SHORT COMMUNICATION

Rainfall prediction based on the relationship between rainfall and El Niño Southern Oscillation (ENSO)

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Abstract: El Niño-Southern Oscillation (ENSO) is a dominant mechanism of global inter-annual climate variability. In this study, the relationship of ENSO to seasonal rainfall over 139 years is described. Ranking both, the seasonal Sri Lankan rainfall and its contemporaneous ENSO index show modest but significant association in January-March, May and July-August and October-December periods. El Niño leads to wetter conditions during May, October-December and to drier conditions during January-March and July-August. Except for January-March the impacts of La Niña are inverse to that for El Niño. This relationship between rainfall and ENSO during October-December, January-March, July-August and May are statistically significant. This association can be used to predict rainfall during the planting phase and the harvesting phase of *Maha* (October-March), and during the harvest season of *Yala* (April-August). As ENSO predictions are regularly available, rainfall predictions can be provided 3-6 months in advance.

Keywords: Climate, El Niño, La Niña, *Maha*, Sri Lanka, *Yala*.

INTRODUCTION

El-Nino Southern Oscillation (ENSO) is a shift in the pattern of oceanic warming and atmospheric circulation centered in the Pacific Ocean with implications across the tropics and elsewhere that recurs typically 2 to 7 years apart. Anomalously warm sea surface temperatures in the equatorial Eastern Pacific is referred to as El Niño phase, and its cold analogue is referred to as La Niña. The influence of ENSO on the South Asian climate system varies with the season. The summer (June to September) rainfall in northern India decreases with the El Niño, while in Sri Lanka and southernmost India rainfall increases from October to December [3-5].

Several previous studies have analyzed ENSO-rainfall relationships in Sri Lanka [3, 5-13]. Many of these analyses have considered conventional meteorological seasons that are based on wind-directions (south-west monsoon, north-east monsoon and inter-monsoons) that range in duration from two to five months. These meteorological seasons do not align well with the traditional agricultural seasons[1,14-16]. The seasonal water resources and agricultural planning ("Kanna") meetings are conducted in March and September of each year and the rainfall predictions are needed at these meetings [2].

The predictability of stream flow has been investigated using a principal component regression scheme in a cross-validated model taking the principal components of sea surface temperatures (SST) as the predictors[17]. This has resulted in skillful predictions for stream flow in the *Yala* (April-August) and *Maha* (October-March) seasons. The statistically significant relationship between rainfall and ENSO can be similarly exploited to predict rainfall. ENSO indices are best derived from SST. At present, several forecast centers issue skillful predictions of the seasonal evolution of tropical SST six months in advance[18].

In this study the agricultural seasons and the annual cycle of ENSO influence have been considered

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to identify the seasons that have the highest utility and rainfall predictability (i.e. rainfall is enhanced in Oct-Dec and May and declines in Jan-Mar and June to Aug). It must be noted, however, that from the point of view of the users of this information it is useful to quantify all ENSO based relationships even when they are weak, since they may have profound implications in their respective sectors. This paper describes the evaluation of the relationship between ENSO and rainfall in Sri Lanka through correlation analysis, composite analysis and ranked rainfall, and ENSO indices. A simple scheme for rainfall and skill assessment for all seasons in 2008 and 2009 is presented based on the association between ENSO and seasonal rainfall.

METHODS AND MATERIALS

Rainfall data: The monthly data for the period 1869 to 2007 from 16 widely distributed observatories were obtained from the Sri Lanka Department of Meteorology (Figure 1). A rainfall index for the entire island was constructed by averaging the monthly rainfall for these stations. In addition, regional rainfall indices were constructed by averaging the rainfall of stations falling within climatically homogenous regions that are described under the Regionalization in Climatology

section. Basic statistics for rainfall are provided on a seasonal and regional basis (Table 1). Rainfall anomaly is the departure of rainfall from its (1869 to 2007) long-term average, and the ranked rainfall anomalies were used to construct tercile categories-wettest, normal and driest. These categories were used to compare ranked rainfall anomalies during the three ENSO phases.

ENSO index: An ENSO index in common use known as NINO3 had been constructed as the average SST anomaly for the eastern equatorial Pacific Ocean region of (90°W – 150 °W, 5°S to 5°N) [11]. The ENSO phases are defined as: El Niño (NINO3 $\geq$ 0.5°C), La Niña (NINO3 $\leq$ -0.5°C) and Neutral phases (-0.5° <NINO3 < 0.5°C) [3-4].

Composite analysis: Composite rainfall was computed by averaging the monthly rainfall values when the particular ENSO phase (El Niño, Neutral or La Niña) prevailed (Figure2).

Correlation analysis: The Pearson correlation coefficient was used to identify relationships between ENSO indices and rainfall [19]. A correlation was taken to be significant when the no-correlation null hypothesis was exceeded with a probability of 95%. Significance of correlation values were tested at 1% and 5% levels.
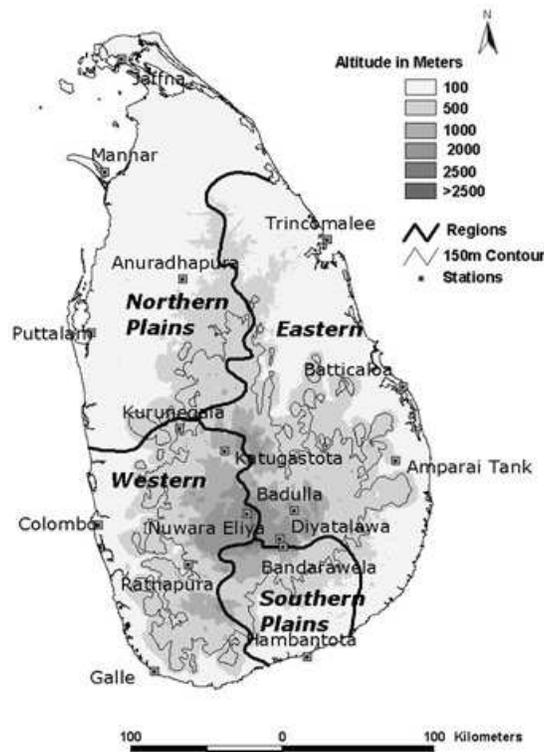
Figure 1: Topography, location of meteorological observatories, and regionalization for Sri Lanka. The 150 m contours that separate the low areas from the hilly areas are indicated.
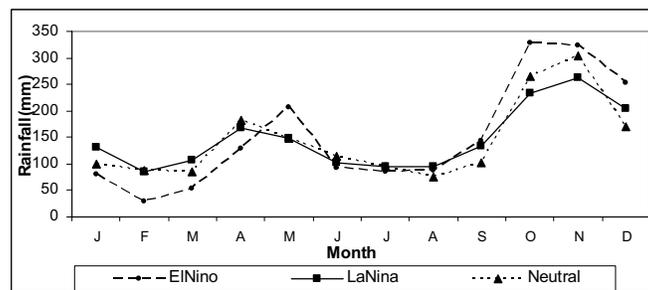
Figure 2: The composite rainfall climatology for all Sri Lanka during El Niño, La Niña and Neutral phases. The characters J to D stand for months from January to December.

Prediction scheme: Rainfall prediction scheme was carried out for all seasons in 2009 and 2010 based on ENSO relationship. Comparison between predicted and the actual rain fall which were segregated into three terciles "below-normal", "near-normal" and "above-normal" are presented in Table 4 along with the prevailing ENSO phase.

Prediction skill assessment: Heidke skill scores are used to provide some measure of forecast quality when the predictions and corresponding observations are expressed in categories [25]. The Heidke score (S) is given by S=100(C-E)/(N-E) where C is the number of forecasts; E is the number of correct forecasts expected by chance, and N is the total number of forecasts.

Climatology:

a) Mean annual cycle: The mean annual cycle of rainfall in Sri Lanka is bimodal[20-21], with a major mode from October to December and a subsidiary mode from April to June (Figure 2). The October to December rainfall coincides with the commencement of the main cultivation season of *Maha* (October to March). The April to June rainfall coincides with the commencement of the subsidiary cultivation seasons of *Yala* (April to August) [1]. The rainfall peaks coincide with the passage of the Inter Tropical Convergence Zone (ITCZ) over the island[10]. Rainfall during these seasons is relatively high throughout the island.

b) Regionalization: The character of the annual climatology by region confirms that there are distinct rainfall characteristics for each region [20]. The Plains region may be divided between the Northern and Southern lobes. The Western and Eastern regions may be further divided into the coastal (<150 m) and hill (>150 m) regions as shown in Figure 1. This regionalization differs

from the demarcation into dry, wet and intermediate zones which is based on the annual total rainfall and does not segregate the island into regions that distinguish the contrasting seasonality in different parts of Sri Lanka due to dominance by different rainfall mechanisms[2, 13]. Accordingly, the "Plains" region includes the stations at Jaffna, Mannar, Anuradhapura, Puttalam and Hambantota. The "Eastern" region includes Trincomalee, Batticaloa, Ampara Tank, Badulla, Diyatalawa and Bandarawela (Diyatalawa and Bandarawela are considered as one station). The "Western" region includes Kurunegala, Katugastota, Nuwara Eliya, Colombo, Ratnapura and Galle.

c) Seasons: Up to the early 20th century, meteorologists demarcated seasons as the Northeast monsoon (November to March) and Southwest monsoon (April to October). This demarcation was revised so as to introduce two additional intervening seasons termed "Inter-Monsoons"; since that period, the following seasons have been used in meteorological analysis: December to February, March to April, May to September, and October to November [23]. While, these are useful for analysis of some meteorological properties such as temperature and wind, they do not match well with the agricultural seasons of *Maha* (October to March) and *Yala* (April to August).

The consistent ENSO influences for October to December, January to March, April to June and July to August (ENSO influence is similar for a set of months) suggest a quarterly breakdown of seasons that correspond to the planting phase of (*Maha*:October-December, *Yala*:Aprl-June) and the harvesting phase of (Maha:January-March, Yala:July-August). Therefore, the ENSO influence by seasons starting in October is described here. In addition to these, May and July-August were taken into account since they correlate well with ENSO compared to corresponding quarter.

RESULTS

The composite rainfall is computed by averaging the monthly rainfall values when the particular ENSO phase (El Niño, Neutral or La Niña) was prevalent.

October to December (OND)

The ENSO index shows a strong positive correlation with the OND rainfall in all regions at the 1% significant level (Table 2). Thus it is evident that El Niño conditions favor rainfall for the entirety of Sri Lanka during (October, November, December) (OND) season. During the 46 seasons in which the El Niño phase prevailed, 22 had rainfall above the normal tercile (Table 3). In the normal tercile, out of the 47 seasons El-Niño prevailed in 12 seasons while in 16, La Niña prevailed. Further during 46 seasons in which La Nina phase prevailed, in 24 seasons

the rainfall is below the normal tercile. There is a slight drop of predictability in the Eastern Hills region that is subject to orographic rainfall. Based on these correlation values and the contingency table, the rainfall in early *Maha* has high predictability.

January to March (JFM)

Apart from the Eastern region, rainfall in all the other regions show significant correlations with ENSO (Table 2). While the overall correlation between NINO3 and rainfall for the entire record is modest, an examination of the annual climatology (Figure 2) shows that rainfall during El Niño phases is diminished in comparison to that during the La Nina phase. This relationship leads to low correlation values that mask the actual predictability. Of the 46 wettest tercile of seasons, 30 had neutral ENSO conditions (Table 3).

Table 1: The mean standard deviation (SD) and percentage of annual rainfall for quarterly and annual rainfall for all of Sri Lanka and for the three climatic regions are provided in mm. Details are provided for May (M) and July to August (JA) periods as well.

Region		JFM	AMJ	M	JAS	JA	OND	Total
Sri Lanka	Mean	292	460	165	340	207	799	1891
		15.40%	24.30%		17.90%		42.20%	100%
	SD	127	101	76	95	67	184	217
Plains	Mean	171	212	74	100	49	706	1191
(Northern and		14.30%	17.80%		8.40%		59.20%	100%
Southern)	SD	116	89	62	58	40	210	230
Eastern	Mean	374	233	84	227	133	848	1682
		22.20%	13.80%		13.50%		50.40%	100%
	SD	194	65	44	78	58	227	282
Western	Mean	319	764	276	563	356	827	2473
		12.90%	30.90%		22.80%		33.40%	100%
	SD	118	163	125	169	125	180	285

Table 2: The correlation of rainfall with NINO3 from 1869 to 1998, for different regions and entire Sri Lanka. Correlation values that have significance levels for 1% and 5% are 0.22 and 0.17 and are shown in bold and italics respectively (n=130).

Region	JFM	AMJ	M	JA	OND
Northern Plains	**-0.23**	**0.23**	**0.28**	**-0.32**	**0.41**
Southern Plains	*-0.17*	*0.2*	*0.17*	-0.1	**0.41**
Eastern	-0.11	0.11	**0.22**	**-0.37**	**0.44**
Eastern Coast	-0.04	0.02	0.09	**-0.3**	**0.4**
Eastern Hills	-0.13	0.07	**0.23**	**-0.31**	**0.34**
Western	*-0.2*	*0.18*	**0.25**	**-0.19**	**0.46**
Western Coast	-0.18	0.16	**0.22**	-0.04	**0.45**
Western Hill	**-0.17**	*0.18*	**0.23**	**-0.26**	**0.48**
Sri Lanka	**-0.18**	**0.22**	**0.29**	**-0.29**	**0.51**

Table 3: The numbers of events in the three tercile categories -Wettest, Normal, Driest – that prevailed during El-Nino, La-Nina and Neutral events during different seasons

Season	Tercile category	Number of events			
		El-Nino	Neutral	La-Nina	Total
	Wettest	22	14	10	46
OND	Normal	12	19	16	47
	Driest	6	16	24	46
	Wettest	6	30	10	46
JFM	Normal	12	23	12	47
	Driest	16	17	13	46
	Wettest	15	24	7	46
AMJ	Normal	9	29	9	47
	Driest	11	29	6	46
	Wettest	21	15	10	46
M	Normal	13	17	16	46
	Driest	6	16	24	46
	Wettest	9	21	16	46
JA	Normal	12	18	17	47
	Driest	14	24	8	46

Table 4: Comparison between predicted (Pre.) and actual (Act.) rain fall terciles below normal (BN) ,near normal (NN) and above normal (AN) along with the prevailing ENSO condition (EC) (El Nino-EN, Neutral-N , La Nina –LN)

Year	Seasons																							
	JFM			AMJ			JAS			OND			May			JA		
	EC	RF		EC	RF		EC	RF		EC	RF		EC	RF		EC	RF	
		Pre.	Act		Pre.	Act		Pre.	Act		Pre.	Act		Pre.	Act		Pre.	Act
2008	LN	AN	AN	N	NN	NN	N	NN	NN	N	AN	AN	N	AN	BN	EN	BN	NN
2009	N	AN	BN	EN	AN	BN	EN	BN	BN	EN	AN	NN	EN	AN	BN	EN	BN	BN

The decrease of predictability in the Eastern coast is likely due to cyclonic storms from the Bay of Bengal that reaches this coast.

April to June (AMJ)

Of the annual island-wide rainfall 24% occurs during this period (Table 1). The positive rainfall correlations with NINO3 indices are significant at the 5% level except for the Eastern record (Table 2).

In the last three decades this correlation has dropped to insignificant levels due to a drop of the ENSO influence on the rainfall of April and June but not May (Table 2). Of the 46 seasons that account for the wettest tercile 15 were in the El Niño phase (Table 3). This is a small tilt of the odds due to ENSO. In contrast to the weak relationship between ENSO and rainfall during the April

and June season, the May ENSO-rainfall correlation of all regions except Eastern coast has strengthened to 1% significance level and southern plains to 5%. Of the 46 seasons that account for the wettest tercile, 21 were in the El Niño phase (Table 3).

July to August (JA)

This is generally a dry period in the entire island except in the Southwest. During September South-Westerlies diminish. As September is a transitional month from a dry to a wet period and between periods of opposing ENSO influences, the rainfall in the latter half of September has characteristics akin to the October to December season and thus is omitted from this analysis. The July-August rainfall has a NINO3 correlation (r = -0.29) that is highly significant for the entire island. Of the 46 seasons that account for the wettest tercile, 16 were in the La

Niña phase as would be expected due to the negative correlations (Table 3). Similarly, of the 46 driest tercile seasons 14 were coincident with the El Niño phase.

DISCUSSION

The ENSO rainfall correlation during *Yala* (Jul-Aug) is greater outside the Western region and the Southern plains, which garners orographic rainfall in this season (Table 2). Orographic rainfall and cyclonic storms in Sri Lanka diminish the correlation between ENSO and rainfall. For instance, the Eastern region receives cyclonic storms from the Bay of Bengal and orographic rainfall from November to January: the ENSO correlations diminish for the Eastern region during January to March period. Similarly the Western region receives orographic rainfall when the westerlies are strongest during the period July to August and the ENSO correlations diminish in the Western region.

The predictability based on ENSO for rainfall is high from October to December. Even while the predictability of rainfall is modest for the period January to September, the accumulation of modest influence of ENSO over the period January to March and July to August leads to profound implications for various sectors. For example, there is reduction of stream flow for *Yala* during El Niño episodes[2]. The rice cultivation in the *Yala* (April to August) season is significantly reduced during the El Niño period[1]. As the role of regional land surface and Indian Ocean sea surface conditions in modulating the climate is understood the prediction scheme presented here based on ENSO is likely to be improved.

A prediction scheme based on the seasonal ENSO index and the dominant precipitation tercile that is expected based on history up to 2007 was used to predict the precipitation for 2008 and 2009. A simple measure of skill based on the Heidke score shows that this prediction scheme scores 25. This is a useful level of skill and comparable in skill to those for other ENSO-influenced areas such as Indonesia, Northeast Brazil and Eastern Africa [24].

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