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Predictability of Sri Lankan rainfall based on ENSO

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ABSTRACT: Investigating the year-round rainfall of Sri Lanka provides understanding into the South Asian monsoon system as it compliments studies on the Indian summer monsoon. The El Niño-Southern Oscillation (ENSO) is a primary mode of climate variability of this area. Here, the predictability of Sri Lanka rainfall based on ENSO is quantified based on composite analysis, correlations and contingency tables. The rainfall is modestly predictable based on ENSO during January–March, July–August and October–December. El Niño typically leads to wetter conditions during October to December and drier conditions during January to March and July to August on average. The correlations of ENSO indices with rainfall are statistically significant for October to December, January to March and July to August and an analysis based on contingency tables shows modest predictability. The use of ENSO indices derived from the central Pacific sea surfaces improves the predictability from January to June. The predictability in the mountain regions is diminished when garnering orographic rainfall. The predictability in the east is diminished during the cyclone season. The predictability based on ENSO for October to December rainfall is robust on a decadal scale while the predictability of January to March and July to August rainfall has acquired significance in recent decades. An ENSO-based scheme that is adapted to each season and region, and takes account of decadal variations can thus provide skillful rainfall predictions. Copyright © 2007 Royal Meteorological Society

KEY WORDS ENSO; monsoon; Sri Lanka; seasonal climate prediction

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1. Introduction

The rainfall of Sri Lanka (Figure 1) is under the influence of the vast Asian Monsoon system. The monsoon regions of the world have been defined based on a reversal of the mean wind direction by at least 120° during the annual cycle (Ramage, 1971) and this includes Sri Lanka where the wind direction changes from northeasterly during the boreal winter to westerly during the summer. The analysis of Sri Lankan rainfall is important as it provides an insight into the Asian monsoon and the climate of the tropical Indian Ocean. Rainfall in Sri Lanka is year-round and its study complements that of the Indian summer monsoon rainfall that extends from June to September. The rainfall during the rest of the year is important to the 150 million people who inhabit Southern Peninsular India and the Maldives in addition to Sri Lanka, as it affects the principal sectors of employment and livelihood such as agriculture, water resources, fisheries and tourism.

Sri Lanka has a bimodal climatology with the heaviest rains from October to December and subsidiary rains from April to June (Figure 2). Sri Lanka receives modest rainfall even in the remaining drier months. Further details of the climatology are presented in Section 3.

The El Niño/Southern Oscillation (ENSO) phenomenon is now recognized as a primary mode of seasonal climatic variability, particularly in the tropics (Ropelewski and Halpert, 1987). ENSO is a shift in the pattern of oceanic warming and atmospheric circulation centered in the Pacific Ocean with implications across the tropics that recurs typically 2–7 years apart. The phases of the ENSO phenomena associated with anomalously (by at least 0.4 °C) warm and cold sea surface in the equatorial eastern Pacific Ocean are referred to as El Niño and La Niña respectively. A significant ENSO influence has been identified on Sri Lankan rainfall and temperature (Rasmusson and Carpenter, 1983; Ropelewski and Halpert, 1987; Suppiah, 1996). The ENSO teleconnection is through large-scale east–west shifts in the 'Walker circulation' of the Indo–Pacific regions. During an El Niño event, the tropical convection and the associated rising limb of the Walker circulation normally located in the western Pacific shift toward the anomalously warm waters in the central and eastern Pacific. Consequently, there is an anomalous subsidence at low atmospheric levels extending from the western Pacific to South Asia during the boreal summer (Allan *et al*., 1996). This subsidence leads to the reduction of rainfall over India and Sri Lanka from January to September. However, after October, the ENSO influence on Sri Lankan rainfall

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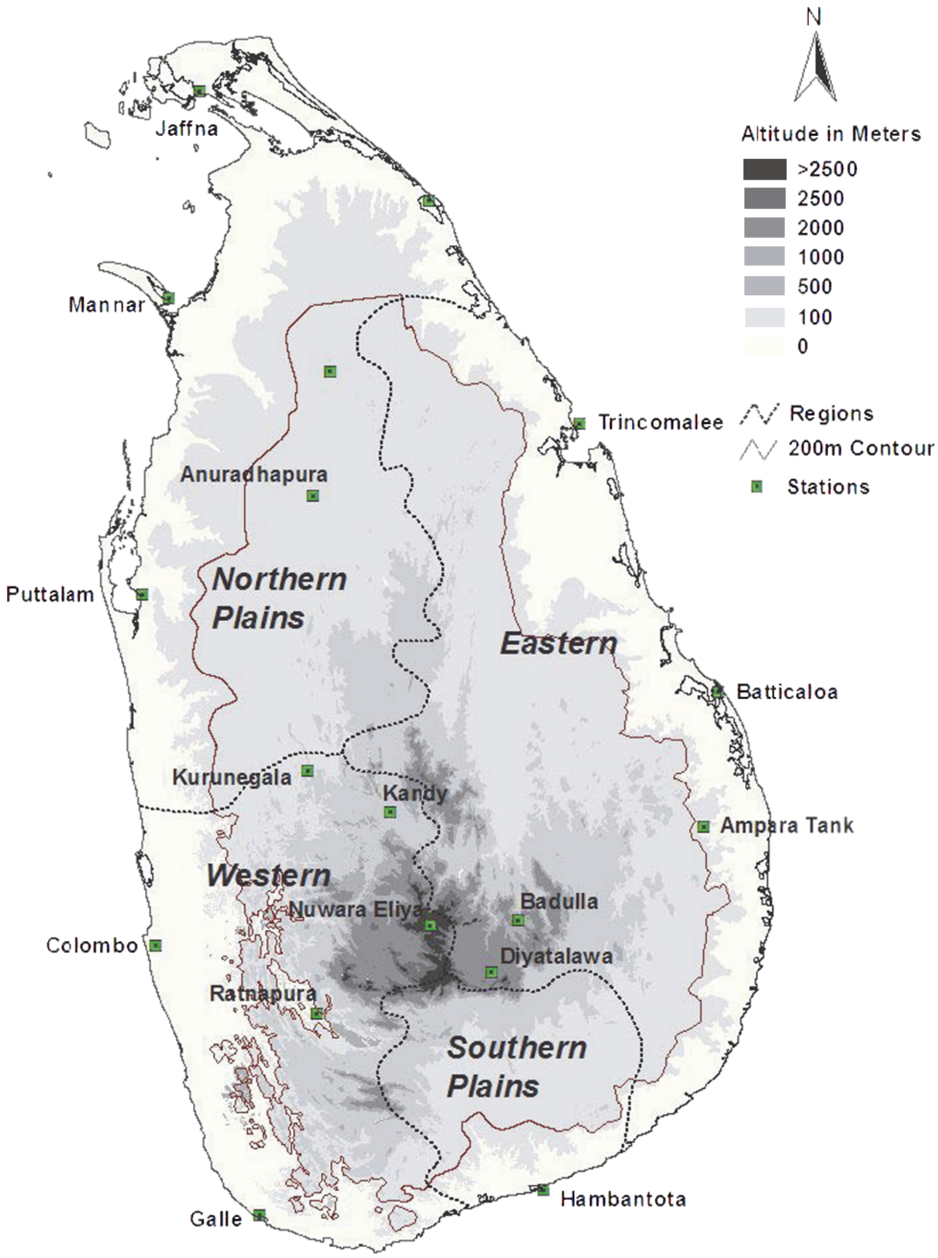

Figure 1. Topography, location of meteorological observatories, and regionalization for Sri Lanka is shown. The 200 m contour that can be taken to separate the low areas from the hilly areas is indicated as thin lines. This figure is available in colour online at www.interscience.wiley.com/ijoc

undergoes a reversal, with anomalous convection that prevailed over eastern Africa until September extending to cover an area that includes Sri Lanka until December. During El Niño events, the rainfall is enhanced from October to December and diminished from January to March and July to August (Rasmusson and Carpenter, 1983; Suppiah, 1996; Zubair, 2002b).

The influence of the ENSO on the South Asian monsoon system differs by season. The monsoon rainfall in northern India decreases with the El Niño during summer and increases in Sri Lanka and southernmost India from October to December (Rasmusson and Carpenter, 1983). Twenty-one of the 26 years with low Southern Oscillation Index (SOI) were associated with high rainfall in Sri Lanka (Ropelewski and Halpert, 1987, 1989). The

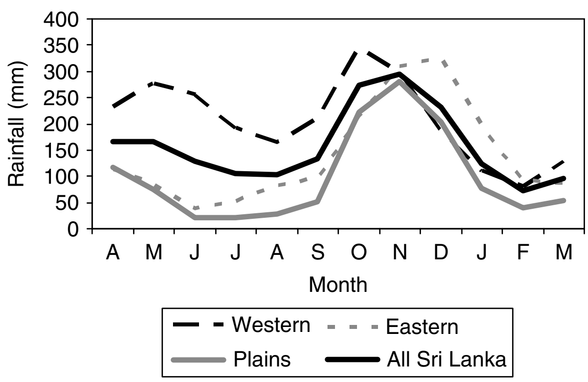

Figure 2. The rainfall climatology for all of Sri Lanka and for the Western, Eastern, Plains regions based on records from 1869 to 2004. The letters on the x-axis represents initials of months from April to March.

significant SOI-rainfall relationships for Sri Lanka were detailed for the October–November and July–August seasons (Suppiah, 1989, 1996, 1997; Kane, 1998; Malmgren *et al*., 2003).

In recent decades, there has been progress in predicting the evolution of the ENSO phenomena in the Pacific Ocean (Goddard *et al*., 2001). Forecast centers issue modestly skillful predictions of the seasonal evolution of tropical sea surface temperatures (SST) 5 months in advance (for example, Goddard *et al*., 2001). Thus, the relationship between rainfall and ENSO can be exploited to predict seasonal rainfall. Such statistical predictions based on teleconnections with surface temperatures provide an alternative basis for seasonal climate prediction that complements and often improves on those based on global climate models (Barnston *et al*., 2005). SST based indices for ENSO are preferable over the SOI because they are explicitly predicted, have less high-frequency noise and represent the ENSO influence over the Asian monsoon region more compactly (Soman and Slingo, 1997).

Previous detailed analyses of ENSO-rainfall relationships for Sri Lanka (Suppiah, 1989, 1996, 1997; Fernando *et al*., 1995; Sumathipala and Punyadeva, 1998; Kane, 1998; Punyawardena and Cherry, 1999; Malmgren *et al*., 2003) were based on seasons defined by wind-directions, which do not match with the agricultural seasons. The seasons in use also ranged from 2 to 5 months, while contemporary seasonal predictions are most developed at a 3-month time scale. Early studies did not resort to these seasons (Rasmusson and Carpenter, 1983; Ropelewski and Halpert, 1987, 1989) but do not provide an analysis for all seasons or information on regional and decadal variability.

The goal of this paper is to characterize the ENSO relationships with Sri Lankan rainfall in a manner that leads to maximum useful predictability. Here, we consider the availability of quarterly seasonal predictions, the agricultural cycle, and the annual cycle of ENSO influence to choose the seasons that give the highest utility and predictability. We also provide a detailed evaluation of the ENSO-related predictability of rainfall for Sri Lanka through correlation analysis, composite analysis and contingency tables of rainfall and SST.

2. Data and methods

2.1. Rainfall data

The monthly data for 16 observatories were obtained from the Sri Lanka Department of Meteorology ranging from 1869 to 2004 (Table I and Figure 1). Regional rainfall indices were constructed by averaging the values for the stations within the region. Basic statistics for rainfall are provided in Table II. The data for Jaffna has gaps from January 1991 to May 2001, and the data for Mannar has gaps from May 1990 to December 1992. These gaps were filled with a reconstruction algorithm using data of other stations that were correlated highly with the data of the missing stations in other periods following Peterson and Easterling (1994).

2.2. SST and ENSO indices

SST reconstructions from 1869 to 2003 were obtained from Kaplan *et al*. (1998). ENSO indices are estimated as the average SST anomaly for the respective regions as shown in Figure 3. The SOI has been obtained following Ropelewski and Jones (1987).

2.3. Correlation analysis

The Pearson correlation coefficient was used to identify relationships between ENSO indices and rainfall (Press *et al*., 1992). A correlation was taken to be significant when the no-correlation null hypothesis was exceeded with a probability of 95% and highly significant when the probability was 99%. The rainfall data for all quarterly seasons had insignificant lag-1 autocorrelation. The quarterly rainfall time series were identified as Gaussian by the Kolomogorov–Smirnov test and the chi-square test. Note that the April to June rainfall was identified as Gaussian by the chi-square test. The chi-square test is less sensitive to discrepancies in the extreme tails compared to

Table I. Rainfall stations of the Sri Lanka Department of Meteorology segregated into the Plains, Eastern, Western and Hill regions.

Station name	Latitude	Longitude	Elevation	Duration
Plains Region				
Jaffna	9.65	80.02	4	1871–2004
Mannar	8.98	79.92	4	1870–2003
Anuradhapura	8.33	80.38	93	1870–2004
Puttalam	8.03	79.83	2	1869–2003
Hambantota	6.12	81.13	16	1869–2004
Eastern Region				
Trincomalee	8.58	81.25	3	1866–2004
Batticaloa	7.72	81.70	3	1869–2003
Ampara Tank	7.28	81.67	27	1876–2003
Badulla	6.98	81.05	670	1869–2003
Diyatalawa	6.82	80.97	1248	1901–1993
Western Region				
Kurunegala	7.47	80.35	116	1885–2003
Kandy	7.33	80.63	477	1869–2004
Nuwara Eliya	6.97	80.77	1895	1869–2004
Colombo	6.90	79.87	7	1869–2004
Ratnapura	6.68	80.40	34	1869–2004
Galle	6.03	80.22	13	1869–2003

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Table II. The mean, standard deviation (SD) and percent of annual rainfall for quarterly and annual rainfall for all of Sri Lanka and for the three climatic regions and the hill country. Details are provided for May (M) and July to August (JA) seasons as well.

Region		AMJ		JAS		OND	JFM	Total
			M		JA			
All-Sri Lanka	Mean	426	153	318	184	777	302	1819
		23.4%	–	17.5%	–	42.7%	16.6%	–
	SD	94	71	90	43	176	132	212
Plains	Mean	217	77	111	56	654	176	1158
		18.7%	–	9.6%	–	56.4%	15.2%	–
	SD	82	57	54	36	184	103	203
Eastern	Mean	231	83	223	127	856	410	1721
		13.4	–	13.0%	–	49.8%	23.8%	–
	SD	65	44	76	57	227	214	291
Western	Mean	759	275	571	339	821	322	2462
		30.8%	–	23.2%	–	33.3%	13.1%	–
	SD	165	124	162	116	181	119	290
Hill country	Mean	470	148	402	262	737	329	1938
		24.2%	–	20.8%	–	38.0%	17.0%	–
	SD	140	92	124	100	200	164	315

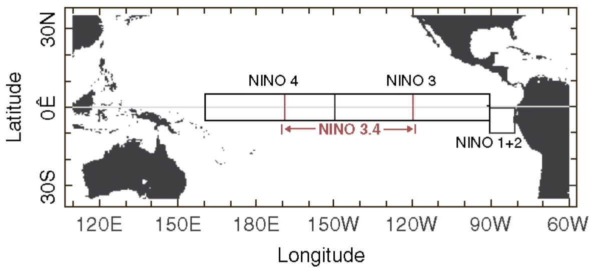

Figure 3. The different regions that are used in the definition of the ENSO indices are shown. The area for both NINO1 and NINO2 are shown together with NINO2 being the top half of the rectangle. The SST anomalies in each region are averaged to obtain the respective indices. This figure is available in colour online at www.interscience.wiley.com/ijoc

the Kolmogorov–Smirnov test. The analyses were compared with Spearman's ranked correlation, which is a nonparametric test that is useful to check for robustness of relationships in non-Gaussian data.

2.4. Composite analysis

Composites of rainfall are presented for the El Niño, Neutral and La Niña phases. Here we define the ENSO phases as: El Niño (NINO3 $>0.5\,^{\circ}$C) and La Niña (NINO3 $<-0.5\,^{\circ}$C) when these anomalies were sustained for at least 5 months (Trenberth, 1997). All other occasions were identified as the neutral phase. Composites were constructed by averaging the rainfall in periods where each of the ENSO phases prevailed.

2.5. Contingency tables

A contingency table may be constructed to identify the influence of ENSO on a variable such as rainfall based on historical data (Wilks, 1995). ENSO phases may be segregated depending on the prevalent value for an ENSO index into three categories: El Niño, Neutral and La Niña. Similarly, the rainfall may be segregated in terciles based on the historical record and representing 'below-normal', 'near-normal' and 'above-normal'. The occurrences of ENSO phases and rainfall conditions in different tercile combinations are tabulated.

2.6. Forecast skill assessment

Heidke skill scores are used to provide some measure of forecast quality when the forecasts and corresponding observations are expressed in categories (Wilks, 1995). The Heidke score (S) is given by $S = 100\,(C\text{-}E)/(N\text{-}E)$, where C is the number of correct forecasts, E is the number of correct forecasts expected by chance and N is the total number of forecasts. In the computation of the Heidke score, we used the observed occurrences of rainfall and ENSO episodes to determine the probabilities expected by chance.

3. Climatology

3.1. Mean annual cycle

The mean annual cycle of rainfall in Sri Lanka (Figure 2) is bimodal with a major mode from October to December and a subsidiary mode from April to June (Thambyahpillay, 1954, Domroes, 1974). The October to December rainfall coincides with the commencement of the main cultivation season of *Maha* (October–March). The April to June rainfall coincides with the commencement of the subsidiary cultivation season of *Yala* (April–September) (Zubair, 2002b). The rainfall peaks coincide with the passage of the Inter-Tropical Convergence Zone (ITCZ) over the island around May and October. Rainfall during these seasons is relatively high throughout the island. During

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other periods, there is regional variability primarily due to orographic and cyclonic influences.

3.2. Cyclonic influences

Storms and Cyclones affect the rainfall, particularly along the North-Eastern coast (Zubair, 2004). From November to January, storms and cyclones are steered toward Eastern Sri Lanka by the prevailing northeasterlies.

3.3. Orographic influences

An anchor shaped central mountain massif runs North–South in southern Sri Lanka (Figure 1). The rainfall in the western region is enhanced from April to October due to orographic rainfall on the windward side of this mountain ridge during the southwest monsoon (Zubair, 2002a). Similarly there is enhanced orographic rainfall in the eastern side from November to February during the northeast monsoon.

3.4. Regionalization

The character of the annual climatology by region suggests that at least three distinct rainfall regions should be considered. Puvaneswaran and Smithson (1993) proposed such regions, which are referred to here as the Plains, Eastern Region, and Western Region (Figure 1). The Plains region may be divided between the northern and southern lobes. The western and eastern region may be further divided into the coastal (<200 m) and hill (>200 m).

3.5. Seasons

Up to the early 20th century, meteorologists demarcated seasons as the northeast monsoon (November–March) and southwest monsoon (April–October). This demarcation was revised so as to introduce two additional intervening seasons termed 'Inter-Monsoons' (Bamford, 1922). Since then, the following seasons have been used in meteorological analysis: December to February, March to April, May to September, and October to November. While, these are useful for analysis of some properties such as wind and temperature, they do not match with the agricultural seasons of *Maha* (October–March) and *Yala* (April–August).

Many of the ENSO events start in the boreal summer and can last for more than 2 years. We constructed composites of ENSO-related rainfall anomalies that start in April as they evolve over a maximum of the next 24 months (Figure 4). The rainfall during El Niño events is less than normal in July and August, more than normal from October to December and less than normal from January to March (Figure 4). There are some differences in the details of the response during La Niña episodes between the response in the year that the ENSO episode commences and in subsequent years. Further discussion follows in Section 4.

The alternating ENSO influences for October to December, January to March, April to June and July to August suggests a quarterly breakdown of seasons that correspond to the planting and harvesting phases of *Maha* and *Yala* seasons. In the next section, the ENSO relationship with the rainfall is described by this seasonal breakdown.

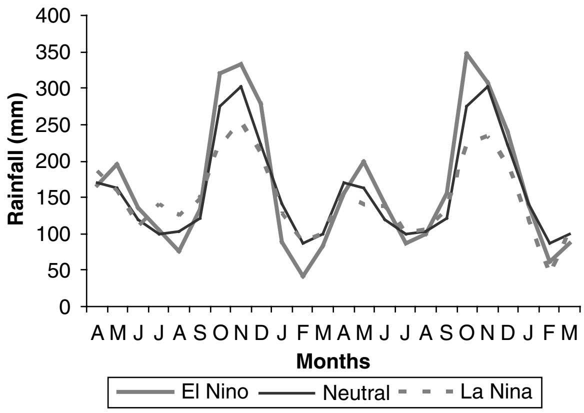

Figure 4. The composite rainfall climatology for all Sri Lanka during El Niño, La Niña and Neutral phases from 1869 to 1998. This rainfall when each of the three ENSO phases was prevalent was identified starting from April until the ENSO phase died (but no further than 24 months). Thereafter the climatology of each of these phases from April of the start year to 24 months on was computed. The majority of the ENSO extreme phases starts out sometime in the boreal summer and does not last as long as 2 years. The numbers that were averaged to obtain the rainfall averages ranged from 7 to 33 incidences with the lower values in the first and last 3 of the 24 months shown here.

4. ENSO-rainfall relationships by season

4.1. April to June (AMJ)

This season accounts for 23.4% of the annual island-wide rainfall (Table II). The strongest SST influence on April to June rainfall is from the central equatorial Pacific Ocean (Figure 5(a)). The negative rainfall correlations with NINO3 and with NINO4 indices are significant at the 99% level for the entire record (Table III). The correlation of rainfall with NINO4 is greater than that with NINO3 (Table III). The eastern regional rainfall alone shows correlations that are statistically insignificant (Table IV).

An examination of the April to June correlation shows that the correlation has dropped during the last three

Table III. The concurrent correlation between quarterly all-island and regional Sri Lanka rainfall with various ENSO indices for the period from 1869 to 1998. Significance levels for 1 and 5% are 0.22 and 0.17 and are shown in bold and bold italics respectively ($n = 130$).

Index	AMJ		JAS		OND	JFM
		M		(JA)		
NINO12	0.11	***0.19***	−0.13	**−0.26**	**0.48**	**−0.23**
NINO3	**0.22**	**0.29**	−0.14	**−0.29**	**0.51**	***−0.18***
NINO34	**0.25**	**0.29**	−0.13	**−0.24**	**0.52**	**−0.24**
NINO4	**0.28**	**0.33**	−0.12	***−0.19***	**0.48**	**−0.28**
SOI	***−0.17***	−0.02	**0.3**	**0.32**	**−0.43**	0.14

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Table IV. The correlation of rainfall with NINO3 from 1869 to 1998 for the regions. The correlations with NINO4 are presented in brackets for the first half of the year. Significance levels for 1 and 5% are 0.22 and 0.17 and are shown in bold and bold italics respectively ($n = 130$).

Region	AMJ		JAS		OND	JFM
		M		(JA)		
Plains	***0.19*** (**0.31**)	**0.23** (**0.29**)	−0.10 (−0.10)	**−0.30** (**−0.30**)	**0.42**	**−0.23** (**−0.32**)
Northern plains	**0.23** (**0.33**)	**0.28** (**0.30**)	***−0.19***	**−0.32**	**0.41**	**−0.23** (**−0.27**)
Southern plains	***0.20*** (**0.25**)	***0.17*** (0.14)	**0.24**	−0.1	**0.41**	***−0.17*** (**−0.25**)
Eastern	0.11 (***0.17***)	**0.22** (**0.25**)	**−0.25**	**−0.37**	**0.44**	−0.11 (***−0.19***)
Eastern coast	0.02 (0.08)	0.09 (0.13)	**−0.25**	−0.3	0.4	−0.04 (−0.15)
Eastern hills	0.07 (0.14)	**0.23** (**0.26**)	−0.15	**−0.31**	**0.34**	−0.13 (***−0.20***)
Western	***0.18*** (***0.20***)	**0.25** (**0.26**)	−0.1	***−0.19***	**0.46**	***−0.20*** (**−0.26**)
Western coast	0.16 (***0.21***)	**0.22** (**0.30**)	0.11	−0.04	**0.45**	***−0.18*** (**−0.26**)
Western hill	***0.18*** (0.16)	**0.23** (***0.18***)	**−0.22**	**−0.26**	**0.48**	***−0.17*** (**−0.23**)
Hills	0.15 (***0.18***)	**0.25** (**0.26**)	**−0.29** (**−0.26**)	**−0.35** (**−0.24**)	**0.47**	***−0.20*** (**−0.27**)
All Sri Lanka	**0.22** (**0.28**)	**0.29** (**0.31**)	−0.14	**−0.29**	**0.51**	***−0.18*** (**−0.25**)

decades (Figure 6). Examining the correlations by month, we find that this is due to a drop in correlations during April and June but not during May (Figure 6). The ENSO-rainfall correlation during May has strengthened to 95% significance levels. The correlations were significant even when the SST field led the rainfall by 3 months (Table V). The prediction of May rainfall based on NINO3 index yields a Heidke skill score of 21 while that for April to June rainfall yielded only 8.7 (Table VI(a)).

4.2. July to August (JA)

September is a transitional month with the influence of the tropical convergence zone extending over Sri Lanka. The correlations between ENSO and rainfall changes from negative in July to August, to positive in October. The correlations between ENSO indices and rainfall, which are statistically significant for July and August are not so for the July to September season (Table III). We concentrate on the prediction of the July to August rainfall rather than for the July to September season as the former has greater predictability.

The strongest SST influence on the July–August rainfall is from the Eastern equatorial Pacific SST (Figure 5(b)). The all island rainfall-NINO3 correlation ($r = -0.29$) is highly significant. The correlations of July–August rainfall with NINO3 were higher than that with other NINO indices (Table III). These correlations drop when the SST field leads the rainfall (Table V) and this may be related to the so called 'spring barrier' of predictability of ENSO (Webster and Yang, 1992). The ENSO rainfall correlation is greater outside the Southern Plains and Western regions, which garners orographic rainfall in this season. This suggests that the ENSO predictability does not extend to orographic rainfall in this season. On a decadal scale, the correlations range from $r = 0.25$ to -0.5 (Figure 6). The correlations have been above significant levels in the last decades. This is consistent with Kumar *et al.* (1999) the analysis for India although that analysis was for the June to September season.

There is a difference between the influence of ENSO of seasonal rainfall between the early phases of an ENSO episode and its influence when it lasts longer than a year (Figure 4). The seasonal rainfall increases in the early phase of a La Niña but is similar to normal as the La Niña extends beyond a year.

4.3. October to December (OND)

This is the start of the main cultivation season and the entire island gets high rainfall. The Northern Plains region gets 60% of its rainfall during these 3 months and this percentage drops slightly in the eastern and western regions. The simultaneous correlation between

Table V. The correlation of All-Sri Lankan rainfall with NINO3 from 1869 to 1998 with the rainfall lagging NINO3. Significance levels for 1 and 5% are 0.22 and 0.17 respectively ($n = 130$). The correlations with NINO4 are presented in brackets for the first half of the year.

Lag (Months)	AMJ		JAS		OND	JFM
		M		(JA)		
0	**0.22**	**0.29** (**0.31**)	−0.14	**−0.29**	**0.51**	***−0.18*** (**−0.25**)
3	***0.18 (0.20)***	***0.21*** (**0.25**)	0.07	−0.04	**0.44**	***−0.18*** (−0.12)
6	0.09	0.14	***0.21***	0.15	**0.36**	−0.11

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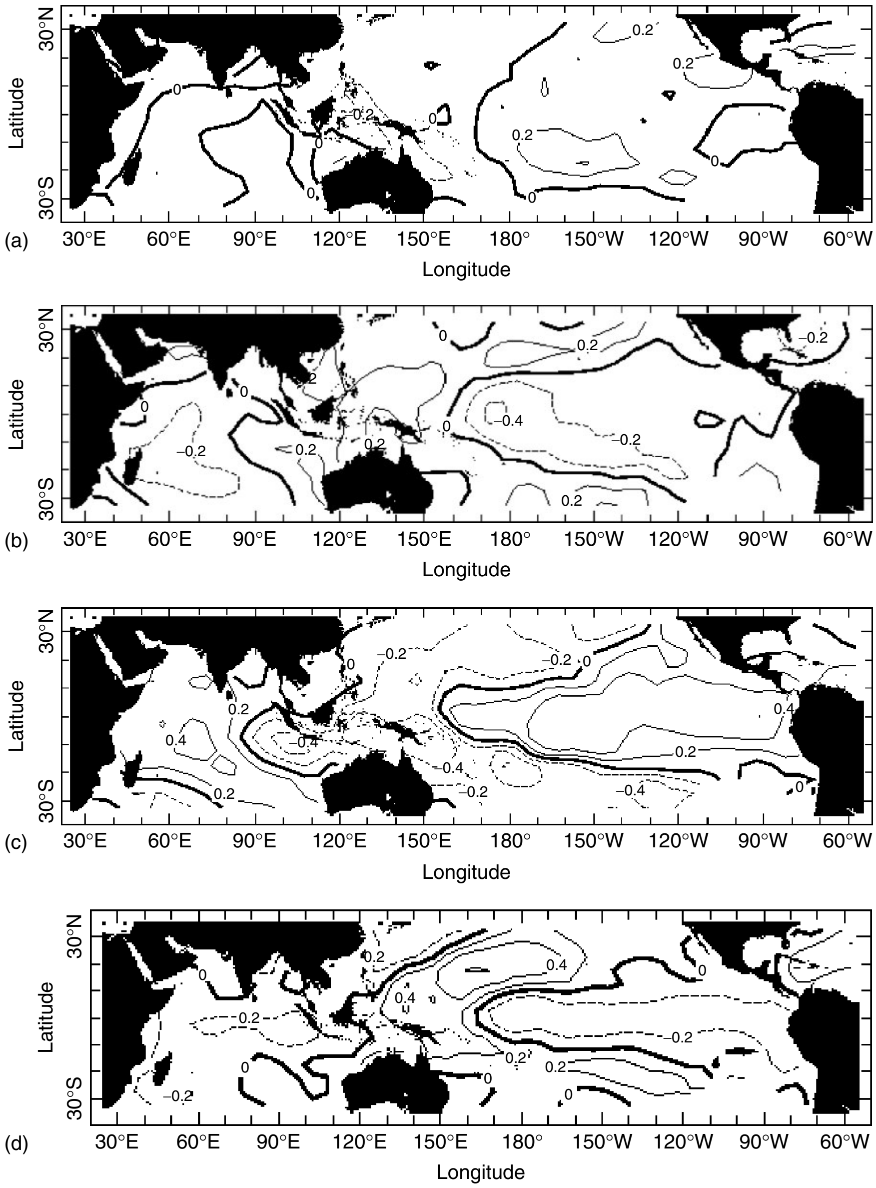

Figure 5. The correlation coefficient between the Sri Lankan rainfall and the SST for 1869–1998 is shown for (a) April to June (b), July to August (c) October to December and (d) January to March.

October to December rainfall and SST brings out high correlations in the equatorial Eastern and Central Pacific Ocean reminiscent of the ENSO signature (Figure 5(c)). All ENSO indices provide strong correlations (Table III) and the significance of these correlations prevailed even when the rainfall lagged SST by 6 months (Table V). The correlation has been robust over the decades except for a brief drop in the 1930s (Figure 6) and for all regions (Table IV). There is a slight drop of predictability in the Eastern Hills region that is subject to orographic rainfall. In recent decades, the ENSO relationship with the Sri Lankan rainfall has strengthened (Figure 6) (Zubair and Ropelewski, 2006).

The regional analysis of ENSO influence on rainfall has largely been along the lines of the regions identified in Section 3 with the Eastern and Western region further broken up into a coast and hill region. Since, some relationships may be manifest best, if the hill-country region alone were considered, we include the results in Table IV in the row identified as 'Hills'. Indeed, the correlations for the Hills region was largely similar to that for the Western and Eastern Hill regions but were enhanced in all the seasons from January to September and reached levels of statistical significance even when the separate Western and Eastern Hills region did not do so. Thus, the provision of regional climate predictions for a broader Hills region is likely to be more skillful.

4.4. January to March (JFM)

The JFM rainfall which accounts for 16.6% of the annual (Table II) is weakly influenced by the central Pacific Ocean SST (Figure 5(d)). It has inverse correlations with NINO3, NINO34 and NINO4 that are significant at the 95% and 99% level respectively (Table III). The correlation is relatively weaker in the Eastern region

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Table VI. The NINO3 departures and the All-Sri Lankan rainfall anomalies from 1869 to 1998 were ranked in three categories each. The rainfall departures were categorized in three terciles by the seasonal rainfall and the tercile boundaries are indicated.

VI (a1): *April–June*: Heidke Skill score is 8.7 based on the assumption that El Niño yields a wet tendency and La Niña to a dry tendency.

	Wettest	Normal	Driest
El Niño	18	10	7
Neutral	19	27	30
La Niña	6	7	6
	>16.6 mm		<−17 mm

VI (a2): *May*: Heidke skill score is 21 based on the assumption that El Niño yields a wet tendency and La Niña to a dry tendency.

	Wettest	Normal	Driest
El Niño	22	10	6
Neutral	16	27	27
La Niña	5	7	10
	>24 mm		<−45.5 mm

VI (b): *July–August*: Heidke skill score is 23 based on the assumption that El Niño leads to a dry tendency and La Niña to wet tendency.

	Wettest	Normal	Driest
El Niño	8	6	18
Neutral	17	25	19
La Niña	18	13	6
	>9.5 mm		<−22 mm

VI (c) *October–December*: Heidke skill score is 19 based on the assumption that El Niño yields a dry tendency and La Niña to wet tendency.

	Wettest	Normal	Dry
El Niño	23	7	5
Neutral	14	18	20
La Niña	6	19	18
	>21.6		<−34.8

VI (d) *January–March*: Heidke skill score is 16 on the assumption that both El Niño and La Niña predict dry tendency and Neutral tends to wet.

	Wettest	Normal	Driest
El Niño	4	14	15
Neutral	30	20	15
La Niña	9	10	13
	>15 mm		<−24.5

that garners orographic and cyclonic rainfall during this season (Table IV). These correlations are significant even when the SST field leads the rainfall by 3 months (Table V).

The correlation between JFM rainfall and NINO3 has varied significantly on a decadal scale (Figure 6). The overall correlation between NINO3 and rainfall for the entire record is modest (Table III). This is because the rainfall during both El Niño and La Niña phases are diminished in comparison to that during the Neutral phase leading to low correlation values between ENSO indices and rainfall that masks the actual predictability. The correlation of NINO3 with the entire rainfall record is modest ($r = -0.18$). If the correlation was carried out only for periods when NINO3 >0.0, then the correlation is magnified ($r = -0.34$). The correlation for periods when NINO3 <0.0, is in the opposite sense ($r = 0.22$). On average, the seasonal rainfall is diminished during the phases of La Niña and particularly El Niño.

The predictability in this season is brought out better by the use of a contingency analysis (Table VI(d)) rather than correlation analysis. The Heidke skill based on the premise that, dry conditions are expected during El Niño and La Niña and wet conditions are expected during Neutral conditions leads to a score of 16. The rainfall in all regions shows significant correlations with ENSO save the coastal Eastern region. The diminishing of predictability in the Eastern coast is likely due to cyclonic storms from the Bay of Bengal that pass on to this coast. All regions have better prediction based on NINO4 rather than NINO3.

The influence of ENSO on seasonal rainfall between the early phases of an ENSO episode and its influence when it lasts longer differs. The rainfall during January to March is similar to the normal in the early phase of a La Niña but drops as the La Niña extends beyond a year.

The relationships reported here for July to August, October to December and January to March ENSO and rainfall anomalies were examined year by year. This examination showed that in general stronger ENSO events brought about a stronger precipitation anomaly with a few exceptions. However, there were no discernible contrasts in the relationship between rainfall and ENSO phase based on whether the strength of the ENSO phase was weak or strong.

4.4.1. *Relationships of Sri Lankan rainfall with other potential predictors*

The relationships based on ENSO is moderate and any operational prediction scheme needs to take account of other potential predictors. While an extensive set of predictors have been identified for the Indian summer monsoon (Kumar *et al.*, 1995), similar comprehensive work for Sri Lankan rainfall is yet to be reported. The potential predictors include the Indian Ocean SSTs, the Eurasian land conditions and volcanic and aerosol influences. Relationships betweeen the first empirical orthogonal function (EOF) of the Indian Ocean SST with Sri Lanka rainfall was reported by Suppiah (1988) as follows: October to November season had statistically significant positive

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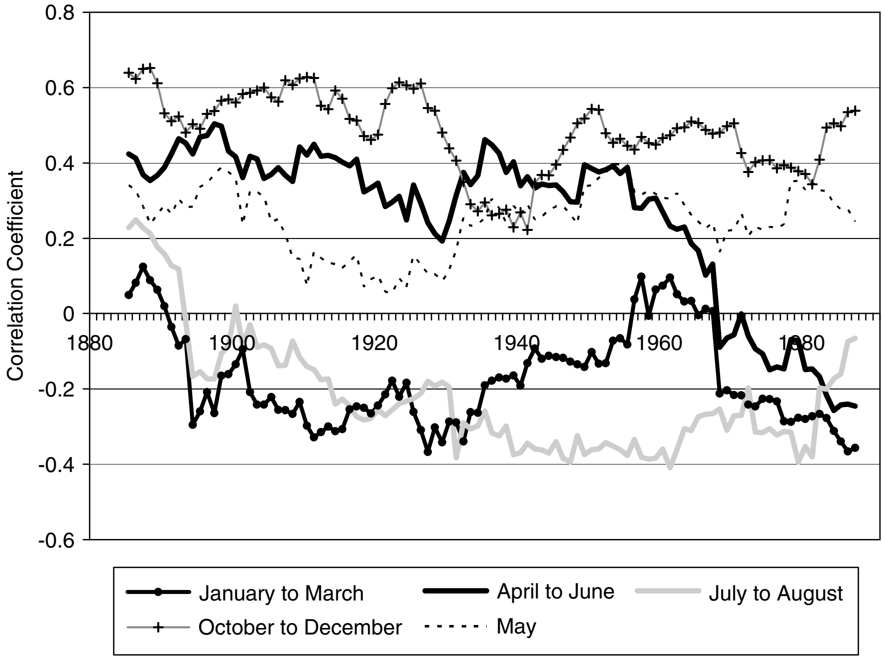

Figure 6. The correlation coefficient between the all-Sri Lankan seasonal rainfall and NINO3 computed with a running window of 31 years in four different seasons. The ordinate shows the central year of the running window. Correlation values that are +/−0.36 and 0.46 are significant at 95 and 99% levels.

correlations while the March to April season had a negative but statistically insignificant relationship. A strong relationship exists between the Indian Ocean Dipole in the September to December season and Sri Lanka rainfall (Zubair *et al.*, 2003b). The relationship during the other seasons was found to be weak. In addition, relationships between the October to November rainfall and volcanic eruptions have been identified (Mukherjee *et al.*, 1987). There have been as yet no studies on the impact of Eurasian snow cover or land surface conditions of South Asia on Sri Lanka climate. All of this work suggests a set of potential predictors, which should be revisited for the agricultural seasons.

5. Results and discussion

Sri Lankan rainfall is modestly predictable based on ENSO during July–August, October–December and January–March. During July to August and January to March, El Niño leads to drier conditions. During October to December, El Niño leads to wetter conditions. For La Niña, this relationship was inverted for all seasons except for January to March, when the rainfall during the La Niña phases declines as well. There are subtle differences in the influence of ENSO on seasonal rainfall between the early phases of an ENSO episode and its influence when it lasts longer. The rainfall during January to March is similar to the normal in the early phase of a La Niña but drops as the La Niña extends beyond a year. Similarly, the rainfall during July to August during a La Niña is on average higher than normal but the difference is not sustained in an extended event.

The central equatorial Pacific Ocean provides the strongest climate forcing from January to June, and the eastern equatorial Pacific SSTs have the stronger influence from July to August. Both central and eastern equatorial Pacific SSTs contribute strongly to ENSO correlations during the October to December season. ENSO indices based on the Central Pacific from January to June and based on the Eastern Pacific from July to August yield the best predictions. From October to December, there is a strong association of rainfall with all ENSO indices.

Orographic rainfall and cyclonic storms diminish the correlation between ENSO and rainfall. For instance, the Eastern hills region receives orographic rainfall from November to February and the Northeastern coastal region receives cyclonic storms from the Bay of Bengal from November to January. The ENSO correlations are diminished for the Eastern region for October to March. Similarly, the Western region receives orographic rainfall when the westerlies are strongest from July to August and the ENSO correlations are diminished in the Western region.

There has been significant decadal variability in the ENSO relationship; in recent decades, the predictability has been strengthening for the January to March and October to December seasons but not for the July to August season.

A simple measure of skill based on the Heidke Score shows that a prediction scheme based on ENSO scores in the range from 16 to 21 for selected seasons (January to March, May, July to August and October to December). These skill scores are modest but are still useful and comparable in skill to those for other ENSO influenced

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areas such as Indonesia, Northeast Brazil, and eastern Africa (Mason *et al*., 1999).

The physical mechanisms that leads to modulation of Sri Lanka's climate by ENSO are related to the seasonal changes in the geography of the Walker circulation which results in enhanced convection over Sri Lanka in October to December and enhanced subsidence during the rest of the year (Rasmusson *et al*., 1999). The reversal in ENSO influence from a largely drying tendency during El Niño events from April to September to a wetter tendency in October to December is related to the southeastward extension of the zone of subsidence that persists over the Indian subcontinent in summer (Zubair and Chandimala, 2006), leading to enhanced convection over Sri Lanka and southern India during the October to December season (Zubair and Ropelewski, 2006). The drying tendency in the following January to March is due to subsidence setting in over Sri Lankan region again during El Niño events (Rasmusson *et al*., 1999).

While, the predictability is modest for rainfall from January to September, the accumulation of modest influence of ENSO over January to March and July to August leads to profound implications for various sectors. For example, there is strong reduction of stream flow from January to September during El Niño episodes (Zubair, 2003a). The rice production in the *Yala* (April–August) season is significantly reduced during El Niño periods (Zubair *et al*., 2002b).

Ultimately the test of the predictions lies in its utility. Some progress has already been made in using ENSO information in Sri Lanka. Rice and coconut are the crops that affect food security the most. Analysis of the ENSO impact on rice (Zubair *et al*., 2005) and on coconut (Peiris, 2004) are used in policy-making and seasonal planning. Currently seasonal rainfall predictions are monitored by the Sri Lanka government agencies in providing guidance on the choice of crops and extent of land to be cultivated at the start of each agricultural season. These efforts shall be assisted by improved diagnostics and predictions toward which this paper is a contribution.

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