MAUSAM, **56**, 3 (July 2005), 617-626

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Contrasting pre-monsoon features associated with early and late onset of southwest monsoon over Kerala

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(*Received 1 September 2004, Modified 29 October 2004*)

सार – इस शोध–पत्र में मानसून–पूर्व ऋतु के दौरान वर्षा के शीघ्र प्रारम्भ होने (2004) से और वर्षा के देर से आरम्भ होने (2003) के प्रत्येक वर्ष संबंधित तुलनात्मक लक्षणों की जाँच की गई है। इस शोध–पत्र में इन दोनों वर्षों के दौरान मई माह में निम्न स्तरीय पवनों के साप्ताहिक विकास और मध्य तथा ऊपरी स्तरीय पवनों के मासिक लक्षणों, समुद्र सतह तापमान, वर्षा का जल, निर्गमनी दीर्घतरंग विकिरण (ओ.एल.आर.) और माध्य समुद्र तल दाब प्रवणताओं का विश्लेषण किया गया है।

इनसे प्राप्त हुए परिणामों से वर्ष 2004 में मानसून के शीघ्र प्रारम्भ होने के दौरान निम्न स्तरीय पवन से दक्षिणी अरब सागर में नकारात्मक एस.एस.टी. विसंगति से संबंद्ध मई माह के प्रारम्भ से चक्रवाती प्रवाह सहित प्रबल क्रास भूमध्यरेखीय प्रवाह का पता चलता है जबकि वर्ष 2003 के मानसून के देर से आरंभ होने के दौरान अरब सागर में सकारात्मक एस.एस.टी. विसंगति से संबंद्ध जून के प्रथम सप्ताह तक बने हुए कमजोर क्रास भूमध्यरेखीय प्रवाह का पता चलता है। मध्य और ऊपरी क्षोभमंडलीय प्रवाह से मानसून के देर से प्रारंभ होने वाले वर्ष 2003 की अपेक्षा मानसून के शीघ्र प्रारंभ होने वाले वर्ष 2004 के दौरान बहुत प्रबल पूर्वी विसंगतियों के साथ–साथ मई माह में प्रबल तिब्बती चक्रवातरोधी का पता चलता है। मई माह के दौरान संवहनी गतिविधि वर्ष 2004 में मानसून के शीघ्र प्रारंभ होने के दौरान दक्षिणी चीन सागर की अपेक्षा हिंद महासागर में अधिक प्रबल थी जो वर्ष 2003 में मानसून के देर से प्रारंभ होने के दौरान इसके एकदम विपरीत थी। हिंद महासागर में नमी की बहुत गहरी परत के साथ मई 2003 के दौरान होने वाली वर्षा की तुलना में मई 2004 में होने वाली वर्षा में पानी की मात्रा अधिक थी। मानसून के देर से प्रारंभ होने वाले वर्ष 2003 की अपेक्षा मानसून के शीघ्र प्रारंभ होने वाले वर्ष 2004 के दौरान शीत ऋतु से ग्रीष्म ऋतु तक दाब प्रवणताओं की पहले की वापसी के साथ अप्रैल और मई माहों के मानसून–पूर्व महीनों के दौरान दक्षिणी और पश्चिमी भारत के मध्य याम्योतरी दाब प्रवणता सामान्य से अधिक थी।

ABSTRACT. Contrasting features pertaining to a year each of early monsoon (2004) and late monsoon onset (2003) are examined during the pre-monsoon season. The weekly evolution of low level winds during the month of May and the monthly features of middle and upper level winds, Sea Surface Temperature (SST), Precipitable water, Outgoing Longwave Radiation (OLR) and mean sea level pressure gradients are analysed during both these years in the present study.

The result shows that during the early onset year of 2004 the low level wind indicates strong cross equatorial flow with cyclonic flow from the beginning of May associated with negative SST anomaly over the southern Arabian Sea; whereas, during the late onset year of 2003, the low level flow indicates weak cross equatorial flow persisting upto the first week of June associated with positive SST anomaly over the Arabian Sea. The middle and upper tropospheric flow indicate stronger Tibetan anticyclone during the month of May accompanied by very strong easterly anomalies during the early onset year of 2004 compared to that of late onset year 2003. The convective activity during May was stronger over the Indian region compared to that over the south China Sea during early onset year of 2004, which is just the opposite during the late onset year 2003. The precipitable water was higher than normal during May 2004 accompanied by very deep moist layer over the Indian region compared to that of May 2003. The meridional pressure gradient between southern and northern India were stronger than normal during the pre-monsoon months of April and May with earlier reversal of pressure gradients from winter to summer during the early onset year of 2004 compared to that of late onset year of 2003.

Key words – Indian summer monsoon, Monsoon onset, Outgoing longwave radiation, Precipitable water, Sea surface temperature.

1. Introduction

The date of onset of the southwest monsoon over Kerala is very crucial as it marks the beginning of the rainy season for the Indian land mass. In general, the onset of the broad scale Asian monsoon occur in many stages which represent significant transitions in the large-scale atmospheric and ocean circulations over the region

(Rao 1976; Wu and Zhang 1998). The monsoon onset can be determined by the seasonal change in either surface winds or local rainfall since the monsoon climate is characterized by an annual reversal of the winds and by a contrast between rainy summer and dry winter. Each year India Meteorological Department (IMD) determines the onset date by a procedure based primarily on the daily rainfall over the stations of Kerala (Anantakrishnan and Soman, 1988). Fasullo and Webster (2003) in their recent study defined the onset and withdrawal of monsoon based on the hydrological cycle by using vertically integrated moisture transport instead of rainfall. The date of monsoon onset over Kerala has got large inter-annual variability with the mean onset date close to 1st June with a standard deviation of about 7 days. During the last 100 years, the monsoon onset over Kerala has occurred as early as 7 May and as late as 22 June.

In addition to rainfall, dramatic changes are noticed in the large-scale atmospheric structure over the monsoon region at the time of onset. Many studies in the past have indicated changes in the atmospheric conditions around the time of onset (Pearce and Mohanty, 1984; Krishnamurthi, 1985; He *et al*., 1987; Kurshaw, 1988; Krishnamurti *et al*., 1990; Yanai *et al*., 1992; Soman and Krishnakumar, 1993; Joseph *et al*., 1994; Roy Bhowmik, 2002). Pearce and Mohanty (1984) while studying the onset of monsoon over southern Asia for the years 1979 to 1982 found that the period prior to onset consists of two main phases : (*i*) a rapid intensification of the Arabian Sea winds associated with substantial increase in latent heat release following (*ii*) a moisture buildup phase over the Arabian Sea during which synoptic and meso-scale transient disturbances develop. Krishnamurti (1985) found that onset of monsoon is associated with rapid increase of the daily precipitation rate, an increase in the vertically integrated humidity and an increase in the kinetic energy of the low-level flows. Webster and Yang (1992) observed that the broad-scale monsoon circulations averaged over the region 5 - 15° N and 40 - 100° E developed from April to May, whereas the phase and amplitude varies considerably from year to year. Li and Yanai (1996) also reported the rapid transition of monsoon circulations during mid May by utilizing model analysis data for the years 1979-92. The association of monsoon onset with the 30 - 50 day oscillation has also been reported by many earlier studies (Sikka and Gadgil, 1980 and many others). Roy Bhowmik (2002) while examining vertical circulation and thermal indices during the pre-monsoon months from April to May during the individual year of delayed, early and normal onset year, found that the Tibetan anticyclone was stronger during the years of early and normal onset associated with stronger vertical zonal index.

During the year 2004 the southwest monsoon arrived in Kerala on 18th May, which is 14 days earlier than normal. Whereas, during 2003 the southwest monsoon had arrived in Kerala on 8th June with a delay of one week. The present paper discusses various aspects of contrasting features prior to and also at the time of the onset of monsoon during the early onset year of 2004 and late onset year of 2003. The data used and the methodology for this study are discussed in section 2. The evolution of different meteorological parameters prior to the onset of monsoon during 2004 and 2003 are discussed in Section 3. Finally, a summary of the results is presented in Section 4.

2. Data and methodology

The monthly and daily values of various meteorological parameters like lower and upper level winds, geopotential height, precipitable water content and mean sea-level pressure obtained from the National Centre for Environmental Prediction (NCEP) reanalysis (Kalnay *et al*. 1996) during the early onset year of 2004 and late onset year of 2003 are used in the present study. In order to study the spatial and temporal evolution of convective anomalies associated with the monsoon onset, the Outgoing Long-wave Radiation (OLR) data measured from Advanced Very High Resolution Radiometers aboard National Oceanic and Atmospheric Administration polar orbiting spacecraft (Gruber and Krueger 1984) are used for the said two years. Optimum Interpolation (OI) SST V2 data provided by the NOAA-CIRES climate Diagnostics Centre, Boulder, Colorado, USA, from their web site at http://www.cdc.noaa.gov/is also used in the present study.

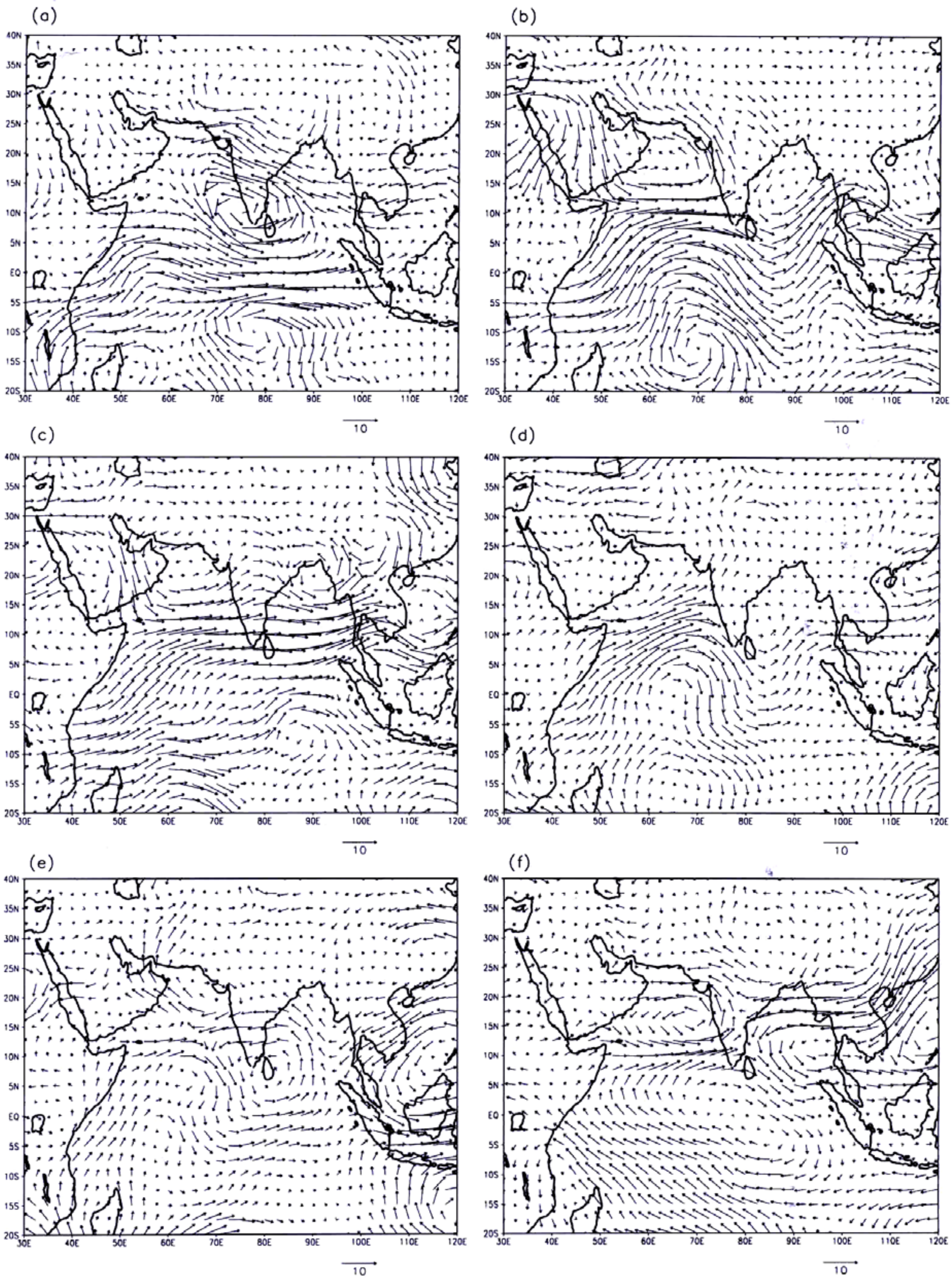
The evolution of daily, weekly and monthly values of various parameters are analysed during winter and pre-monsoon months upto the month of May during the early onset year of 2004 and late onset year of 2003.

3. Results and discussions

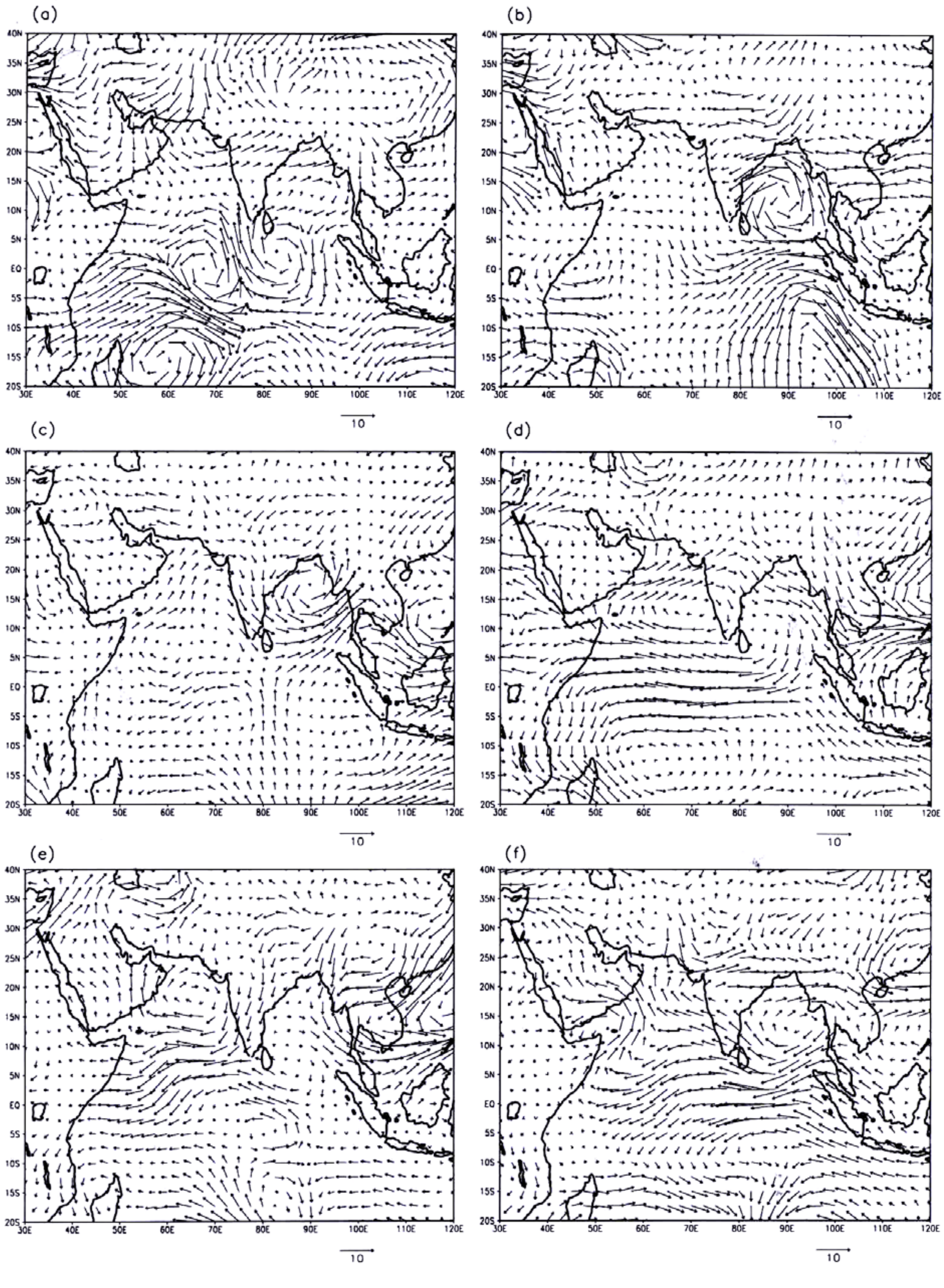
In this section the evolution of various meteorological parameters pertaining to the onset of southwest monsoon over India during 2003 and 2004 are discussed.

3.1. *Low-level flow*

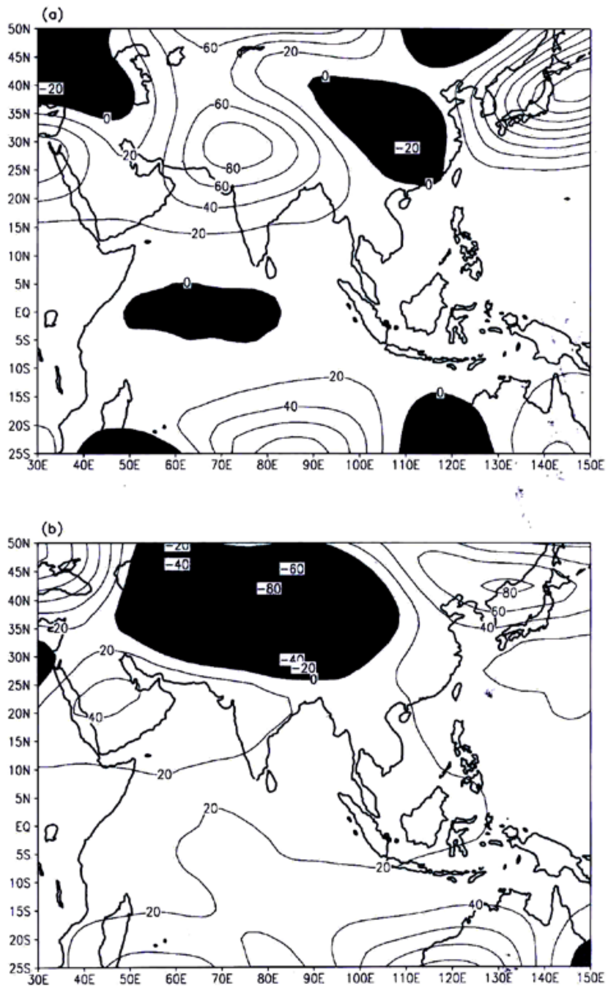
The low-level wind anomalies at 850 hPa level for the six weeks starting from 1st May to 11th June during 2004 and 2003 are shown in Fig. 1 and Fig. 2 respectively. It is seen from Fig. 1 that strong cross equatorial flow off Somali coast associated with strong anomalous southwesterly/westerly winds were seen over



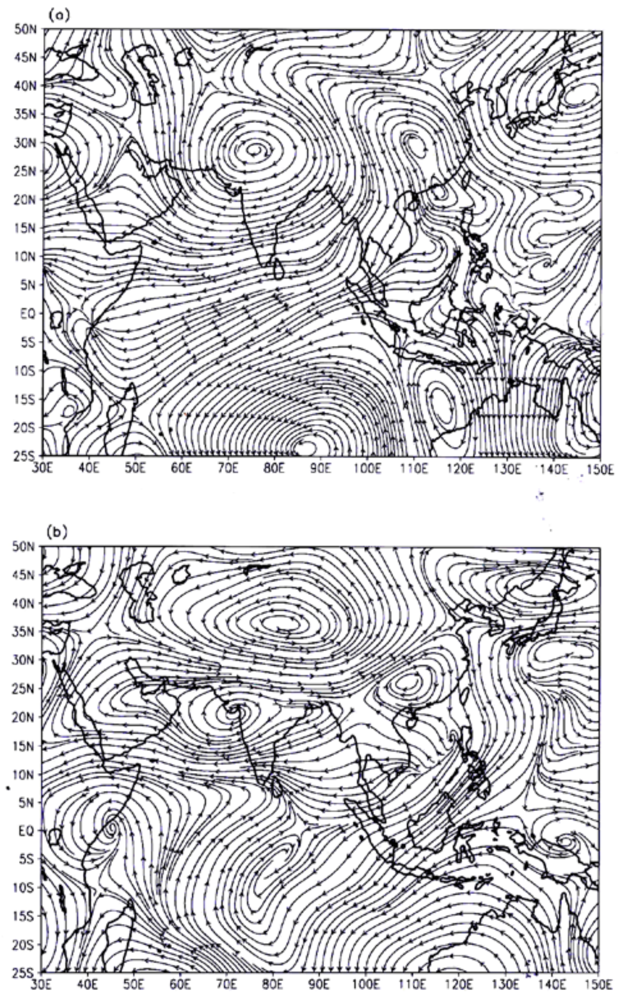
Figs. 1(a-f). Weekly 850 hPa wind anomalies in m/sec for the early onset year of 2004 during (a) 1-7 May, (b) 8-14 May, (c) 15-21 May, (d) 22-28 May, (e) 29 May - 4 June and (f) 5-11 June



Figs. 2(a-f). Weekly 850 hPa wind anomalies in m/sec for the late onset year of 2003 during (a) 1-7 May, (b) 8-14 May, (c) 15-21 May, (d) 22-28 May, (e) 29 May - 4 June and (f) 5-11 June



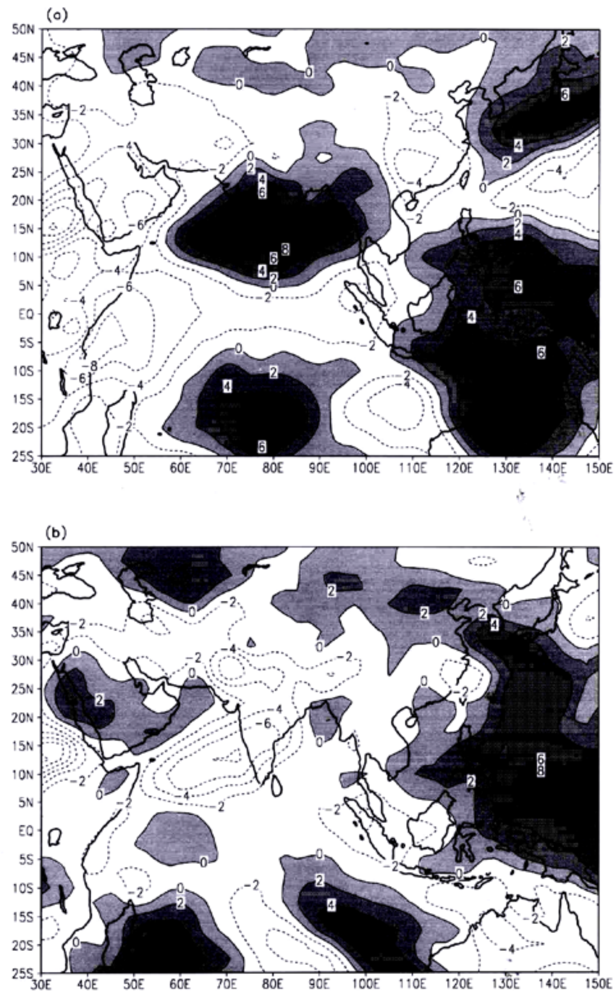
Figs. 3(a&b). 200 hPa geopotential anomalies in gpm during the month of May (a) for the early onset year of 2004 and (b) for the late onset year of 2003. Negative anomalies shaded



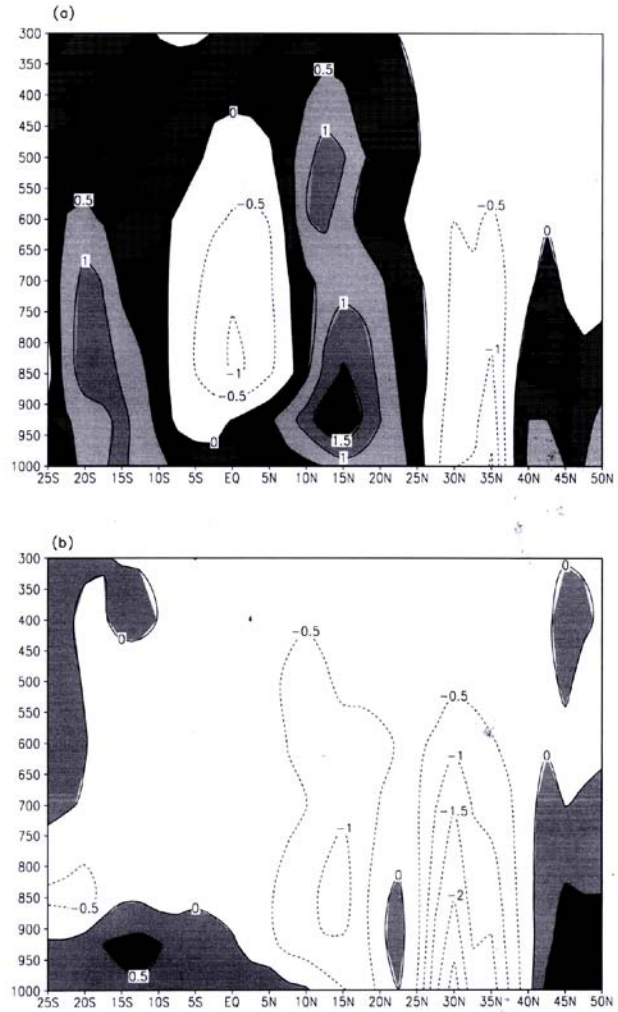
Figs. 4(a&b). 200 hPa circulation anomalies in m/sec during the month of May (a) for the early onset year of 2004 and (b) for the late onset year of 2003

the Arabian Sea from the first week of May onwards during the early onset year of 2004. It is seen from Fig. 1 that during the 2nd and 3rd week of May, 2004 [Figs. 1(b&c); prior to the onset and during the onset week], there exists anomalous cyclonic circulations over, the Bay of Bengal and the Arabian Sea. It may be mentioned here that the two systems, (*i*) severe cyclonic storm during 6 to 10 May over the Arabian Sea and (*ii*) very severe cyclonic storm during 17 to 19 May over the Bay of Bengal, strengthened the monsoon circulation, which led to early onset of monsoon during 2004. During the subsequent three weeks after the monsoon onset [Figs. 1(d-f)] the strong southwesterly/southerly flow persisted with presence of anomalous cyclonic circulations over the Bay of Bengal and the Arabian Sea regions.

On the contrary, during 2003 when the monsoon onset was late by one week, the anomalous low level flows were easterly over the Arabian Sea associated with very week cross equatorial flow during the entire month of May and also during the first week of June (Fig. 2). During the 2nd and 3rd week of May [Figs. 2(b&c)] the presence of anomalous cyclonic circulation over the Bay of Bengal is basically due to presence of a very severe cyclonic storm from 10 to 20 May. However, unlike 2004 where the system over Bay of Bengal formed at higher latitude (around 18.5° N) and was supported by strong cross equatorial flow, the system during 2003 formed at lower latitude close to 6° N and was not associated with strong cross equatorial flow over the Arabian Sea. It is seen from Figs. 2(d&e) that a strong anticyclone is present over the Arabian Sea during the subsequent two weeks,



Figs. 5(a&b). Precipitable water content anomalies in kg/m^2 during the month of May (a) for the early onset year of 2004 and (b) for the late onset year 2003. Positive anomalies shaded

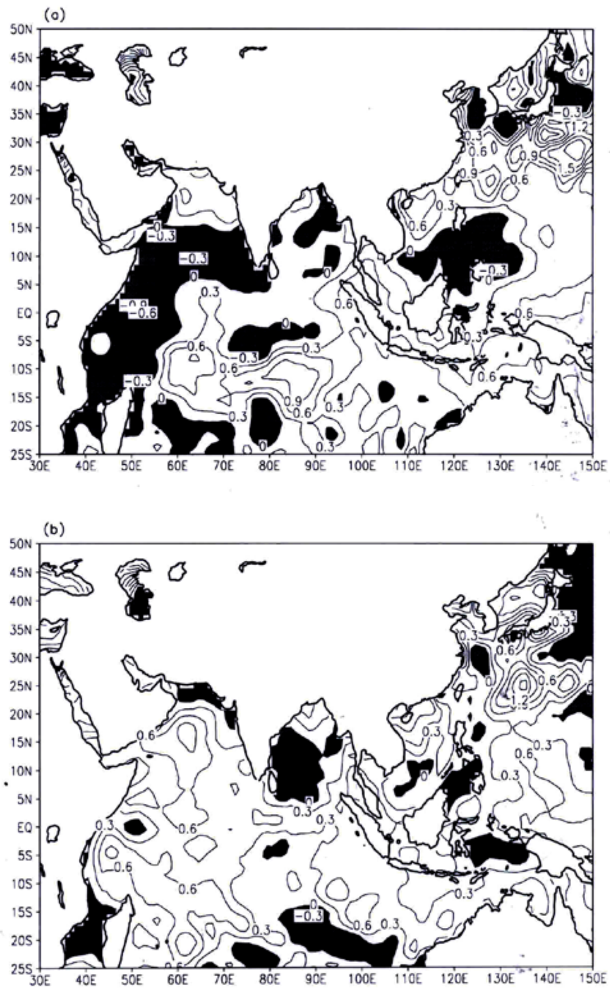


Figs. 6(a&b). Latitude-height plot of specific humidity in gm/kg during the month of May averaged over the longitude from 60° E to 90° E. (a) for early onset year 2004 and (b) for late onset year 2003. Positive values shaded

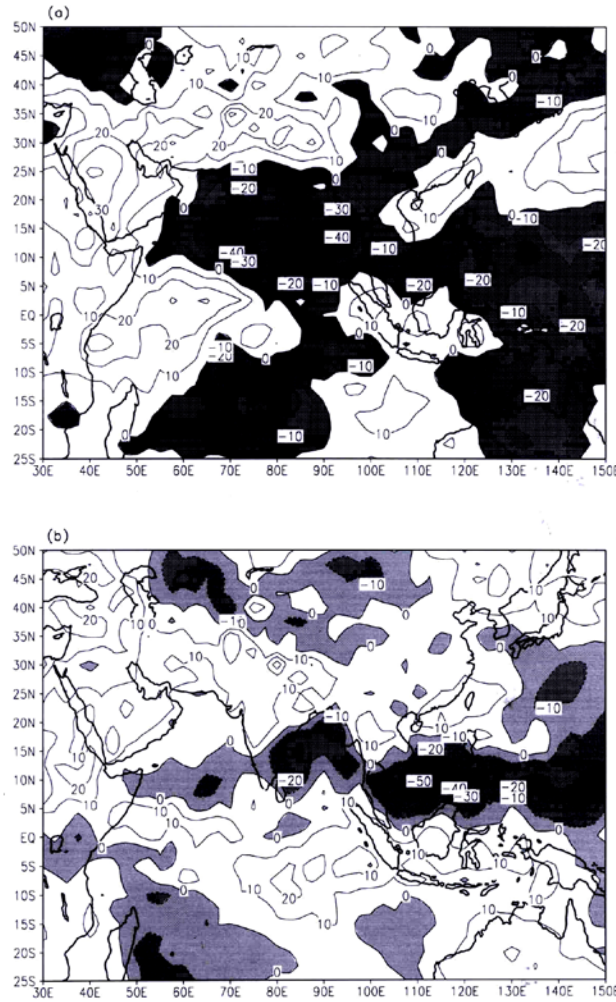
for week ending 28th May and week ending 4th June, which, perhaps, prevented monsoon to arrive over Kerala coast. As shown in Fig. 2(f), though the anticyclone over the Arabian Sea weakened during the subsequent week from 5 to 11 June, the easterly anomalies over the Arabian Sea indicate establishment of weak southwest monsoon flow during the week. However, it may be mentioned here that the composite wind anomalies from 8th June (onset date) to 14th June indicate very strong monsoon flow with southwesterly/westerly anomalies over the Arabian Sea (Fig. not shown). Thus, during 2003, the establishment of strong low-level monsoon flow over the Arabian Sea occurred very late compared to that of the early onset year of 2004 and there were no organized cross equatorial flow during the entire month of May and first week of June during the late onset year of 2003.

3.2. *Upper tropospheric geopotential/circulation anomalies*

During the onset period, transitions occur in the upper tropospheric levels also. The pronounced features are the rapid northward migration of sub-tropical westerly jet stream, establishment of strong easterly over the southern part of the country and the rapid intensification and northward migration of Tibetan anticyclone due to strong heating over the region. To examine the intensity of the anticyclone during the early and late onset year, the geopotential height anomalies at 200 hPa during the month of May for 2004 and 2003 are shown in Figs. 3(a&b). It is seen from Fig. 3(a) that during May 2004 (the year of early onset), the geopotential anomalies show positive values over large part of north-west India



Figs. 7(a&b). Sea surface temperature anomalies in °C during the month of May (a) for the early onset year of 2004 and (b) for the late onset year of 2003. Positive anomalies shaded



Figs. 8(a&b). Outgoing longwave radiation in watts/m^2 during the month of May (a) for the early onset year of 2004 and (b) for the late onset year of 2003. Negative anomalies shaded

extending eastward upto Tibetan region, which indicate stronger anticyclone associated with stronger heating of Tibetan region. On the other hand the late onset year of 2003, a large parts of Indian subcontinent including Tibetan region shows large negative geopotential anomalies associated with very weaker anticyclone [Fig. 3(b)].

The corresponding circulation anomalies at upper troposphere (200 hPa) during the month of May also shows contrasting features for the early onset year of 2004 and late onset year of 2003 [Figs. 4(a&b)]. During the early onset year of 2004 the subtropical westerly jet stream shifted quite to the north with the ridge line along around 28° N [Fig. 4(a)]. Whereas, during the late onset year of 2003 [Fig. 4(b)], the anticyclone is very weak and the subtropical ridge line is seen quite to the south along around 22° N, thereby the strong sub-tropical westerlies penetrates to more southern latitude. These results are also in agreement with that of Joseph *et al.*, (1994), where they have shown that during the onset time the subtropical westerly jet stream becomes weaker and the jet core shifts to the north and the equatorial tropical easterly jet stream gets established.

3.3. *Precipitable water content and moisture profiles*

As discussed earlier, many studies (Krishnamurthi, 1985; Soman and Krishnakumar, 1993 etc.) have indicated that humid layer deepens abruptly over the Arabian Sea and Indian Peninsula shortly before the onset of southwest monsoon. The monthly anomaly of precipitable water during the month of May 2004 and 2003 is shown in Figs. 5(a&b). It is seen from Fig. 5(a) that during the early onset year of 2004, the moist layer deepens over the Arabian Sea, Bay of Bengal and over the peninsular & central part of the country as indicated by positive anomalies over these regions. But during the late onset year of 2003 the precipitable water anomalies show large negative values over the Somali coast, Arabian Sea and the main land of India, suggesting a weak moisture flow to southern peninsula. Presence of very deep moist layers during May 2004 compared to that of May 2003 over the Indian region can also be seen from the specific humidity profiles averaged over the longitudes of 60° E - 90° E [Figs. 6(a&b)]. The specific humidity anomalies show large positive values over a deep layer (upto 300 hPa) over the Indian region from around 5° N to 25° N during 2004 [Fig. 6(a)] and it is negative during 2003 [Fig. 6(b)] over the Indian region.

3.4. *Sea surface temperature and convection anomalies*

As the monsoon brings moist air to the southern tip of India, the Sea Surface Temperature (SST) over the southern part of Arabian Sea decreases from warmer SSTs during the pre-monsoon months before the onset. The summer monsoon experiments (ISMEX-73, MONSOON-77 & MONEX-79) conducted over the Arabian Sea have revealed a dramatic drop in SST over the Arabian Sea warm pool in association with the onset vortex and/or the onset of the summer monsoon (Rao, 1990). Also with the arrival of monsoon the convective activity increases over the Arabian Sea and subsequently the convective area moves northward. The SST anomalies during 2004 and 2003 for the month of May associated with early and late onset of monsoon are shown in Fig. 7(a) & Fig. 7(b) respectively. It is seen from Fig. 7(a) that associated with early onset of monsoon during 2004 the SST anomalies show cooling of the order of 0.3° C to 1° C over the southern Arabian Sea. Also seen is the cooling over east African coast north of Madagascar associated with more upwelling due to strong cross equatorial flow as shown in Fig. 1. During the late monsoon onset year of 2003, the SST anomalies over the Arabian Sea and east African coast shows warming of the order of 0.3° to 0.6° C [Fig. 7(b)] associated with weak cross equatorial flow as shown in Fig. 2.

With the arrival of monsoon the convective activity increases over the Arabian Sea and subsequently the convective area moves northward. From the evolution of tropical convection, Joseph *et al.*, (1994) found that a narrowband of convection forms close to equator, 4 pentads before the monsoon onset and this band grows

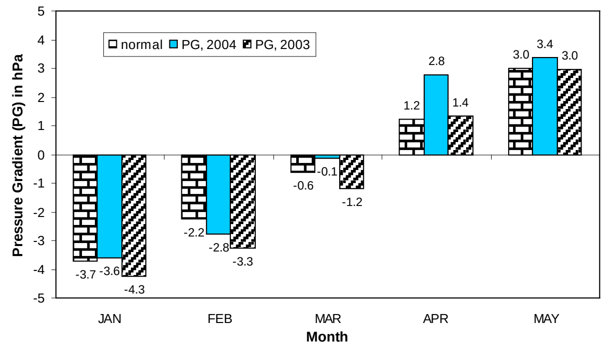


Fig. 9. South-north meridional pressure gradients in hPa from January to May (southern area chosen is from 10° N - 12.5° N, 75° E - 85° E and the northern area is from 25° N - 27.5° N, 75° E - 85° E) for the early onset year of 2004 and for the late onset year of 2003

rapidly in area and intensity and moves northward steadily resulting in monsoon onset over Kerala. The convection zones associated with early and late onset of monsoon were studied by utilizing the Outgoing Longwave Radiation (OLR) anomalies for the months of May during 2004 and 2003 is shown in Fig. 8(a) & Fig. 8(b). It is seen from Fig. 8(a) that the convective activity increases over Arabian sea, Bay of Bengal and Indian land mass particularly to the south of 25° N during the early onset year of 2004. Whereas, during late onset year of 2003, the convective activity over the Arabian Sea is quite subdued compared to that of 2004.

It is also seen here that the convective activity during the month of May over the south China Sea and western Pacific are more pronounced to that of Indian region for the late onset year of 2003 as revealed by higher negative anomalies over the south China Sea and west Pacific as compared to that over the Indian region [Fig. 8(b)]. On the contrary, during the early onset year of 2004 the convective activity is less over the western Pacific and south China Sea as compared to that over the Indian region as indicated by more negative anomalies over the Indian region compared to that over the western Pacific and south China Sea [Fig. 8(a)]. It may be mentioned here that Joseph *et al.*, (1994) found similar result from the composite analysis with rapid break-up of convection over the western Pacific about 10 days prior to the onset of monsoon.

3.5. *Reversal of pressure gradient*

One of the very important features associated with the establishment of monsoon circulation over Indian subcontinent is the reversal of pressure gradients. The reversal of pressure gradients occurs during the transition from the winter to the summer and *vice versa*. However, the reversal of pressure gradients does not occur uniformly in time throughout the atmosphere. In order to study the magnitude and timing of reversal of pressure gradients during 2004 and 2003, the monthly mean sea level pressure difference (south-north) from January to May over the Indian region during 2004 and 2003 were analysed and the results are shown in Fig. 9. The southern area chosen is bounded by 10° N - 12.5° N, 75° E - 85° E and the northern area by 25° N - 27.5° N, 75° E - 85° E. The corresponding normal pressure gradient values are also compared in Fig. 9. It is seen from Fig. 9 that the winter pressure gradients (January and February) was stronger during the late onset year of 2003 compared to that of early onset year of 2004 and also with respect to the normal as indicated by more negative values of south-north pressure difference during 2003. But during the pre-monsoon months from April to May the reverse pressure gradients are stronger during 2004 compared to that of 2003 and also with respect to normal as indicated by more positive values in 2004. During the transition month of March the smaller negative value of pressure gradients during 2004 indicate early reversal of pressure gradients compared to that of 2003 and also with respect to normal. The 10 days moving average of daily south-north pressure difference between these two regions from 1st January to 31st May indicate earlier reversal of pressure gradients (became positive for the first time between 10th and 19th March) during the early onset year of 2004 compared to that of late onset year of 2003, when the reversal of pressure gradients occurred between 22nd and 31st March. Thus, it is seen that during the early monsoon onset year of 2004 the reversal of pressure gradient occurred about two weeks earlier than that of late monsoon onset year of 2003 and also the magnitude of pressure gradient is very high during April and May for the early monsoon onset year of 2004 compared to that of the late monsoon onset year. Thus, the earlier reversal and establishment of pressure gradients may have contributed in an early onset of monsoon and the opposite may have a delayed onset.

4. Summary and conclusions

Contrasting features pertaining to early monsoon onset year of 2004 and late monsoon onset year of 2003 as brought out by the present study are as follows :

(*i*) The evolution of low-level winds at 850 hPa level shows strong cross equatorial flow off Somali coast associated with strong anomalous southwesterly/westerly winds from the 1st week of May during the early onset year of 2004. Whereas, during the late monsoon onset year of 2003 the low level wind anomalies indicate persistent presence of an anomalous anticyclone over the Arabian Sea associated with easterly anomalies over the region through out the month of May and also during the first week of June, which is also accompanied by very weak cross equatorial flow.

(*ii*) The upper level wind anomalies at 200 hPa during the month of May indicate presence of strong easterly over the southern tip of India with stronger Tibetan anticyclone and northerly position of subtropical ridge along around 28° N during the early onset year of 2004 compared to that of late onset year of 2003.

(*iii*) The convective activity during the month of May has been stronger over the Indian region during the early onset year of 2004 as compared to that of late onset year of 2003. Also, the stronger convective anomalies over the Indian region compared to that over the south China Sea and west Pacific during the early onset year of 2004, which is just the opposite for the late onset year of 2003.

(*iv*) The precipitable water in the month of May has been higher than normal over the Indian region during early onset year of 2004 alongwith very deep moist layer over the Indian region as compared to that of late onset year of 2003.

(*v*) The meridional south-north pressure gradients between southern and northern part of the country has been stronger than normal during the pre-monsoon months of April and May during early onset year of 2004 as compared to the late onset year of 2003. The reversal of meridional pressure gradient from winter to summer over the Indian region occurred about 2 weeks earlier (about 10 March) during the early onset year of 2004 compared to that of late onset year of 2003 (around 22nd March). The early reversal and establishment of strong pressure gradients may be responsible for an early onset during 2004.

Acknowledgements

The authors are thankful to the Director General of Meteorology, India Meteorological Department, New Delhi for his encouragement to carry out this research work. Thanks are also due to the NCEP for providing surface and upper level data used in the present study and also to NOAA for providing OI SST data used in the present study.

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