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Rainfall Variation over Andhra Pradesh and Comparison with All Indian Rainfall during El Nino/La Nina

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Abstract

Indian monsoon onset over Kerala (climatological mean is on 1st June with a deviation of ±10 days, but there are some exceptions), then monsoon progresses throughout India. Over Andhra Pradesh (AP), the summer monsoon or Southwest monsoon provides rainfall from June through September. An El Nino/La Nina event affects global phenomena such as the summer monsoon. Nino 3.4 index served as an index for forecasting El Nino/La Nina events. Nino 3.4 Sea Surface Temperature (SST) anomalies were used for this study to identify the El Nino/La Nina years, and they have been subdivided further as strong, moderate, and weak for a better understanding of the event in detail on rainfall. AP is having a special feature that, there are two types of climatic types for the study along with the variations over India. The Southwest monsoon rainfall Variations have been studied monthly (JJAS) and other seasons for the study period from 1950-2014 years and presented the results. The variations of AP rainfall (APRF) during different El Nino/La Nina years and compared with AIRF (AIRF). Previous studies concluded that there is a lag in AIRF after the El Nino event occurs, so we checked the feature for the AP. The monthly variations in the rainfall during El Nino/La Nina reveal that, there is a deficit in AIRF and APRF during El Nino years. During the La Nina years, excessive rainfall was found. Whereas during El Nino, there is an ambiguity in the rainfall being lower than normal rainfall while compared to the monthly and seasonal rainfall.

Subject Areas

Atmospheric Sciences, Environmental Sciences, Hydrology

Keywords

Andhra Pradesh Rainfall (APRF), All India Rainfall (AIRF), El Nino/La Nina, Seasonal Variation, Annual Variation

1. Introduction

The Indian summer monsoon is the most prominent monsoon system across the Globe. Monsoon systems have characterized by the reversal of wind, rainy and dry seasons. The Monsoon system is a complex process that impacts various regional parts. The monsoon "onset" over Kerala (MOK) and "withdrawal" from the southern tip of the Indian continent (around 10_N) delineates the monsoon season. In some years, monsoon "onset" takes significantly earlier than June 1, while "withdrawal" takes place weeks after September 30. The net rainfall received during the summer monsoon period is about 80% of the annual rainfall [1] over June through September (JJAS). The seasonal mean rainfall can also be influenced by significant variations in the length of the rainy season. Monsoonal climates have a well-defined peak rainfall season during which the majority of the annual rainfall occurs.

The monsoon is not only a result of the seasonal reversal of wind and consecutive rainfall, but various other factors like land surface processes, ocean-atmospheric feedback, etc., leading to a complex climate system. The monsoon systems can also be viewed as the seasonal migration of the Intertropical Convergence Zone (ITCZ), the subtropical land regions get precipitation due to a region of intense boundary layer convergence associated with deep atmospheric convection [2] [3]. The fundamental driving mechanisms of the monsoon cycle are the cross-equatorial pressure gradients resulting from the differential heating of land and ocean, modified by the rotation of the earth and the exchange of moisture [4]. Previous studies suggest moisture flux provides a pivotal source for the Indian summer monsoon rainfall, though the evaporation from the Arabian Sea is quite significant. These monsoonal systems are typically characterized by seasonal reversals of the circulation and associated precipitation, driven by changes in the meridional temperature gradient between the hemispheres and differential heating of the land and oceans [5] [6] [7].

Several researchers studied analyzing monsoon rainfall over a large region to identify the trends, that are important to ascertain the computed trend across that regional monsoon rainfall for the country as a whole as well as for smaller regions. The inter-annual variability of AIRF has been linked to variations in Sea Surface Temperatures (SST) over the equatorial Pacific and Indian Oceans, Eurasian snow cover, etc. [8]-[15]. Analyzing monsoon rainfall to identify trends, is also essential to ascertain the computed trend across that region [16]. Long-term trends of India The monsoon season may significantly influence the interannual variability of the seasonal mean monsoon rainfall and its teleconnection with other global phenomena such as the El Nino and Southern Oscillation (ENSO).

The relationship between El Nino events and the Indian monsoon has studied by many researchers since 1980 [9] [10] [11] [17] [18] [19] [20]. Analysis of the long-term data suggests that, there is an inverse relationship between the El Nino events and AIRF. Most severe droughts over India have occurred in association with El Nino events.

During El Nino years, the Walker Circulation altered due to the changes in the Pacific Ocean. During El Nino, the lifting and sinking of air and therefore rainy and dry conditions move with the warmer and colder SSTs to form the pattern in the Pacific Ocean and the atmosphere. Asymmetries between the life cycles of atmosphere-ocean phenomena during warm and cold episodes have been documented in detail by Larkin and Harrison [21]. El Nino growth further is enhanced by a subsequent warm Kelvin wave in boreal summer, which is driven by the anomalous westerlies related to surface cooling and downdraft air over the eastern pole of the growing IOD [22]. The El Niño-Southern Oscillation (ENSO) events, as the strongest interannual signal in the tropics, are one of the most important prediction sources for the regional monsoon rainfall (e.g. [23]-[31]). Many studies have shown that the different phases of ENSO events can lead to distinct behavior of summer monsoon rainfall.

This paper reveals the seasonal and annual rainfall variations over AP (APRF). Later gives the comparison study between APRF and all India rainfall (AIRF). Also, provides information on rainfall during El Nino/La Nina years in the study period.

2. Data and Methodology

AP and All India monthly homogeneous rainfall data from IITM, Pune, India for the period of 1950-2014 has used for this study. The network selected under these constraints consists of 306 almost uniformly distributed stations [32] for which monthly rainfall data are available from 1871 (https://tropmet.res.in/static_pages.php?page_id=53). Seasonal cumulative rainfall data was computed with monthly rainfall and analyzed the variations. Further, interannual variations analyzed concerning global phenomena such as El Niño/La Nina. **Figure 1** reveals the AP with India.

The classification of the El Nino and La Nina periods obtained on Nino 3.4 index. The Oceanic Nino Index (ONI) has become the de-facto standard that NOAA uses for identifying El Nino (warm) and La Nina (cool) events in the tropical Pacific using the running 3-month mean of SST anomalies for the Nino 3.4 region. Events are defined as five consecutive months at or above +0.5 anomaly for warm (El Nino) events and at or below −0.5 anomaly for cold (La Nina) events. The threshold is further broken down into Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4), and Strong (≥1.5) events. For a report for an event to be weak, moderate, or strong it much has equaled or exceeded the threshold for at least three months (Ref: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php).

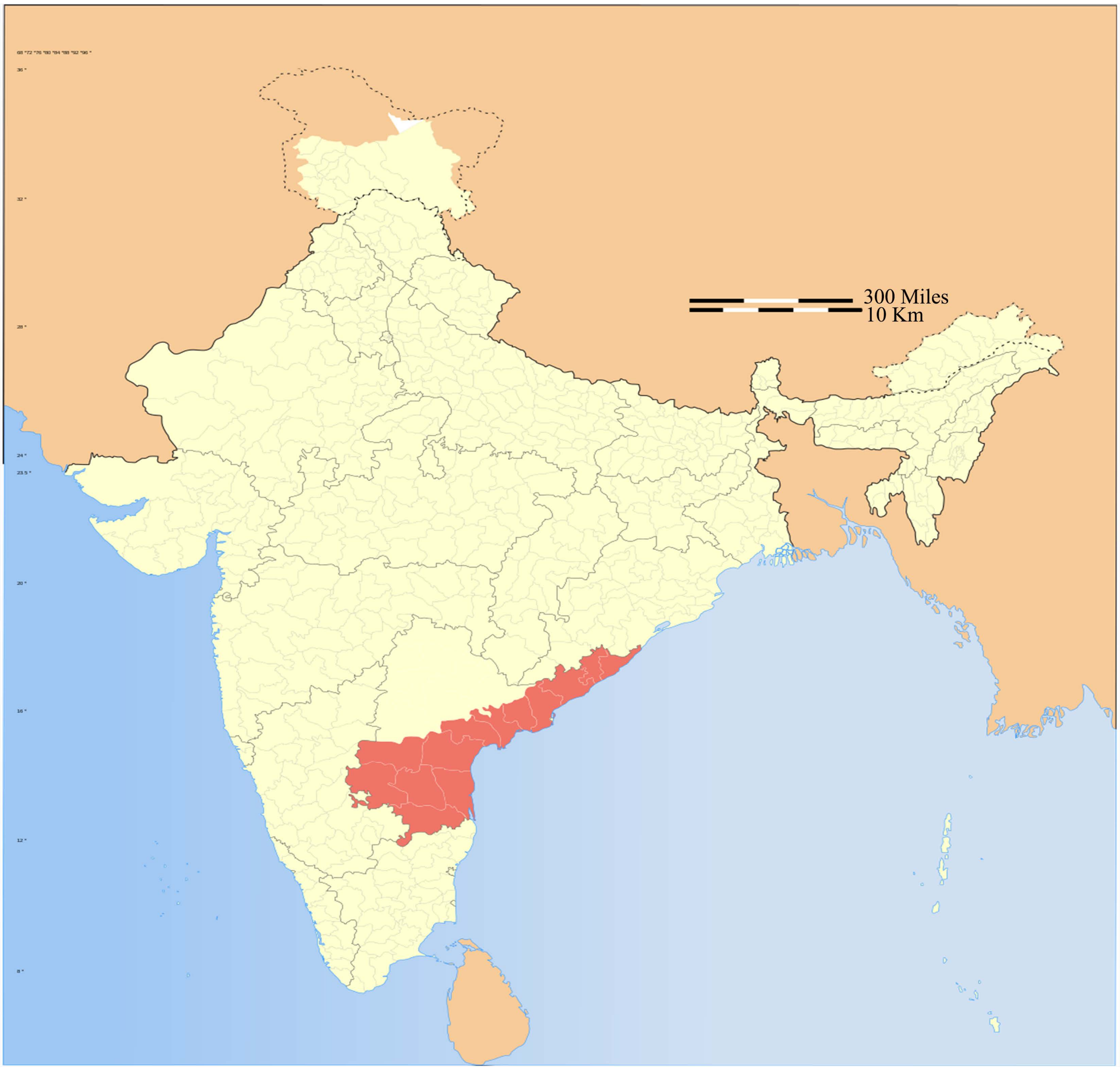

Figure 1. Andhra Pradesh with India map.

3. Results and Discussions

3.1. Variation of Rainfall over Andhra Pradesh

AP monthly rainfall data utilized for a period from 1950 to 2014 used to compute the seasonal cumulative rainfall to find the variations. Indian climate is mainly related to monsoons, with seasons given as follows: January and February as winter, March to May as the pre-monsoon season, June through September as the monsoon season, and October to December as the post-monsoon season. The seasonal rainfall anomalies are given in Figure 2. The winter season indicates lower rainfall anomalies than other seasons. The pre-monsoon season also depicts lower rainfall, the years 1969 (151.3 mm), 1971 (111 mm), 1990 (397.2 mm), and 1995 (222.6 mm) shows higher rainfall anomalies of more than

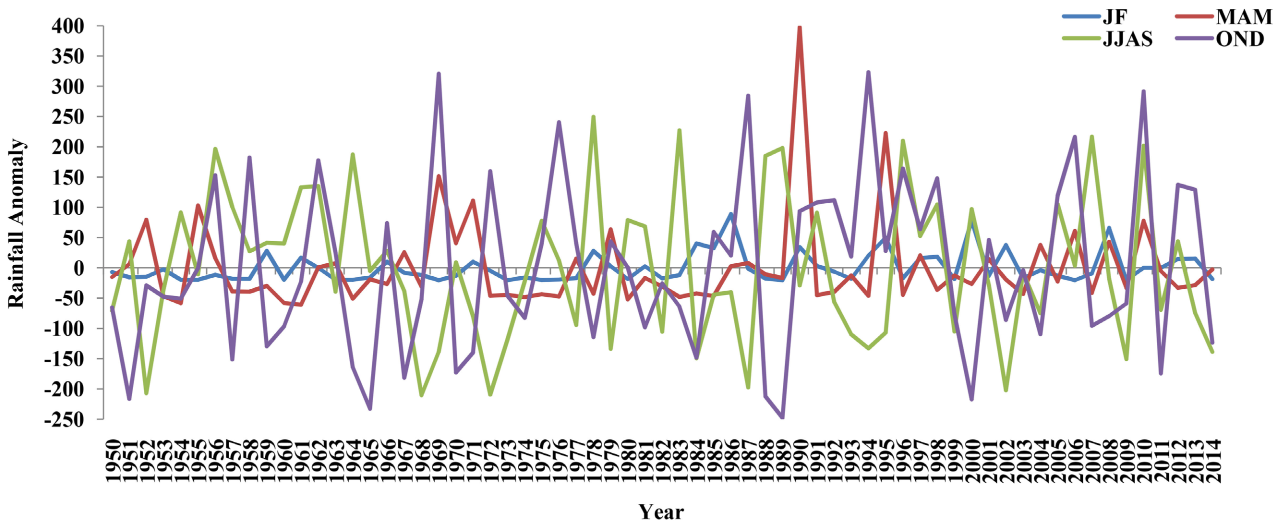

Figure 2. Andhra Pradesh seasonal rainfall anomaly variation during the study period (1950-2014) (seasons are related to India, January and February as winter, March to May as pre-monsoon season, June through September as monsoon season and October to December as post-monsoon season).

100 mm. When we check the summer season, the rainfall varied each year, to a global phenomenon. The higher negative anomalies can observed during the years 1952 (−207 mm), 1968 (−210.5 mm), 1972 (−209.3 mm), 1987 (−197.2 mm), 2002 (−202.1 mm), and 2009 (−150.6 mm). However, higher positive anomalies can be observed in 1978 (249.5 mm), 1983 (227 mm), 1996 (209.9 mm), 2007 (216.6 mm), and 2010 (201.6 mm). Post-monsoon season reveals higher negative anomalies in the years 1951 (−216.5 mm), 1965 (−232.8 mm), 1989 (−247.8 mm), and 2000 (−217.2 mm). However, higher positive anomalies were observed in the years 1969 (320.4 mm), 1976 (240.3 mm), 1987 (284.2 mm), 1994 (323 mm), and 2010 (291.5 mm). The seasonal rainfall anomaly variations in the AP reveals, higher rainfall anomalies observed in the post-monsoon season. This can be explained as the rainfall in the post-monsoon rainfall occurred due to retrieval of monsoon or northeast monsoon as well as cyclones over Bay of Bengal.

Variation of annual rainfall anomalies over AP illustrated in Figure 3, which reveals the interannual variations. Higher positive annual anomalies are in the years 1969 (112.5 mm), 1990 (173.6 mm), and 2010 (173.5 mm), and higher negative anomalies are in the years 1965 (−93.1 mm), 1968 (−86.5 mm), 1984 (−80.6 mm), 2009 (−78.4 mm), 2011 (−76.9 mm) and 2014 (−86 mm). Higher rainfall occurred during weak El Niño (1969), Normal year (1990), and Strong La Nina (2010). This indicates in Normal years and Strong La Nina years has higher rainfall than normal rainfall. However, higher rainfall occurred in weak El Nino also. During El Nino events, there are higher negative anomalies (1965 Strong El Nino, 1968, 2009 Moderate El Nino and 2014 weak El Nino) and in La Nina (1984 weak La Nina, 2011 moderate La Nina). When comparing the annual rainfall variations, APRF indicates a positive increasing trend.

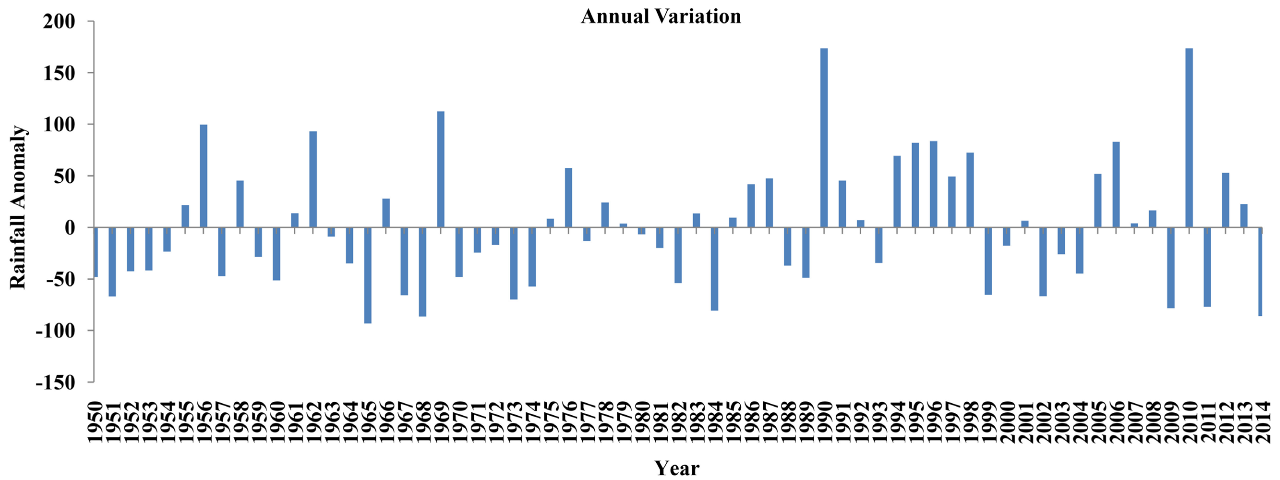

Figure 3. Andhra Pradesh annual rainfall anomaly variation during the study period (1950-2014).

3.2. Variation of Rainfall during El Nino/La Nina

During the study period (1950-2014), Table 1 indicates several El Nino/La Nina/Normal years. Further, El Nino/La Nina years have divided into strong, moderate, and weak. As given in the Table 1, the rainfall during those years averaged, and the rainfall anomalies presented in Figure 4. From Figure 4, it is clear that the Normal year is showing more than normal anomalies (31.8). However, weak El Nino indicates higher rainfall (29) just below the Normal year rainfall anomaly. Strong El Nino and moderate El Nino reveal lower rainfall anomalies (−58.3). However, moderate El Nino rainfall anomalies lowest (v98.8) of any other El Nino years and La Nina years. Strong La Nina illustrates higher rainfall (33) than a Normal year. However, moderate La Nina shows the lowest (−19.8) in La Nina year and weak La Nina is lower than normal rainfall (−3.6). When compared to the Normal years, strong El Nino indicates lower rainfall, especially in the year 2014 had rainfall of 721.5 mm, and strong La Nina produces higher rainfall, which indicates strong La Nina year 2010 produced the highest rainfall (1575.5 mm).

Figure 5 depicts the variation of monsoon seasonal months variation in global phenomenon (El Nino/La Nina). When there is a strong El Nino, June and September months reveal positive anomalies, July and August month's exhibit negative anomalies. Moderate El Nina showing negative anomalies in summer season months. In weak El Nina, June, July, and September months show negative anomaly, but August month indicates a positive anomaly (0.6), but it is a little higher than normal rainfall. In Normal years the rainfall increase from June to July, decrease in August, then increase in September. In strong La Nina, June indicates a negative anomaly; however other months (July, August, and September) depict positive anomalies. In moderate La Nina, June displays a positive rainfall anomaly, July exhibits a negative rainfall anomaly, and then August and September had positive rainfall anomalies. Moderate La Nina produced higher rainfall than strong La Nina. Weak La Nina in June and August shows negative

Table 1. El Nino/La Nina/ Normal years during the study period (1950-2014).

Strong El NIno	Moderate El Nino	Weak El Nino	NORMAL years		Strong La Nina	Moderate La Nina	Weak La Nina
1957	1951	1953	1952	1985	1955	1970	1950
1965	1968	1958	1959	1989	1973	1998	1954
1972	1986	1963	1960	1990	1975	2007	1956
1982	1987	1969	1961	1992	1988	2011	1964
1991	1994	1976	1962	1993	1999		1971
1997	2002	1977	1966	1996	2010		1974
	2009	2004	1967	2001			1983
		2006	1978	2003			1984
		2014	1979	2008			1995
			1980	2012			2000
			1981	2013			2005

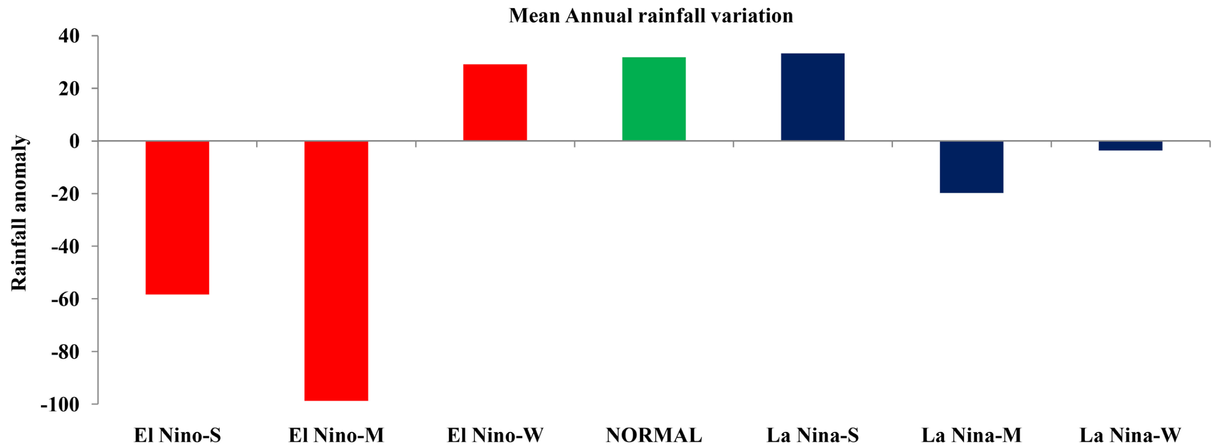

Figure 4. Mean Andhra Pradesh annual rainfall anomaly variation during the study period (1950-2014) in different global phenomenon.

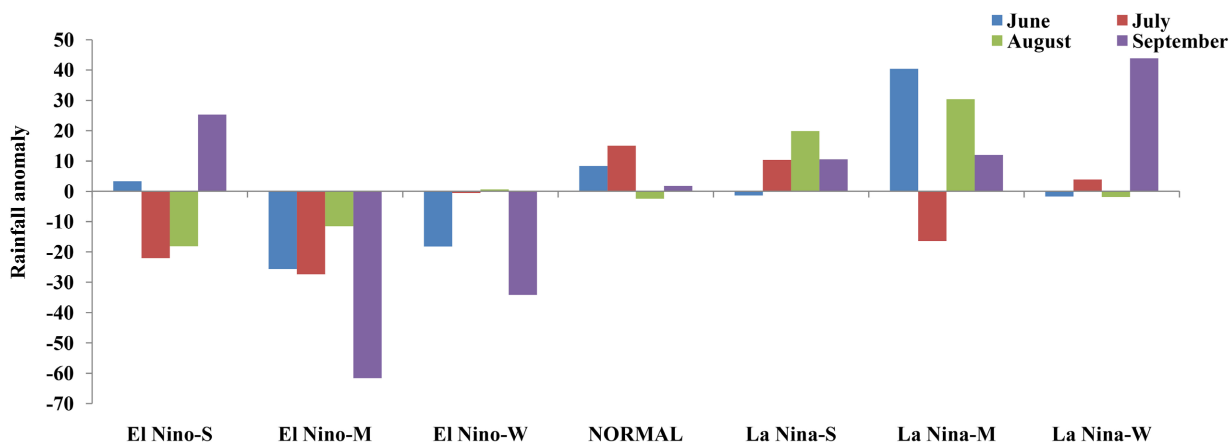

Figure 5. Mean Andhra Pradesh summer month's (JJAS) rainfall anomaly variations during the study period (1950-2014) in different global phenomenon El Nino/La Nina.

anomalies, and July and September are positive anomalies. However, September shows a higher rainfall anomaly than other months.

3.3. Variation of AIRF Anomalies

All India rainfall (here after AIRF) seasonal anomaly variations are presented in Figure 6. When compared with other seasons, winter season (JF) rainfall is lower and varies between −17.6 (negative anomaly) and 21 (positive anomaly). In the pre-monsoon season (MAM), lower rainfall observed in 1979 (−26.6), 1990 (−61.3), 1992 (−28), and 2012 (−31.2). However, higher rainfall occurred in the years 1956 (33), 1971 (32.7), 1977 (36.5), 2004 (40.7), and 2006 (39.6). Summer monsoon season (JJAF) observed higher rainfall in the years 1956 (143.7), 1959 (104.6), 1961 (180.7), 1975 (123.1), 1983 (116.2), 1988 (122), and 1994 (113.3). However lower rainfall occurred in the years 1951 (−100.7), 1965 (−130.2), 1972 (−186.6), 1979 (−131.7), 1982 (−104.3), 1987 (−142.4), 2002 (−177.5), 2009 (−171.8) and 2014 (−103), which reveals the effect of El Nino/ La Nina on all India summer monsoon rainfall, especially strong El Nino years 1965, 1972, 1982 and 1987, and moderate El Nino years 1951, 2002, and 2009 noticed lower rainfall. However, 2014 is a weak El Nino which also recognized lower rainfall. In the post-monsoon season (OND) lower rainfall found in the years 1965 (−48.5), 1984 (−41.5), 1989 (−47.1), 2000 (−59.5), and 2011 (−57.8). However, the years 1955 (64.6), 1956 (87.1), 1997 (68), and 1998 (54.1) witnessed higher rainfall. When comparing the different seasons, the summer monsoon season recorded the highest rainfall than other seasons.

AIRF annual rainfall anomalies are given in Figure 7. Higher rainfall anomalies noticed in the years 1956 (137.4), 1961 (174.4), 1975 (116.8), 1983 (109.9), 1988 (115.2), and 1994 (107). Except for 1994, which is moderate El Nino, all other years are La Nina years. Lower rainfall anomalies found in the years 1951

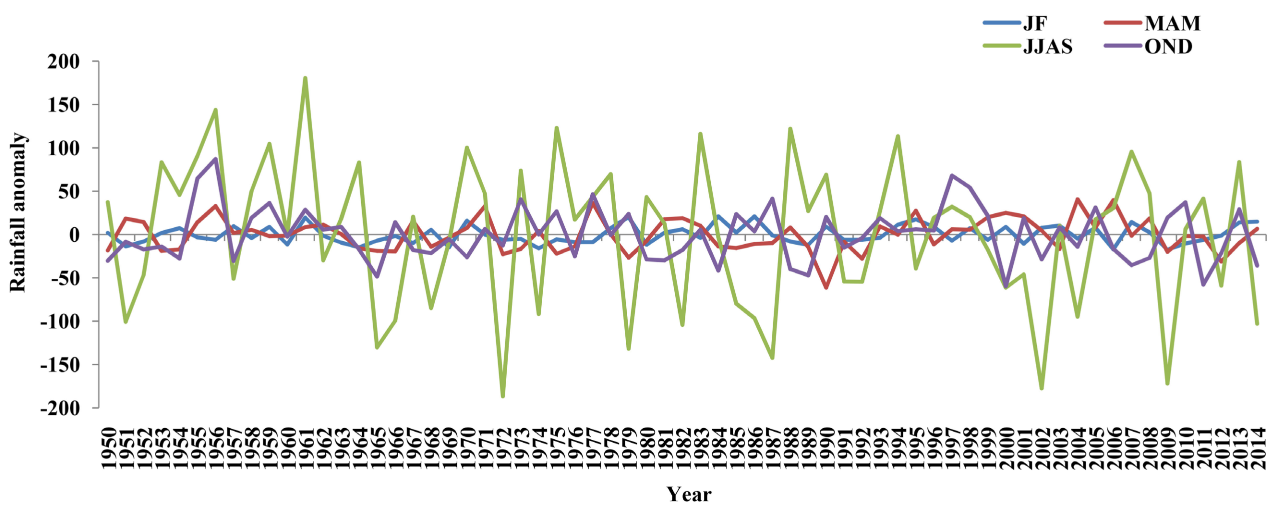

Figure 6. Andhra India seasonal rainfall anomaly variation during the study period (1950-2014) (seasons are related to India, January and February as winter, March to May as pre-monsoon season, June through September as monsoon season and October to December as post-monsoon season).

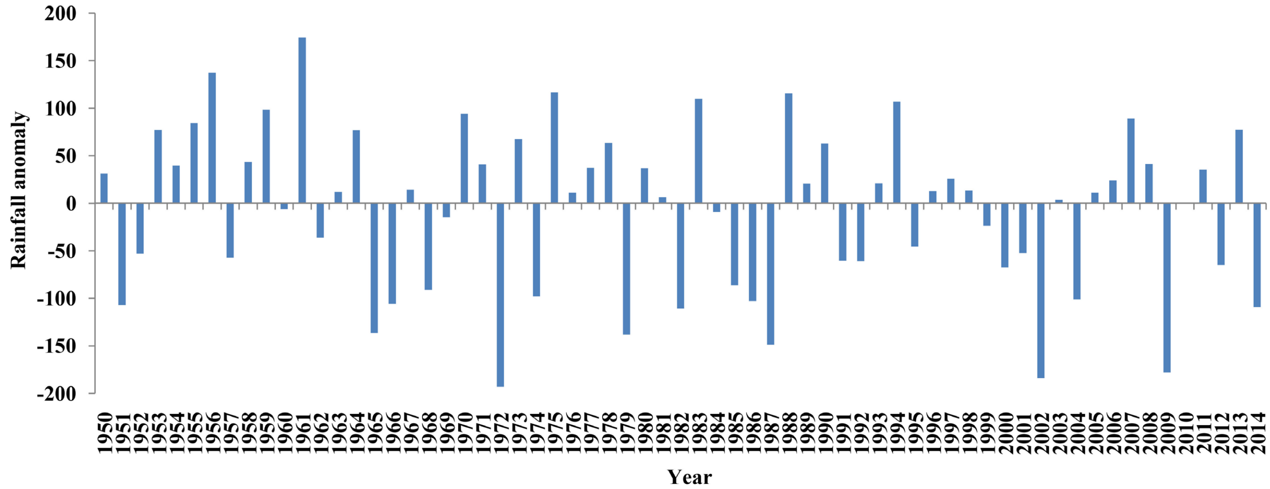

Figure 7. All India annual rainfall anomaly variation during the study period (1950-2014).

(−107), 1965 (−136.5), 1966 (−105.8), 1972 (−192.9), 1979 (−138), 1982 (−110.6), 1986 (−102.8), 1987 (−148.7), 2002 (−183.8), 2004 (−101), 2009 (−178.1) and 2014 (−109.3). Lower rainfall occurred in the above given are El Nino years except 1966 and 1979, which are normal monsoon years. The year 1966 is a Normal year but the year 1965 is an El Nino year which infers El Nino affecting the next year, so 1966 marked a lower rainfall anomaly.

Annual AIRF anomalies during El Nino (strong, moderate, and weak), normal monsoon, and La Nina (strong, moderate, and weak) given in Figure 8. From Figure 8, the lowest rainfall of −104.2 and −102.5 observed during strong El Nino and moderate El Nino respectively. However, weak El Nino also noticed lower rainfall than average rainfall. The average rainfall anomaly in the Normal years indicting almost zero anomalies i.e., the average rainfall occurring. We can find higher rainfall in La Nina; however, the higher rainfall anomalies are reducing from strong La Nina to weak La Nina. From Figure 8, it can be concluded that rainfall produced during El Nino is lower and higher in La Nina

Monthly rainfall anomalies of AIRF during El Nino/La Nina in the monsoon season are given in Figure 9. In the strong El Nino, all the monsoon months indicate lower rainfall than normal. July month accounting for lower rainfall than June, and August month indicates a lower negative anomaly, which reveals an increase in rainfall. Then September months is the lowest of all other monsoon months. In moderate El Nino, the entire monsoon month's rainfall occurred is less. September month is accounting for the lowest rainfall. In the weak El Nino, June and September found lower rainfall, but July and August accounting higher rainfall. Because of higher rainfall in July and August, the monsoon seasonal rainfall recorded positive anomalies. In Normal year, in June and July month recorded positive rainfall. However, in August and September months, negative anomalies detected. The mean normal year's rainfall is almost equal to the average rainfall in the monsoon season. In the strong La Nina, rainfall increased as the month progresses, and the maximum rainfall was in September. Moderate La

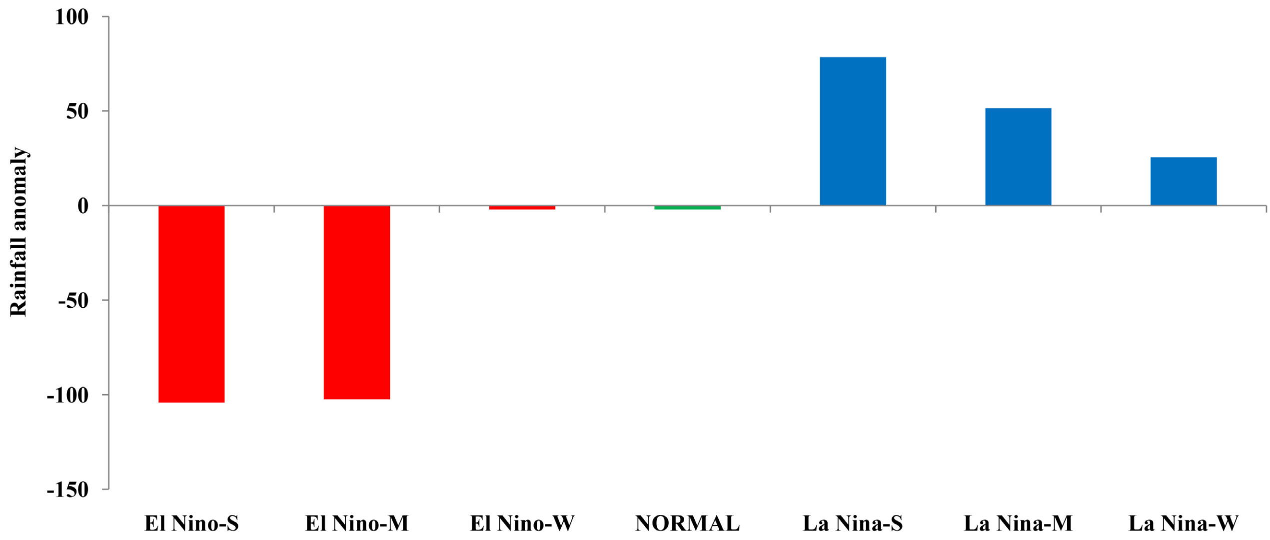

Figure 8. All Indian mean annual rainfall anomaly variation during the study period (1950-2014) in different global phenomenon.

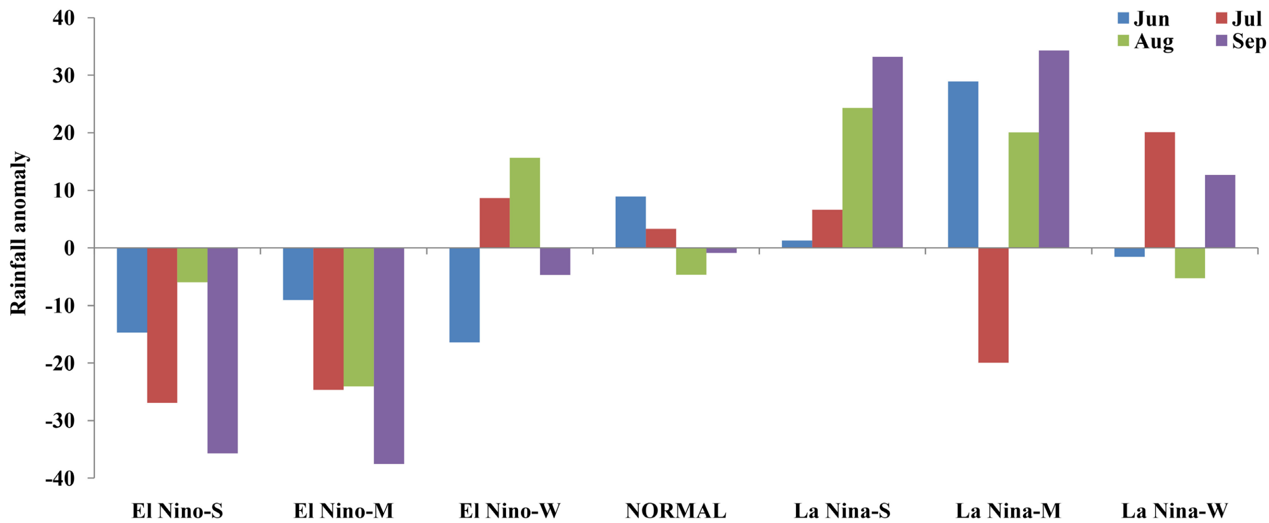

Figure 9. Mean all India summer month's (JJAS) rainfall anomaly variations during the study period (1950-2014) in different global phenomenon El Nino/La Nina.

Nina also showed higher rainfall than strong La Nina, however, July month indicated a lower negative rainfall anomaly. Weak La Nina confirmed positive rainfall anomalies in July and September, but June and August's months are negative anomalies. The seasonal rainfall in the weak La Nina is higher than the normal mean rainfall.

3.4. Relation of Annual AP Rainfall and AIRF with Nino 3.4 Index

The relation between the AP annual rainfall anomaly and Nino 3.4 index is depicted in Figure 10. The left side of the figure indicates the Nino 3.4 index (which averaged annually), and the right side of the Y-axis represents the AP rainfall anomaly. The rainfall anomalies illustrate a positive trend. However, Niño 3.4 index is a negative trend. AP rainfall anomalies and Nino 3.4 index have an inverse relationship with each other. The strong El Nino years indicated negative rainfall anomalies in the years 1972 (−16.9) and 1982 (−53.9), however positive rainfall anomalies were noticed in the years 1987 (1.3) and 1997 (49.4). While moderate El Nino years (2002 and 2009) reveal negative rainfall anomalies (−66.7 and −78.4 respectively). However, in weak El Niño years, 2006 shows a positive anomaly of 83.1, and 2014 indicates a negative anomaly of −85.9. In the strong La Nina years, positive rainfall anomalies noticed in the years 1975 (8.4) and 2010 (173.5). While moderate La Nina years 1998 and 2007 reveals positive rainfall anomalies of 72.4 and 3.8 respectively. However, in weak La Nina years, 1995 and 2005 show a positive anomaly of 81.9 and 51.9 respectively.

Figure 11 represents the all-India annual rainfall and Nino 3.4 index variations. AIRF anomalies and Niño 3.4 index are illustrating a negative trend. The strong El Nino years are indicating negative rainfall anomalies in the years 1972 (−234.6), 1982 (−103.9), and 1987 (−118.5). While moderate El Nino years (2002 and 2009) reveal negative rainfall anomalies (−200.8 and −196.8). However, in weak El Niño years, 2006 shows a positive anomaly of 29.5 and 2014 indicating a negative anomaly of −124.2. In the strong La Nina years positive rainfall anomalies noticed in the years 1975 (111.5) and 2010 (24.4). While moderate La Nina

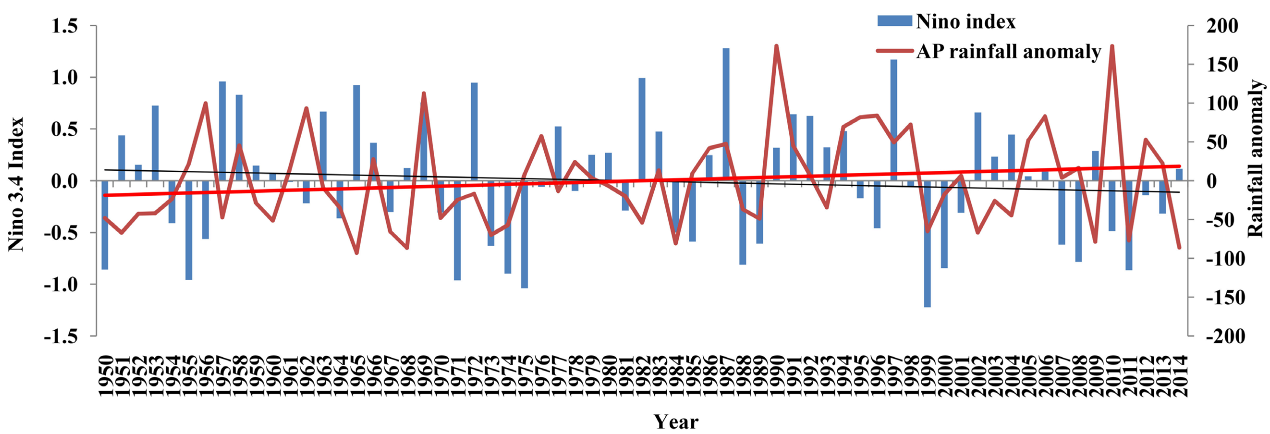

Figure 10. Annual AP rainfall anomalies and Nino 3.4 index variations during the study period (1950-2014).

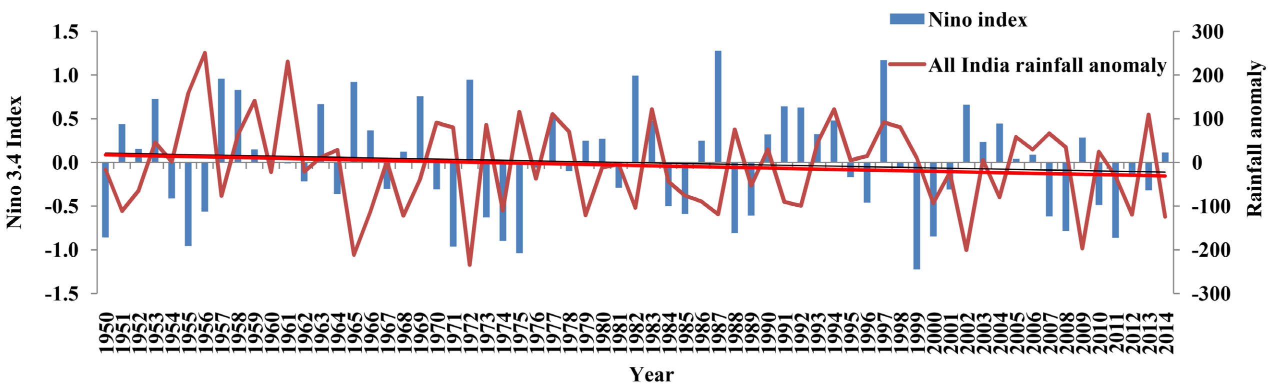

Figure 11. All India annual rainfall anomalies and Nino 3.4 index variations during the study period (1950-2014).

years 1998 and 2007 reveals positive rainfall anomalies of 80 and 66.5 respectively. However, the weak La Nina years 1995 and 2005 show a positive anomaly of 5 and 57.9 respectively.

4. Discussion

During the summer monsoon period, the net rainfall received is about 80% of the annual rainfall [1] over June through September (JJAS). The rainfall shows an inverse relation with the El Nino years. Excess rainfall can observed when there is a La Nina episode prevails. Annual rainfall anomalies of AP rainfall illustrate a higher rainfall than AIRF. When comparing seasonal variations, the winter season reveals lower rainfall for AP rainfall and AIRF. Pre-monsoon rainfall has APRF indicating higher rainfall anomaly than AIRF, for example, in the year 1990 APRF is a positive higher anomaly (397.2), and AIRF is a negative anomaly (−61.3). Monsoon onset may happen in May month, which increases the seasonal rainfall. During the monsoon season, AIRF reveals higher rainfall than other seasons, the same can observed in APRF. As it is well known that India depends on monsoon rainfall, higher rainfall occurs in the monsoon months (IIAS). Particularly on the all India time scale, the monsoon rainfall is not having any trend and is mainly random over a long period [18], however, AIRF is distinct from AIRF. The variability of the monsoon rainfall linked with the El Nino-Southern Oscillation (ENSO). The relation between the monsoon rainfall and ENSO is comparable to be statistically non-stationary and non-periodic [33]. In other El Nino years, AIRF and APRF were normal or excess. This relationship found to be more or less the same, even if we use the Nino-3.4 index. The occurrence of El Nino generally associated with a weak monsoon (rainfall less than normal rainfall), and La Nina is associated with a strong monsoon (rainfall more than normal rainfall) [34]. Post-monsoon seasonal rainfall anomalies are higher in APRF than in AIRF. Higher rainfall over AP is mainly in the post-monsoon season due to the retrieval of monsoon (or winter monsoon) as well as tropical cyclones in the Bay of Bengal. The post-monsoon tropical cyclone intensities are higher and increasing future [24] [35], tropical cyclone rainfall occurs over the east coast of India, which increases APRF in the post-monsoon season.

The inverse relationship between ENSO and the monsoon rainfall has so far linked to the modification of large-scale environment for organized convection associated with the eastward shift of the Walker circulation [19] [36] [37] [38]. The analysis of rainfall anomalies in El Nino years illustrates both positive and negative anomalies, higher rainfall occurring in the monsoon season can relate to another global phenomenon like Indian Ocean Dipole (IOD). IOD may alter the circulation and variations in rainfall [39]. The combination of negative IOD with El Nino results in negative rainfall anomaly or deficit in rainfall, and when positive IOD combines with El Nino results in positive rainfall anomaly [40].

Monsoon seasonal rainfall anomalies during El Nino/La Nina of APRF and AIRF indicate different patterns. APRF illustrates lower rainfall in Strong and

Moderate El Nino; however weak El Nino has a positive anomaly. AIRF shows negative anomalies in El Nino. APRF in La Nina indicates a different pattern to AIRF. In strong La Nina, both AIRF and APRF indicate higher rainfall anomalies, however moderate and weak La Nina is lower anomalies in APRF and AIRF are higher positive anomalies. During moderate El Nina, both APRF and AIRF indicated the lowest rainfall anomalies. During the El Nino episodes, the rainfall varies from drought to normal [41]. However, normal or more than normal rainfall occurs during the La Nina conditions prevail.

5. Conclusions

- The variations APRF in post-monsoon reveals the higher rainfall, however AIRF in the post-monsoon season is lower. APRF discloses distinct variations in post-monsoon with AIRF.
- Annual rainfall variations of APRF illustrate a positive trend and AIRF indicates a negative trend.
- Monthly variations in the monsoon season indicate the different rainfall in the months from June to September. July month is the major for monsoon seasonal rainfall.
- In the strong El Nino the rainfall extended to October.
- Variations in AIRF indicate lower rainfall in El Nino and higher rainfall in La Nina. However, APRF displays different, weak El Nino reveals higher rainfall anomaly and La Nina (moderate and weak) indicates lower rainfall anomaly.
- AIRF and APRF divulge negative relation with Nino 3.4 index (from **Figure 9** and **Figure 10**).
- Observing both El Nino and La Nina events, one can emphasize that La Nina is always associated with excess rainfall (above normal rainfall). In the case of the El Nino event, even though rainfall is predominantly deficient (below normal), at times it can be normal.

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Conflicts of Interest

The authors declare no conflicts of interest.

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