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Synoptic weather conditions during ARMEX

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सार – इस शोध पत्र में अंतः मौसमी समय श्रृंखला में वर्षा, पवन और मेघ पैटर्न आदि जैसी देखी गई कुछ विशिष्ट विशेषताओं के कुछ डोक्यूमेंटेशन के साथ आरमेक्स कार्यक्रम के दो चरणों के दौरान भारतीय उपमहाद्वीप पर बनने वाली प्रमुख सिनॉप्टिक मौसम की स्थितियों का संक्षेप में विवेचन इस आशा के साथ किया है कि ये इनपुटस् आगे चलकर नैदानिक अथवा पूर्वानुमानिकी अध्ययनों के लिए आरमेक्स के आँकड़ों पर कार्य कर रहे अन्य शोधकर्ताओं के लिए सहायक सिद्ध होंगे । आरमेक्स के चरण – I (15 जून – 16 अगस्त 2002) के दौरान तीव्र प्रेक्षण की पाँच अवधियाँ ऐसी थी जब भारत के पश्चिमी तट के कुछ भागों में भारी वर्षा हुई। तीव्र प्रेक्षणों की विभिन्न अवधियों के दौरान बनने वाले महत्वपूर्ण सिनॉप्टिक तंत्रों का विवेचन किया गया है। आरमेक्स के चरण – II में (15 मार्च – 10 अप्रैल 2003 और 15 मई – 15 जून 2003) में तीव्र प्रेक्षण की केवल एक अवधि ऐसी थी जो केरल में मानसून के आरम्भ और उसके तटीय कर्नाटक के कोंकण–गोवा की तरफ बढ़ने के साथ मेल खाती थी। इस शोध पत्र में इस अवधि के दौरान वर्षा के वितरण के साथ–साथ सिनॉप्टिक स्थितियों का विवेचन किया है। गतिक ऊर्जा और बर्हिगामी दीर्घ तरंग विकिरण जैसे कुछ नैदानिक प्राचालों को भी इस शोध पत्र में प्रस्तुत किया गया है।

ABSTRACT. The paper briefly describes the salient synoptic weather conditions that prevailed over Indian subcontinent during the two phases of ARMEX programme along with some documentation of some unique observed features *e.g*. rainfall, wind and cloud pattern, etc. in intraseasonal time scale with the hope that these inputs will be helpful to other researchers working on ARMEX data for further diagnostic or prognostic studies. There were five intense observation periods (IOP) during ARMEX phase-I (15 June - 16 August 2002) when some parts of West Coast of India received heavy rainfall. Important synoptic systems that prevailed during different IOPs are described. In the ARMEX phase-II (15 March - 10 April 2003 and 15 May - 15 June 2003) there was only one IOP which coincided with the onset of monsoon over Kerala and its advance into Coastal Karnataka and Konkan-Goa. The synoptic conditions along with rainfall distribution during this period are described in the paper. A few diagnostic parameters like kinetic energy and outgoing long-wave radiation are also presented.

Key words – ARMEX, Off-shore trough, Warm pool, Monsoon onset, Kinetic energy.

1. Introduction

The present paper discusses briefly the advance of the monsoon 2002 and the monthly rainfall distribution in the season, which recorded 19% below normal rainfall resulting in an All-India drought year. It presents the salient synoptic conditions that prevailed over Indian subcontinent during ARMEX phase-I in which there were five Intense Observation Periods (IOP) when some pockets of the West Coast of India experienced heavy rainfall. In the ARMEX Phase-II, there was only one IOP which coincided with the onset phase of the monsoon 2003 over Kerala and its further advance into Coastal Karnataka and Konkan-Goa. The paper also discusses important synoptic conditions and the rainfall patterns during this period as well changes in a few diagnostic parameters like kinetic energy and outgoing long-wave radiation (OLR) over Arabian Sea.

2. Data and analysis

The surface and upper-air synoptic charts for various isobaric levels during the period 15 June – 16 August 2002 and 15 May to 15 June 2003 available at Northern Hemispheric Analysis Centre (NHAC), India Meteorological Department (IMD), New Delhi, were critically examined to identify the important meteorological systems over the Indian region with particular reference to the West Coast of India. Satellite imageries and radar pictures were also examined while assessing the potential of rainfall producing weather systems. Further, using the daily rainfall data, significant rainfall distribution along the West Coast were analysed for discussing the variation in the spatial pattern of rainfall. The study has also utilized the IMD's operational regional model products for diagnostic analysis.

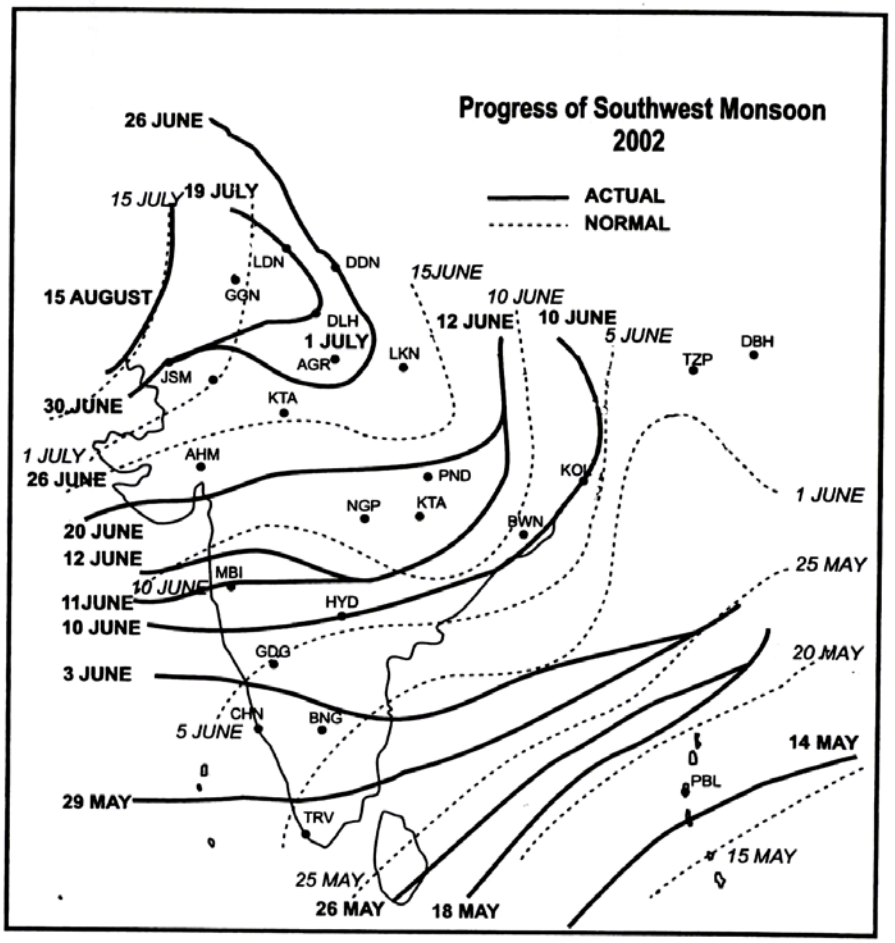


Fig. 1. Progress of Southwest monsoon 2002

3. Discussion of results

(a) *ARMEX Phase-I (15 June to 16 August 2002)*

The year 2002 was characterized by abnormal behaviour of monsoon (Gadgil, 2003; Sikka 2003 and Kalsi *et al*., 2004). The onset of the southwest monsoon over Kerala was on 29 May, 3 days earlier than its normal date 1 June. The onset phase was rather subdued, as there was no onset vortex in the form of a depression/cyclone either in Arabian Sea or Bay of Bengal. Only the synoptic system present was a trough off West Coast. This is not very uncommon as in recent years, for example 1999, 1997, 1996, 1995, 1994, 1990 and 1989 also there were no intense low-pressure systems as onset vortex during the onset of monsoon over Kerala.

By 12 June 2002, the south-west monsoon had covered peninsular India, northeastern region and some parts of east central India as per normal schedule. Its further advance was halted for a week due to absence of any favourable synoptic condition. With the formation of a low-pressure system on 20 June over northwest Bay of Bengal, which moved across central parts of the country, the monsoon advanced into central India and Gangetic plains. However, with the weakening of this low, there was a sudden breakdown in the monsoon circulation pattern, which prolonged till mid July. As a result, monsoon progress was exceptionally delayed over northern India and it covered entire India only on 15 August, a record delay of one month (Fig. 1)

As a result of abnormal behaviour in the advance of monsoon and pronounced break conditions, the rainiest month July recorded a record low rainfall with the All-India rainfall deficiency being 51.5%. From the monthly rainfall distribution (Fig. 2) it may be noted that there was a considerable improvement in the rainfall scenario during the month of August as there were a series of low pressure systems which revived the monsoon circulation pattern.

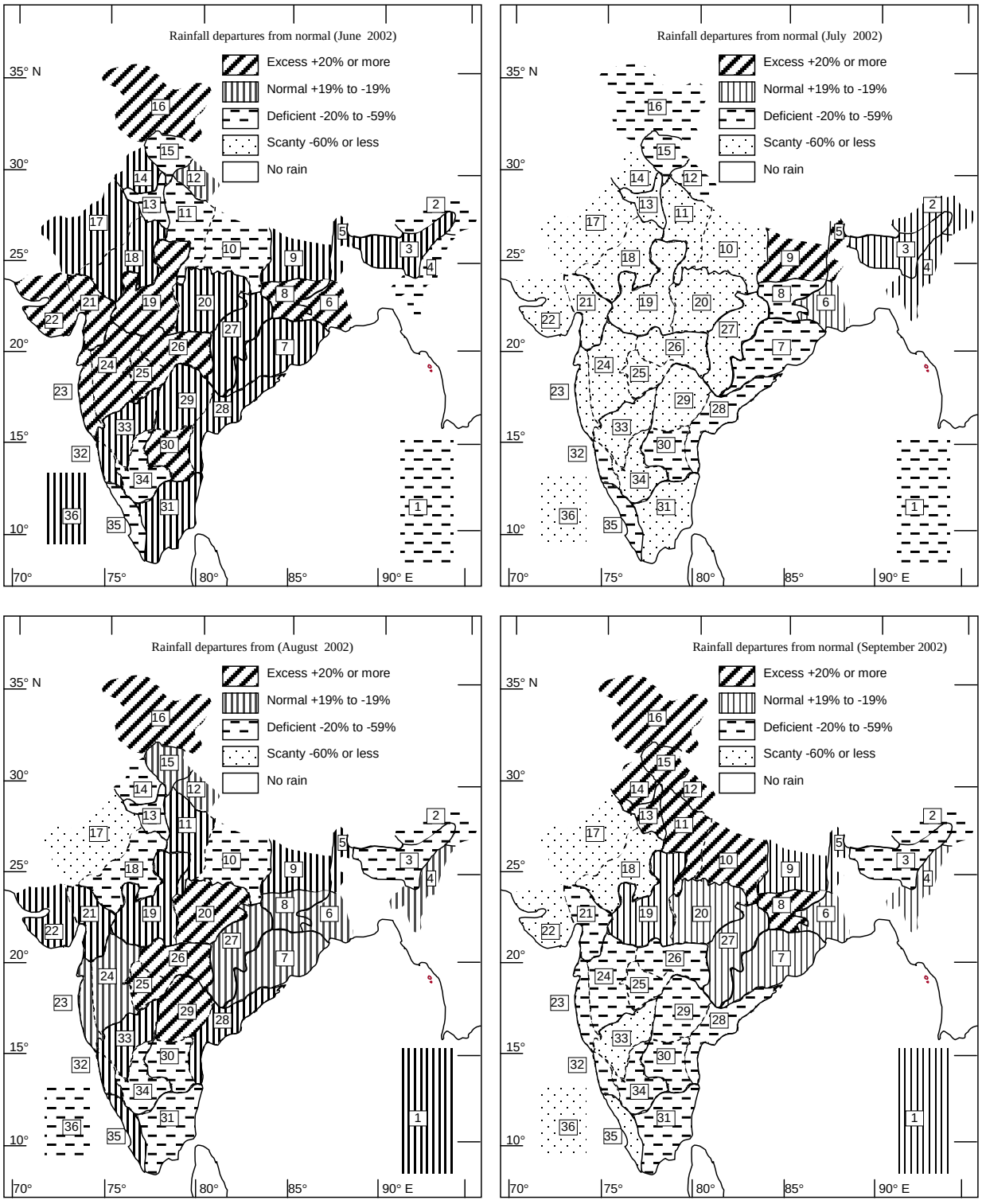
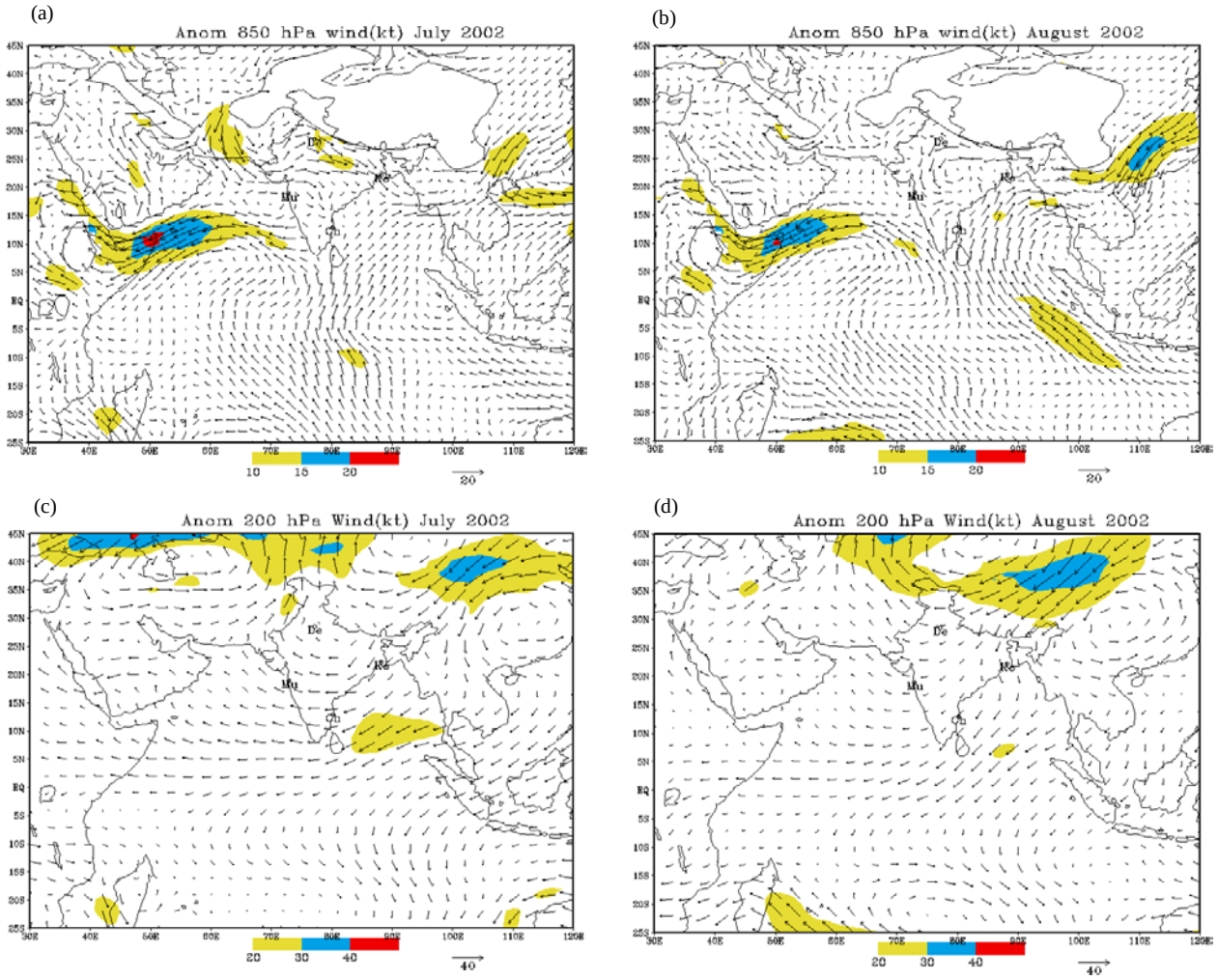


Fig. 2. Meteorological sub-division wise rainfall distribution over India on monthly time scale for June to September 2002

The wind anomaly Figs. 3(a-d) for 850 hPa and 200 hPa clearly show the recovery in the monsoon conditions during August in contrast to the weak monsoon circulation of July. Monthly anomaly wind fields at 850 hPa from



Figs. 3(a-d). Monthly wind anomaly (a) July, 850 hPa, (b) August 850 hPa, (c) July 200 hPa and (d) August 200 hPa (all for the year 2002)

Fig. 3(a), show clearly the weak monsoon situation in July with easterly anomaly of 10-20 knots over Arabian Sea(shaded area) and monsoon trough nearly absent. At 200 hPa in Fig. 3(c), strong westerly anomaly of 30-40 knots was observed over northwest India with Tibetan high shifted to southward by about 5° latitude (between 25° - 30° N) in actual wind pattern. However, during August in Figs. 3(b&d), anomaly fields of both 850 hPa and 200 hPa show recovery of the monsoon circulation with a cyclonic circulation over central India at 850 hPa, strong easterly jet and Tibetan high situated in its normal position (between 30° - 35°N) at 200 hPa.

As stated earlier, there were five IOPs during ARMEX Phase-I (15 June – 15August 2002) when parts of West Coast of India experienced heavy rainfall as listed below :

(*i*) 26-27 June

(*ii*) 17-20 July

(*iii*) 2-4 August

(*iv*) 7-11 August and

(*v*) 14-16 August.

We briefly describe the important synoptic systems that prevailed during these IOPs along with the significant rainfall amounts recorded by various stations in the meteorological subdivisions of West Coast.

(*i*) *IOP 26-28 June*

A well marked low pressure area lay over east Madhya Pradesh and neighbourhood on 25 June. The system moved westward and lay over west Madhya Pradesh and adjoining north Madhya Maharashtra on

TABLE 1

IOP 26-27 June, 2002 (rainfall in cm)

Date	Gujarat	Maharashtra	Karnataka	Kerala and Lakshadweep
26 June	Ahwa 25 Karjana 17 Sonagadh 13 Mandvi 13 Madhuban 12 Navsari 11 Baroda 11	Manjalegaon 17 Asti 17 Patoda 12 Beed 12 Gervai 11 Kaij 11	No significant amount	No significant amount
27 June	Pardi 61 Valsad 54 Bansda 33 Umbergaon 30 Navsari 26 Chikhali 22 Dharampur 21 Karjan 19 Ahwa 19 Surat 15 Mahuva 14	Bhira 32 Thane Belapur 12 Mahabaleshwar 12 Nasik 10	Agumbe 6	Palghat 4

TABLE 2

IOP 17-20 July, 2002 (rainfall in cm)

Date	Gujarat	Maharashtra	Karnataka	Kerala and Lakshadweep
17 July	Dabholi 10 Ahwa 6 Karjan 5	Khed 12 Mahabaleshwar 9 Bhira 6 Chiplun 6 Mubad 6	Agumbe 7	-
18 July	Ahwa 3 Bansada 3 Dharampur 3 Jafrabad 3	Koyana 12	Jalgalbet 5 Dharmasthla 3 Bhagamandala 3	Punalur 2
19 July	Madhuban 3	Ratnagiri 3	Agumbe 3	Kodungallur 4 Piravom 4 Kanjirapally 4
20 July	Sanrampur 10 Dohad 7 Jhalod 4 Sivsa 4 Songadh 4	Mahabaleshwar 5 Chiplun 5	Agumbe 4 Kota 3 Karkala 3	-

26 June. The associated cyclonic circulation extended upto 500 hPa level. The system weakened next day over west Madhya Pradesh and adjoining Gujarat, but the upper air cyclonic circulation persisted over northwest Madhya Pradesh and adjoining Gujarat and south Rajasthan till 29 June. During this IOP the off-shore trough lay from north Gujarat coast to Karnataka coast.

Under the influence of these synoptic systems, many stations in Maharashtra and Gujarat states received heavy to very heavy rainfall (Table 1) and the monsoon covered entire Gujarat state by 28 June. Due to the heavy rains, surface transport got disrupted for a few days in these two states. Critical examination of 3 hourly INSAT cloud imageries suggests that within the synoptic scale flow

TABLE 3

IOP 2-4 August, 2002 (rainfall in cm)

Date	Gujarat	Maharashtra	Karnataka	Kerala and Lakshadweep
2 August	--	Malkpur 7 Nandura 6	Gadag 9 Gulbarga 5 Belthangady 3	Mannarkad 3 Kayamkulam 3 Varkala 3 Haripad 3 Chengannur 3 Amini Divi 7 Minicoy 4 Agathi 3
3 August	Bayad 3	Pathardi 9 Ahmednagar 8 Sholapur 7 Ratnagiri 3	Agumbe 9 Mangalore 1 Panambur 1 Karwar 1	Vyathiri 3
4 August	Prantij 5 Balasinor 4	Goa (Panjim) 9 Thanebelapur 6 Alibagh 6 Jalgaon 4 Aurangabad 4	Agumbe 8 Karwar 5 Kollur 4 Udipi 4	Munnar 3 Vadakara 3 Amini Divi 5

TABLE 4

IOP 7-11 August, 2002 (rainfall in cm)

Date	Gujarat	Maharashtra	Karnataka	Kerala and Lakshadweep
7 August	Daman 9 Umergaon 9 Pardi 8 Valsad 8	Mahabaleshwar 28 Mumbai(SCZ) 19 Dahann 10 Bhira 9 Mumbai (Colaba) 7	Londa 8 Hidal Dam 6 Bhagamandala 5 Siddapuar 4	Vythiri 4 Munnar 4
8 August	Karjan 22 Hansoi 18 Jambughoda 14 Surat 13 Halol 11 Dharampur 10	Mahabaleshwar 19 Thane Belapur 16 Bhandup 15 Alibag 14 Murud 10 Mumbai 10 Dharavi 10 BARC 10	Kollur 7 Bantwal 4 Panambur 4 Agumbe 4	Aluva 5 Kottayam 3 Kozhikode 3 Cial Kochi 3
9 August	Umbergaon 10 Sivasa 9 Madhuban 9 Pardi 8	Mahabaleshwar 12 Ratnagiri 12 Goa 9 Vengurla 9 Bhira 8	Nilkund 19 Honavar 13 Londa 13 Kollur 12 Khanapuara 9 Srisi 8 Manchikeri 8 Kundapura 8 Dharmasthala 7 Kota 7 Puttur 7	Kannur 4 Alathur 4
10 August	Umberagaon 11 Madhuban 6	Alibag 19 Bhira 15 Ratnagiri 12 Mahabaleshwar 11 Dhanu 9 Mumbai 9 Goa 8 Dharavi 8 Thane Belapur 8 Bhandup 7	Karwar 7 Honawar 4	Vythiri 7 Aluvia 6 Kodungalur 5 Cial Kochi 5 Palakkad 5
11 August	Valsad 9 Daman 8	Mahabaleshwar 12 Bhira 8 Goa 7	Agumbe 14 Mangaloe 4	Karipur 7 Munnar 7 Perinthalmanna 6 Kozikode 5

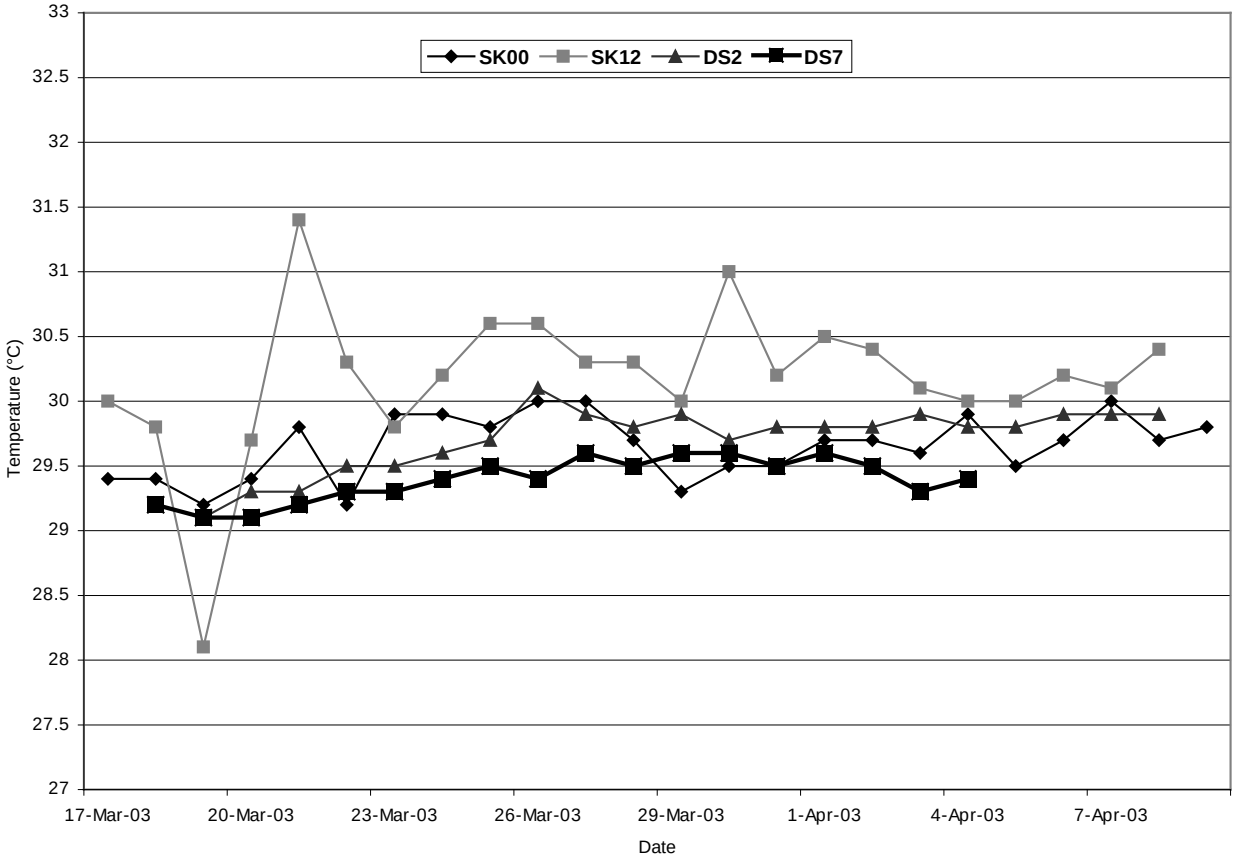


Fig. 4. The sea surface temperature (SST) data over Lakshadweep Islands region for the period 17 March to 8 April, 2003 from four different Buoys

TABLE 5

IOP 14-16 August (rainfall in cm)

Date	Gujarat	Maharashtra	Karnataka	Kerala and Lakshadweep
14 August	Ahwa 2	Mahabaleshwar 4 Bhjira 2 Matheran 2	Shimoga 2	Thalasserry 14 Perinthalamanna 7 Angdipuram 7
15 August	Idar 2	Mahabaleshwar 3	Agumbe 3 Karwar 2 Sirsi 2	Kochi 1 Karipur 1
16 August	Godhara 3 Baroda 2 Borsad 2	Mahabaleshwar 8 Bhira 4 Goa 2	Agumbe 11 Subramanya 11 Sringeri 9 Puttur 8 Karkala 7 Siddapura 7	Kodungallur 13 Kannara 11 Alpuzzha 11 Haripad 10 Kochi 10 Enamackal 8 Vaikom 8 Irrikur 7

pattern, there existed a meso-scale system over south Gujarat and north Maharashtra coast with a life time of a few hours on 26 June between 0000 UTC and 0600 UTC.

(*ii*) *IOP 17-20 July*

Weak monsoon condition prevailed during this IOP, but monsoon advanced over parts of northern India in this period. The important synoptic systems in this IOP were as follows: (a) A feeble low pressure system formed over northwest and adjoining central Bay of Bengal off Orissa coast on 17 July. The system moved inland and lay over Chattisgarh and adjoining Madhya Pradesh on 19 July and became less marked next day. As the low it resulted only in a partial recovery of monsoon. Rainfall activity along West Coast stations was generally moderate to heavy in this IOP (Table 2).

(*iii*) *IOP 2-4 August*

In this IOP, a cyclonic circulation lay between 2.1 and 4.5 km a.s.l. over east-central Arabian Sea off Maharashtra Coast and persisted there till 5 August. Another upper air cyclonic circulation extending upto mid tropospheric levels lay over central parts of Madhya Pradesh during this period. The trough of low pressure area lay off south Maharashtra – Kerala coast on 2 and 3 August and extended to entire West Coast on 4 August. These systems caused good rainfall activity along West Coast stations outside Gujarat coast in general (Table 3).

(*iv*) *IOP 7 – 11 August*

This was another IOP when monsoon was more active. The important synoptic systems were as follows : On 7 August, an upper air cyclonic circulation lay over northwest Bay of Bengal extending up to 7.6 km a.s.l., which generated a feeble low pressure area off Orissa coast on 8 August. The system moved inland next day and became less marked on 10 August. The off-shore trough from north Maharashtra coast to Kerala coast persisted in this period. These synoptic systems caused generally moderate to very heavy falls along entire West Coast (Table 4).

(*v*) *IOP 14-16 August*

This was the last IOP in which mainly Kerala and Karnataka coastal belts experienced widespread moderate to heavy rainfall (Table 5). Maharashtra and Gujarat comparatively received less amounts. The important synoptic system responsible for this IOP was the trough of low pressure off Maharashtra coast to Kerala coast.

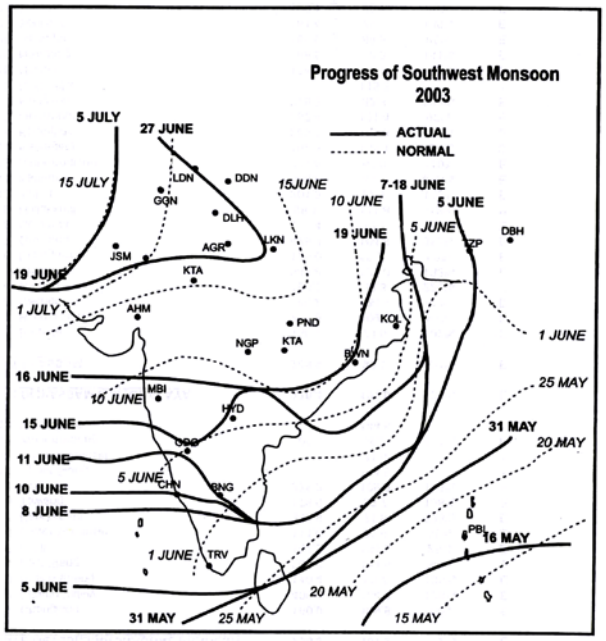


Fig. 5. Progress of Southwest monsoon 2003

(b) *ARMEX Phase-II (15 March to 10 April & 15 May to 15 June, 2003)*

During the period 15 March to 10 April 2003, which was primarily meant for observing the formation and development of warm pool over southwest Arabian Sea, synoptically there was no significant weather system. The sea surface temperature (SST) data over Lakshadweep Islands region (Fig. 4) showed about 1° C warming in the period 17 to 25 March.

During the period 15 May to 15 June, 2003, the main feature was the onset and advance of monsoon over West Coast of India. The year 2003 was characterized by late onset over Kerala (8 June) while its further progress was generally smooth without any long stagnation and it covered entire country by 5 July, 10 days before normal date (Fig. 5). The late onset over Kerala may be attributed to the formation and movement of a severe cyclonic storm over the Bay of Bengal in the period 10-19 May, which recurved and moved towards Myanmar coast. This disturbed the circulation pattern in the lower tropospheric levels over the peninsular India leading to the penetration of hot dry northwesterly flow to more southern latitudes. It may be mentioned here that Andhra Pradesh experienced prolonged severe heat wave during the period 20 May to 10 June because of this abnormal wind pattern.

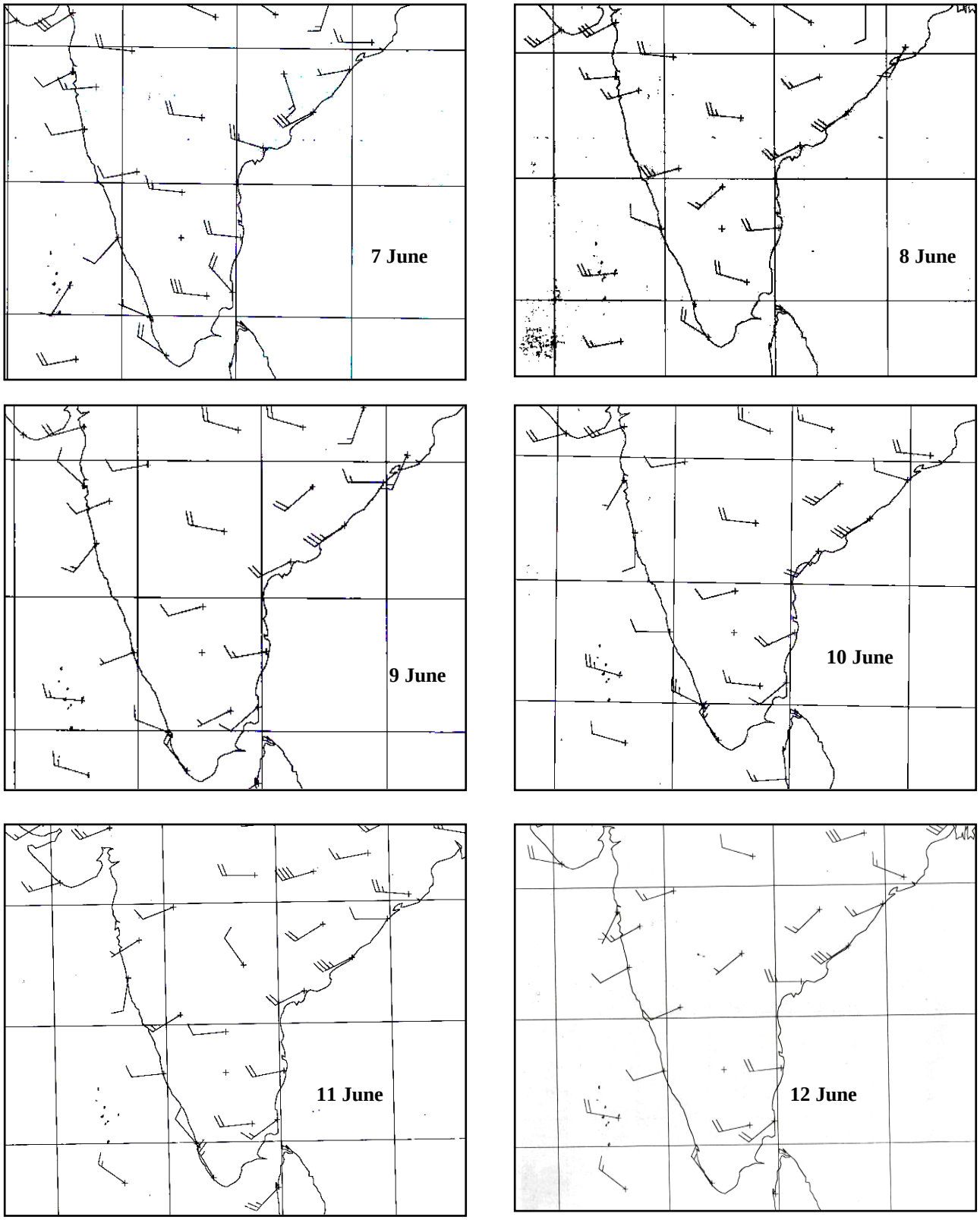


Fig. 6. Winds at 0.9 km asl for the period 7 to 12 June, 2003

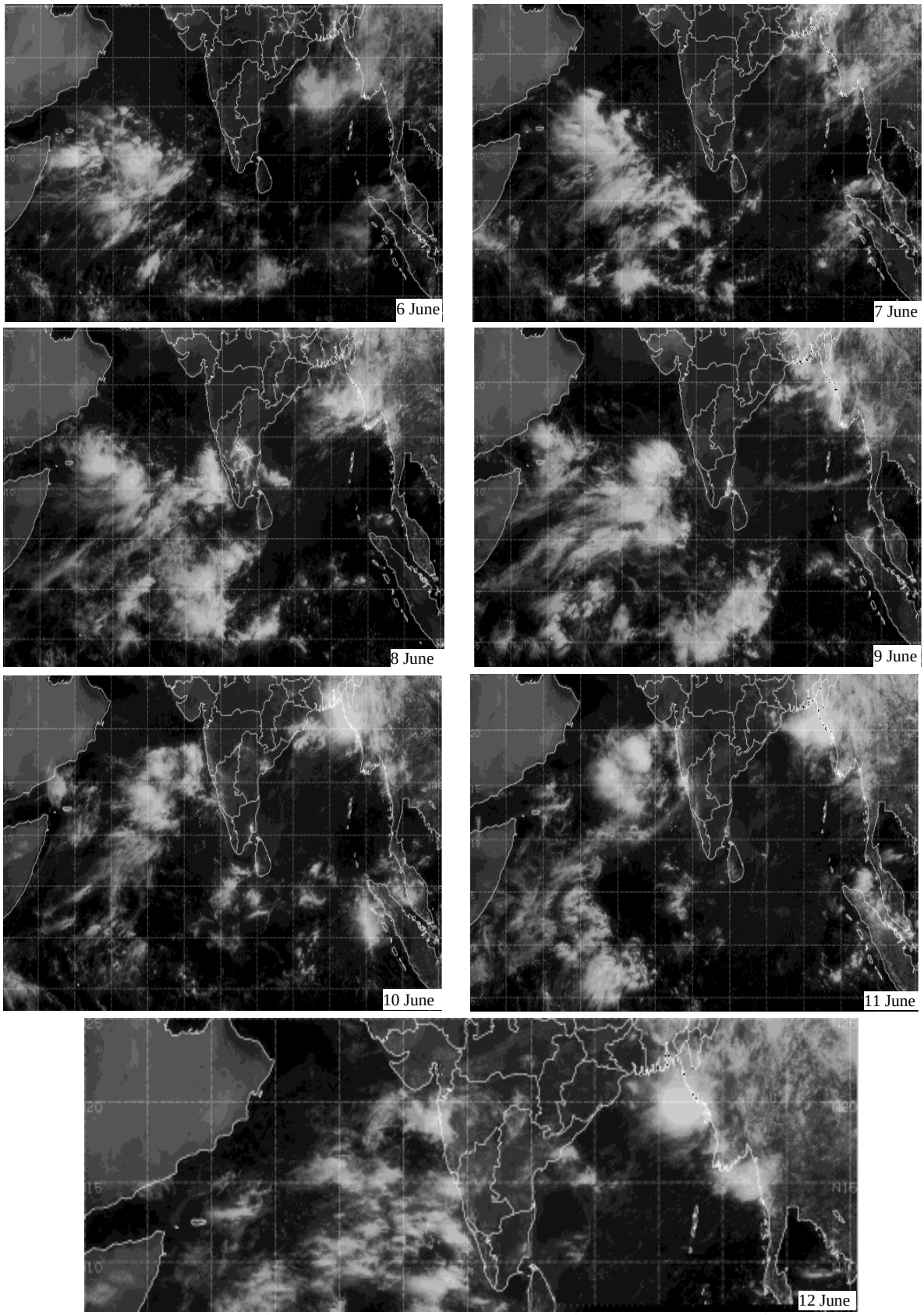


Fig. 7. Satellite pictures showing movement of convective clouds associated with progress of monsoon along west coast for the period 6-12 June, 2003

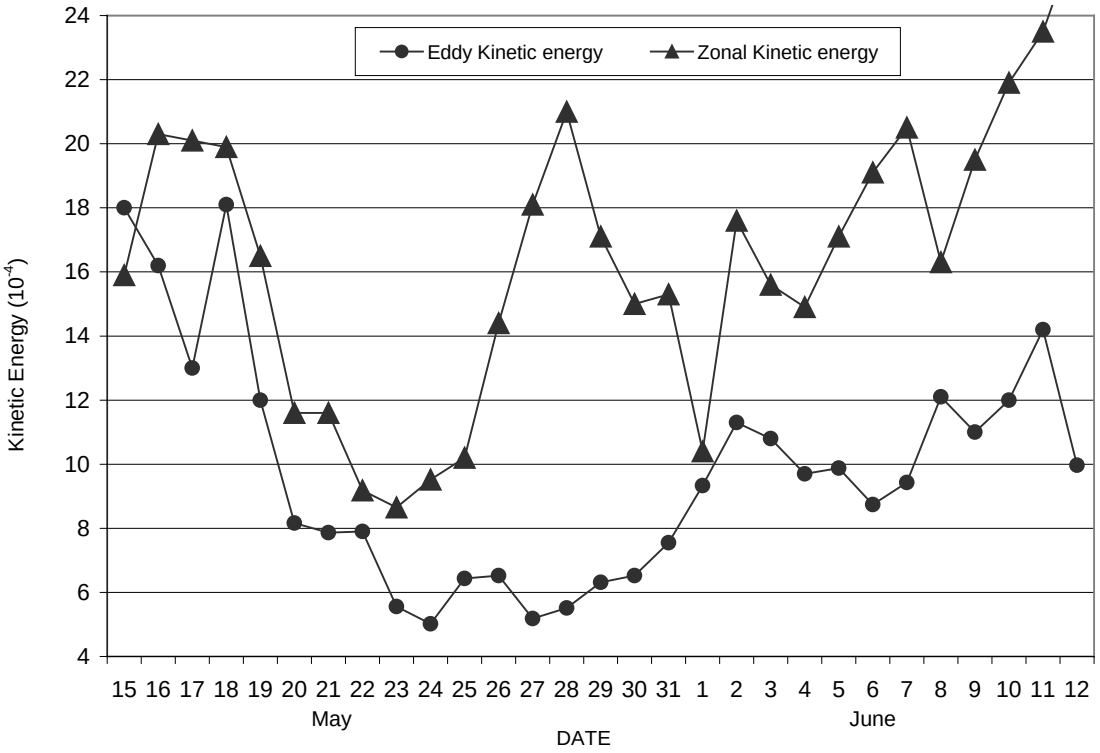


Fig. 8. The 850 hPa kinetic energy (both zonal and eddy) over the domain 50°-100° E and 10°S-20°N for the period 15 May - 12 June, 2003

TABLE 6

Weekly rainfall (mm)

Week ending	Kerala	Lakshadweep	Coastal Karnataka	Konkan & Goa
14 May 2003	26(-29%)	79 (+319%)	5(-63%)	0(-100%)
21 May 2003	275(-4%)	143 (+7%)	56 (-49%)	0(-99%)
28 May 2003	5(-93%)	1(-98%)	0(-99%)	0(-1000%)
4 June 2003	5(-95%)	11(-86%)	1(-99%)	0(-99%)
11 June 2003	42(-74%)	51(-40%)	25(-86%)	12(-88%)
18 June 2003	155(+9%)	172(+147%)	238(+5%)	169(+3%)
25 June 2003	305(+87%)	120(+62%)	633(+149%)	293(+84%)
Cumulative R/F (1 June to 25 June, 2003)	498(-9%)	356(+25%)	893(+24%)`	580(+14%)

There was only one IOP during ARMEX Phase-II programme from 7-12 June, which coincided with the onset of monsoon over Kerala. There was no intense onset vortex in the form of a depression/cyclone either in the Arabian Sea or Bay of Bengal. Only the synoptic system present was a trough off Kerala-Karnataka coast. In addition, a weak trough in the low level monsoon westerlies along West Coast could be seen on most of the days during this IOP (Fig. 6). Though there was no intense low pressure system during onset phase, monsoon was vigorous in Kerala on 8 June. Monsoon advanced into coastal Karnataka on 10 June and to Goa on 11 June. It further advanced into Ratnagiri on 15 June and covered entire Konkan-Goa coast on 16 June. During this IOP, initially Kerala had good rainfall which subsequently extended upto Konkan-Goa coast (Table 6). Satellite cloud imageries indicate northward propagation of cloud belt from 5° - 10° N up to 20° N off Mumbai coast in a

week's time (Fig. 7). However, low level westerlies did not show any significant strengthening during this IOP. The 850 hPa kinetic energy (both zonal and eddy) over the domain 50° - 100° E and 10° S - 20° N showed a gradual increase in its magnitude from 27 May onwards (Fig. 8) (Roy Bhowmik, 2002). Even the available SST data did not show any sudden fall in Lakshadweep area with the onset phase. Analysis of daily OLR data from Kalapana satellite showed northeastward propagation of low OLR values from west Arabian Sea to east Arabian Sea in the period 8 June to14 June.

All these suggest that the monsoon onset in 2003 was a gradual process, no burst could be identified either in the kinetic energy or fall in SST values. However, the West Coast received good rainfall probably in association with the off-shore trough and the mild trough in the low level monsoon westerlies.

4. Conclusions

The study has examined the various synoptic conditions that prevailed during ARMEX programme. The salient findings are as follows :

(*i*) In 2002, southwest monsoon showed abnormal behaviour in terms of its advance as well as rainfall activity. The country witnessed prolonged break/weak monsoon conditions resulting in a record deficiency in July rainfall and All-India drought.

(*ii*) During ARMEX Phase-I programme, there were five IOPs, 1 each in June and July and 3 in August. The June IOP was the most intense one as many stations in Maharashtra and Gujarat recorded very heavy rainfall (13 cm and more). The main synoptic system during this IOP was the well marked low pressure system which moved nearly westward from central parts of Madhya Pradesh to Gujarat and adjoining north Maharashtra. Off-shore trough was mainly confined to Gujarat and Konkan-Goa coast. As such, coastal Karnataka and Kerala didn't receive any heavy amounts in this IOP.

(*iii*) Monthly anomaly wind fields at 850 hPa show clearly the weak monsoon situation in July with easterly anomaly of 10-20 knots over Arabian Sea and monsoon trough nearly absent. At 200 hPa, strong westerly anomaly was observed over northwest India with Tibetan high shifted to southward by about 5° latitude (between 25° – 30° N). However, during August, the anomaly fields show recovery of the monsoon circulation.

(*iv*) During ARMEX-II, there was one IOP (7 - 12 June, 2003) which coincided with the onset phase of monsoon over Kerala. In 2003, monsoon advanced over Kerala on 8 June, a delay of one week. No onset vortex formed during this phase, although, a trough of low pressure off Kerala-Karnataka coast was seen in the sea level; in addition a mild trough was present in the lower level wind field (upto 2.1 km a.s.l.). The 850 hPa kinetic energy field showed a gradual increasing trend from 27 May, but no sudden jump in its magnitude was seen during the onset phase. Satellite cloud imageries showed the northward propagation in the maximum cloud zone from near equator to 20° N latitude belt in the Arabian Sea in a week's time. The OLR data showed northeastward shift of low OLR values from western Arabian Sea to eastern Arabian Sea during advance phase of monsoon along West Coast.

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