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POST-MONSOON SEA SURFACE TEMPERATURE AND CONVECTION ANOMALIES OVER INDIAN AND PACIFIC OCEANS

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ABSTRACT

We have studied sea surface temperature (SST) anomalies over the Indian and Pacific Oceans (domain 25 °S to 25 °N and 40 °E to 160 °W) during the three seasons following the Indian summer monsoon for wet monsoons and also for dry monsoons accompanied or not by El Niño. A dry monsoon is followed by positive SST anomalies in the longitude belt 40 to 120 °E, negative anomalies in 120 to 160 °E and again positive anomalies east of 160 °E. In dry monsoons accompanied by El Niño the anomalies have the same sign, but are much stronger. Wet monsoons have weak anomalies of opposite sign in all three of the longitude belts. Thus El Niño and a dry monsoon have the same types of association with the Indian and Pacific Ocean SSTs.

In the sector 40 to 120 °E SST anomalies first appear over the western part of the Indian Ocean (June to September) followed by the same sign of anomalies over its eastern part and China Sea (October to March). By March after a dry monsoon or El Niño the Indian Ocean between 10 °N and 10 °S has a spatially large warm SST anomaly. Anomalies in deep convection tend to follow the SST anomalies, with warm SST anomalies producing positive convection anomalies around the seasonal location of the intertropical convergence zone.

KEY WORDS: dry and wet monsoons; SST anomaly; convection anomaly; tropical biennial oscillation; El Niño

1. INTRODUCTION

During the Asian summer monsoon, under the influence of its strong low-level winds in the form of a cross-equatorial low-level jet stream (Bunker, 1965; Joseph and Raman, 1966; Findlater, 1969), the northern Indian Ocean experiences a large cooling of its surface layer, when the other ocean basins of the Northern Hemisphere warm. The amplitude of this cooling from May to August is largest in the western Arabian Sea and decreases to the east, as may be seen from Joseph and Pillai (1987). A dry (deficiency in monsoon rainfall over India) monsoon is followed by a spatially large warm sea surface temperature (SST) anomaly over the tropical Indian Ocean, which is found to persist up to the following monsoon (Joseph and Pillai, 1984, 1986; Shukla, 1987; Rao and Goswamy, 1988; Terray, 1995). A dry Indian monsoon is followed by a spatially large cold SST anomaly over the tropical west Pacific Ocean and a warm anomaly over the equatorial east Pacific Ocean (Yasunari, 1990).

Many of the dry monsoons are associated with El Niños (Sikka, 1980; Rasmusson and Carpenter, 1983). During an El Niño, warm SST anomalies occur over the equatorial Pacific Ocean east of 160 °E and cold SST anomalies occur in the west Pacific Ocean, particularly over the tropical northwest Pacific during the period from March to May of the El Niño year to March to May of the following year (Weare, 1976; Rasmusson and Carpenter, 1982). During part of the same period, warm SST anomalies are seen over the equatorial Indian Ocean (Tourre and White, 1995, 1997). Thus whether it is a dry Indian monsoon or an El Niño, the

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associated SST anomalies over the Indian and Pacific Oceans are similar in their spatial extent and also the sign of the anomaly.

In the climatic year April to March, as defined by Yasunari (1991), there is a well-defined annual cycle for the atmosphere over the Indian–Pacific Ocean basins. Asian summer monsoon currents prevail over the Indian Ocean during June to September. This is followed by the Asian winter (Australian summer) monsoon current during December to March. In the Pacific Ocean, easterly trade winds prevail throughout the year; however, once every few years the trade winds weaken and El Niños develop from a small-amplitude SST anomaly signal in March to May (MAM), reaching maximum intensity and aerial extent by December–February (DJF) and generally dying away by the following MAM season (Rasmusson and Carpenter, 1982). From the data presented in their paper, it is inferred that the magnitude of the warm SST anomaly associated with the El Niño in the east Pacific Ocean rapidly increases across the Indian summer monsoon season (June to September), showing a close association between the Indian summer monsoon and the El Niño.

Recent research has shown that the Indian summer monsoon, east-Asian summer monsoon, El Niño and the SST anomalies over the Indian and Pacific Oceans have strong biennial components (Meehl, 1987, 1997; Rasmusson *et al*., 1990; Yasunari, 1990; Yasunari and Seki, 1992; Shen and Lau, 1995; Tomita and Yasunari, 1996). The mechanism for this oscillation, which is called the tropical biennial oscillation (TBO) and which is different from the stratospheric quasi-biennial oscillation (QBO), is not yet clear. Here, a reference is given to Brier (1978) regarding periodicities of close to 2 years. Some authors have suggested active participation of the Indian summer monsoon and the Indian and west Pacific Ocean basins (Meehl, 1997). In the current study we have examined the anomalies in SST and deep convection over the Indian and Pacific Oceans during the three seasons following the Indian summer monsoon, September–November (SON), DJF and MAM. We have studied composites of dry monsoons (Indian) accompanied and not accompanied by El Niño and of wet monsoons (Indian) during the period 1961 to 1987.

2. DATA USED

The domain studied is between latitudes 25 °S and 25 °N and longitudes 40 °E and 160 °W. SST data are monthly averaged SST over 2° latitude–longitude squares from the COADS data set for the period 1961 to 1985. Parthasarathy *et al*. (1994) have derived a long, homogeneous Indian summer monsoon rainfall (ISMR) series (for June to September) for the period 1871 to 1990 based on 306 well-distributed rain gauge stations and also covering most areas of India. The long-term mean ISMR is 852.4 mm and its standard deviation is 84.7 mm. A dry year is taken as a year when ISMR is one standard deviation or more below the long-term mean and a wet year is when ISMR is one standard deviation or more above the long-term mean. Table I gives the ISMR and the percentage departure from the long-term mean for each year of the period 1961–87. We have used highly reflective cloud (HRC) data as derived by Garcia (1985) to represent deep convection. HRC data are available for 1971 to 1987 for 1° latitude–longitude squares for the latitude belt 25 °S to 25 °N. In the case of HRC we have defined a wet year as one in which ISMR is plus half a standard deviation or more, as there are very few years with plus one standard deviation in the period 1971 to 1987 for which HRC data are available.

3. POST-MONSOON SST ANOMALIES

To see the slow evolution of SST anomalies, 3 month averages of SST anomaly were studied for dry monsoons accompanied by El Niño (the years are 1965, 1972 and 1982). Positive SST anomalies appear off the Somalia–Arabian coasts by June–August and increase in intensity and area by SON, when the SST anomaly over the Arabian Sea becomes +0.4 to +0.6 °C. The core of the warm anomaly moved northwards from off the Somali coast to off the Arabian coast (Figure 1(a)) and strengthened during SON (Figure1(b)) and then moved eastwards and weakened. The anomaly covered a maximum area by the SON season (Figure 1(b)). During the same season (SON), another positive anomaly develops over

Table I. ISMR and its departure from the long-term mean in standard deviation (SD) units (dry and wet years chosen are also indicated). W: wet; D&E: dry and El Niño; D: dry and no El Niño

Year	ISMR (mm)	Departure in terms of SD	Category for SST	Category for HRC
1961	1020.3	+2.0	W	
1962	809.9	−0.5		
1963	857.9	+0.1		
1964	922.6	+0.8	W[a]	
1965	709.4	−1.7	D&E	
1966	739.9	−1.3	D	
1967	860.1	+0.1		
1968	754.6	−1.2	D	
1969	831.0	−0.3		
1970	939.8	+1.0	W	
1971	886.8	+0.4		
1972	652.9	−2.4	D&E	D&E
1973	913.4	+0.7		W
1974	748.1	−1.2	D	D
1975	962.9	+1.3	W	W
1976	856.8	+0.1		
1977	883.2	+0.4		
1978	909.3	+0.7		W
1979	707.8	−1.7	D	D
1980	882.8	+0.4		
1981	852.2	0.0		
1982	735.4	−1.4	D&E	D&E
1983	955.7	+1.2	W	W
1984	836.7	−0.2		
1985	759.8	−1.1		D
1986	743.0	−1.3		D
1987	697.3	−1.8		D&E

[a] Included in W composite for SST.

the ocean area between the Indo-China peninsula and the Philippine Islands. This anomaly grows in intensity and area over the following months. By DJF (Figure 1(c)) this warm anomaly has reached +0.4 to +0.8 °C, and now extends to the seas north of Australia. This anomaly is associated with the boreal winter monsoon (summer monsoon of Australia). By the following February–April there is an extensive oceanic area from 40 to 120 °E between 10 °S and 10 °N having positive SST anomalies (figure not shown). It is suggested that the warm SST anomaly is generated under the combined action of the south Asian summer monsoon (June to September) and the southeast Asian winter monsoon (October to March). This anomaly persisted during the following MAM season (Figure 1(d)) although there was slight weakening of the anomaly.

For dry years unaccompanied by El Niño (1966, 1968, 1974, 1979), SST anomalies in the Indian and Pacific Oceans have the same sign as in the case of dry monsoons accompanied by El Niño, but the magnitude of the anomaly is less than 0.2 °C. Wet monsoons (1961, 1964, 1970, 1975 and 1983) have similar weak SST anomalies but of opposite sign (figures not given). Regarding this, Hastenrath *et al*. (1993) found cold SST anomalies during the post monsoon season (October and November) over the western Indian Ocean during the high phase of the southern oscillation (SO). It is known that wet monsoons generally occur during the high SO phase. Figure 2 gives the difference in SST between the D&E composite and the W composite (see Table I and below) for (a) SON after the monsoon, (b) DJF after the monsoon and (c) the following MAM. The magnified warm area in the Indian Ocean and the cold area in the west Pacific Ocean may be seen.

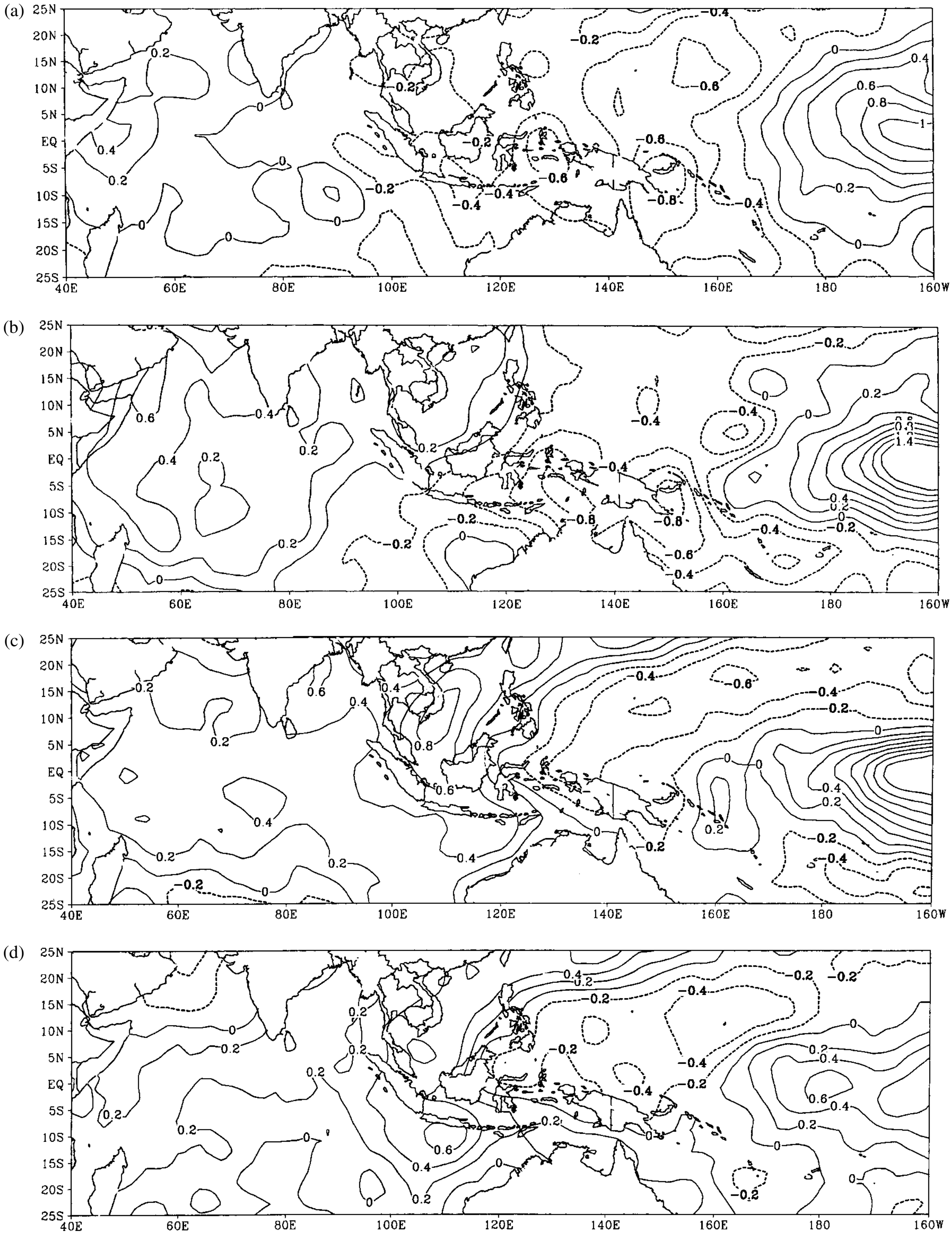

Figure 1. Composite SST anomaly for D&E (1965, 1972, 1982) for: (a) JJA; (b) SON after monsoon; (c) DJF after monsoon; (d) MAM after monsoon

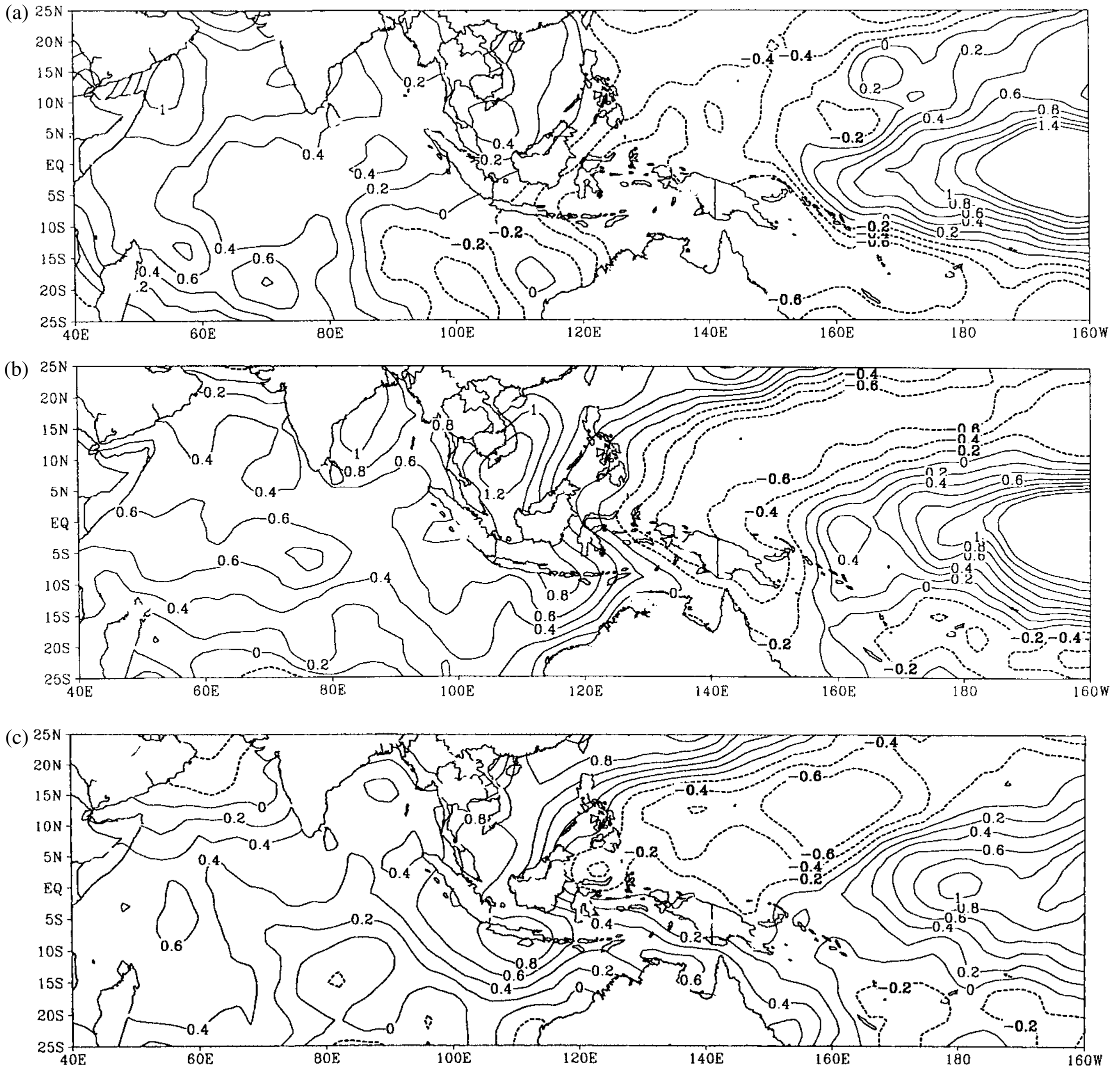

Figure 2. SST difference (D&E – W) for: (a) SON after monsoon; (b) DJF after monsoon; (c) MAM after monsoon

4. POST-MONSOON CONVECTION ANOMALIES

SST and deep convection are related in a complicated way (Gadgil *et al.*, 1984; Waliser *et al.*, 1993; Zhang, 1993). Introduction of an additional factor, i.e. divergence in the lower troposphere, makes the SST–convection relation more realistic (Graham and Barnet, 1987). Lau *et al.* (1997) found that convection is more related to divergence than to SST. There are a large number of studies in the literature showing that, when an El Niño occurs, deep convection (cumulo-nimbus) leads to negative anomalies around the maritime continent (longitude belt 100 to 150 °E) and positive anomalies around the international dateline (180 °E) (Philander, 1990 and references cited therein). Whether convection anomalies occur in the Indian Ocean in association with El Niño is not known. The literature also does not provide information regarding convection anomalies related to the variability of the Indian summer monsoon. We have studied ISMR and the associated anomalies in convection as represented by HRC for the three seasons following the Indian monsoon.

This study is restricted to the period 1971 to 1987, for which the HRC data are available. HRC is considered as a good index for organized deep convection (Waliser *et al.*, 1993). We have formed three groups of years for making composites of convection anomalies: (a) dry years accompanied by El Niño, termed D&E, (b) dry years not accompanied by El Niño, termed D, and (c) wet years (as defined by rainfall more than ISMR plus half a standard deviation), termed W.

Figure 3 gives the HRC climatology (1971 to 1987) for the three seasons SON, DJF and MAM. In general, convection is most intense during DJF and least during MAM. In order to augment the anomalies, we present the HRC differences (D minus W) composites as done for SST. Figure 4 gives the positive and negative anomalies in HRC (D&E minus W) for the SON season after the monsoon. It is seen that negative anomalies exist around the maritime continent and positive anomalies around the dateline. It may be noted that there is also a large area of positive anomalies over the equatorial Indian Ocean. Figure 5 gives the positive and negative anomalies in HRC for D minus W for the same season (SON). The anomalies are weaker than the earlier case for both positive and negative. Figure 6 gives the positive and negative HRC anomalies for the D&E minus W case of the DJF season after monsoon, and Figure 7 gives similar features for the following MAM season. It is seen that positive and negative anomalies are in the same location, but they are stronger than in SON during the DJF season. The anomalies in the MAM season are in the same location as in the

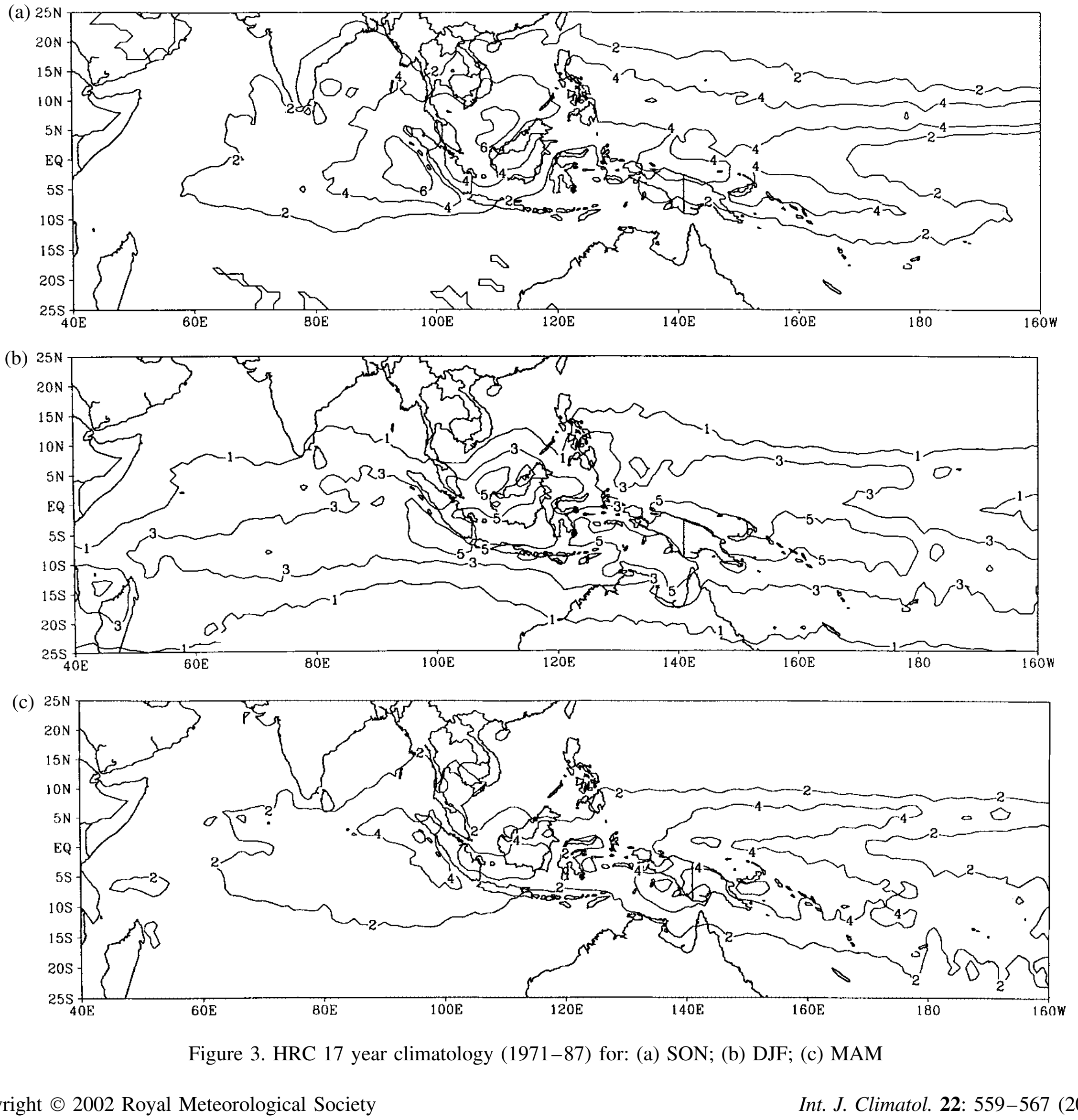

Figure 3. HRC 17 year climatology (1971–87) for: (a) SON; (b) DJF; (c) MAM

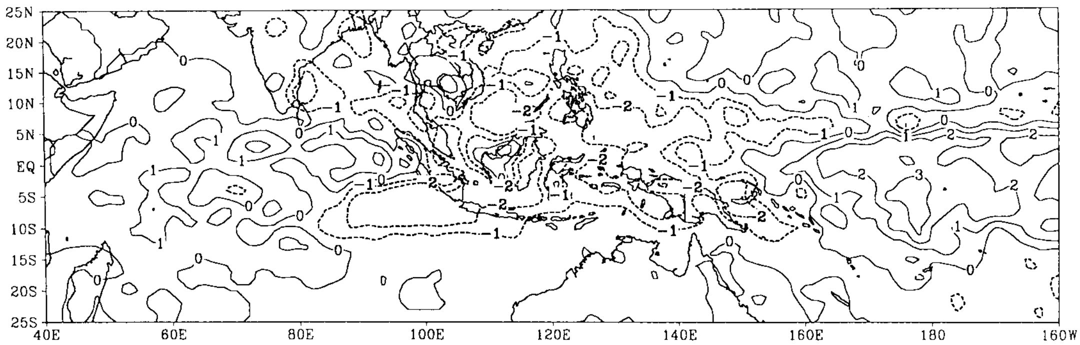

Figure 4. HRC difference (D&E – W) for SON after monsoon

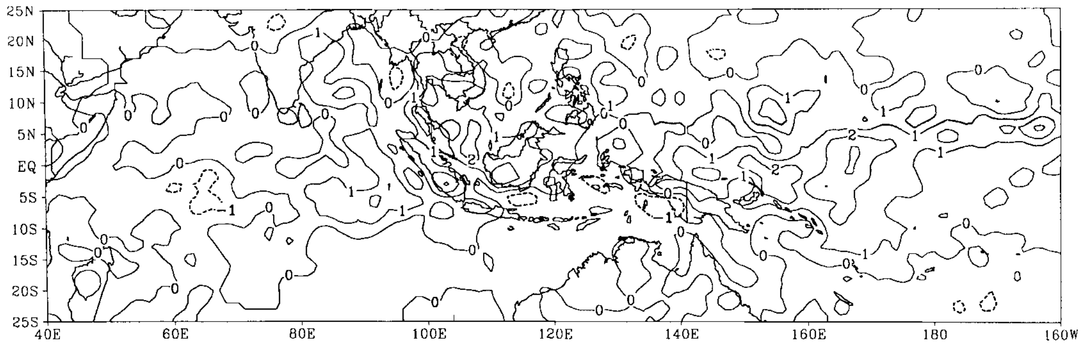

Figure 5. HRC difference (D&E – W) for SON after monsoon

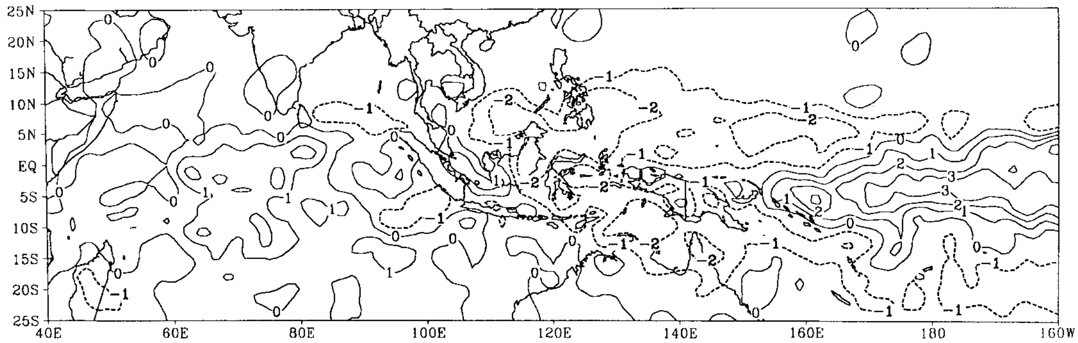

Figure 6. HRC difference (D&E – W) for DJF after monsoon

previous SON, but they are weaker than that of the previous DJF season. Thus we find that two areas of positive anomalies exist, one over the Indian Ocean and the other around the dateline, and an area of negative anomalies exists around the maritime continent during the three seasons SON, DJF and MAM after a dry monsoon with or without El Niño. We examined the convection anomaly for the 1976 monsoon, which was normal but occurred in an El Niño year. Figure 8 gives the anomalies in convection during the SON season of 1976. The anomalies are similar to that of a dry monsoon, but the longitudinal separation of the positive anomalies of the Pacific and Indian Oceans is not as much as in Figure 4.

The results obtained from the composite study as described in Section 3 have been compared with the results of a correlation study between ISMR and SST (in 2° squares) for the period 1961–85. This study confirms that following dry years the post-monsoon period (SON, DJF and MAM) has positive SST anomalies

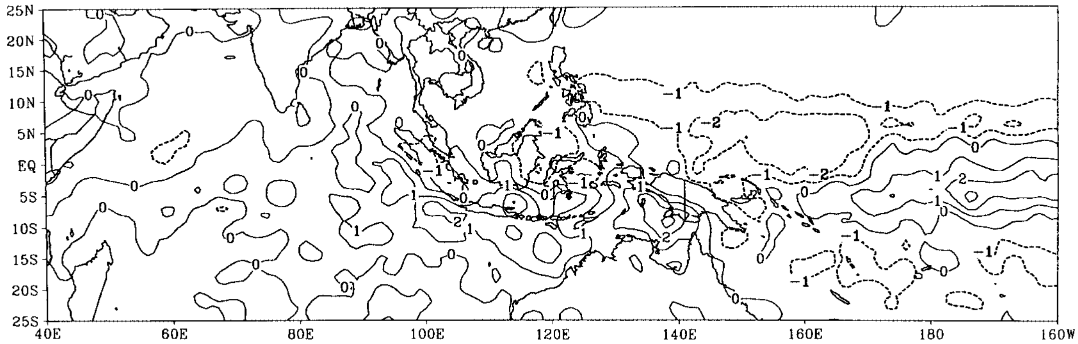

Figure 7. HRC difference (D&E − W) for MAM after monsoon

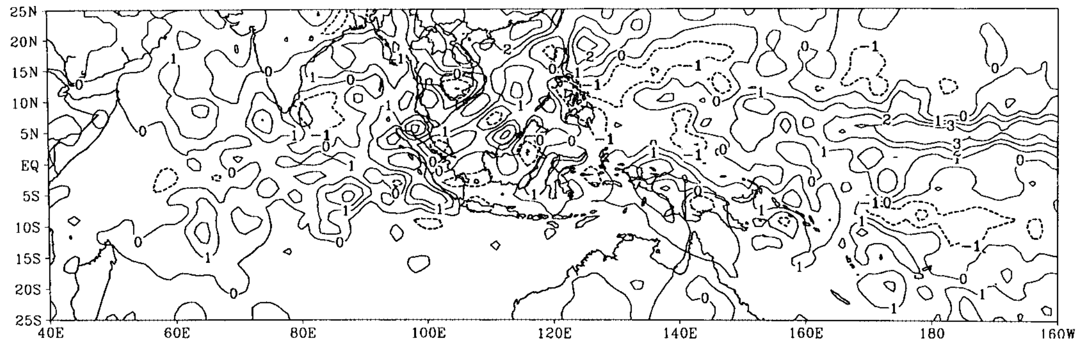

Figure 8. HRC anomaly for SON after 1976 monsoon

over the Indian Ocean and equatorial east Pacific Ocean and negative anomalies over and around the maritime continent. Convection anomalies in a similar correlation study for the period 1971–87 confirm the results given in this section as obtained from composites.

5. DISCUSSION AND CONCLUSIONS

From the foregoing sections it is clear that there are two types of SST anomaly pattern occurring over tropical areas of the Indian and Pacific Oceans during the three seasons SON, DJF and MAM following the Indian summer monsoon, *viz.* dry and wet.

(a) Positive SST anomalies over the Indian Ocean and also over the equatorial east Pacific Ocean (40–120 °E and east of 160 °E) and negative anomalies between 120 and 160 °E occur in association with a dry monsoon and also El Niño. In those years when these two phenomena take place together the anomalies are much more intense, with the contribution from the monsoon being much smaller than that from the El Nino.
(b) These three zones have weak anomalies of opposite sign associated with a wet monsoon or La Nina.
(c) Convection anomalies behave in a similar way; positive convection anomalies corresponding to positive SST anomalies and *vice versa*, except that convection anomalies occur only over areas where the intertropical convergence zone produces convection during these seasons. (Convection anomalies thus occur over a smaller area than SST anomalies.) This confirms the findings on the relation between SST and convection discussed in Section 4.

The results of this study should be important in relation to the interannual variability of the meteorology of the area. The Indian monsoon, El Niño and the two oceans (Indian and Pacific) have important roles in this variability.

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