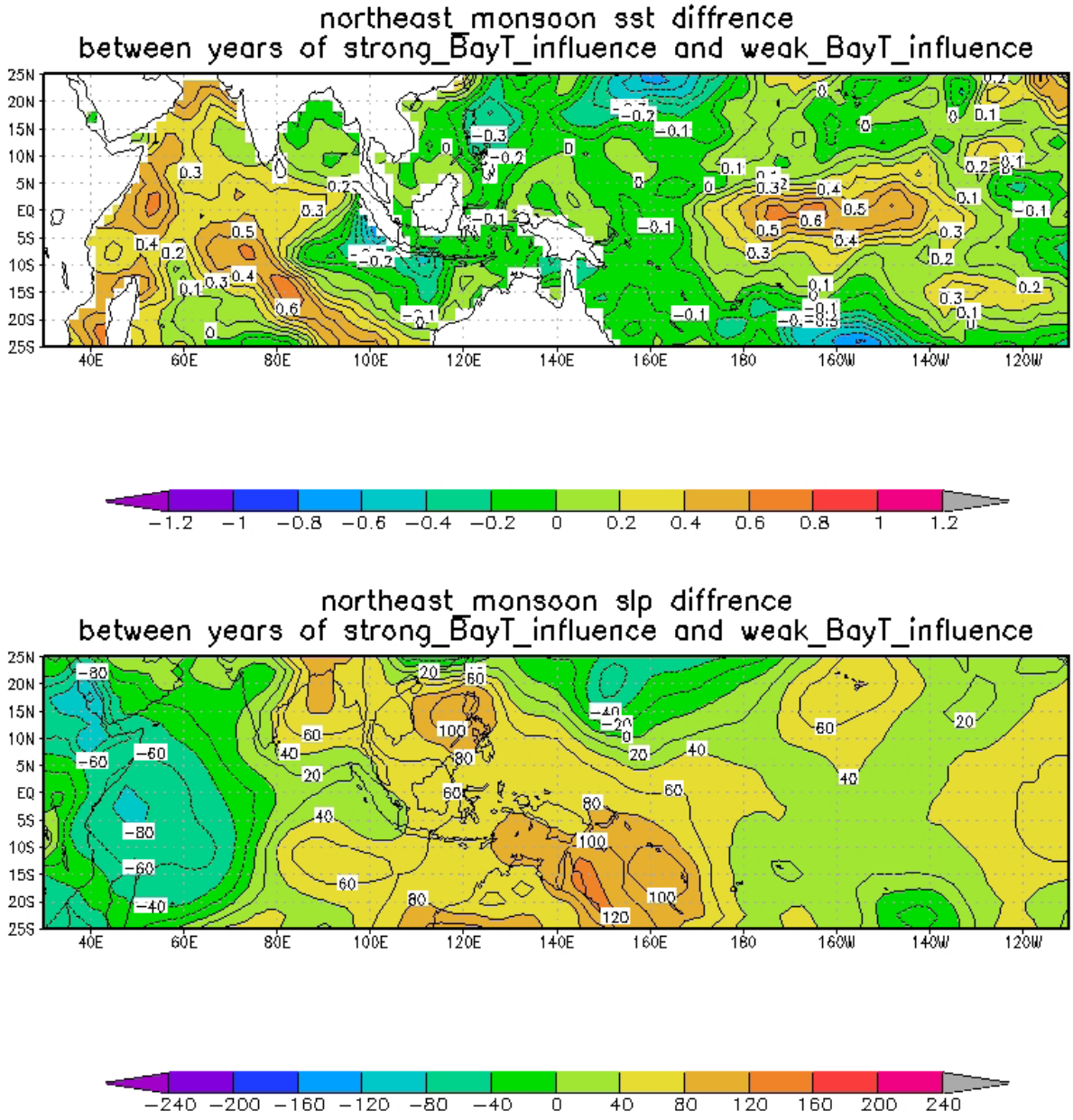
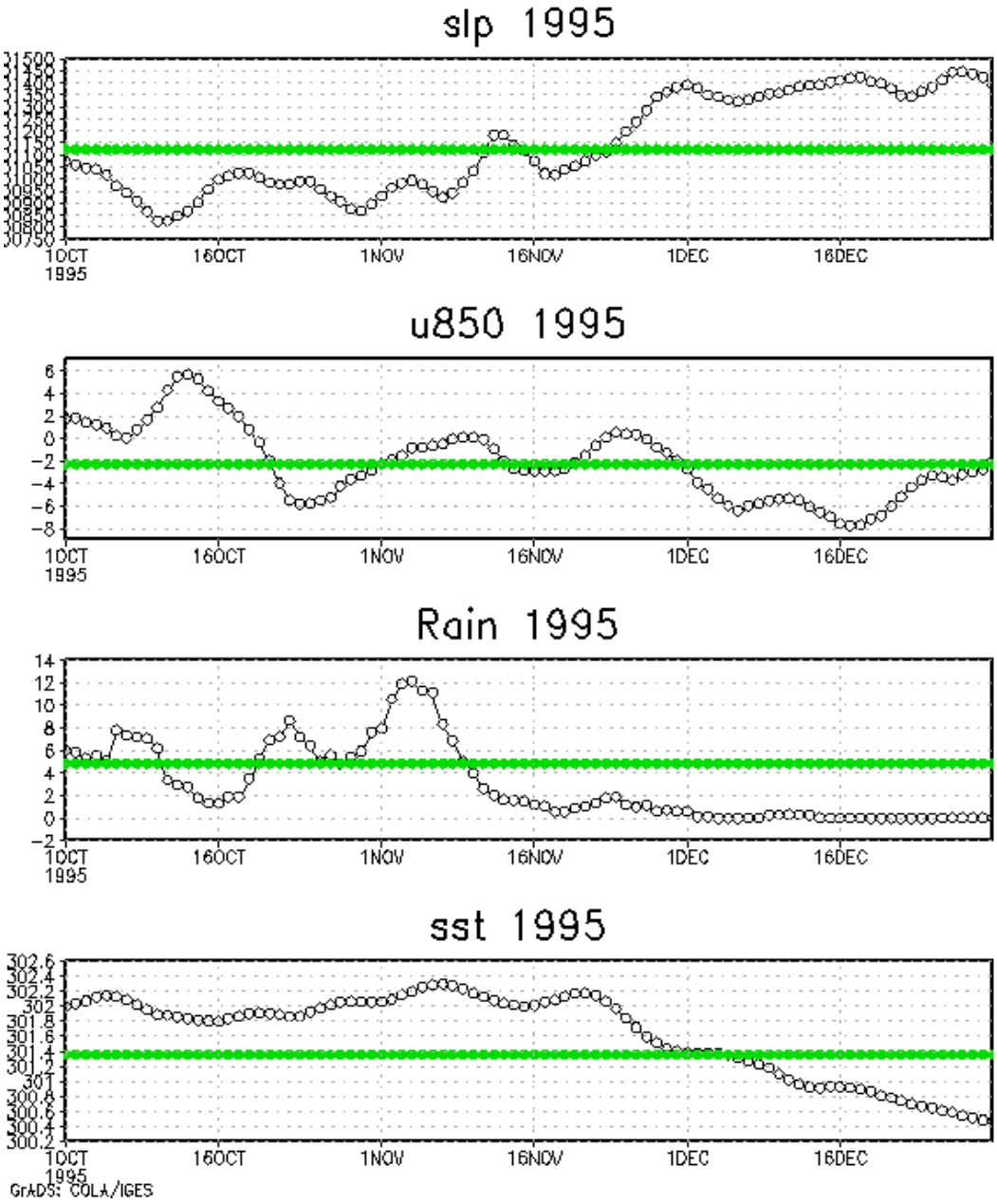

northeast_monsoon sst diffrence
between years of strong_BayT_influence and weak_BayT_influence
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
40E
60E
80E
100E
120E
140E
160E
180
160W
140W
120W
−1.2 −1 −0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1 1.2
northeast_monsoon slp diffrence
between years of strong_BayT_influence and weak_BayT_influence
−240 −200 −160 −120 −80 −40 0 40 80 120 160 200 240

Fig: 16



1995: A year SLP of Arabian Sea showed more influence on the NE monsoon rainfall of southern Peninsular India.

Fig: 17

VIII. CONCLUSION

North east monsoon of southern peninsular India doesn't follow any simple rule within the season. But the most striking oscillations that can be distinguished out of its seasonal flow is 1-5days, 10-20 days and 20-60 days mode of raining in response to various ocean features (Table 1&2). The first two types are generally seen in week and normal years. The last long type raining is exclusive for an excess NE monsoon year. It is the 10-20 days rain pattern which is subjected to maximum variation at any year in the examined all 58 years. Very week years 1-2 days and 3-5 days oscillation is only seen. Somewhat normal monsoon

brings forth a mixture of all the three types of rain still the last mode is very rare. 20-60 day rainfall revolves around 20 days itself not going much beyond 30 in a normal excess year. If at all it is raining beyond thirty days there must be the presence of strong La Nina or a combined effect of more than one positive effect because any other oscillation alone can't drag the rain at such a long pace including a positive IOD or cyclonic disturbances. La Nina years, Positive IOD and positive EQUINOO all results in heavy rain in SP contributing longer pace of rain. Maximum amount of rain is generally seen in October and decreasing subsequently until December. Rainy days can sustain beyond December if it is a La Nina year. Two separate peaks of rain within the season is another commonly noticeable feature. El Nino years, Negative IOD and Negative EQUINOO naturally ends up with drought conditions over SP. The combinations of different oscillations manipulate the scene beyond prediction. The combination of two positive events may push the rainy days to the extreme end of the 20-60 day cycle whereas the combination of two opposite oscillations bleaks the performance of rain. Preference of control to the rain pattern goes to the relatively stronger one in that case.

As regards the local and remote effect of air–sea parameters on the rain pattern of NE monsoon of SP the rainfall over the region is found to respond well with the Bay of Bengal SST and Arabian Sea SLP. The remote effect of ENSO of the Pacific basin on boreal winter of SP is very obvious as its amplitude remains rather less with IO basin. Long term effect like inter decadal and biennial variations in rain of SP can be seen in response with ENSO. The local SST of Bay of Bengal can exert good control and can contribute bountiful rain to SP if it is remaining cool and steady for longer time. On the other hand if the same box of Bay of Bengal is comparatively warmer than usual Arabian Sea SLP holds the key role in deciding the meager rainfall pattern of SP. Bay of Bengal temperature puts forth a control on the intra-seasonal variability of NE monsoon rainfall for years of positive DMI and La Nina years whereas Arabian Sea SLP dictate the same whenever negative DMI sustains as well as in El Nino years. The study (Table: 3) reveals 90% statistically significant correlation between Bay of Bengal temperature and rainfall for 34 years, in which nearly 20 years displayed 99% correlation. In the case of Arabian Sea Pressure rainfall showed 90% significant correlation for 35 years studied and half of them with 99% correlation.

Table 1: Long active period of northeast monsoon occurred in last 58 years when it rained for more than 15 days on which rainfall amount (mm/day) were greater than the mean climatology value.

Year	onset date	End date	Duration days
1960	21/10	25/11	36
1961	18/10	5/11	18
1962	6/10	30/10	25
1964	26/10	15/11	20
1966	6/10	25/10	20
1969	6/10	25/10	20
1972	15/10	8/11	24
1973	14/10	4/11	21
1976	5/11	27/11	23
1977	7/10	29/10	23
1978	16/10	10/11	26
1979	3/11	23/11	21
1986	26/10	10/11	26
1987	7/10	31/10	25
1990	18/10	5/11	18
1991	19/10	8/11	20
1992	3/11	23/11	21
1993	29/10	14/11	17
1994	11/10	14/11	34
1995	20/10	9/11	20
1997	13/10	12/11	31

Table 2: Long break period of northeast monsoon more than 15 days of absence of rain

Year	Commencement of the dry phase	Last date of the dry phase	Duration in days
1960	16/12	31/12	15
1961	16/12	31/12	15

1964	1/12	20/12	20
1970	2/12	25/12	24
1974	3/12	21/12	19
1977	15/12	31/12	16
1982	15/12	31/12	16
1984	7/12	28/12	22
1989	16/12	31/12	15
1990	11/12	31/12	21
1994	1/12	15/12	15
1995	2/12	31/12	30

Table 3: Intra-seasonal correlation between rainfall and local meteorological parameters

Year	Correlation: Rain with	Correlation: Rain with
	Arabian sea pressure	Bay surface temperature
1960	-0.35	0.527
1961	-0.076	0.529
1962	-0.475	0.678
1963	-0.475	0.283
1964	-0.271	0.439
1965	-0.612	-0.022
1966	-0.284	0.413
1967	-0.288	0.284
1968	-0.001	0.346
1969	-0.328	0.178
1970	-0.558	0.526
1971	-0.423	0.078
1972	-0.3	0.251
1973	-0.404	0.2
1974	-0.374	0.367
1975	-0.364	0.567
1976	-0.42	0.393
1977	-0.491	0.629
1978	-0.462	0.147
1979	-0.566	0.334
1980	-0.538	0.379
1981	-0.484	0.439
1982	-0.276	0.393
1983	-0.239	0.221
1984	-0.358	0.349
1985	-0.472	0.335
1986	-0.557	0.37
1987	-0.268	0.332
1988	-0.191	0.36
1989	-0.335	0.488
1990	-0.546	0.428
1991	-0.52	0.489
1992	-0.6	0.417
1993	-0.433	0.4
1994	-0.386	0.621
1995	-0.612	0.566
1996	-0.404	0.107

1997	-0.192	0.364
1998	-0.515	0.385

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