The Strengthening Relationship between ENSO and Northeast Monsoon Rainfall over Sri Lanka and Southern India

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ABSTRACT

Recently, it was reported that the relationship of the Indian southwest monsoon rainfall with El Niño–Southern Oscillation (ENSO) has weakened since around 1980. Here, it is reported that in contrast, the relationship between ENSO and the northeast monsoon (NEM) in south peninsular India and Sri Lanka from October to December has not weakened. The mean circulation associated with ENSO over this region during October to December does not show the weakening evident in the summer and indeed is modestly intensified so as to augment convection. The intensification of the ENSO–NEM rainfall relationship is modest and within the historical record but stands in contrast to the weakening relationship in summer. The intensification of the circulation is consistent with the warming of surface temperatures over the tropical Indian Ocean in recent decades. There is modestly intensified convection over the Indian Ocean, strengthening of the circulation associated with ENSO (Walker circulation), and enhanced rainfall during El Niño episodes in a manner consistent with an augmented ENSO–NEM relationship.

1. Introduction

While the boreal summer phase of the Asian monsoon has been well investigated through studies of the Indian southwest monsoon rainfall, its behavior during the other seasons has received less attention (Pant and Kumar 1997). During the fall, the zone of maximum monsoon rainfall migrates to southern India, Sri Lanka, and the neighboring sea (Fig. 1a). The rainfall during this period is of immense societal significance to 150 million people as it supports the main cultivation season known as Maha in Sri Lanka and Rabi in southern India (Zubair 2002)

The low-level wind field over South Asia is southwesterly during the boreal summer. Starting in October, it switches to northeasterly as the winter progresses (Fig. 2a). During the summer, rain falls all over South Asia but is diminished over (southern) peninsular India and Sri Lanka. After October, the rainfall is enhanced over peninsular India, Sri Lanka, and the equatorial eastern Indian Ocean and is diminished to the north (Fig. 2b).

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The Indian Meteorological Department refers to October to December period as the northeast monsoon (Dhar and Rakecha 1983) but this season also is referred to as the winter monsoon (e.g., Nageswara Rao 1999) and postmonsoon (e.g., Singh and Sontakke 1999). In Sri Lanka, the northeast monsoon was used to designate the November to March period initially and thereafter to refer to December to February (Bamford 1922). Since January to March is relatively dry over southern India and Sri Lanka (Fig. 1c), we refer to October to December as the northeast monsoon (NEM) consistent with the designation of the Indian Meteorological Department.

While the summer monsoon rainfall over India usually decreases during El Niño events, quite the opposite occurs in Sri Lanka and Southern India from October to December (Dhar and Rakecha 1983; Rasmusson and Carpenter 1983; Ropelewski and Halpert 1987; Suppiah 1997; Nageswara Rao 1999; Singh and Sontakke 1999; Kripalani and Kumar 2004). Recently, a weakening of the relationship between the Indian southwest (summer) monsoon and the El Niño–Southern Oscillation (ENSO) was reported (Kumar et al. 1999). To assess whether this weakening relationship extends to the NEM, we investigate the relationship between ENSO and the NEM rainfall in Sri Lanka and southern India.

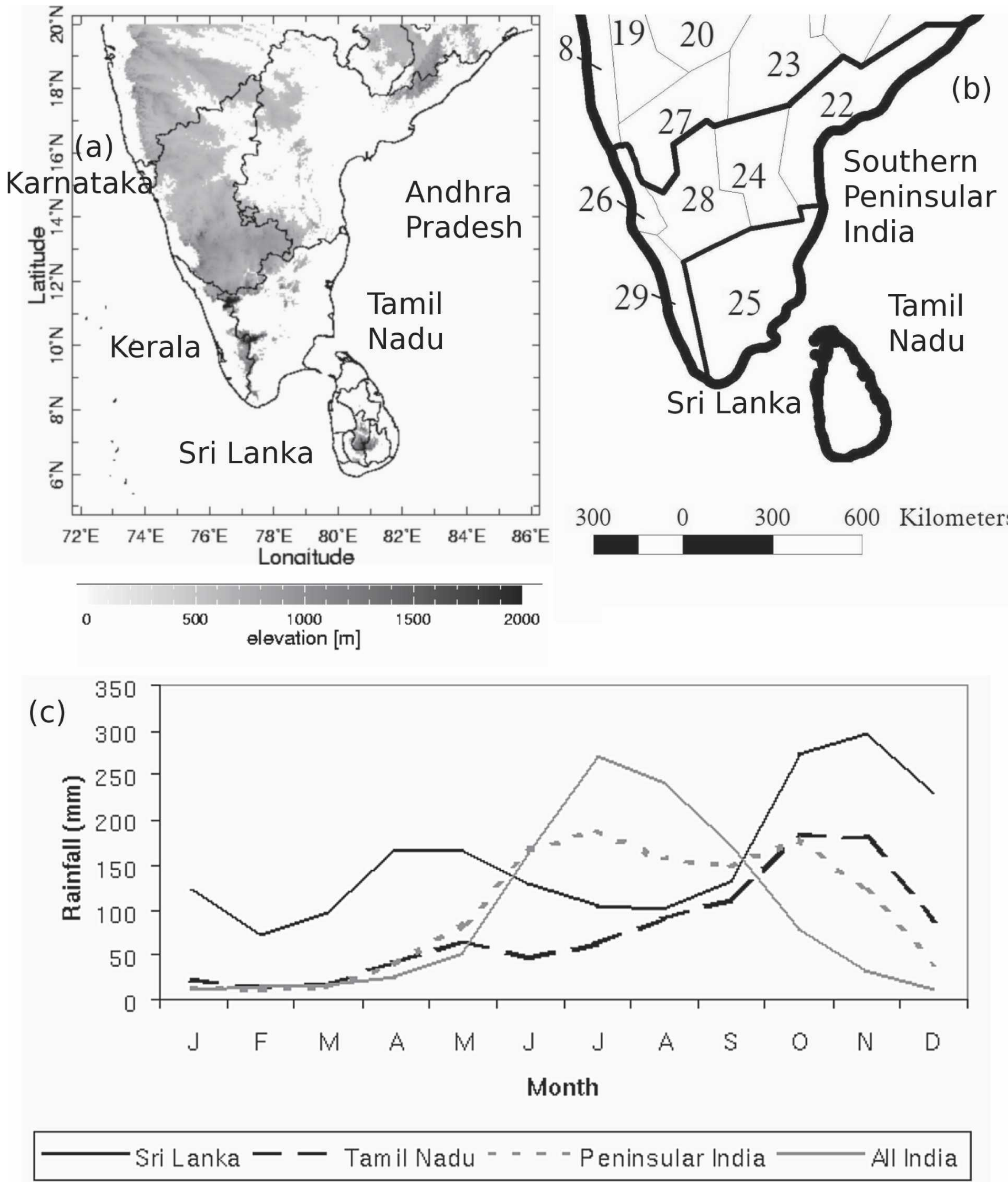

FIG. 1. (a) Sri Lanka and the Indian states that are included at least partially in (southern) peninsular India. Elevation is indicated as a gray shade with values below 500 m masked out. The Western Ghats mountain range runs parallel to the western coast. The Eastern Ghats is a smaller and discontinuous range parallel to the eastern coast. (b) A representation of peninsular India that includes the subdivisions of Coastal Andhra Pradesh (22), Rayalseema (24), South Interior Karnataka (28), Coastal Karnataka (26), Kerala (29), and Tamil Nadu (25). (c) Monthly rainfall climatologies for Sri Lanka, Tamil Nadu, peninsular India, and all India for the period of record.

2. Data

The following monthly datasets were used in the analysis: 1) Sea surface temperature (SST) reconstructions from 1869 to 2003 were obtained from Kaplan et al. (1998). The Niño-3 ENSO index is defined as the average SST anomaly over the Pacific region (5°S–5°N, 90°–150°W). 2) Velocity potential (χ) and circulation fields were obtained from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis (Kalnay et al. 1996). 3) Rainfall data for 1871 to 2002 for Sri Lanka were obtained from its Department of Meteorology for 16 stations (details in Zubair et al. 2003) and

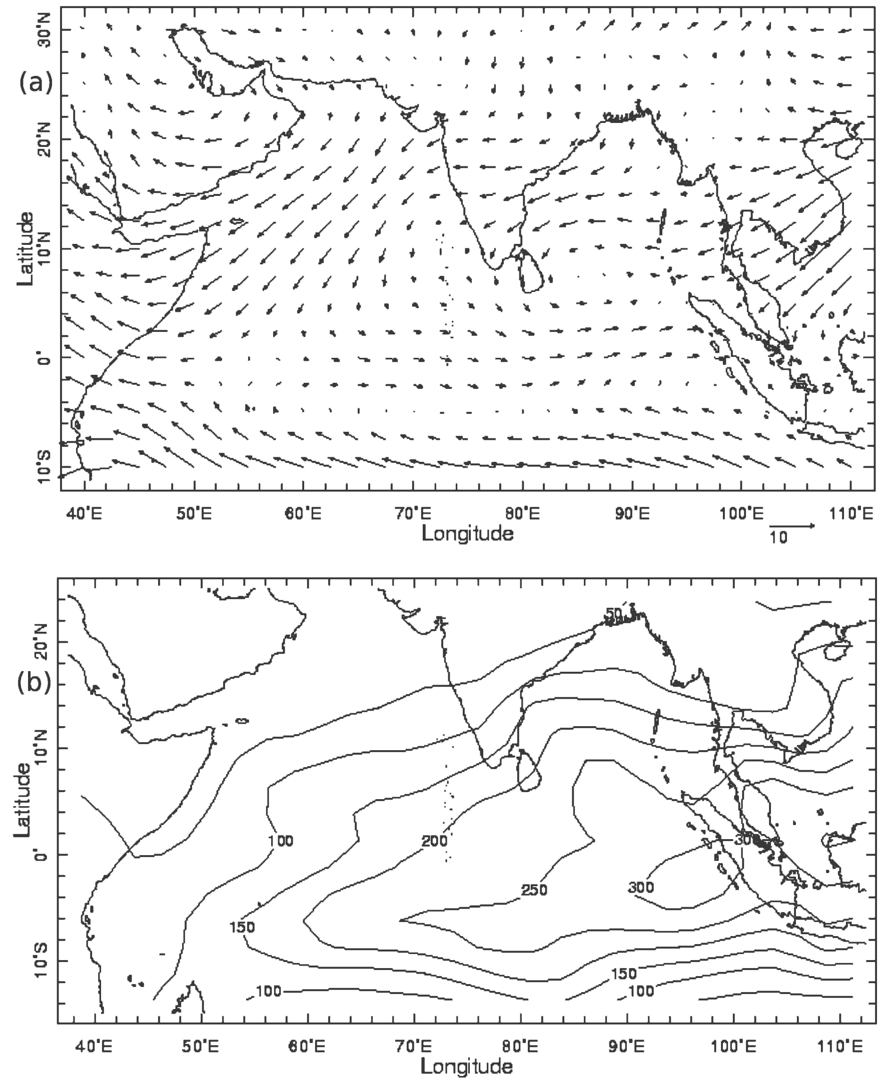

Fig. 2. (a) The mean low-level wind field at 925 mb during October to December for 1958–2002 (m s^{-1}). (b) The mean monthly rainfall during October to December for 1979 to 2004 (mm $month^{-1}$).

for subdivisions in India (Fig. 1b) were obtained from the Indian Institute of Tropical Meteorology (Pant and Rupa Kumar 1997). 4) Outgoing longwave radiation (OLR) data from 1974 onward were obtained from the Climate Prediction Center of the National Oceanic and Atmospheric Administration. (5) Climate Anomaly Monitoring System–OLR Precipitation Index (CAMS–OPI) rainfall estimates based on combination of satellite and station observations were also obtained from the Climate Prediction Center (Janowiak and Xie 1999).

3. Analysis

Peninsular India and Sri Lanka receive a large fraction of their annual rainfall during the NEM (Fig. 1c and Table 1) and we concentrate on the ENSO-NEM rainfall relationship in this region. The Sri Lanka and peninsular India rainfall shows correlation with the simultaneous ENSO index of Niño-3 that is significant at the 99% level from 1871 to 2002 (Table 2). There are sharp regional variations in the ENSO–NEM rainfall correlations in India and only in Tamil Nadu and adjacent regions is the relationship consistent over the period of record. The correlation of Niño-3 with Sri Lankan rainfall is stronger than that with Tamil Nadu rainfall, which in turn is stronger than that with the peninsular India rainfall (Table 2). As the Sri Lankan rainfall has the strongest NEM–ENSO relationships, we use it as a representative rainfall index to examine the influence of global fields. The simultaneous corre-

TABLE 1. Annual rainfall, mean NEM rainfall overall, and that during El Niño and La Niña episodes for 1958–2002. NEM rainfall is given within parentheses as a percent of annual rainfall.

Region	Annual rainfall	Mean NEM rainfall	NEM rainfall El Niño	NEM rainfall La Niña
Sri Lanka	1853	780 (42%)	885	718
Peninsular India	1170	345 (29%)	382	307
Kerala (29)	2784	479 (17%)	511	429
Tamil Nadu (25)	923	458 (49%)	499	405
Coastal Karnataka (26)	3407	247 (7%)	279	235
South Interior Karnataka (28)	873	208 (24%)	231	193
Rayalseema (24)	743	219 (29%)	228	204
Coastal Andhra Pradesh (22)	1006	383 (38%)	451	328

lation between NEM rainfall and SST brings out high correlations in the equatorial eastern Pacific Ocean reminiscent of the ENSO signature (Fig. 3a). We also characterize the large-scale atmospheric circulation associated with ENSO through examination of the velocity potential to provide a basis for comparison with the earlier work on the summer monsoon described in Kumar et al. (1999).

The contingency table (Table 3) compares the influence of ENSO on NEM rainfall for the early (1958–80) and later (1981–2002) periods. During both periods, El Niño conditions are associated with a tendency toward wetter conditions and La Niña conditions are associated with a tendency toward drier conditions. Here we use the Heidke skill to assess the strength of these associations (Wilks 1995). The Heidke score (S) is given by $S = 100\ (C–E)\ /\ (N–E)$, 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. Here, El Niño conditions are associated with wetter conditions, Neutral conditions with near-normal rainfall and La Niña with drier conditions. Where there is a perfect association, the Heidke skill score yields a score of 100, a perfectly negative relationship the score would be −50, and when there is only random association, the score tends to 0. The Heidke skill score for the association between ENSO and Sri Lanka NEM rainfall during 1958–80 was 9 and during 1981–2002 was 25. The latter score is somewhat higher than those typically experienced in operational precipitation forecasts for the United States. These figures show that the predictability of NEM rainfall based on ENSO has certainly not decreased and, in fact, has been enhanced during the latter period. The contingency table also shows that the relationship during La Niña appears to be strengthening as much as that during El Niño. In much of the remaining analysis, we report on the behavior during El Niño episodes alone for brevity.

TABLE 2. The correlations of NEM rainfall for Sri Lanka, peninsular India, and subdivisional India with simultaneous Niño-3 for the full record and for the two decades before and after 1980 are tabulated. Correlations that are significant at 90%, 95%, and 99% are shown in italics, bold italics, and bold, respectively.

Region/period	1871–2002	1958–80	1981–2002
Sri Lanka	**0.51**	***0.47***	**0.64**
All India	−0.09	−0.29	0.30
Peninsular India	**0.23**	0.30	***0.44***
Kerala (29)	***0.21***	0.28	0.22
Tamil Nadu (25)	**0.38**	*0.41*	***0.44***
Coastal Karnataka (26)	0.01	0.08	0.02
South Interior Karnataka (28)	0.08	***0.45***	***0.50***
Rayalseema (24)	0.01	0.21	0.24
Coastal Andhra Pradesh (22)	−0.06	0.33	0.37

As reported previously by Kumar et al. (1999), the relationship between the Indian southwest monsoon rainfall and Niño-3 has dropped below the 99% significance level since 1980 (Fig. 3b). The relationship between Sri Lanka NEM rainfall and Niño-3 largely stayed significant at the 95% level through the last 140 yr and has surpassed the 99% significance level since 1980. The Tamil Nadu NEM rainfall too maintains its (smaller) correlation with ENSO over the historical record increasing to 95% significance levels in recent decades. The peninsular India NEM rainfall had a weak relationship with Niño-3 for a hundred years since 1871 but this relationship has strengthened to the 95% significance level in the late 1970s.

The rise in ENSO–NEM correlation over peninsular India is derived particularly from the northern subdivisions where there has been an increase in correlations since 1980 (Fig. 4). These three subdivisions coastal Andhra Pradesh (22), Rayalseema (24), and south interior Karnataka (28) receive 39%, 29%, and 24% of their respective annual rainfall during the NEM. The low-level circulation over peninsular India has intensified in the easterly direction in recent decades (Fig. 3c) and this shall lead to enhanced orographic rainfall (Sarker 1966) to the windward side of the Western Ghats mountain range (Rayalseema and south interior Karnataka) and the Eastern Ghats mountain range (Coastal Andhra Pradesh). The correlation for the subdivisions along the western coast (Kerala and Coastal Karnataka) has remained at past levels (Table 2). These subdivisions lie to the lee of the Western Ghats mountain range during the NEM and do not garner orographically induced rainfall. These findings suggest

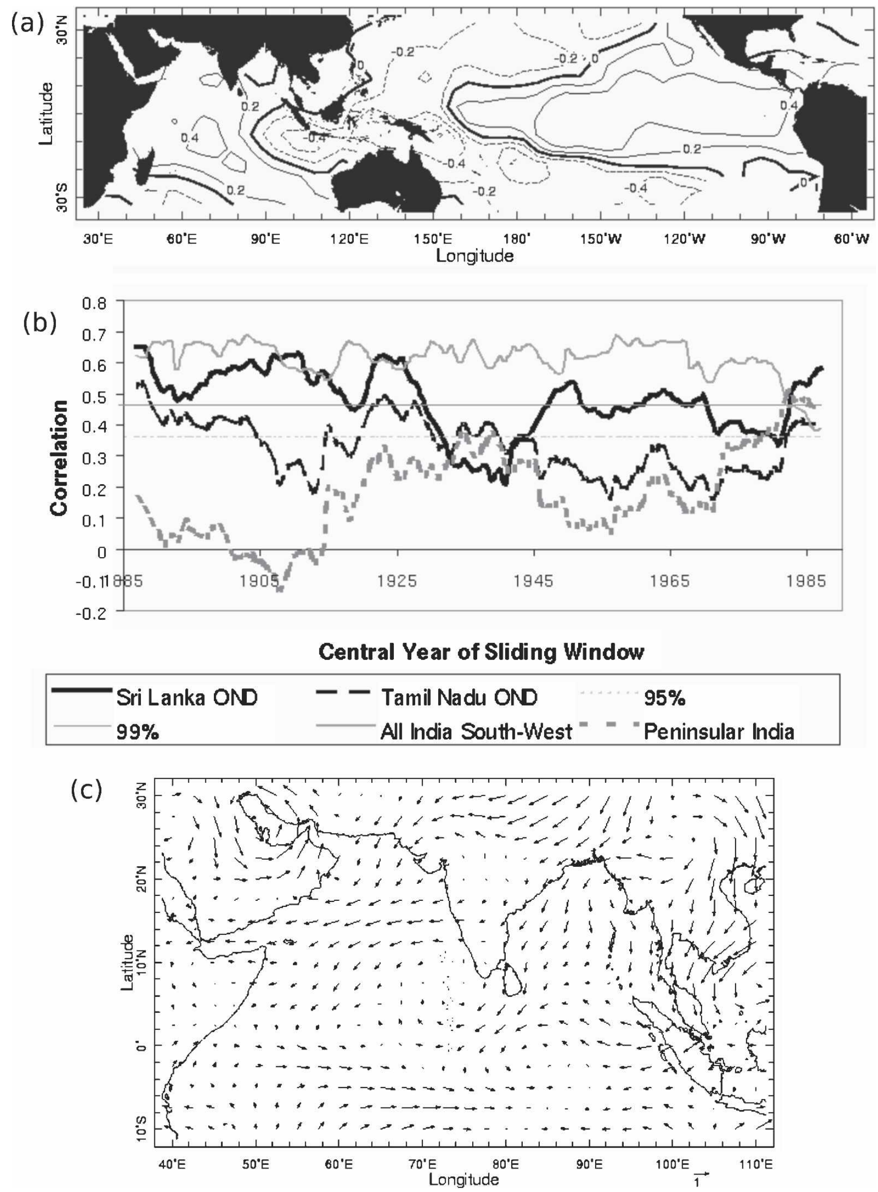

FIG. 3. (a) The correlation of October to December sea surface temperatures with simultaneous Sri Lanka rainfall for 1958–2002. (b) Sliding correlations with a 31-yr window of Niño-3 with simultaneous Sri Lankan, Tamil Nadu, and peninsular India NEM rainfall are shown. A similar sliding correlation of all-India southwest monsoon rainfall and simultaneous Niño-3 is also shown with its sign changed to positive to facilitate comparison. Correlation values at 0.36 and 0.46 are significant at 95% and 99% levels and these thresholds are shown. (c) The difference between 1981–2002 and 1958–80 in the mean October to December low-level circulation at the 925 mb (m s^{-1}).

that changes in the monsoon circulation in recent decades is strengthening the zonal component of the low-level flow that in conjunction with regional orography results in stronger ENSO–NEM relationships in parts of peninsular India.

Kumar et al. (1999) argue that the decreases in the ENSO–precipitation relationships during the summer monsoon season over the recent decades reflect large-scale changes in the character of the atmospheric circulation anomaly patterns associated with ENSO. Indeed, their analysis shows significantly different global 200-hPa velocity potential anomaly patterns in the latter versus the earlier period. In contrast, El Niño composite anomalies for the October to December season

TABLE 3. Contingency tables for the ENSO association with a composite index of areally weighted Sri Lanka and Indian NEM rainfall for (top) 1958–80 and (bottom) 1981–2002. Wet, normal, and dry were defined based on tercile boundaries with wet being 100 mm above normal, dry being 130 mm below normal, and normal being values in between. Normal rainfall was taken as values within half a standard deviation of the mean rainfall. El Niño and La Niña phases were identified as seasons where the average Niño-3 values were greater than 0.5°C and less than −0.5°C, respectively.

	1958–80		
	Wet	Normal	Dry
El Niño	3	1	2
Neutral	4	3	3
La Niña	1	3	3
	1981–2002		
	Wet	Normal	Dry
El Niño	4	1	2
Neutral	3	4	2
La Niña	1	2	3

show only subtle changes in the velocity potential anomaly patterns and a slightly enhanced magnitude between the earlier and later periods (Fig. 4). This is consistent with the relatively stable and slightly enhanced relationships between these anomaly fields and ENSO-related precipitation over peninsular India and Sri Lanka during the October to December season. Note that the interpretation of the changes in the 200-hPa velocity potential should be limited to large-scale features alone (Rasmusson et al. 1999). Examination of lower level vertical velocity shows unambiguously that there is convection over peninsular India and Sri Lanka during the NEM.

We note, however, that part of the enhanced magnitude of the anomalies during the later period may be due to the overall tendency for slightly stronger circulations features in the NCEP–NCAR reanalysis (Kalnay et al. 1996) because of the introduction of satellite data in 1979. The later period includes the two strongest ENSOs of the twentieth century, 1982/83 and 1997/98,

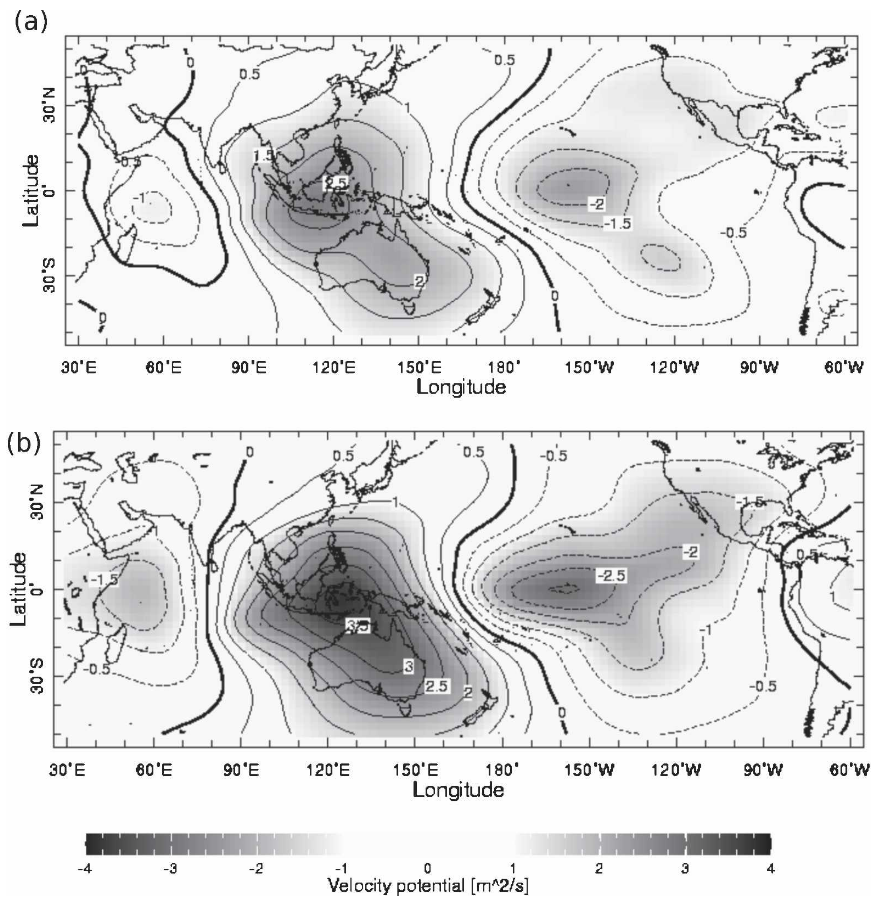

FIG. 4. Composites of the October to December velocity potential anomalies ($\chi \times 10^{-6}$ m^2 s^{-1}) at 200 mb for El Niño seasons before and after 1980 are shown as (a) before 1980: 1963, 1965, 1968, 1969, 1972, 1977, and (b) after 1980: 1982, 1986, 1987, 1991, 1994, 1997, 2002.

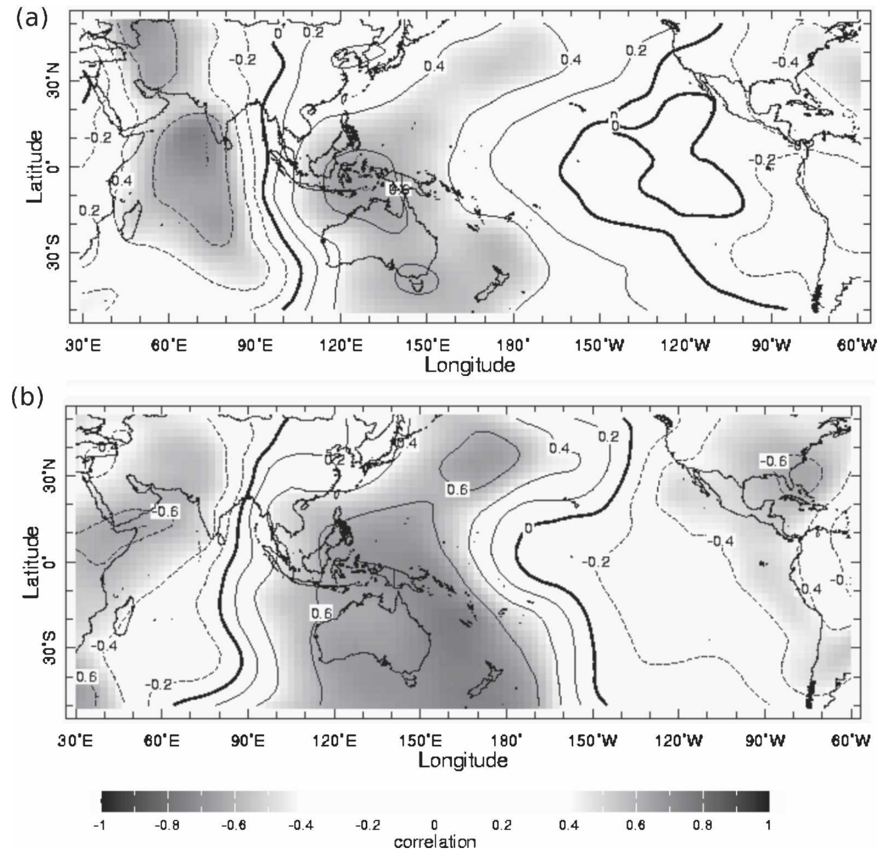

FIG. 5. Correlations of Sri Lanka northeast monsoon rainfall with 200-hPa velocity potential (χ) for (a) 1958–80 and (b) 1981–2002.

which should also add to increasing the magnitude of the anomaly fields. However, these results hold even if we construct composites of anomalies for the 1980 to 2002, which leave out the 1982/83 and 1997/98 episodes. Yang et al. (2002) note that there is greater uncertainty in the NCEP–NCAR reanalysis for the period before 1968. A repeat of our analysis for the earlier period restricted to 1968 to 1980 shows no large differences from the results presented here.

Kumar et al. (1999) found that the correlations between the all-India southwest monsoon rainfall and the 200-hPa velocity potential was strong between 1958 and 1980 and weakened considerably and shifted southeastward between 1981 and 1997. To assess whether there have been similar changes in the NEM, we constructed correlations of the Sri Lankan NEM rainfall with the 200-hPa velocity potential fields for two periods, 1958 to 1980 and 1981 to 2002 (Fig. 5). The patterns of the correlations structure over the tropical Indian Ocean region do not show significant changes between the two periods and, in particular, show no evidence of the weakening in correlations that was evident for the summer monsoon in Kumar et al. (1999). In contrast, there is a small, but clear, increase in the magnitudes of the NEM precipitation–velocity potential correlation fields during the latter period. These modest shifts in the correlation structure are consistent with the observed increase in the ENSO correlations with NEM rainfall.

The central tropical Indian Ocean has warmed by between 0.1° and 0.2°C during the NEM period (not shown) when comparing the 1981–2002 period with that of 1958–80 period. It is not clear whether the increased sea surface temperatures are at all related to the slight increase in the ENSO–precipitation correlations during the NEM. However, the OLR shows enhanced cloud cover over the region during more recent El Niño episodes (Fig. 6). The analysis of evidence for cloud cover from OLR data is complicated by the fact that it is only available from 1974. The OLR composites during El Niño episodes are based on data from the early and later halves of the record. Note also that the composites of OLR during El Niño episodes during the 1981–2002 period is significantly more negative over Sri Lanka and southern India than that during the only El Niño episode between 1974 and 1980 (1977).

Examination of vertical velocity fields (not shown)

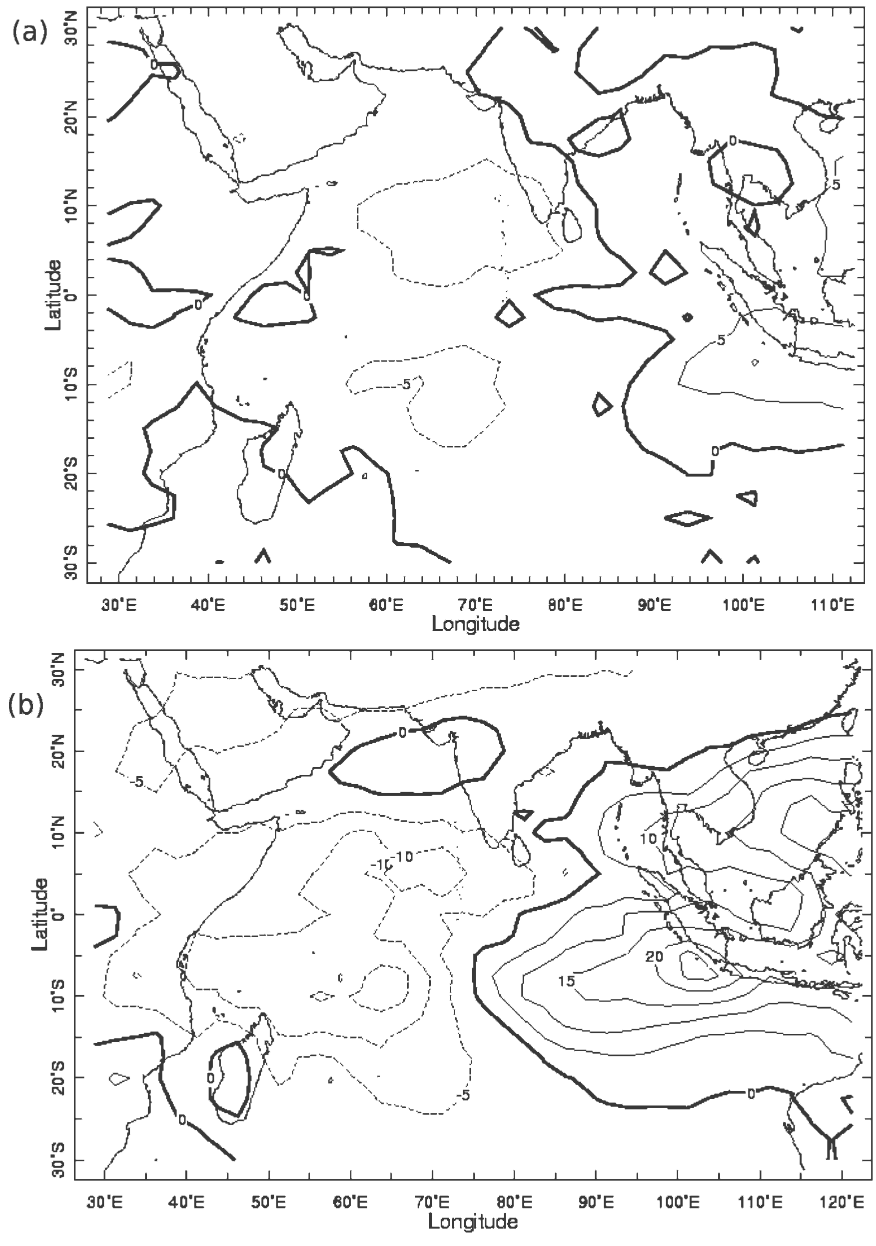

FIG. 6. The composite outgoing longwave radiation (W m^{-2}) during El Niño events for the two halves of the observational record from 1974–2002: (a) 1974–89 and (b) 1990–2002.

also shows a slight intensification of the vertical velocities in the latter period over the region receiving high NEM rainfall. The enhanced convection is likely to act to strengthen the zonal circulation associated with ENSO leading to increased cloudiness and precipitation over Sri Lanka and southern peninsular India during El Niño episodes.

4. Discussion

In contrast to reports on the weakening of the ENSO–southwest monsoon rainfall relationship, we have documented the strengthening of the relationship between northeast monsoon rainfall in southern peninsular India and Sri Lanka after the 1980s. The ENSO–NEM rainfall correlation that had been significant to the 95% level in Sri Lanka has exceeded the 99% significance level in recent decades; the ENSO–NEM rainfall relationship in Tamil Nadu has recently attained a 95% significance level. Even though these ENSO–NEM rainfall relationships have strengthened lately, it is within the range that has been observed in the past 130 yr. The modulation of OLR fields in the El

Niño episodes during the latter half of the available record supports the evidence based on rainfall for the slight strengthening of ENSO–NEM relationship.

If we consider peninsular India as a single entity, there has been a remarkable rise in the correlation of the northeast monsoon rainfall and ENSO that is beyond the historical range. The rainfall over South Interior Karnataka, Rayalseema, and Coastal Andhra Pradesh that lie on the windward side of the Western Ghats mountain range show relatively enhanced correlation with ENSO. This regional rise may be attributed to a slight enhancement of the low-level circulation in recent decades during the NEM that leads to relative increase in the orographic component of rainfall.

Kumar et al. (1999) suggest that the weakening of the relationship between ENSO and summer Indian monsoon rainfall might be ascribed, in part, to a shift in the mean position of the Walker circulation in the recent period compared to the earlier record. Indeed, their analysis shows a dramatic shift in the structure of the correlations between monsoon rainfall and velocity potential as well as dramatic changes in velocity potential anomaly composites during El Niño in comparing the two periods. Replicating their analysis for the NEM, we do not find similar evidence for large shifts in the character of the correlations between monsoon rainfall and ENSO nor do we find large shifts in the character of the ENSO composites except for larger magnitudes in the anomaly fields.

The sea surface temperatures over the Indian Ocean have warmed in recent decades in the central and western Indian Ocean and this is likely to modulate both the monsoon circulation and the influence of ENSO. The warming in the Indian Ocean follows a pattern reminiscent of ENSO response of the Indian Ocean SSTs. This warming is consistent with the intensified convection over the Arabian Sea extending to Sri Lanka since 1980s.

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