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Evaluation of dynamical and thermal anomalies associated with the summer monsoon of 1997 and 1999

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सार – 1997 का वर्ष प्रबल एल नीनों के द्रुत विकास के रूप में जाना जाता है तथा 1999 के दौरान तक ला नीना घटना प्रबल रही । 1997 (सामान्य से अधिक वर्षा ; >100%) और 1999 (सामान्य से कम वर्षा ; <100%) की इन घटनाओं के प्रति भारत की संपूर्ण मानसून वर्षा की प्रतिक्रिया असामान्य प्रकार की रही। इस शोध पत्र में भूमंडलीय माप गतिकीय और तापीय विसंगति अक्षांकों के संबंध में इसके कारणों की जाँच की गई है। इस अध्ययन की मुख्य उपलब्धियाँ हैं : (क) वर्ष 1999 में दक्षिणी पश्चिमी मानसून का शीघ्र आरंभ होना उत्तरी हिंद महासागर पर क्षेत्रीय असामान्यता के सकारात्मक प्रबल उर्ध्वाधर अपरूपण से संबद्ध था। (ख) 1997 में अगस्त और सितंबर के दौरान मानसून के पुनः सक्रिय होने के लिए भारत के देशांतर पर सक्रिय प्रतिलोमित हैडले परिसंचरण महत्वपूर्ण योगदान देता प्रतीत होता है। (ग) मई 1999 में क्षोभमंड़लीय तापमान की सकारात्मक असामान्यताओं ने तिब्बत के पठार का काफी क्षेत्र समेटा है। (घ) वर्ष 1997 की तुलना में मानसून के शीघ्र आरंभ होने वाले वर्ष 1999 में मई के महीने के दौरान तिब्बती पठार पर भूराजनैतिक ऊँचाई असामान्यता 200 है.पा. पर काफी अधिक थी। (ड.) भारतीय क्षेत्र पर मई 1999 के दौरान नकारात्मक असामान्यता की प्रधानता पर ला नीना का प्रभाव दृष्टिगोचर होता है।

ABSTRACT. The year 1997 was characterized by rapid development of a strong El Nino event and during 1999, a La Nina episode prevailed. The response of all India monsoon rainfall to these events in 1997 (above normal rainfall; >100%) and 1999 (below normal rainfall; <100%) was of unusual nature. In this paper, the reasons for this have been investigated in terms of planetary scale dynamical and thermal anomaly indices. The major findings of this study are (a) The early onset of south west monsoon in 1999 was associated with the stronger positive vertical shear of zonal anomaly over the north Indian Ocean, (b) Development of an active inverse Hadley circulation over Indian longitude appears to play an important role to reactivate monsoon during August and September in 1997, (c) Positive anomalies of tropospheric temperature occupied larger area over the Tibetan Plateau in May 1999, (d) The geopotential height anomaly at 200 hPa over the Tibetan Plateau during the month of May in 1999, in the year of early onset, was considerably higher compared to 1997 and (e) The dominance of negative anomalies of mean sea level pressure during May in 1999 over Indian region reflected the La Nina influence.

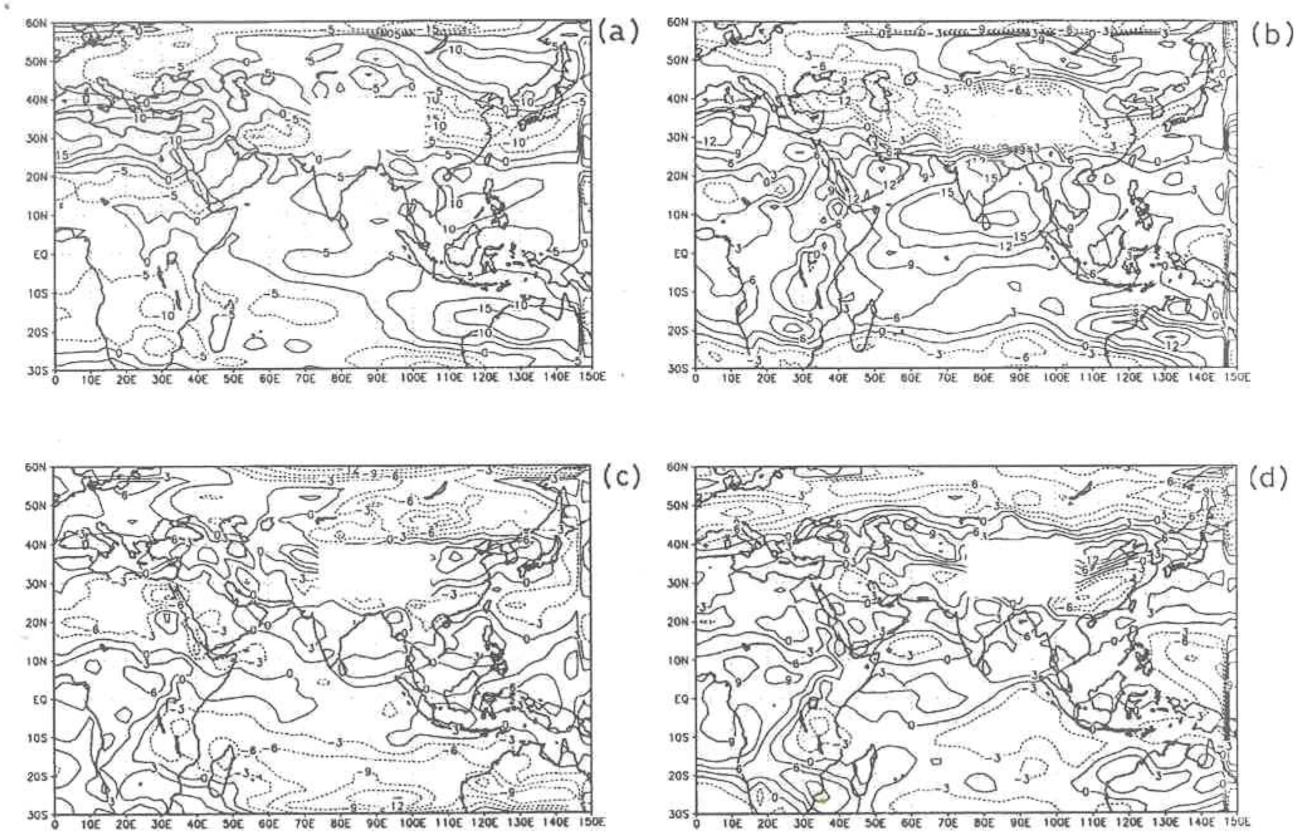
Key words – El Nino, Monsoon, Dynamical monsoon index, Hadley circulation, Tropospheric thermal anomaly.

1. Introduction

The southwest monsoon of 1997 was dominated by an El Nino event whose intensity was unprecedent of the century. From the known influence of El Nino to all India monsoon rainfall index (AIRI), it was expected that monsoon rainfall of 1997 would be well below normal. But it was 2% above normal. Thus response of AIRI to El Nino event of 1997 was of unusual character. Again La-Nina condition prevailed in 1999. The above normal monsoon rainfall was expected from the behaviour of La-Nina in 1999, but the AIRI was 4% below normal.

Indian monsoon is termed as good (bad) monsoon if the season's (June-September) rainfall departure from the long term normal is greater (less) than 10% and is normal otherwise. As such during both the year monsoon was normal. But the major difference noticed is in the monsoon onset dates. In 1997 onset over Kerala was on 9 June, 8 days delay from the normal date (1 June) and in 1999 it was on 25 May, 7 days in early. This difference between two onset dates was of 15 days. Another difference observed is that in 1999, during the first half of the season (June to July) monsoon was more active compared to the second half (August to September), while in 1997 the second half of the monsoon was more active than first half.

The purpose of this paper is to examine the monthly planetary scale dynamical and thermal anomaly indices



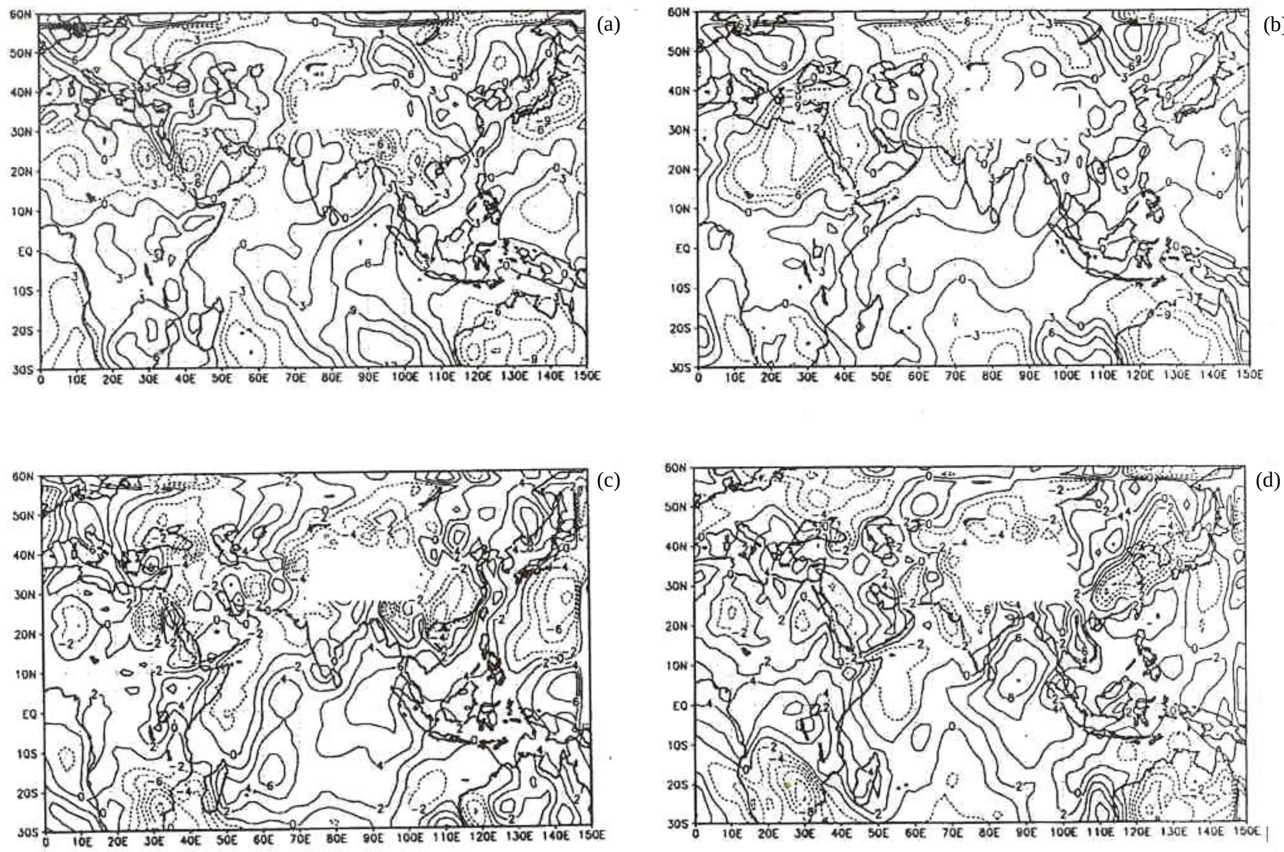
Figs. 1(a-d). Monthly anomalous vertical shear of zonal wind (ms^{-1}) between 850 and 200 hPa (u_{850}-u_{200}) for the month of (a) May 1997, (b) May 1999, (c) August 1997 and (d) August 1999

that prevailed during pre-monsoon and monsoon months in 1997 and 1999, with a goal to understand this unusual response of monsoon to El Nino and La Nina events.

2. Choice of indices

The years of strong and weak monsoon over Indian subcontinent have been studied in relation to the variation of the atmospheric/oceanic circulation system by many researchers (Wang and Fan, 1999; Thapliyal *et al*., 1998; Li and Yanai, 1996; Ju and Slingo, 1995; De *et al*., 1995; Webstar and Yang, 1992, Meehl, 1987 etc.). Study of Meehl (1987) suggests that tropical east west circulation in the Asia/Pacific sector provides a connection between the Asian summer monsoon and El Nino. In another approach Webster and Yang (1992) demonstrated that El Nino can have a substantial impact on lower tropospheric westerlies and upper tropospheric easterlies over the summer monsoon domain. They used a Dynamical Monsoon Index (DMI) to classify Asian monsoon system by the intensity of anomalous vertical shear of zonal wind between 850 and 200 hPa (u_{850}-u_{200}) averaged over the domain between Lat. 0° to 20° N and Long. 40° to 110° E. Wang and Fan (1999) used Hadley Monsoon Circulation Index (MHI), defined as meridional wind shear between 850 and 200 hPa (v_{850}-v_{200}) averaged over the domain between Lat. 10^{o} to 20^{o} N and Long. 70° to 101° E and made an intercomparison with DMI with reference to AIRI. Using the monthly data from June to September for 40 years 1958-97 from NCEP-NCAR reanalysis, they noted that the correlation coefficient (CC) between MHI and AIRI is 0.64 where as between DMI and AIRI is 0.52. The CC between MHI and DMI is 0.29.

The studies of Li and Yanai (1996) are based on the concept on the significance of Tibetan Plateau as an elevated heat source for abrupt seasonal changes. Using monsoon intensity index based on magnitude of the summer mean anomaly of the 200-500 hPa temperature



Figs. 2(a-d). Same as in Fig. 1 except for the meridional wind (ms^{-1})

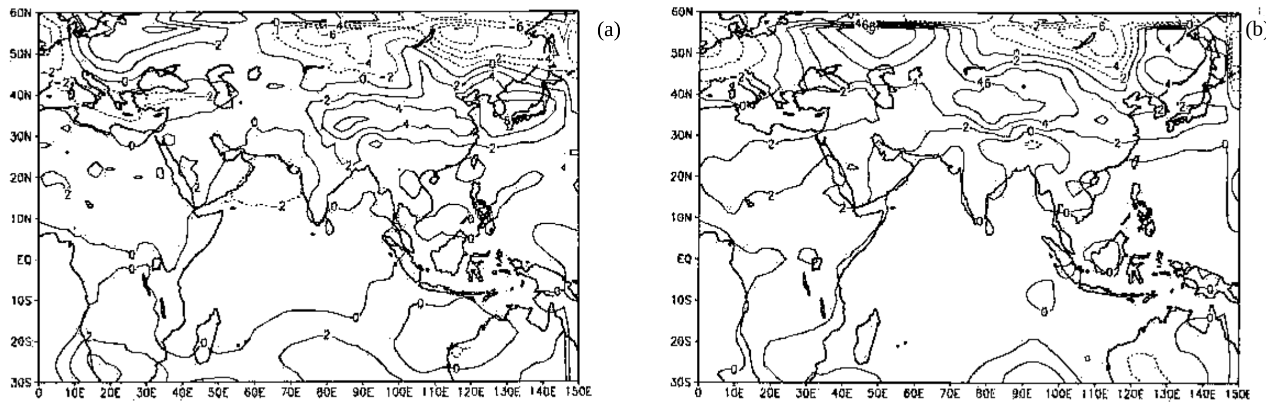
(T_{500}-T_{200}) they demonstrated that strong (weak) Asian monsoon years are associated with positive (negative) tropospheric thermal anomalies over most of the central and north eastern Asia but negative (positive) anomaly over Indian Ocean.

In this paper the responses of the Indian summer monsoon to the major El Nino event of 1997 and La Nina event of 1999 have been investigated in terms of the following large scale monthly anomalies of pre monsoon and monsoon months: (a) Zonal vertical shear anomaly (DMI), (b) Meridional vertical shear anomaly (MHI), (c) Tropospheric thermal anomaly, (d) 200 hPa circulation anomaly, (e) 200 hPa geopotential height anomaly and (f) Mean sea level pressure anomaly.

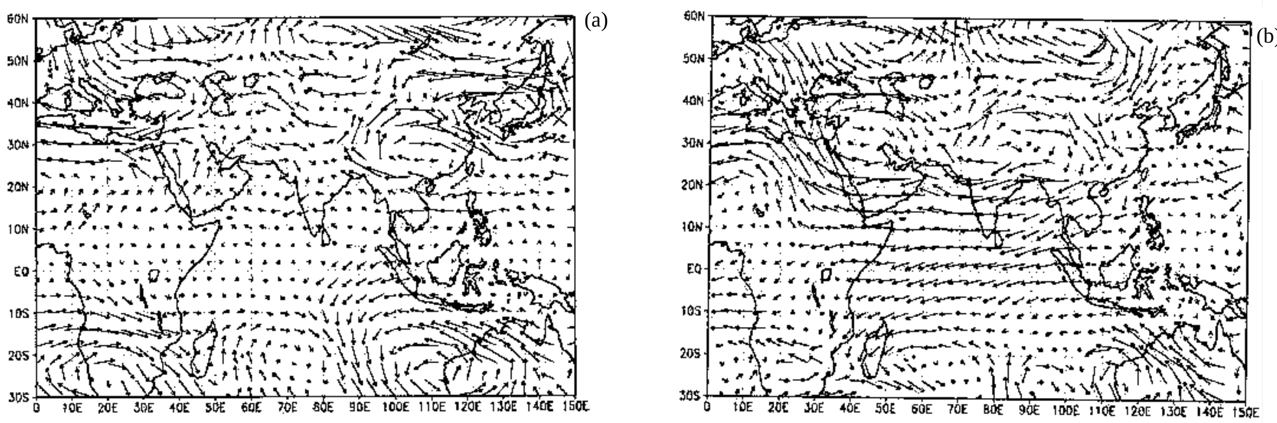
3. Data sources

The primary data used are from the daily analysis field for the year 1997 and 1999 (at the resolution 1° × 1° Lat/Long.) from the operational forecasting system of the India Meteorological Department (IMD), known as Limited area Analysis and Forecast System (LAFS). The LAFS is a complete system consisting of real time processing of data received on Global Telecommunication System (GTS), decoding and quality control procedures handled by AMIGAS software, 3-D multivariate optimum interpolation scheme for objective analysis and multilayer primitive equation model. The first guess fields for running the analysis scheme are obtained online from National Center for Medium Range Weather Forecasting (NCMRWF), New Delhi.

Monthly anomaly data are derived using climatology data (1979-89) at the resolution 1° × 1° Lat./Long. from the National Center for Environment Prediction (NCEP), Washington. In this study monthly anomaly of May is considered as representative month for the pre-monsoon month. As the onset process continues till July (normal date of onset to cover entire India is 15 July), August is considered as the representative month for the southwest monsoon season. Using these



Figs. 3(a&b). Monthly anomalous temperature difference (°C) between 200 and 500 hPa (T_{500}-T_{200}) for the month of (a) May 1997 and (b) May 1999



Figs. 4(a&b). Monthly anomalous wind field (ms^{-1}) at 200 hPa for the month of (a) May 1997 and (b) May 1999

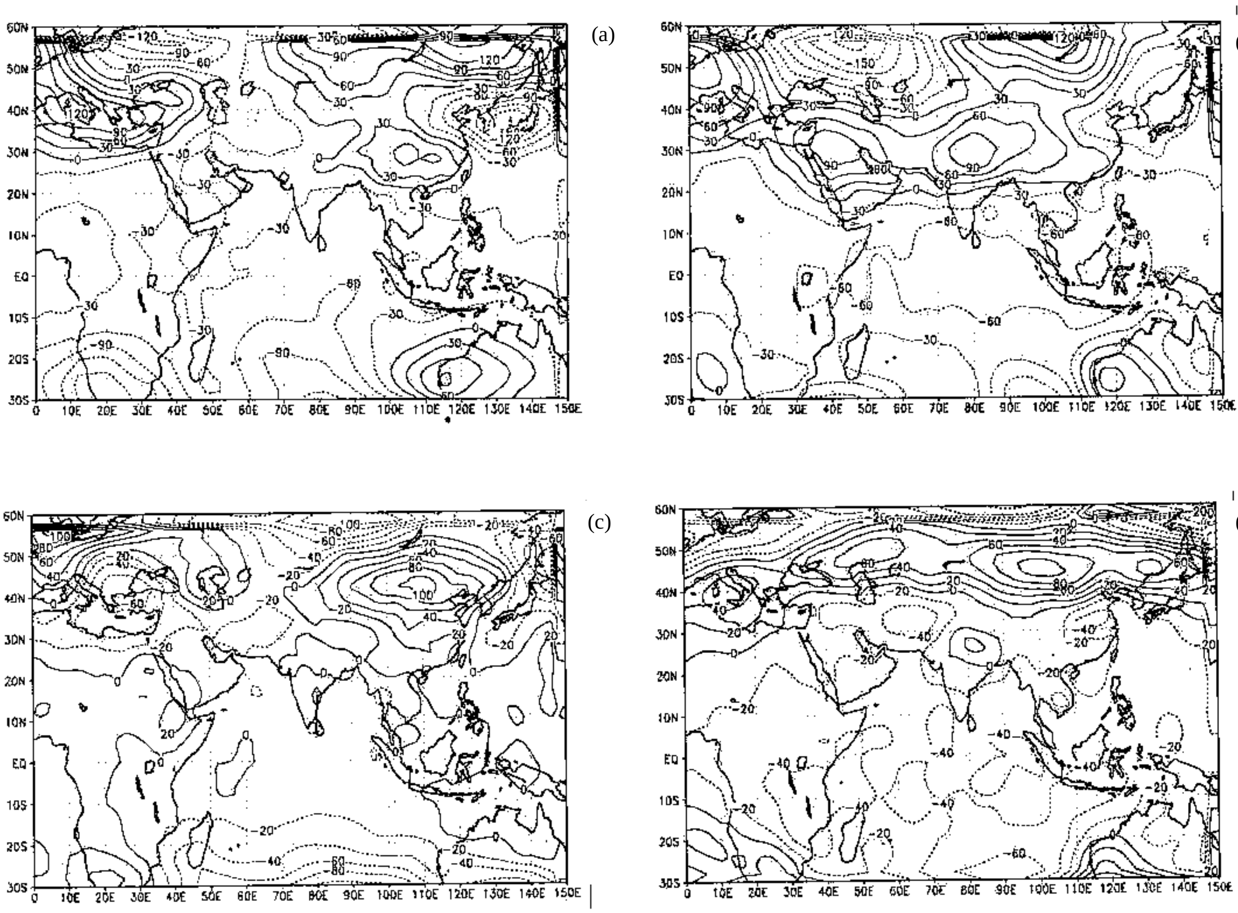
anomalies, DMI (u_{850}-u_{200}), MHI (v_{850}-v_{200}) and (T_{500}-T_{200}) are computed.

4. Results and discussion

(a) *Zonal vertical shear* (*DMI*)

Figs. 1(a-d) presents the anomalies of zonal wind vertical shear (u_{850}-u_{200}) for the month of May and August during 1997 and 1999 respectively. In the month of May 1997 positive anomalies of order 5 ms^{-1} confined over eastern part of Indian Ocean and also over the Bay of Bengal. While in 1999 during May the shear anomalies are found to be significantly stronger (10 to 15 ms^{-1}) over the Arabian Sea and Bay of Bengal along Long. 10° N. However, during August in both the years anomalies over Arabian Sea were negative and no appreciable difference was noticed over the north Indian Ocean.

The major difference that noticed is the stronger positive anomalies prevailed over Arabian Sea and Bay of Bengal during May in the year 1999. This is consistent with the results documented by Webster and Yang (1992) that during El-Nino years the lower (upper) tropospheric westerly (easterly) flow is weaker, while in La Nina years it tends to be stronger. Thus delayed (early) onset in the El Nino (La Nina) year of 1997 (1999) may be well connected with the weak (strong) shear of zonal wind over the north Indian Ocean. Ju and Slingo (1995) also noted that the greatest impact of El-Nino related boundary forcing on the strength of monsoon circulation tends to occur during the onset phase of monsoon. In El Nino years



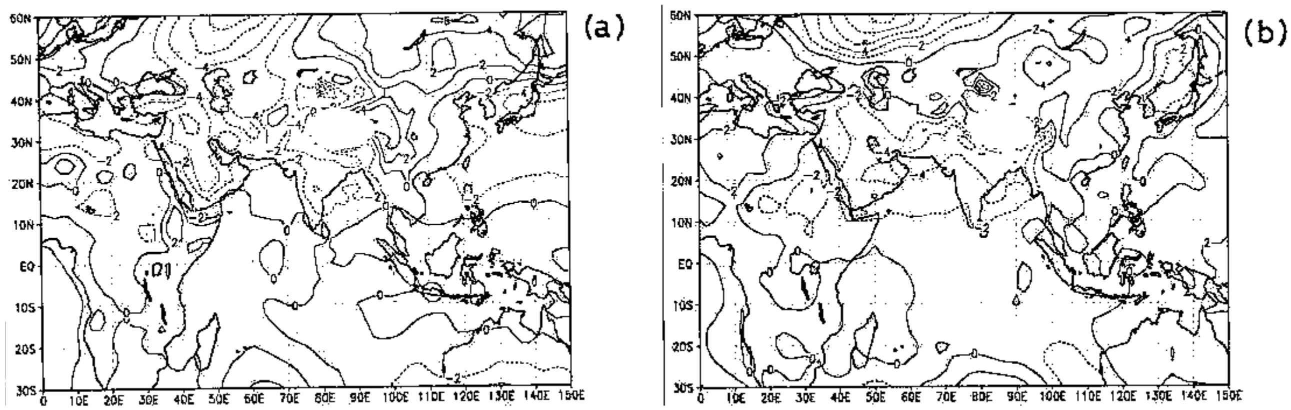
Figs. 5(a-d). Same as Fig. 4, except for the geopotential height (gpm) at 200 hPa for the month of (a) May 1997, (b) May 1999, (c) August 1997 and (d) August 1999

the strength of monsoon, in general, is influenced by the modulation of Walker circulation because of implied additional subsidence over the west Pacific and south east Asia due to systematic eastward shifting of convection.

(b) *Meridional vertical shear* (*MHI*)

Figs. 2(a-d) illustrates the anomalies of meridional vertical shear (v_{850}-v_{200}) for the month of May and August during 1997 and 1999 respectively. During May, 1997 positive anomaly shear is seen over Indian Ocean east of Long. 80° E with maximum value over south Indian Ocean. During August positive anomalies (4 to 6 ms^{-1}) occupied over the large areas in the north Indian ocean, extending north upto Arabian Sea and Bay of Bengal. This shows development of strong inverse Hadley circulation with ascending limb over Indian monsoon domain. During May 1999 positive anomaly (4 ms^{-1}) extended over Indian Ocean from north of Lat. 10° S to Bay of Bengal, showing southward shift of the inverse Hadley circulation, compare to May 1997. In August, 1999 positive anomaly (6 ms^{-1}) confined over Bay of Bengal and adjoining Indian Ocean, east of Long. 80° E., indicating eastward shifting of the inverse Hadley circulation, compare to 1997.

The fact that appears from the results of meridional vertical anomalies is that development of active inverse Hadley circulation during monsoon season may play an important role to activate the monsoon activity. Southward shifting of the inverse Hadley circulation in May 1998 was associated with the early onset of monsoon. The season's above normal rainfall of 1997 appears to be inconsequence with the enhanced effect of inverse Hadley circulation over the larger domain in the north Indian Ocean. But in 1999, the Hadley circulation could not influence the Indian monsoon may be because of east - ward shifting of its location. Development of this type of active inverse Hadley circulation during the monsoon



Figs. 6(a&b). Same as in Fig. 4, except for the mean sea level pressure (hPa)

1988, causing above normal monsoon rainfall is well demonstrated by Krishnamurti *et al*. (1990).

(c) *Tropospheric thermal anomaly*

Figs. 3(a&b) shows the anomalies of 200-500 hPa layer temperature (T_{500}-T_{200}) for the month of May during 1997 and 1999 respectively. In both the years large positive temperature anomalies (4° - 6° C) covered most of the Eurasia between Lat. 30° N and 40° N. In 1997, the location of positive anomaly over Tibetan area was found slightly to the east and confined over a smaller area.

The evolution of vertical difference of temperature anomalies reflects the development of the meridional temperature gradient over Tibetan Plateau during month of May in both the years which is considered to be a favorable condition for a good monsoon (Li and Yanai, 1996). The major difference that noticed is that in 1999 positive anomaly of tropospheric temperature anomaly occupy larger areas over the Tibetan Plateau. The Tibetan heat source is mainly contributed by sensible heating. It is noticed that heat of condensation over the Indian Ocean does not cause appreciable temperature change over Indian Ocean because of compensating effect of adiabatic cooling. It is the sensible heating over the Tibetan Plateau in the month of May that leads to reversal of meridional temperature gradient. Yanai *et al*. (1992) further demonstrated the thermal influence of Tibetan Plateau as a dominant factor driving monsoon circulation. This also supports the fact (Vernerkar *et al*., 1995) that excessive Eurasian snow cover may lead to weaker summer monsoon.

(d) *200 hPa wind anomaly*

The anomalies of 200 hPa wind for the month of May during 1997 and 1999 respectively are shown in Figs. 4(a&b). During 1997 in May an anomalous anticyclonic circulation was seen over north-east India. A weak cyclonic circulation over northwest India was also noticed. In May 1999, anomalous anti-cyclonic circulation was seen over northern India. Thus during both the years, 200 hPa wind anomaly pattern shows presence of anomalous anticyclonic circulation over northern parts of the country which is considered to be another favourable condition for a good monsoon (Pai *et al*., 1998). But easterlies associated are found to be stronger over the Peninsular India during May 1999.

(e) *200 hPa geopotential height anomaly*

Figs. 5 (a-d) represents the anomalies of 200 hPa layer geopotential height anomaly for the month of May and August during 1997 and 1999 respectively. During 1997, in the month of May positive anomalous height of order 40 gpm centered near Lat. 35° N and Long. 110° E. In August, biggest change in the height occurred where maximum amplitude of height anomaly increased to 100 gpm and centered around Lat. 40° N/Long. 110° E. During 1999 the positive anomaly (90 gpm) centered near

Lat 30° N/Long. 80° E in May and maintained the same intensity in August with location near Lat. 42° N and Long**.** 100° E. Thus prominent differences in the 200 hPa geopotential height were noticed in the month of May. The higher geopotential height anomaly at 200 hPa over the Tibetan Plateau during the month of May in the year 1999 was associated with the early onset of monsoon.

(f) *Mean sea level pressure anomaly*

The anomalies of mean sea level pressure for the month of May during 1997 and 1999 are shown in Figs. 6(a&b) respectively. In both the year during May negative anomaly of mean sea level pressure prevailed over the Arabian Sea, Bay of Bengal and major parts over the country. But in 1999 the magnitude of negative anomaly was of order 4 hPa where as in 1997 it was 2 hPa. The dominance of negative anomalies in 1999 over Indian region are evidence of La Nina episode.

5. Conclusions

The following conclusions can be drawn from the inter-comparison of anomaly pattern between the year 1997 and 1999:

(*i*) During May in the year of early onset, DMI over the north Indian ocean was considerably stronger, suggesting early (delay) onset in the La Nina (El Nino) year of 1999 (1997) may be well connected with the strong (weak) shear of zonal wind over the north Indian Ocean.

(*ii*) In August 1997 positive value of MHI covered a larger domain over the north Indian Ocean and adjoining south Indian seas, whereas in 1999 this confined only over the Bay of Bengal. This indicates that development of active inverse Hadley circulation over Indian longitudes played an important role to reactivate monsoon during August and September of 1997.

(*iii*) The meridional tropospheric temperature gradient over the Tibetan Plateau was equally strong during May in both the years. But positive anomalies of tropospheric temperature occupied larger area over the Tibetan Plateau in May 1999.

(*iv*) The anomalous anticyclonic circulation at 200 hPa over northern parts of country was noticed during both the years in the month of May. But in the year of early onset (1999) the easterlies over the peninsular India were stronger.

(v) The geopotential height at 200 hPa over the Tibetan Plateau during the month of May in 1999, in the year of early onset, was considerably higher compared to 1997.

(vi) In both the years during May negative anomaly of mean sea level pressure prevailed over Indian region. But in 1999 the magnitude of negative anomaly was higher. This may be due to La Nina influence.

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