Role of the ITCZ over the North Indian Ocean and Pre-Mei-Yu Front in Modulating July Rainfall over India

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ABSTRACT

Southwest monsoon rainfall over India during July 2002 was the lowest since instrumental records of rainfall data have been available. The present study is an attempt to examine some of the probable causes for this unprecedented low rainfall during July. It is found that the strength of the intertropical convergence zone (ITCZ) over the north Indian Ocean and the pre-mei-yu front over the northwest Pacific Ocean during the month of May has significant positive correlation with the July rainfall over India, and it can be used as a precursor for predicting July rainfall over India. The activity of the ITCZ over the north Indian Ocean and pre-mei-yu front in May is an indicator of the strength of first monsoon intraseasonal oscillation (ISO). It was also found that the ITCZ over the north Indian Ocean and pre-mei-yu front were not active during May 2002, probably because of the weak ISO activity during the first half of the monsoon season.

1. Introduction

In spite of growing industrialization, Indian economy still depends upon the rain-fed agricultural production. Moreover, the summer monsoon rainfall is also important for hydroelectric power generation and achieving drinking water requirements. Therefore, performance of the southwest monsoon over India plays a very crucial role in affecting the quality of life in the Indian subcontinent.

The southwest monsoon season (June–September) accounts for 75%–90% of the annual rainfall of the country. Out of these four months, more than 60% of the seasonal rainfall occurs during July and August, July being the rainiest month. Therefore, rainfall during the month of July has a decisive role in determining the overall performance of the southwest monsoon and its subsequent impacts.

Table 1 shows the correlation matrix of monthly rainfall for the monsoon season and all-India summer monsoon rainfall (AISMR) for the period 1979–2002. It may be seen that the correlation between all-India July rainfall (AIJR) and AISMR is 0.80. From the rainfall records of 102 yr (1901–2002), it has been found that in six out of seven years when July rainfall was below 20% of its normal value, seasonal rainfall was below 10% of its normal value and those six years ended as drought years. It may be mentioned that drought is defined when all India monsoon rainfall is below 90% of its normal value. This shows the importance of July rainfall in influencing the overall performance of southwest monsoon rainfall. Once July rainfall deficiency in a year exceeds 20%, it is most likely that monsoon seasonal (June–September) rainfall over India would also be deficient (less than 90% of its normal value) and the year would be a drought year.

Southwest monsoon rainfall over India during July 2002 was the lowest since instrumental records of rainfall data have been available. Southwest monsoon rainfall in July 2002 for the country as a whole was only 49% of its long period average (LPA). During July 2002, rainfall departure in 32 out of 36 meteorological subdivisions over India was negative. The deficiency was more than 50% in 26 meteorological subdivisions. Southwest season rainfall for the country as a whole was 19% below normal. This had significant and widespread negative impact on the agricultural production, the levels of reservoirs, and power generation.

Interestingly, most of the operational and experimental forecasts based on statistical and dynamical models (Rajeevan 2001) predicted a normal monsoon in 2002. This implies that most of the precursors based on the known teleconnections/atmospheric forcings, including the North Atlantic Oscillation (Srivastava et al. 2002), were favorable for monsoon 2002, except for the evolution of a moderate El Niño. Therefore, the failure of monsoon 2002, contrary to the prediction, has again focused the limitations in our understanding of monsoon variability. It has also opened new challenges for forecasters/researchers to examine the monsoon variability

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TABLE 1. Correlation matrix of monthly rainfall for the monsoon season and AISMR for the period 1979–2002.

	Jun	Jul	Aug	Sep	Jun–Sep
Jun	1.000	0.451	0.052	−0.158	0.455
Jul		1.000	0.155	0.405	0.800
Aug			1.000	0.291	0.594
Sep				1.000	0.667
Jun–Sep					1.000

in a new perspective and to examine new precursors for the season, especially for the month of July.

The present study is designed to examine the precursors and physical causes for the variability of July rainfall. In this study, we report the relationships between the strength of the intertropical convergence zone (ITCZ) over the north Indian Ocean and the pre-mei-yu front over the northwest Pacific Ocean in May and monsoon rainfall over India in July.

2. Data and methodology

For this study, we have used monthly mean outgoing longwave radiation (OLR) data derived from the observations taken by polar-orbiting National Oceanic and Atmospheric Administration (NOAA) satellites. These data are available at 2.5° × 2.5° resolution for the period 1979–2002. These data were obtained from the National Centers for Environment Prediction (NCEP). AIJR and AISMR data for the same period were taken from the records of the India Meteorological Department. The time series of rainfall for the country as a whole was prepared by averaging (area weighted) rainfall data of 36 meteorological subdivisions.

We have calculated the correlation coefficients between May OLR anomalies over the Indian and west Pacific Oceans and AIJR. We have also examined the correlations between AIJR and the OLR anomaly index averaged over the ITCZ area over the North Indian Ocean and pre-mei-yu front region over the northwest Pacific Ocean.

3. Results and discussions

a. Spatial correlation pattern and indices of OLR anomaly

Figure 1 shows the spatial pattern of correlation coefficients between OLR anomalies during the month of May and AIJR calculated with the data 1979–2002. Correlation coefficients that are significant at the 5% (1%) level are shaded light (dark). It may be seen that a large area over the equatorial Indian Ocean just north of the equator has significant negative correlations with AIJR. Similarly, a small area over the northwest Pacific shows the significant negative correlations with AIJR. Enhanced convection in May over these areas may indicate above-normal rainfall over India in July. We have also prepared composite OLR anomalies of May during the drought years (drought is defined when all-India monsoon rainfall is below 90% of its normal). The years considered are 1979, 1982, 1986, 1987, 1991, and 2002. However, in 1991 the rainfall deficiency was −9%, very close to the definition of the drought. The composite OLR anomalies are shown in Fig. 2. It may be seen that large positive OLR anomalies are observed over the east equatorial Indian Ocean and also over the pre-mei-yu

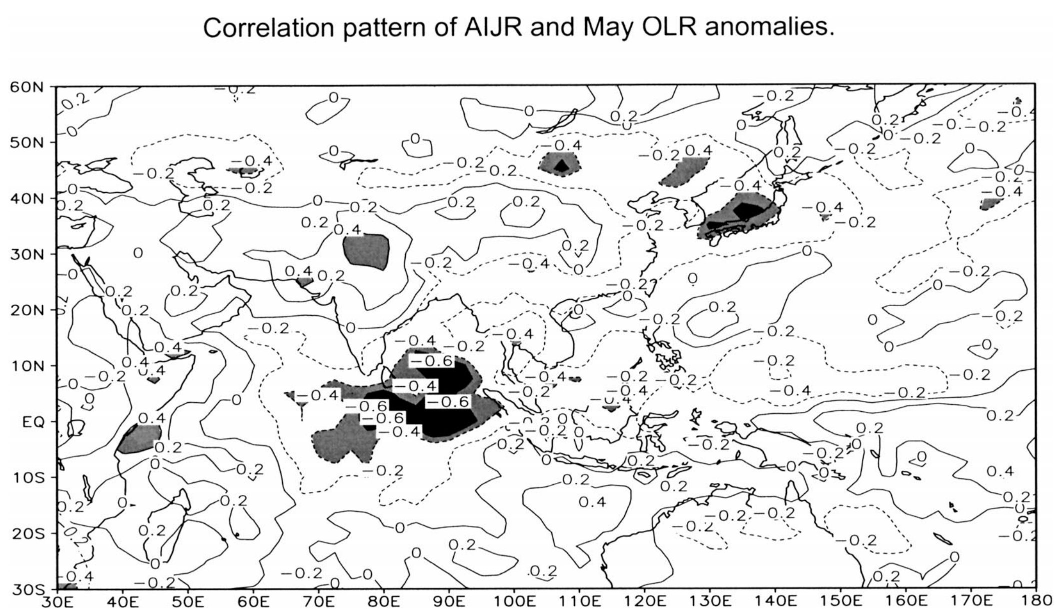

FIG. 1. Spatial pattern of correlation between May OLR anomalies and AIJR for the period 1979–2002. Area of 95% (99%) significance level is shaded light (dark). Contour interval is 0.2. Negative (positive) correlation is indicated by dotted (continuous) lines.

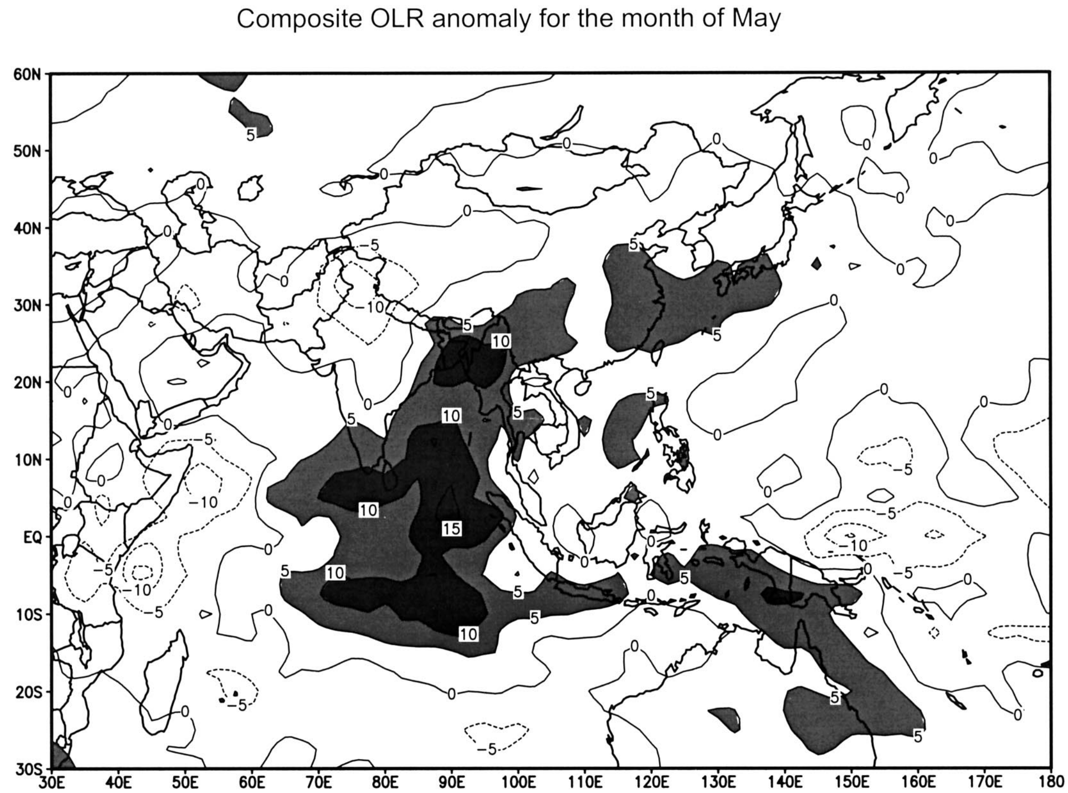

FIG. 2. Composite OLR anomalies in May averaged for six years (1979, 1982, 1986, 1987, 1991, and 2002). Contour interval is 5 W m^{-2}. OLR anomalies >5 W m^{-2} (10 W m^{-2}) are shaded light (dark).

front region, highlighting weaker-than-normal convection.

We have further derived two OLR anomaly indices averaged over the areas bound between 0°–5°N, 80°–120°E and 30°–42.5°N, 117.5°–172.5°E, respectively, to examine their usefulness as the precursors for predicting July rainfall over India. These areas respectively coincide with the position of ITCZ over the north Indian Ocean and pre-mei-yu front region over the northwest Pacific Ocean. These two OLR anomaly indices have correlation of −0.65 and −0.67, respectively, with AIJR, which are statistically significant at the 0.1% level. The time series of the two indices vis-à-vis AIJR data for the period 1979–2002 are shown in Fig. 3. It may be seen that in most of the years, when July rainfall departure was negative, OLR departure was positive and vice versa. It may further be seen that during the last 4–5 yr, AIJR was on the negative side, while the OLR anomaly index of the pre-mei-yu front region was positive. We have also examined the stability of these relationships by calculating 11-yr moving correlation coefficients. It was found that the correlation coefficients are stable throughout the period.

b. Physical linkage of OLR anomaly indices with AIJR

Several studies (Kawamura and Murakami 1998; Murakami and Matsumoto 1994; LinHo and Wang 2002) have revealed that the meteorological elements of the monsoon season are characterized by the superimposition of fast moving annual cycles (FMAC)/intraseasonal oscillations (ISO) on the slow moving annual cycle (SMAC). It was found that FMAC/ISO does not show its existence until April and its signature is discernible only from May onward. It was also emphasized that usually these two cycles were present in the monsoon season. Further, LinHo and Wang (2002) have shown that the first FMAC/ISO starts in May and remains active until early July. This cycle has predominantly northward movement. It activates the ITCZ and shifts it to the northern position. It also shifts the western Pacific subtropical anticyclone, which extends into the Indo-China region to the far northeast. The shifting of the subtropical Pacific anticyclone makes way for the establishment of synoptic-scale southwesterly monsoon flow beyond the South China Sea. Further, it also paves the way for formation of the pre-mei-yu front, which is the convergence zone of tropical southwesterly and midlatitudinal northwesterly flow. Thus, the activation of the ITCZ and formation of the pre-mei-yu front during May is actually related to the first ISO/FMAC of the season. Thus, the OLR anomaly of the ITCZ region and the pre-mei-yu front area appears to be an indirect manifestation of the strength of the first ISO, which has a significant bearing on the performance of the southwest monsoon, especially during the first half of the monsoon.

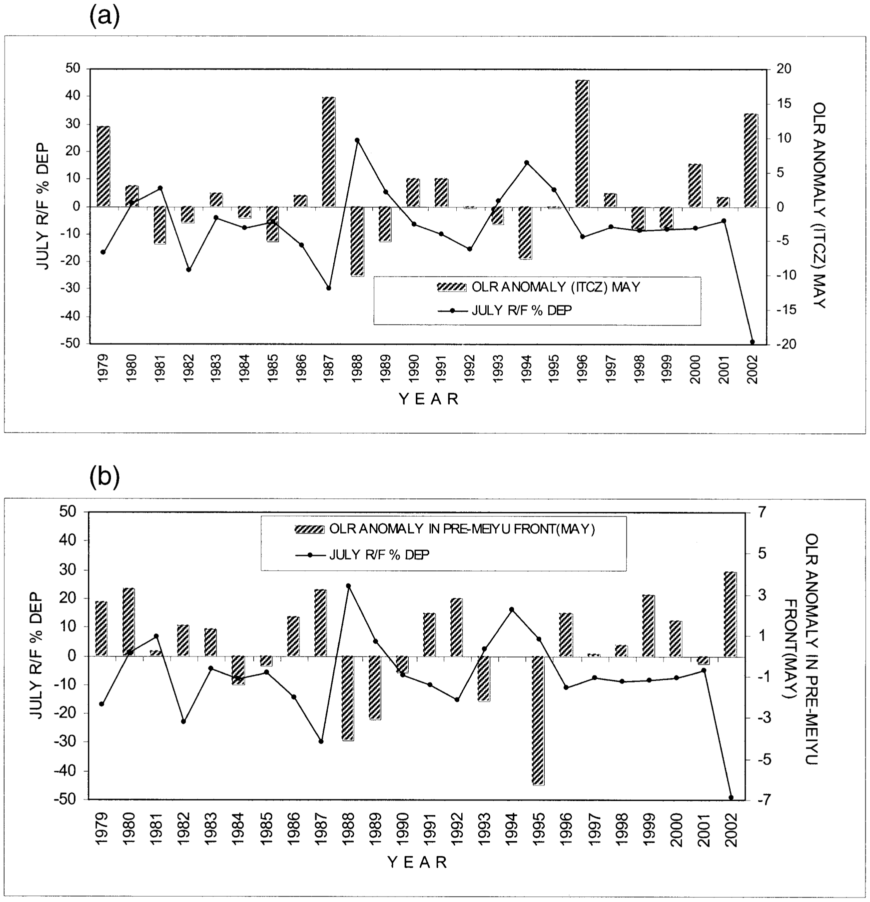

FIG. 3. Time series of area-averaged OLR anomaly over (a) the ITCZ over the north Indian Ocean and (b) the pre-mei-yu front in May and Jul rainfall departure. Period is 1979–2002.

It may be mentioned that Murakami and Matsumoto (1994) have shown that the ITCZ shifts from 5°S in January to 5°N in May over the Indian Ocean. Similarly, area bound between 25°–35°N and 120°E–180° is the region of the pre-mei-yu front. Therefore, July rainfall over India appears to be physically linked to the OLR anomaly of these regions because they carry footprints of the strength of the first ISO.

c. OLR anomalies and the subtropical Pacific anticyclone during May 2002

We have further examined pentad OLR anomalies/ wind vectors at 850 hPa over the Indian and Pacific Oceans during May using the NCEP–National Center for Atmospheric Research (NCAR) reanalysis data. It is found that the OLR anomalies were generally positive over both the regions in all the pentads and there is no appreciable difference in the OLR anomalies for the different pentads of May 2002. A small area over the South China Sea shows negative OLR anomaly in one or two pentads, probably due to localized convection. OLR anomalies over the two regions (ITCZ, pre-mei-yu front) were substantially above normal during May 2002.

Similarly, wind vectors of different pentads at the 850-hPa level do not reflect shifting of the subtropical Pacific anticyclone northeastward. Average wind vectors for the two pentads, for the period 6–10 May and 26–30 May 2002 are shown in Fig. 4. It may be seen that in 2002, the subtropical anticyclone ridge has shifted slightly southward, rather than northeastward. For the comparison, we have shown in Fig. 5, the average wind vectors for the same period in 1995, which was a normal monsoon year. In 1995, the northeast shift of the ridge is clearly noticed. This indicates that the first ISO/FMAC as suggested by LinHo and Wang (2002) was probably not very active in 2002. This had a significant negative impact on the July rainfall of 2002. Thus, it may be inferred that the weaker first ISO might have contributed to poor monsoon performance in July over India.

4. Conclusions

The present study shows that the strength of ITCZ over the north Indian Ocean and pre-mei-yu front over

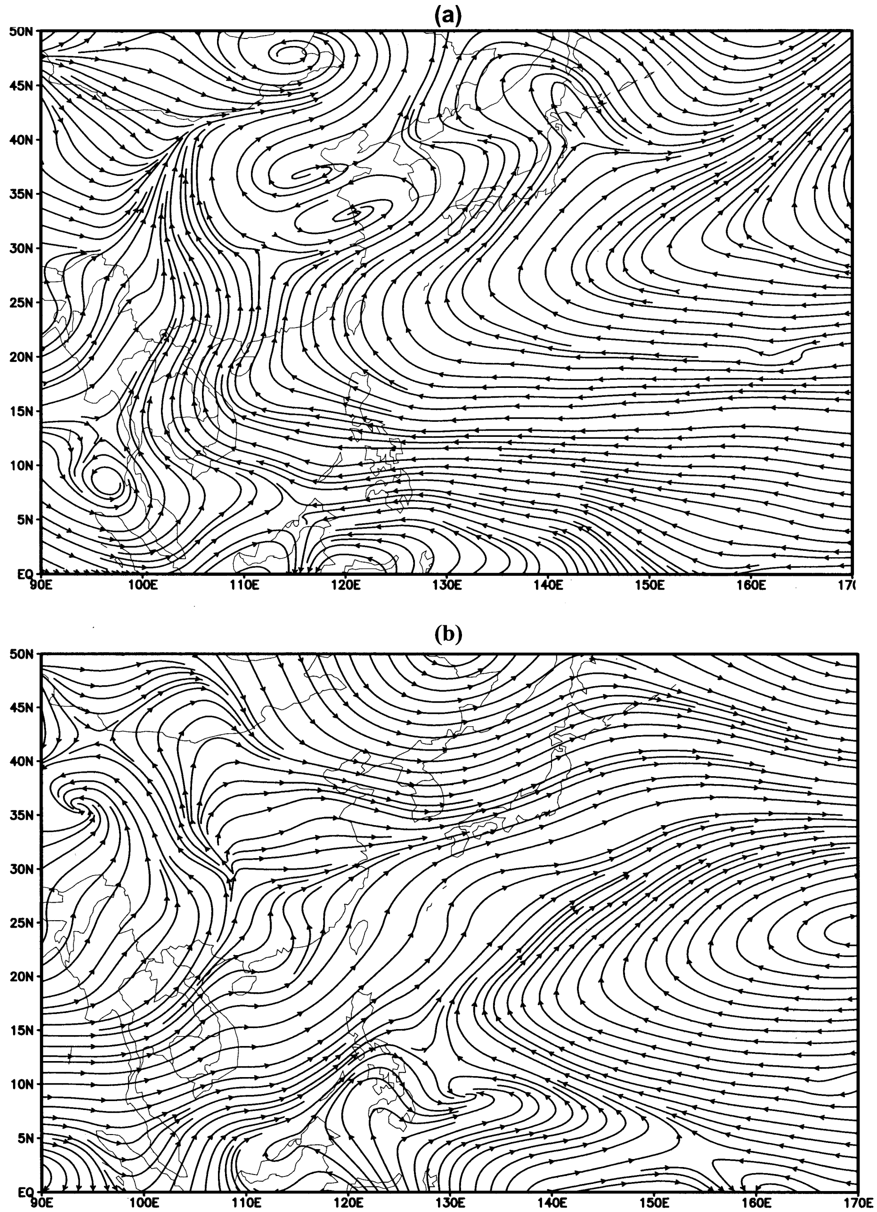

FIG. 4. Average wind vectors at the 850-hPa level for the pentads starting from (a) 6 May and (b) 26 May 2002.

the northwest Pacific Ocean during May is an indicator of the strength of the first ISO. OLR anomalies over these regions that indicate the intensity of the ITCZ and pre-mei-yu front are good precursors for predicting July rainfall over India. Enhanced convection over these regions in May indicates above-normal monsoon rainfall over India in July. In 2002, OLR anomalies of these two regions were significantly above normal due to below-normal convection (nonactivation of the ITCZ and pre-mei-yu front) over those areas. This suggests that the first ISO in May 2002 was not very active. This may be one of the probable causes for high degree of below-normal rainfall during July 2002. There may be many other physical causes for the deficient rainfall activity in July 2002. More detailed studies in this direction are required.

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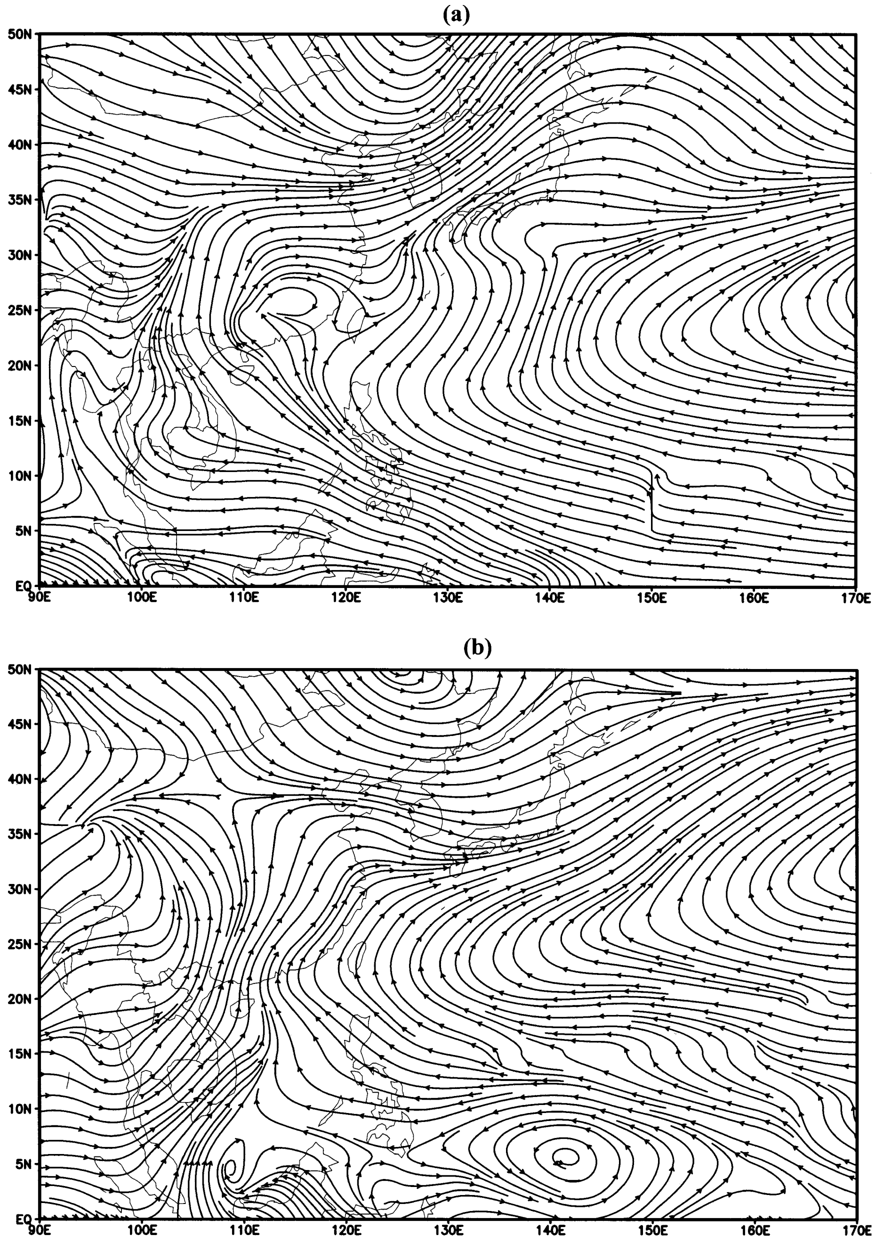

FIG. 5. Same as Fig. 4, but for the year 1995.

study. The pentad NCEP–NCAR wind data were obtained from the NOAA Climate Diagnostics Center. We also thank Mrs. U. J. D'Souza for typing the manuscript and Shri C. N. Shaligram for the graphics.

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