

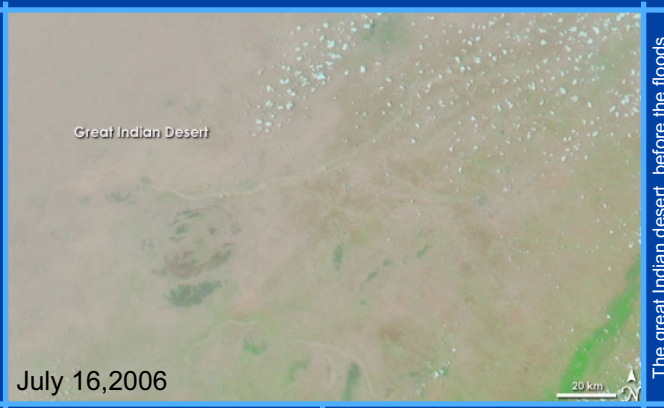


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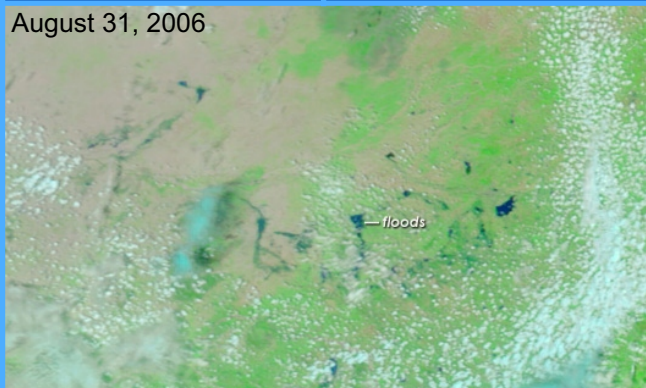
# Monsoon<sup>2006</sup> A Report

N. Jayanthi, M. Rajeevan,  
A. K. Srivastava, Sunitha Devi,  
S. K. Roy Bhowmik and H. R. Hatwar



The great Indian desert before the floods

July 16,2006



The great Indian desert after the floods

August 31, 2006

Floods  
in Northwestern India



NATIONAL CLIMATE  
CENTRE



Source :BBC, UK

IMD Met. Monograph No. : Synoptic Meteorology No. – 4 / 2006



GOVERNMENT OF INDIA  
INDIA METEOROLOGICAL DEPARTMENT

# *Monsoon*<sup>2006</sup> *A Report*

N.Jayanthi, M.Rajeevan,  
A.K.Srivastava, Sunitha Devi,  
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**National Climate Centre  
India Meteorological Department  
Pune**

# Monsoon<sup>2006</sup> *A Report*

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# Monsoon<sup>2006</sup> *A Report*

## **Preface**

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Every monsoon is unique. The 2006 monsoon was not an exception. The 2006 southwest monsoon was statistically a normal monsoon with the seasonal rainfall of 100% of its Long Period Average (LPA). However, rainfall was unevenly distributed in space and time. After an early onset and active spell of about two weeks, monsoon remained weak and subdued till the third week of July. By 26 July, the cumulative seasonal rainfall was deficient by 14%, thus causing apprehensions about the impending drought conditions over the country. But the active monsoon spells during the first half of August changed the rainfall situation. Thereafter, the active monsoon conditions continued unabated except for a brief period. However, the activity was confined only across central India, especially over the western parts. Elsewhere, dry conditions continued most of time, thus contributing to moderate drought conditions in about one third of the districts over the country.

There were many interesting aspects during the season, which need more in-depth study. During the season, as many as 16 low pressure systems formed. In August, 4 monsoon depressions formed over Bay of Bengal, which is a record for maximum number of depressions for the month of August. Is it a signal of reversal of the observed downward trend in the frequency of monsoon depressions during the monsoon season? What has caused the complete revival of monsoon by August and the continuation of active conditions almost unabated for 40 days? The season also witnessed many severe rainstorms causing severe but localized floods over Gujarat, Rajasthan, and Maharashtra. Is it a part of the observed increasing trend in intense rainfall events during the monsoon season? Is it caused due to global warming?

This met monograph is second in the series of monographs dedicated to discuss various aspects of the southwest monsoon season. In this compilation, the authors have discussed many facets of monsoon like onset, withdrawal, important synoptic features, rainfall statistics, large scale circulation anomalies and short-range and long range forecasts. Some critical grey areas, where more research work is required are also highlighted. I am sure this monograph will help the readers to have valuable and authentic information on

2006 monsoon season and it provides the basic material for taking up further research studies.

I congratulate the authors for their valued contribution to this report. For the compilation of this report, many research inputs were also received from NCMRWF, Noida and IITM, Pune which are appreciated and duly acknowledged. I also appreciate the efforts made by the National Climate Centre, in bringing out this valuable report in a short time.

**R.C. Bhatia**

Director General of Meteorology  
India Meteorological Department

# Monsoon<sub>2006</sub> *A Report*

## Chapter – 1

### **Onset, Advance and Withdrawal of Southwest Monsoon**

#### **Monsoon Onset phase**

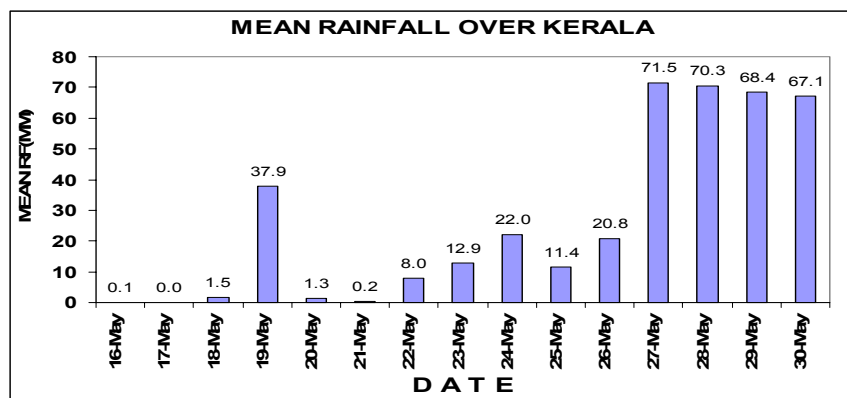
The onset phase of monsoon 2006 was characterized by an early arrival of monsoon over south Peninsula. Monsoon covered the entire country on 24 July, with a delay of about 9 days. Monsoon advanced over Kerala on 26 May, almost a week prior to its normal date. Joseph et al. (2005) suggested that onset over Kerala should be declared not only based on rainfall but additional factors like build up and strength of the monsoon westerlies and the northward movement of Tropical Convergence Zone (TCZ). By considering the associated circulation aspects, in 2005, IMD adopted new criteria for declaring the monsoon onset over Kerala. These criteria replace the criteria of Ananthakrishnan et al. (1967), which was in operational use in IMD for many years. The IMD's new criteria for declaring monsoon onset over Kerala based on rainfall, wind field and OLR are:

**Rainfall:** If after 10<sup>th</sup> May, 60% of the available 14 stations enlisted ( Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Talassery, Kannur, Kasarcode, and Mangalore) report rainfall of 2.5 mm or more for two consecutive days, the onset over Kerala be declared on the second day, provided the following criteria are also in occurrence.

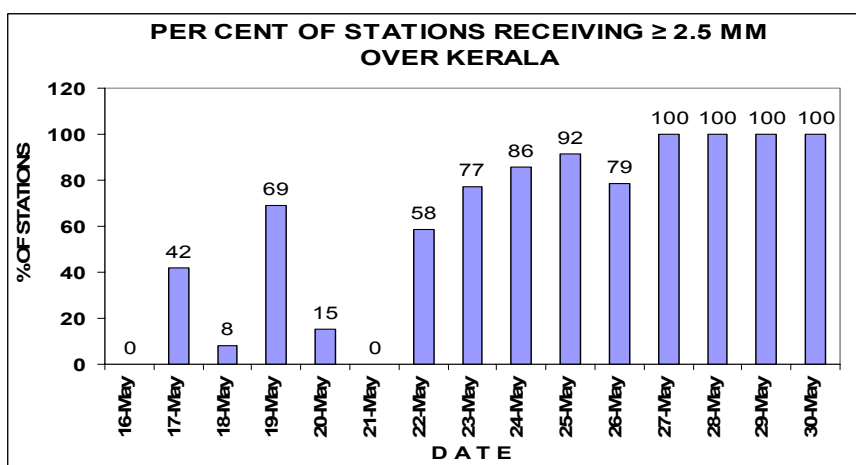
**Wind Field:** Depth of westerlies should be maintained up to 600 hPa, in the box equator to Lat 10<sup>o</sup>N and Long 55<sup>o</sup> E to 80<sup>o</sup> E. The zonal wind speed at 925 hPa over the area bounded by Lat 5<sup>o</sup>N-10<sup>o</sup>N, Long 70<sup>o</sup>-80<sup>o</sup>E should be at least of the order of 15-20 knots.

**OLR:** INSAT derived OLR value should be below  $200 \text{ Wm}^{-2}$  in the box confined by Lat  $5\text{-}10^{\circ}\text{N}$  and long  $70\text{-}75^{\circ}\text{E}$ .

Following the above mentioned criteria, IMD declared the monsoon onset over Kerala on 26 May 2006. Fig.1.1. shows the variation of mean rainfall and per cent of stations recording 2.5 mm or more out of the 14 stations mentioned above. Since 23 May, mean rainfall over Kerala was more than 10 mm.



**Fig.1.1 : a) Mean rainfall (mm) over Kerala (average of 14 stations)**

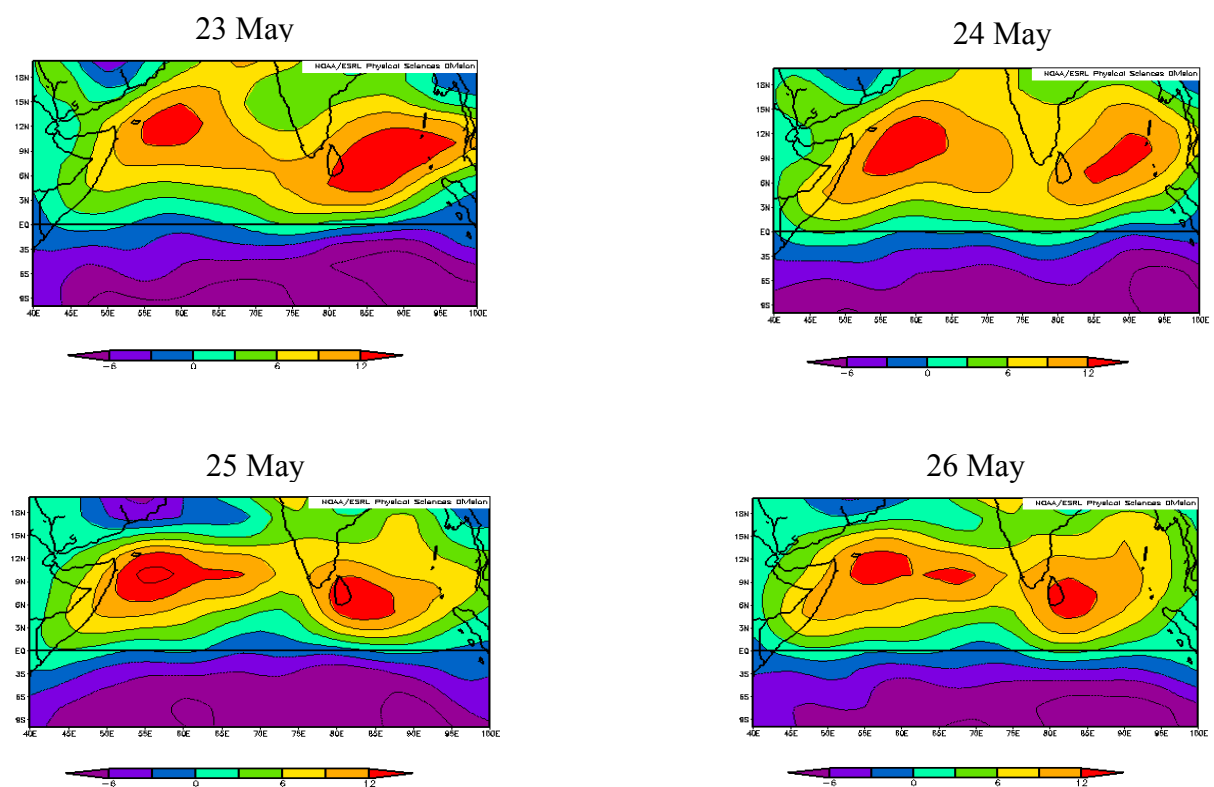


**Fig.1.1 : b) Per cent of stations reporting 2.5 mm or more.**

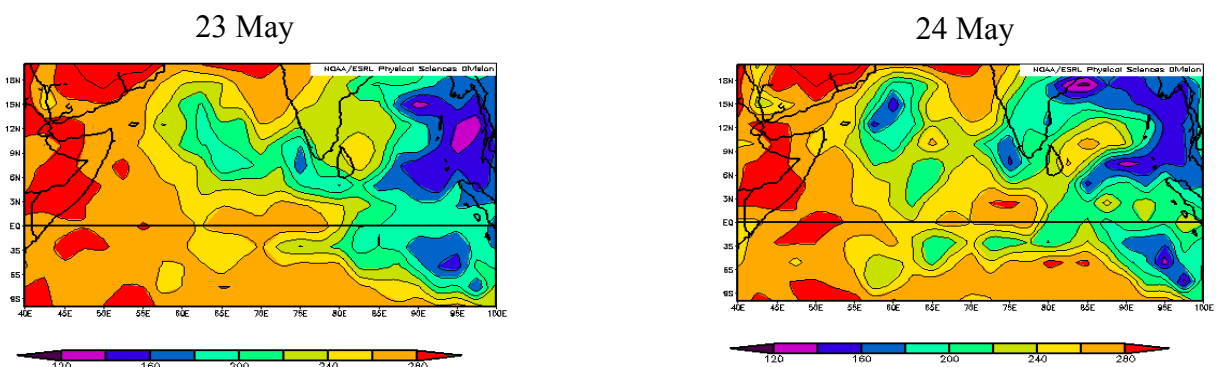
There was moderate rainfall activity over Kerala and neighborhood from 22 May itself. From 23 May onwards, more than 60% of stations were reporting 2.5 mm or more rainfall. On 26 May, 79% of the stations reported rainfall of 2.5 mm or more.

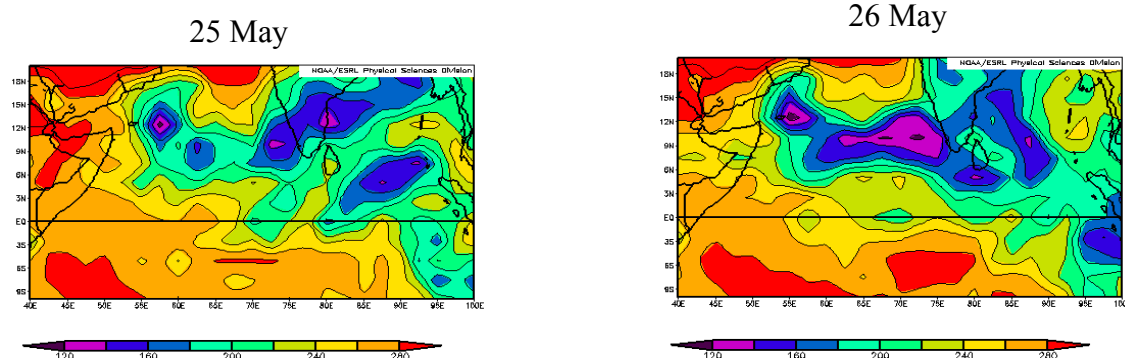
Fig.1.2 shows the zonal wind speed at 925 hPa from 24 to 27 May 2006 and Fig.1.3 shows the OLR values for the same period.

From 23 May, wind speed over the south Arabian sea started increasing and the zone of maximum wind speed started extending towards the south east Arabian sea. By 26 May, an east west zone of high wind speeds was established along and around 10°N with maximum wind speed exceeding 12 m/sec. Fig.1.3 shows the spatial distribution of OLR from 23 to 26 May 2006. On 23 and 24 May, OLR values over the south Arabian sea were more than 200 Wm<sup>-2</sup>. By 25 May, low OLR values less than 200 Wm<sup>-2</sup> were observed off the Kerala coast. However, by 26 May, an east-west zone of OLR values less than 200 Wm<sup>-2</sup> was observed, indicating the northward movement and establishment of maximum convergence zone roughly along 10°N. IMD declared the monsoon onset over Kerala on this day (26 May). On subsequent days, rainfall activity over Kerala increased substantially as shown in Fig.1.1.



**Fig.1.2 : Zonal wind (m/sec) at 925 hPa from 23 to 26 May 2006**

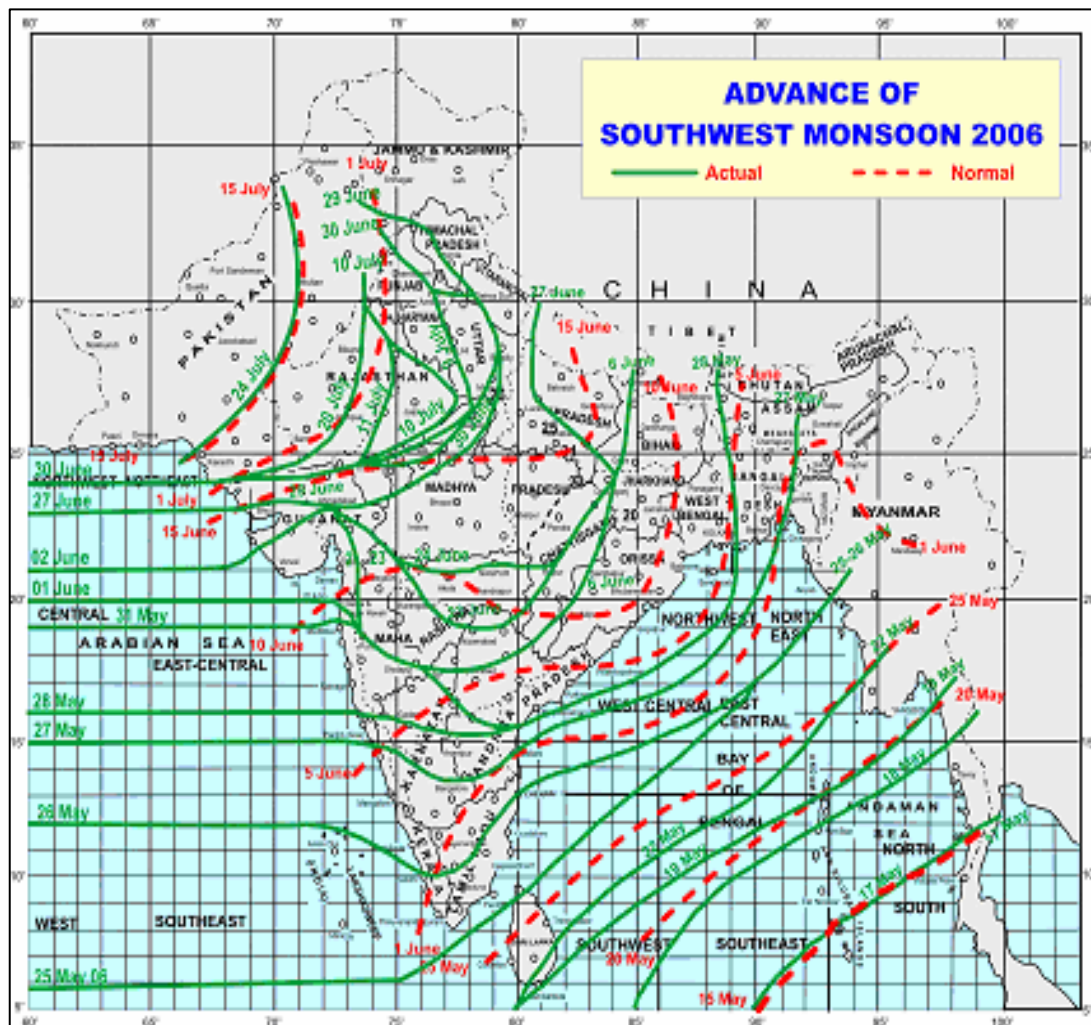




**Fig.1.3: Outgoing Long wave Radiation ( $Wm^{-2}$ ) from 23 to 26 May 2006**

### Monsoon Advance phase

Southwest monsoon advanced over the south Andaman Sea and parts of the southeast Bay of Bengal on 17 May. It advanced over the remaining parts of the southeast Bay and parts of southwest and east-central Bay by 22 May. Monsoon arrived over Kerala on 26 May, almost a week prior to the normal date. As on 31 May, the northern limit of monsoon passed through Lat.19°N/Lon. 60°E, Lat.19°N/Lon. 70°E, Mumbai, Pune, Sholapur, Kurnool, Ongole, Lat.17°N/Lon.85°E, Lat.20°N/Lon. 89°E and Gangtok. It advanced further steadily and covered the western parts of Peninsular India and northeast India by 6 June. The advance along the west coast was rapid in association with an off shore trough along the west coast. As on 6 June, the northern limit of monsoon passed through Lat. 22°N/ Long. 60°E, Lat 22°N/ Long. 68°E, Porbandar, Rajkot, Ahmedabad, Baroda, Pune, Sholapur, Hyderabad, Jagdalpur, Raigarh, Daltonganj and Raxaul. Subsequently, there was a prolonged hiatus from 7 June to 22 June, caused by the intrusion of mid-latitude westerlies. During the last week of June, it advanced further, as a weak current over the remaining parts of Peninsula, central India and also the northern parts of the country outside Haryana, Punjab and Rajasthan. By the end of June, monsoon covered most parts of north Arabian Sea, entire Gujarat state, some parts of east Rajasthan, entire west Madhya Pradesh, some parts of west Uttar Pradesh, entire Himachal Pradesh and parts of Punjab. As on 30 June, northern limit of monsoon passed through Lat. 24°N/ Long. 60°E, Lat. 24°N/ Long. 68°E, Udaipur, Jhalawar, Gwalior, Bareilly, Dehra Dun, Ambala and Amritsar. The second hiatus lasted for 8 days (1 to 8 July). Southwest monsoon which had covered up to some parts of northwest India by 30 June, further advanced into most parts of west Uttar Pradesh and some parts of Haryana including Delhi on 9 July. It covered the entire east Rajasthan and some more parts of west Rajasthan by 11. It advanced into some more parts of west Rajasthan on 20. Southwest monsoon covered the remaining parts of Arabian Sea and of west Rajasthan and thus the entire country on 24 July, about 9 days later than its normal date. The isochrones of onset date for 2006 are shown in Fig. 1.4.

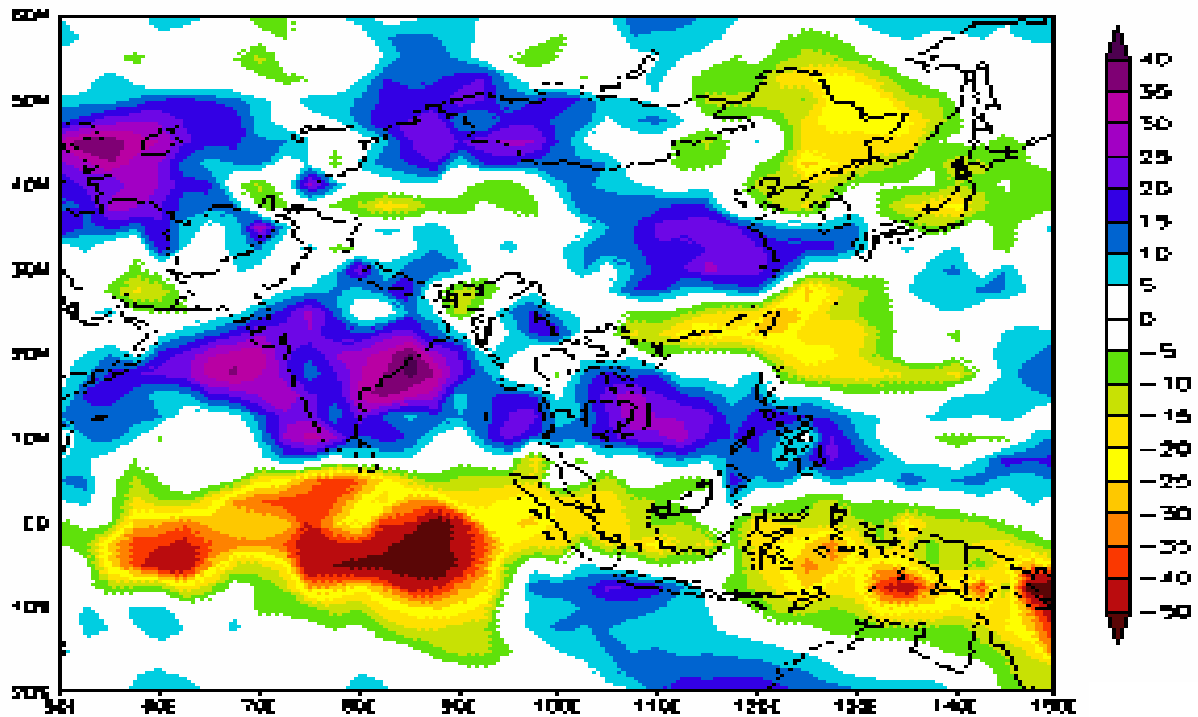


**Fig.1.4 : Progress of Southwest monsoon**

### **The Hiatus: 7-22 June 2006**

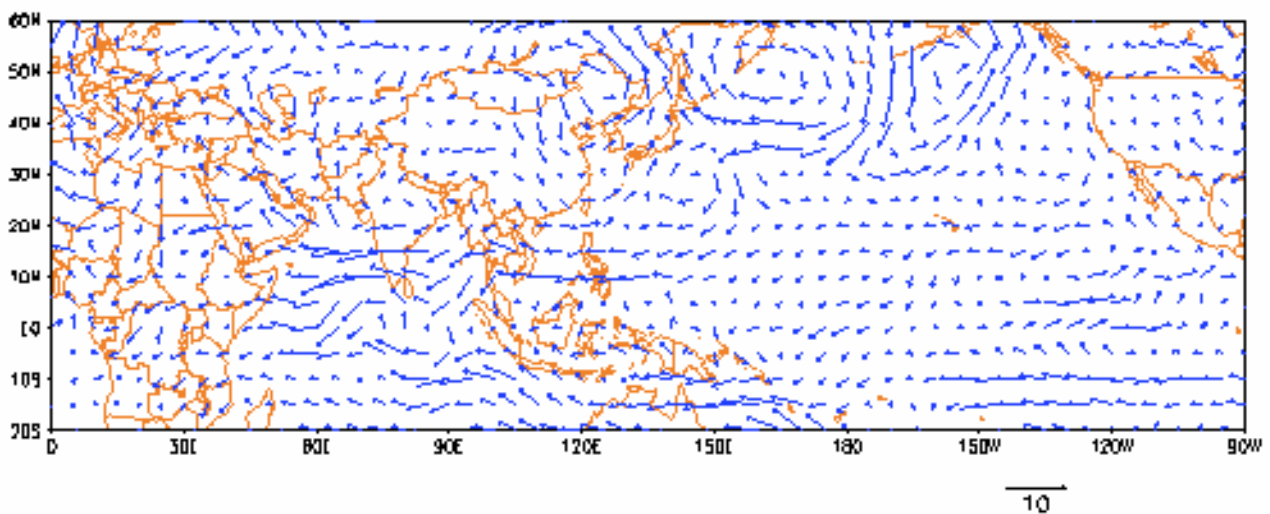
After the onset spell of about two weeks, there was a prolonged hiatus in advancement of monsoon across the country from 7-22 June 2006. The circulation anomalies during this hiatus period are discussed below.

Fig.1.5 shows the OLR anomaly plot for the period 7-22 June 2006. The plot was created using the NOAA OLR data. The plot clearly shows the suppressed convection (positive OLR anomalies) over the Indian region. There is enhanced convection over equatorial south Indian Ocean, especially over the southeast Indian Ocean. Above normal convection is also observed over the NW Pacific.



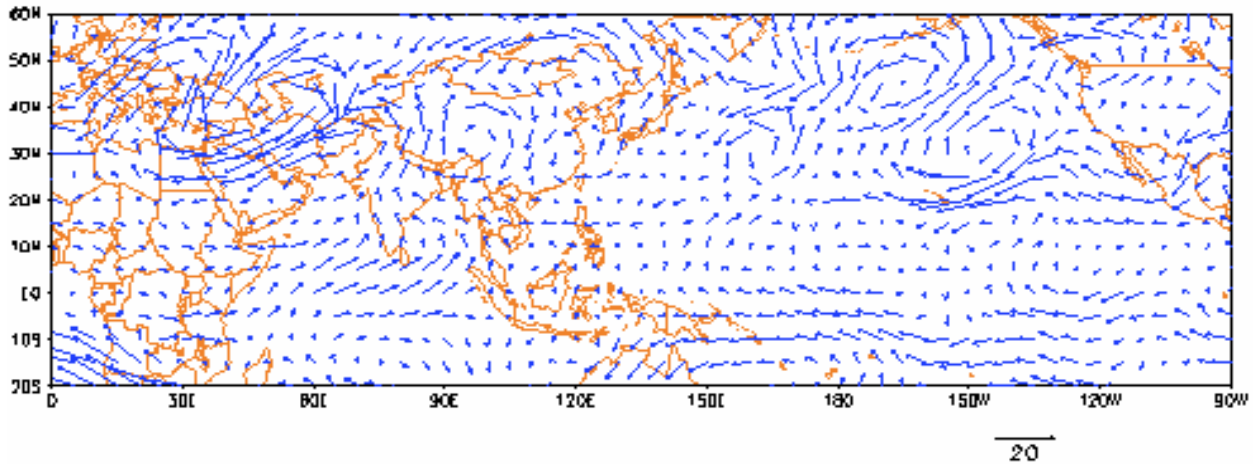
**Fig.1.5: OLR anomalies ( $Wm^{-2}$ ) during the period 7-22 June 2006**

Fig.1.6 shows the 850 hPa wind anomalies during the hiatus period, which shows anomalous cyclonic circulation over the equatorial Indian Ocean, suggesting the oceanic TCZ was very active. Over the Indian region, anomalous anticyclonic circulation prevailed with strong easterly anomalies over south Arabian Sea. This feature represents weak monsoon flow and suppressed rainfall activity over the Indian region.

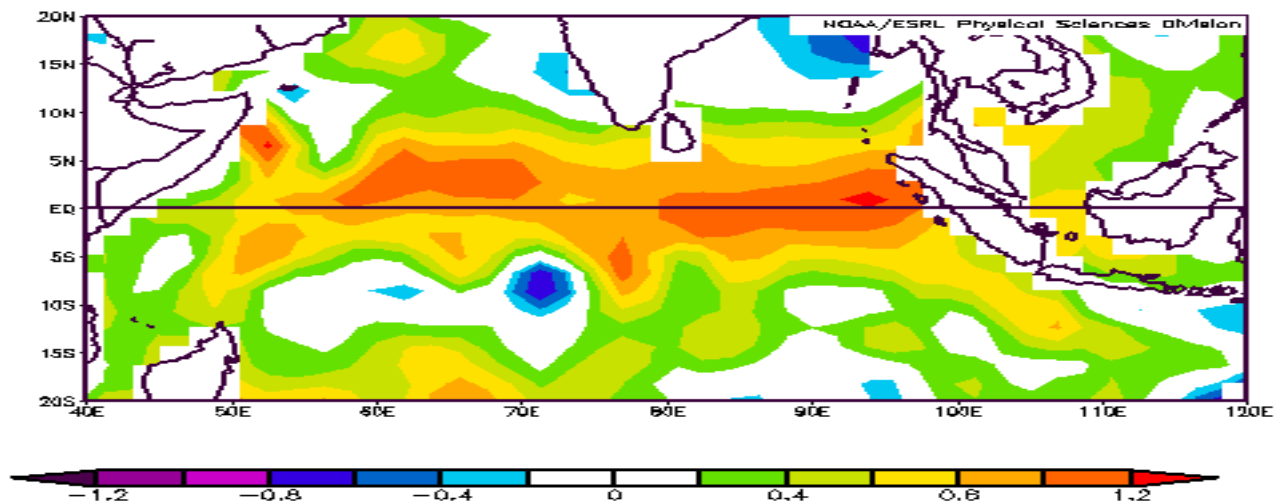


**Fig.1.6: Wind anomalies at 850 hPa during 7-22 June.**

Fig.1.7 shows the wind anomalies at 200 hPa during the hiatus period of 7-22 June 2006. The plot shows anomalous westerlies over the equatorial Indian Ocean and south Arabian sea. However, the sub-tropical anticyclones were stronger than normal.

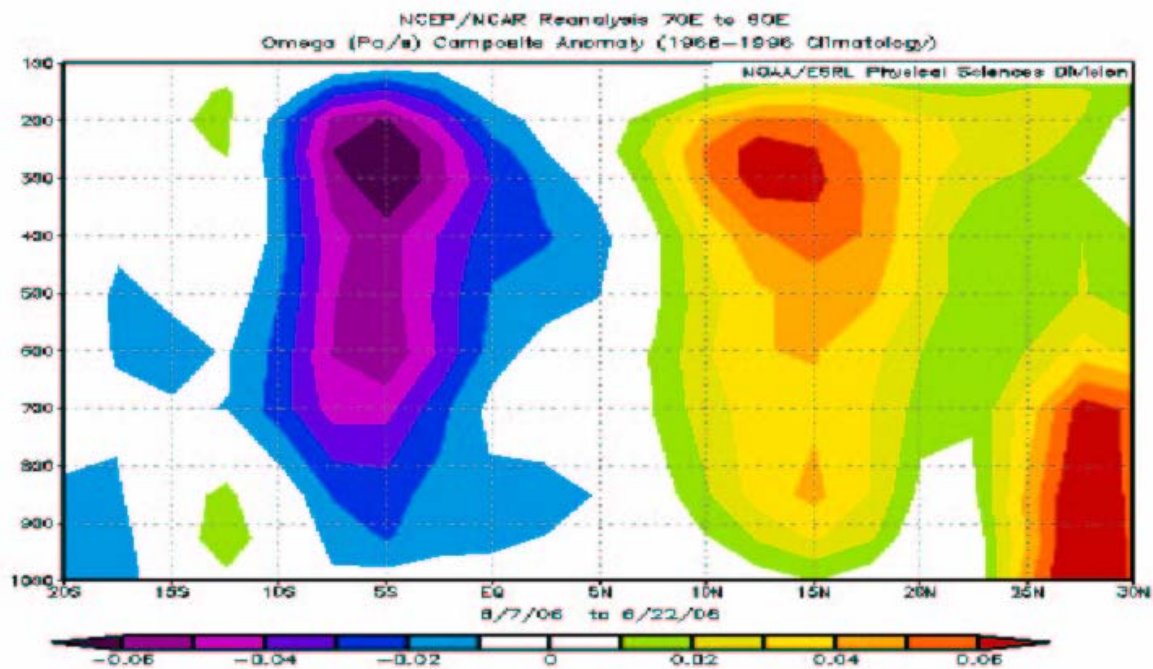


**Fig.1.7: Wind anomalies at 200 hPa during the period 7-22 June**



**Fig.1.8 : SST anomalies ( $^{\circ}$ C) during the period 7-22 June 2006-12-02**

The enhanced convection over the equatorial Indian Ocean is due to above normal sea surface temperature anomalies observed over the equatorial Indian Ocean, as shown in Fig.1.8. Krishnan (2003) et al. and Chandrashekar and Kitoh (1998) addressed the relationship between equatorial Indian Ocean SST anomalies and rainfall over India.

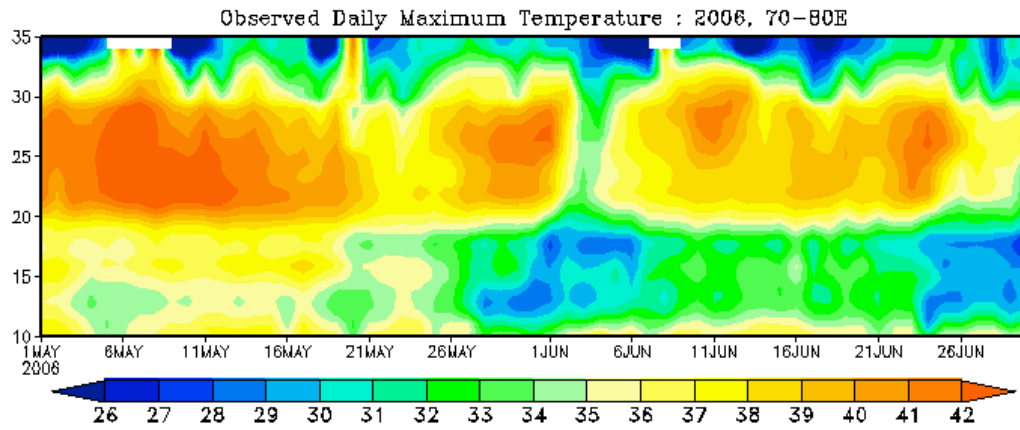


**Fig.1.9: Anomalous Latitude-Height plot of vertical motion (Omega) during the period 7-22 June**

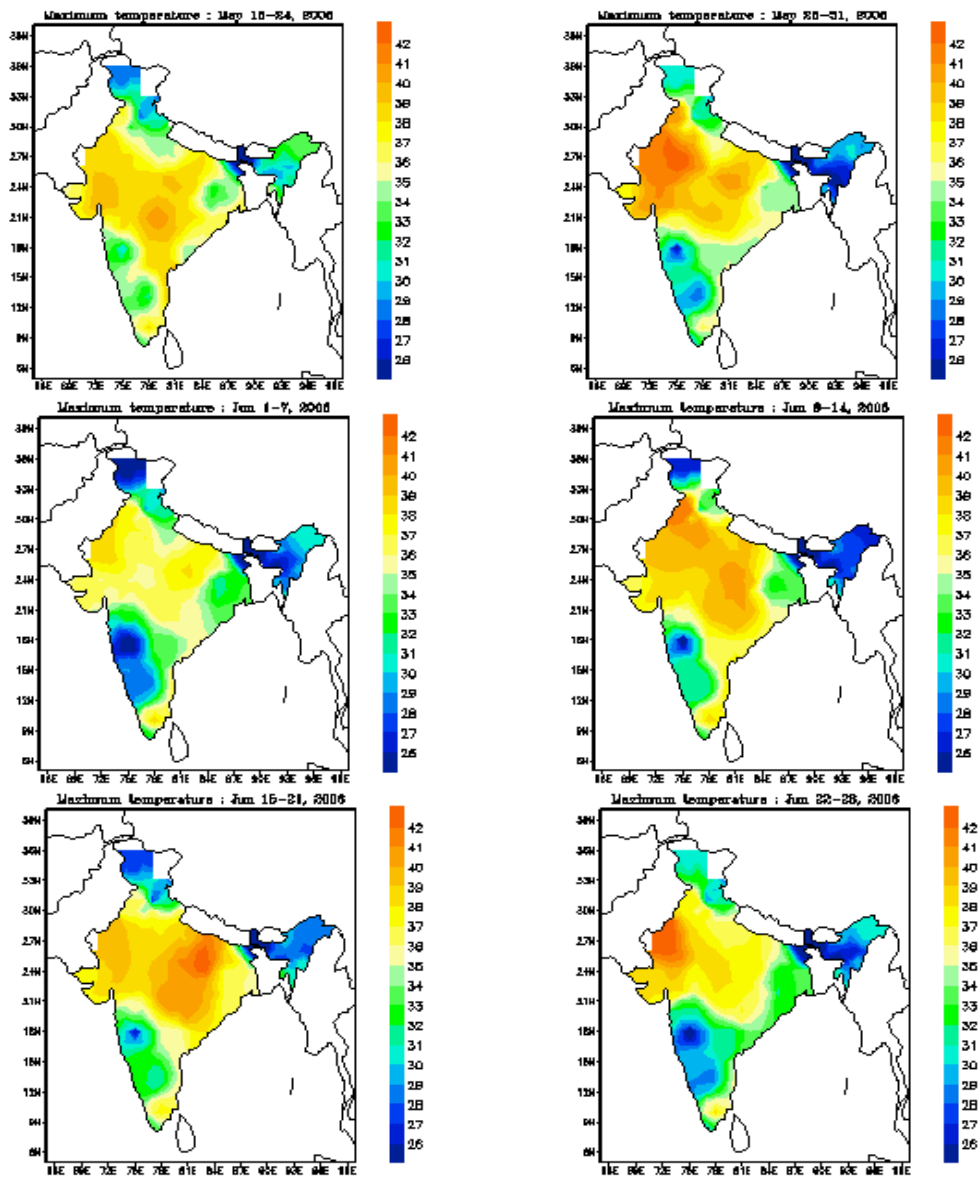
Fig.1.9 shows the Latitude-Height plot of vertical velocity (omega) averaged over the hiatus period. The plot clearly shows an anomalous ascending flow over the equatorial south Indian Ocean and descending flow over the Indian region. The anomalous north-south circulation caused subsidence over the Indian region, causing prolonged hiatus in the advancement of monsoon.

Daily maximum temperature data for 53 well distributed stations published in the Daily Weather Summaries issued by the India Meteorological Department were analysed to examine the association of progress of monsoon and maximum temperatures over the country (J.V. Revadekar and D.R. Kothawale, 2006, *personal communication*). Association of progress of monsoon with the variation of maximum temperature is clearly seen in Fig. 1.10 (Hovmöller plot for latitudinal variation of maximum temperatures with dates, averaged over 70° - 80°E) and in the Fig. 1.11 (spatial patterns).

Before, middle of May to end of May, during the arrival of monsoon, maximum temperatures along the west coast were in the range of 33°C to 35°C and after the arrival of monsoon, temperatures were dropped by 3°C to 4°C. There was no pronounced change in maximum temperatures over central parts of India and temperatures were higher by 5°C to 6°C than Peninsular India (Fig. 1.10). Strong temperature gradients are clearly seen in the plot of spatial patterns (Fig. 1.11) which are associated with the rapid progress of monsoon and the weak temperature gradients are associated with prolonged hiatus of monsoon.



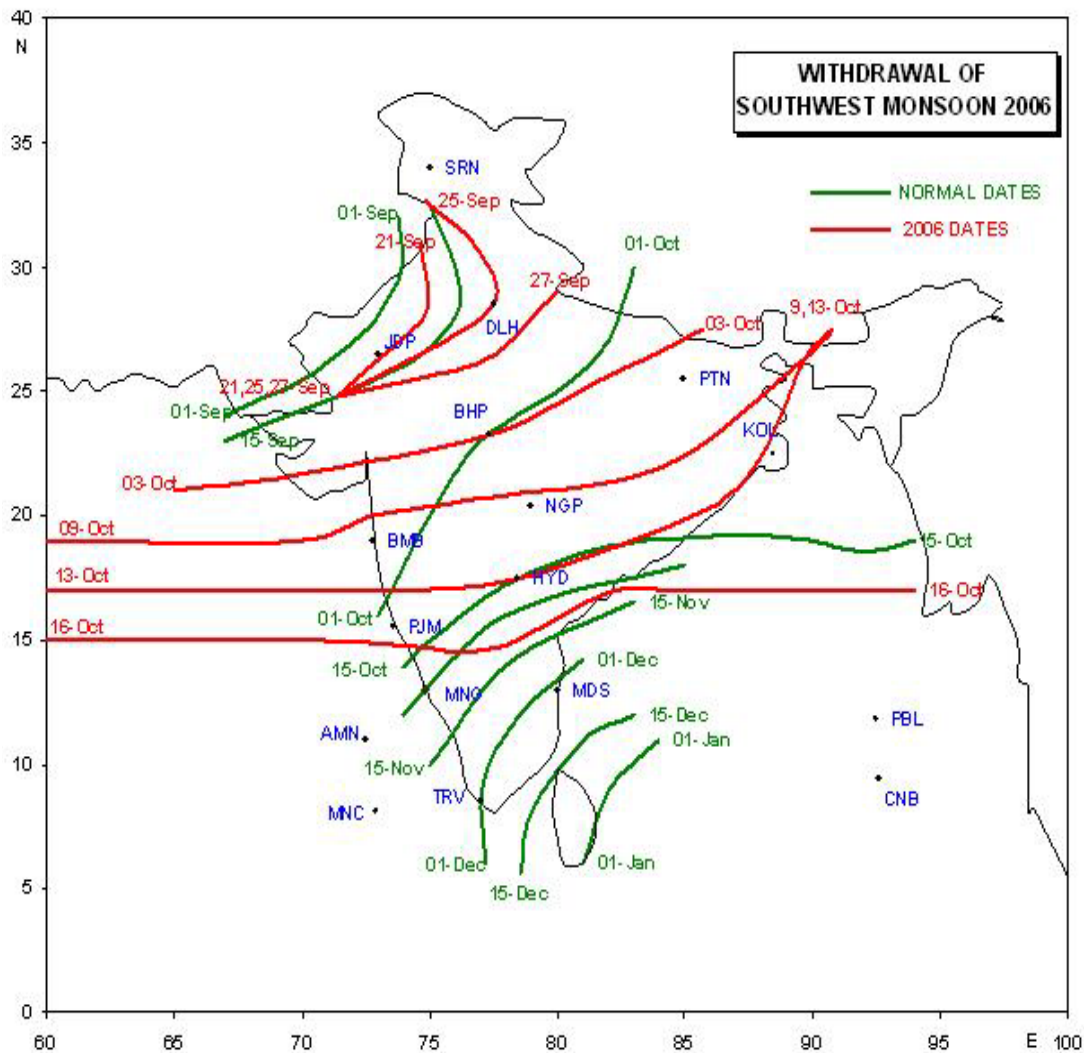
**Fig. 1.10: Latitude-Time plot of maximum temperatures ( $^{\circ}\text{C}$ ), averaged over 70-80E. The hiatus period is shown as red line. (Revadekar and Kothawale, 2006)**



**Fig. 1.11: Spatial Patterns of Maximum Temperatures ( $^{\circ}\text{C}$ ) during the hiatus period (Revadekar and Kothawale, 2006)**

## Withdrawal Phase

There was considerable delay in the withdrawal of monsoon due to formation of low pressure systems over the north Bay in succession and their westward movement. Southwest monsoon withdrew from most parts of West Rajasthan and extreme western parts of Punjab on 21 September. It further withdrew from some more parts of north and northwest India including Delhi on 25. The withdrawal line at the end of September passed through Pilibhit, Bareilly, Dholpur, Sawai Madhopur and Barmer. Southwest monsoon withdrew from the entire country on 17 October. Subsequently, northeast monsoon rains commenced over the south peninsula on 19 October. The monsoon withdrawal over the country is given chronologically in Fig.1.12.



**Fig.1.12 : Monsoon withdrawal dates**

# Monsoon<sub>2006</sub> A Report

## Chapter – 2

### **Semi Permanent Systems and Synoptic Features**

*In this chapter, the details of the semi permanent systems and synoptic features prevailed during the 2006 southwest monsoon season are discussed.*

#### **Semi Permanent systems**

##### **2.1 Monsoon trough**

The heat trough made its appearance at sea level on 1 June extending from Rajasthan to north Bay, but became diffused due to the changes in flow pattern after a week. It re-appeared during the first week of July with the formation of a deep depression over the northwest Bay and shifted northward rapidly with the dissipation of the system.

With a gradual change in the upper tropospheric flow pattern and revival of monsoon activity, the trough regained its normal position at sea level and got established as monsoon trough about 2° to the south of its normal position, when the monsoon covered the entire country on 24 July.

It generally remained south of the normal position (sometimes even 3-4° to the south) during the whole of August, due to the successive formation of depressions over the north Bay. During September, either parts or the entire trough remained close to the foothills during 6 to 13. Also, a secondary trough extended along the eastern parts on a few days during the period. Though regained its normal position in the later part of the month, it gradually got diffused and became less marked from the sea level chart.

## **2.2 Heat Low**

Heat low made its appearance in its near normal position by 23 May and remained more or less in its normal position (though diffused or sometimes even less marked, on many days in June & July) until 4 September. It was less marked on the sea level chart during 8 – 15 June.

The lowest and the second lowest pressure values of the heat low were:

June: 990 hPa (on 27) and 991 hPa (on 10)

July: 985 hPa (on 8) and 988 hPa (on 9 & 10)

Aug: 989 hPa (on 3) and 991 hPa (on 1)

Sept: 997 hPa (on 1) and 999 hPa (on 2)

## **2.3 Tibetan Anticyclone/High**

Tibetan Anticyclone (TA) was established in its near normal position at 500, 300 & 200 hPa on 7 June. But it was absent at 500 & 300 hPa on most of the days during June. In July, quite often it was to the east of the normal position. It remained slightly to the northeast of normal during August and much to the north in September. Though it was noticed up to 30 September, on many days the anticyclone was absent from 10 September onwards.

## **2.4 Tropical Easterly Jet (TEJ)**

Jet speed winds were observed at Thiruvananthapuram from 11 May to 4 October. The maximum wind speed reported was 100 kts (at 128 hPa; 12 UTC of 1 July). It was seen over Chennai from 25 May to 1 October. Maximum wind speed noticed was 90 kts at 149 hPa and 197 hPa respectively on 00 UTC of 18 August & 12 UTC of 4 September. Over Minicoy, it appeared from 25 May to 31 August. Over here, a maximum wind speed of 100 kts was reported on 25 July (12 UTC) & 31 August (00 UTC) at 202 & 200 hPa respectively. Over Port Blair, it appeared on 18 May and was noticed till 2 October. But it was absent almost throughout the month of July. It appeared over Mumbai on 31 May and was present until 13 September. The maximum wind noticed was 95 kts (at 59 hPa at 12 UTC of 27 June).

## **2.5 Sub-Tropical Westerly Jet (STWJ)**

STWJ was seen over Srinagar and Delhi latitudes up to 11 June. Though it shifted northwards thereafter, made re-appearances over stations like Lucknow, Delhi, Srinagar and

Jodhpur during July and sometimes during August. Towards the end of the season, it was observed over Delhi and Srinagar from 29 September onwards.

Summary of these semi-permanent systems for the years 2001-2006 is given in Table 2.1

## **Synoptic disturbances over the Indian Monsoon Region**

The synoptic disturbances which affected the Indian monsoon region in June, July, August and September are given in Tables 2.2 to 2.5 respectively. Summaries of these systems in terms of their frequencies are given in Tables 2.6 and 2.7. The total number of system days during the past 5 years ranged between 185 (in 2000) and 333 (in 2003)

### ***Cyclonic Storms***

A Severe Cyclonic Storm (Mukda) formed over the Arabian Sea in September (21-24 Sept), which weakened *in situ* over the Ocean. The large vertical wind shear associated with the westerly trough and cold air advection might have caused the dissipation.

In the past 35 years there had been only three Cyclonic Storms formed over the Arabian Sea during September viz. the Severe Cyclonic Storm in 2004 (formed on 30 September, recurved towards Gujarat coast and weakened just before landfall), the Severe Cyclonic Storm in 1979 (formed on 18 September, moved away in a northwesterly/ westerly direction) and the Severe Cyclonic Storm in 1974 (formed on 20 September and moved away northwestwards).

The details of the present system are as follows:

Under the influence of an upper air cyclonic circulation over the east central Arabian Sea off south Maharashtra – Goa coasts, a low pressure area formed over there on 15. It concentrated into a Depression and lay centred near Lat.  $19.5^{\circ}$  N/ Long.  $66.0^{\circ}$  E (about 450 km. southwest of Porbandar) at 0300 UTC of 21. It remained practically stationary and intensified into a Deep Depression in the evening, further into a cyclonic storm (Mukda) in the early morning and lay centred near Lat.  $20.0^{\circ}$  N/ Long.  $66.0^{\circ}$  E (about 400 km. southwest of Porbandar) at 0300 UTC of 22. Slightly moving northeastwards, it further intensified into a severe cyclonic storm and lay centred at 1200 UTC near Lat.  $20.5^{\circ}$  N/ Long.  $66.5^{\circ}$  E (about 350 km. southwest of Porbandar) and near Lat.  $21.0^{\circ}$  N/ Long.  $67.0^{\circ}$  E (about 300 km westsouthwest of Porbandar) at 0300 UTC of 23. Remaining practically stationary over there, it weakened into a cyclonic storm at 1800 UTC of 23, into a Deep Depression at 0300 UTC of 24 and into a Depression over the same area at 1200 UTC of 24. During the mid night of 24, it further weakened into a well marked low pressure area over

the northeast and adjoining east central Arabian Sea, persisted there on 25 and started drifting slowly westwards on 26 & 27 and moved away westwards on 28.

## **Depressions**

Altogether 8 depressions formed during the season; seven over the Bay of Bengal and one over the land.

The first Deep Depression formed during 2 – 4 July. As mentioned in the beginning, 4 Depressions formed during August and most of them had a long track across the central India mostly in a west/ northwest direction. Apart from the severe cyclonic storm mentioned above, three more Depressions including the land Depression formed during September.

Tracks of these systems are given in Fig.1 and the details are as follows. Number of storms and depressions formed during the recent years is given in Table-2.8.

### *Deep Depression over the northwest Bay (2 – 4 July)*

Under the influence of an upper air cyclonic circulation, a low pressure area formed over the north Bay on 30 June. It became well marked over there on 1 July and rapidly concentrated into a Deep Depression which lay centred at 0300 UTC of 2 near Lat.  $20.5^{\circ}$  N/ Long.  $89.0^{\circ}$  E and lay centred at 1200 UTC of 2, near Lat.  $20.5^{\circ}$  N/ Long.  $88.0^{\circ}$  E about 150 km southeast of Balasore. Moving westwards, it crossed the Orissa coast between Paradip and Chandbali around 1500 UTC of 2 and lay close to Cuttack at 0300 UTC of 3. Subsequently it moved westnorthwestwards and lay close to Sambalpur (Orissa) at 1200 UTC of 3 and close to Raipur (Chattisgarh) at 0300 UTC of 4. Thereafter, it weakened into a Depression over Vidarbha and neighbourhood by 0900 UTC and lay centred close to Nagpur at 1200 UTC of 4. Continuing its westnorthwestward movement, it lay close to Betul (west Madhya Pradesh) at 0300 UTC of 5. It further weakened into a well marked low pressure area over west Madhya Pradesh and adjoining southeast Rajasthan by the afternoon and lay over south Rajasthan and adjoining west Madhya Pradesh in the evening of 5. It became less marked on 6 July.

### *Deep Depression over the northwest Bay (2 – 5 August)*

Under the influence of an upper air cyclonic circulation, a low pressure area formed over the north Bay off West Bengal – Orissa coasts on 1 August, which became well marked over there in the evening. It concentrated into a Depression and lay centred at 0300 UTC of 2, near Lat.  $20.5^{\circ}$  N/ Long.  $87.5^{\circ}$  E. Drifting southwestwards, it intensified into a Deep Depression and lay centred at 0900 UTC of 2, near Lat.  $20.0^{\circ}$  N/ Long.  $87.0^{\circ}$  E and 1200 UTC near Lat.  $20.0^{\circ}$  N/ Long.  $86.5^{\circ}$  E. Drifting slightly westsouthwestwards, it crossed south

Orissa coast between Puri and Gopalpur around 0300 UTC of 3; when it lay centred near Lat.  $19.5^{\circ}$  N/ Long.  $85.0^{\circ}$  E about 50 km. northnortheast of Gopalpur. Further moving westwards, and then northwestwards, it lay centred near: Lat.  $19.5^{\circ}$  N/ Long.  $84.0^{\circ}$  E at 1200 UTC of 3; Lat.  $20.0^{\circ}$  N/ Long.  $82.5^{\circ}$  E at 0300 UTC of 4 and after weakening into a Depression at 1200 UTC, it lay near Lat.  $20.5^{\circ}$  N/ Long.  $82.0^{\circ}$  E. It lay near Lat.  $21.0^{\circ}$  N/ Long.  $80.0^{\circ}$  E at 0300 UTC of 5. It further weakened into a well marked low over Vidarbha and adjoining southwest Madhya Pradesh in the evening of 5. It lay over: north Madhya Maharashtra and adjoining areas of Vidarbha and southwest Madhya Pradesh on 6 morning; southwest Madhya Pradesh and adjoining north Madhya Maharashtra on 6 evening and over west Madhya Pradesh and neighbourhood on 7. Further weakening into a low pressure area it lay over northwest Madhya Pradesh and adjoining east Rajasthan during 8 to 11; moved over to southeast Rajasthan and neighbourhood on 12; over southeast Rajasthan on 13 and merged with the heat low on 14 August.

#### *Depression over the north Bay (12 August)*

Under the influence of an upper air cyclonic circulation over the north Bay, a low pressure area formed there by the evening of 11, which concentrated into a Depression and lay centred at 0300 UTC of 12, near Lat.  $21.0^{\circ}$  N/ Long.  $88.0^{\circ}$  E (about 100 km. eastsoutheast of Balasore) and at 1200 UTC near Lat.  $21.0^{\circ}$  N/ Long.  $87.5^{\circ}$  E. It crossed Orissa coast, close to Balasore around 1500 UTC of 12; weakened into a well marked low and lay over Chattisgarh and neighbourhood on 13; east Madhya Pradesh and neighbourhood on 14 and as a low pressure area over west Madhya Pradesh and adjoining southeast Rajasthan on 15 & 16; Saurashtra & Kutch and adjoining northeast Arabian Sea during 17 – 19 and became less marked on 20.

#### *Depression over the north Bay (16 – 18 August)*

Under the influence of an upper air cyclonic circulation, a low pressure area formed over the northwest Bay on 15 evening. It rapidly concentrated into a Depression and lay centred at 0300 UTC of 16 near Lat.  $20.5^{\circ}$  N/ Long.  $88.0^{\circ}$  E and at 1200 UTC near Lat.  $20.5^{\circ}$  N/ Long.  $87.0^{\circ}$  E (about 50 km. southeast of Chandbali). Moving further westwards, it crossed north Orissa coast close to Chandbali around 1430 UTC of 16 and lay centred at 1500 UTC near Lat.  $20.5^{\circ}$  N/ Long.  $86.5^{\circ}$  E close to Chandbali. Moving in a northwesterly direction it lay centred at 0300 UTC of 17 near Lat.  $22.0^{\circ}$  N/ Long.  $83.5^{\circ}$  E (about 100 km. east of Champa) and at 1200 UTC near Lat.  $22.5^{\circ}$  N/ Long.  $81.0^{\circ}$  E (about 80 km. west of Pendra). Further moving in a westnorthwesterly direction, it lay centred at 0300 UTC of 18 near Lat.  $23.0^{\circ}$  N/ Long.  $78.0^{\circ}$  E (about 100 km. southeast of Bhopal) and subsequently weakened into a well marked low over northwest Madhya Pradesh and adjoining east Rajasthan in the same evening. It lay as a low pressure area over southeast Rajasthan and adjoining northwest Madhya Pradesh on 19 and over southwest Rajasthan and neighbourhood during 20 – 22.

#### Depression over the northwest Bay ( 29 August – 1 September)

Under the influence of an upper air cyclonic circulation a low pressure area formed over the north Bay on 27, which became well marked over the northwest Bay off Gangetic West Bengal- Orissa coasts on 28. Subsequently it concentrated into a Depression and lay centred at 0300 UTC of 29 near Lat.  $20.5^{\circ}$  N/ Long.  $87.5^{\circ}$  E, about 100 km. eastsoutheast of Chandbali; crossed Orissa coast near Paradip around noon and lay centred at 1200 UTC near Lat.  $21.0^{\circ}$  N/ Long.  $84.5^{\circ}$  E, about 100 km. southeast of Sambalpur. Moving northwestwards, it lay centred at 0300 UTC of 30 near Lat.  $22.0^{\circ}$  N/ Long.  $83.0^{\circ}$  E close to Champa and at 1200 UTC near Lat.  $22.0^{\circ}$  N/ Long.  $81.0^{\circ}$  E, about 100 km. westsouthwest of Pendra. Further moving westnorthwestwards it lay centred at 0300 UTC of 31 August near Lat.  $23.5^{\circ}$  N/ Long.  $79.0^{\circ}$  E (about 50 km. southeast of Sagar) and at 1200 UTC near Lat.  $24.0^{\circ}$  N/ Long.  $78.0^{\circ}$  E (close to Sagar). Subsequently moving northnorthwestwards, it lay at 0300 UTC of 1 September over east Rajasthan and adjoining northwest Madhya Pradesh near Lat.  $26.0^{\circ}$  N/ Long.  $76.5^{\circ}$  E (Close to Sawai Madhopur) and weakened into a well marked low over there in the evening. It moved over to Haryana and neighbourhood on 2, lay as a low pressure area over Punjab and neighbourhood on 3 and became less marked on 4.

#### Depression over the northwest Bay (3 – 4 September)

Under the influence of an upper air cyclonic circulation, a low pressure area formed over the north Bay on 3 early morning, which became well marked in the forenoon, subsequently concentrated into a Depression and lay centred at 1200 UTC near Lat.  $20.5^{\circ}$  N/ Long.  $88.5^{\circ}$  E (about 180 km. southeast of Balasore). Moving in a westnorthwesterly direction, it crossed north Orissa coast close to Chandbali; around 0100 UTC of 4 and lay centred at: 0300 UTC near Lat.  $21.0^{\circ}$  N/ Long.  $86.5^{\circ}$  E (close to Chandbali); at 1200 UTC near Lat.  $22.0^{\circ}$  N/ Long.  $84.5^{\circ}$  E (about 50 km. east of Jharsuguda). Further it moved northwestwards and weakened into a well marked low over north Chattisgarh and adjoining east Madhya Pradesh on 5 and over west Madhya Pradesh and neighbourhood on 6. It lay as a low pressure area over southwest Rajasthan and neighbourhood on 7 & 8 and moved away westwards on 9.

#### Land Depression over Jharkhand (21 – 23 September)

A low pressure area formed over the northeast Bay off Arakan coast and adjoining east central Bay on 18 evening. It lay over the northeast Bay on 19 and became well marked over there in the evening. It lay over Gangetic West Bengal and adjoining northwest Bay on 20 and concentrated into a Depression which lay centred close to Jamshedpur on 21. It moved slightly northwestwards and lay centred over Jharkhand, about 50 km. east of Ranchi on 22. Moving slightly northeastwards, it lay centred close to Dhanbad on 23. It weakened

into a well marked low pressure area over Bihar and neighbourhood on 24 morning, lay as a low pressure area over there on 25 & 26 and became less marked on 27.

#### Depression over the east central and adjoining northwest Bay (28 – 29 September)

A low pressure area lay over the east central and adjoining northeast Bay off Arakan coast on 27; over the east central and adjoining northeast Bay on 28 morning; became a well marked low pressure area at 0600 UTC and concentrated into a Depression over the east central Bay at: 0900 UTC near Lat.  $18.0^{\circ}$  N/ Long.  $89.0^{\circ}$  E (about 380 km. southeast of Paradip); 1200 UTC near Lat.  $18.5^{\circ}$  N/ Long.  $88.5^{\circ}$  E and at 0300 UTC of 29 it lay over the northwest and adjoining central Bay near Lat.  $19.0^{\circ}$  N/ Long.  $86.0^{\circ}$  E (about 125 km. eastsoutheast of Gopalpur). Moving in a westerly direction, it crossed the coast close to Gopalpur near Lat.  $19.0^{\circ}$  N/ Long.  $84.5^{\circ}$  E around 1200 UTC. It continued to move westwards, weakened into a well marked low over south Chattisgarh and neighbourhood at 0300 UTC and moving further westwards, it lay over Vidarbha and adjoining south Chattisgarh at 1200 UTC of 30 September and as a low pressure area over Madhya Maharashtra and adjoining Vidarbha on 1 October. Though it became less marked in the next morning, the associated upper air cyclonic circulation extending upto mid tropospheric levels persisted and lay over Marathwada and adjoining Telangana tilting southwards with height on 2, over Madhya Maharashtra and adjoining north interior Karnataka on 3 and over Konkan & Goa and adjoining east central Arabian Sea on 4, east central Arabian Sea off north Maharashtra coast on 5 and became less marked on 6.

#### Low pressure areas/Well marked low pressure areas

Altogether 7 low pressure areas / well marked low pressure areas formed during the season. Most of them originated as upper air cyclonic circulations. Two of them formed over the land and the remaining five over the Bay of Bengal and subsequently moved over to land. Monthwise breakup of the systems are 1 in June, 4 in July and 1 each in August and September. The total number of low pressure areas during the past 5 years viz., 2000 to 2005 are 13, 10, 10, 12, 8 & 6 respectively.

#### Upper air cyclonic circulations

There were 19 upper air cyclonic circulations (in lower and middle tropospheric levels) formed during the season. The monthwise break up of these are 9 in June, 7 in July, 1 in August and 2 in September.

### Eastward moving cyclonic circulations/western disturbances

There were 25 eastward moving systems as upper air cyclonic circulations. The monthwise break-up was 8 in June, 8 in July, 6 in August and 3 in September.

### Off-shore trough

Off-shore trough along different parts of the west coast (surface and lower levels) persisted on most of the days from 27 May to 25 September except during 19 & 20 June, 30 & 31 August and 3 – 11 September. It was feeble on many days during June, but was very steep in the first week of July and some days in August.

### Cross Equatorial Flow during June – September 2006

The Cross Equatorial flow along the equatorial belt (equator to 5° N/ 5° S) was stronger than normal by 5-10 kts, during the last week of June 2006 (normal: 10-12 kts) and first week of September 2006 (normal: 8-10 kts). It was weaker by about 5 kts in the third and last week of July 2006 (normal: 12-14 kts). Except these, the cross equatorial flow along the equatorial belt was close to the normal during the entire monsoon period, June – September 2006.

The surface winds over the Arabian Sea to the north of 5° N were stronger than normal by 10 kts during the first week of June 2006 (normal: 15-20 kts), second, third and last week of July 2006 (normal: 20-25 kts) and stronger by 10-15 kts during the entire month of September 2006 (normal: 5-10 kts). They were almost normal in the remaining weeks of June to August 2006. (normal: 20-25 kts). The Cross Equatorial flow along the equatorial belt (equator to 5° N/ 5° S) over the Bay of Bengal was almost normal throughout the Southwest monsoon period, June – September 2006, except during the second and third weeks of July, during which it was stronger by 10 kts (normal : 8-10 kts).

The surface winds over the Bay of Bengal to the north of 5° N were nearly normal in the first and last weeks of June 2006, first and second weeks of July 2006 and first, second and last weeks of August 2006. They were stronger by almost 10-15 kts in the second and third weeks of June 2006 (normal: 10-15 kts), entire period during the second fortnight of July 2006 (normal: 10-15 kts), third week of August (normal: 10-15 kts) and throughout the month of September 2006 (normal: 5-10 kts).

### Low Pressure systems in Northwest Pacific Ocean / South China Sea during June to September 2006

There were in all 16 low pressure systems (Intensity of Tropical depression and above) in the northwest Pacific Ocean / South China Sea during June – September 2006. The month wise break-up is given below:

<b>Low Pressure Systems</b>	<b>June</b>	<b>July</b>	<b>August</b>	<b>September</b>	<b>TOTAL</b>
<b>Tropical Depression (T.D.)</b>	0	0	1	2	<b>3</b>
<b>Tropical Storm (T.S.)</b>	1	1	3	0	<b>5</b>
<b>Typhoon</b>	1	2	2	3	<b>8</b>
<b>TOTAL</b>	<b>2</b>	<b>3</b>	<b>6</b>	<b>5</b>	<b>16</b>

Low Pressure Systems in South Indian Ocean during June to September 2006

No low pressure system (TD, TS or Typhoon) was reported in Southern Hemisphere.

Troughs in Westerlies South of 30° N affecting the Indian region and to the North of 30° S during June to September 2006

a) Mid and Upper tropospheric Westerly troughs:

The number of troughs in westerlies which affected the Indian region 30° N and or south of 30° N is as given below:

<b>Atmospheric Level</b>	<b>June</b>	<b>July</b>	<b>August</b>	<b>September</b>	<b>Total</b>
<b>300 hPa</b>	10	1	0	11	22
<b>500 hPa</b>	8	1	2	9	20

b) Upper Air Troughs in westerlies over the South Indian Ocean, which penetrated to the north of 30° south :

(Source: INSAT full disc pictures)

There were 19 upper air troughs in westerlies which moved across the Indian Ocean from west to east to the north of Lat.30° S, in the Southern Hemisphere, during June to September 2006. The month wise break-up is given below:

<b>June</b>	<b>July</b>	<b>August</b>	<b>September</b>	<b>Total</b>
4	4	5	6	19

Intensity of Mascarene HIGH (centred at 30° S/ 60° E) during June to September 2006

<b>Month</b>	<b>*Normal Pressure (hPa) (approx.)</b>	<b>#Actual Pressure (hPa)</b>	<b>Departure from normal hPa (approx)</b>
<b>June</b>	1023.0	1020.6	-2.4
<b>July</b>	1025.5	1025.2	-0.3
<b>August</b>	1026.0	1021.8	-4.2
<b>September</b>	1023.5	1023.5	0.0

(\*Normal based on the means for the base period of 1979-1995

Source : Climate Diagnostic Bulletin, NOAA, June to September 2006)

(#Actual values are in conformity with those obtained from Climate Diagnostic Centre, NOAA.)

The intensity of Mascarene HIGH centred at 30° S / 60° E was below normal by 2.4 hpa in June 2006 and by about 4.2 hpa in August 2006. It was almost normal in the months of July and September 2006.

Intensity of Australian HIGH (centred at 30° S/ 140° E) during June to September 2006:

<b>Month</b>	<b>*Normal Pressure (hPa) (Approx.)</b>	<b>#Actual Pressure (hPa)</b>	<b>Departure from normal hPa (Approx)</b>
<b>June</b>	1022.0	1027.2	+5.2
<b>July</b>	1022.0	1024.5	+2.5
<b>August</b>	1020.5	1025.2	+4.7
<b>September</b>	1018.0	1023.6	+5.6

(\*Normal based on the means for the base period of 1979-1995

Source : Climate Diagnostic Bulletin, NOAA, June to September 2006 )

(#Actual values are in conformity with those obtained from Climate Diagnostic Centre, NOAA.)

The intensity of Australian HIGH centred at 30 ° S / 140 ° E was above normal by about 5 hPa during the months of June, August and September 2006. It was above normal by 2.5 hPa during July 2006.

## **Floods and droughts**

Some of the news papers reported that 'a scrutiny of all the natural disasters in India from 1900 to 2005 revealed that the country witnessed 160 floods, killing 50,964 and leaving 9,034,230 homeless and 675,252,850 affected'.

During the southwest Monsoon (June-September 2006), many states viz. Maharashtra & Goa, Gujarat, Orissa, Madhya Pradesh, Chattisgarh, Rajasthan, Jammu & Kashmir, Uttar Pradesh, Bihar, West Bengal, Assam and Kerala experienced flood situations during various parts of the season, due to Depressions, lows, interaction between the westerly flow with the monsoon current etc. As per media reports, 3,69,000 hectare farm land was affected in 16 districts of Assam (1-11 September). Also lack of rains in the rainiest month of August over northeast India, caused the day temperatures to shoot up over the northeastern parts especially over Assam.

### **The meteorological aspects of severe floods during southwest monsoon – 2006**

The source of the flood data provided in this section are mainly from the website maintained by the Dartmouth flood observatory, supplemented with other media reports and damage reports provided by various RMCs & MCs.

#### ***Assam and Tripura states: (1 – 21 June)***

Brahmaputra and its tributaries including Madura, Barak, Longai, Singla and Kushiara flooded many districts of Assam & Tripura.

Damage: According to media reports, 16 persons in Assam and 5 in Tripura lost their lives. 800 villages and 55,000 hectares of agriculture field submerged in Assam.

Synoptic features: (1) Monsoon advanced over Tripura and parts of Assam on 27 May. (2) Following the first week of June, monsoon was in a weak phase. The upper level divergence provided by a deep westerly trough caused heavy rainfall over the above regions.

#### ***Uttar Pradesh, Bihar and West Bengal (24 June – 3 August)***

Ganges and its tributaries Rapti, Ganga & Varuna overflowed, flooding many districts of Uttar Pradesh, Bihar and West Bengal.

Damage: 160 dead in Uttar Pradesh since the beginning of monsoon. Incessant heavy rains claimed the lives of 17 persons in Bihar and it also caused landslides and disrupted road & rail traffic.

Cause: Heavy rain causing floods & landslides.

Major synoptic features which caused the heavy rainfall:

- (i) An upper air cyclonic circulation over Bihar & adjoining east Uttar Pradesh on 25 which became less marked over west Uttar Pradesh and adjoining areas on 28.

- (ii) A Deep Depression (2 – 5 July) over the Bay which crossed Orissa coast, moved westnorthwestwards and weakened into a low pressure area on 5 over south Rajasthan and adjoining west Madhya Pradesh and became less marked on 6.
- (iii) A low pressure area over the Bay and adjoining Bangladesh and Gangetic West Bengal on 15 July. It became less marked over Chattisgarh and adjoining Jharkhand on 18 July.
- (iv) An upper air cyclonic circulation in mid tropospheric levels over west Uttar Pradesh and adjoining Uttaranchal on 16 & 17.
- (v) A low pressure area over Jharkhand & adjoining Chattisgarh on 21 moved westnorthwest and lay over Madhya Pradesh and adjoining east Rajasthan on 23 and became less marked there.
- (vi) A well marked low pressure area over the north Bay and adjoining West Bengal & Orissa coasts on 28 July, moved inland over Jharkhand, adjoining Orissa and Chattisgarh on 30; weakened into a low pressure area over northwest Madhya Pradesh on 31 and dissipated over west Rajasthan on 1 August.

### ***Orissa (3 – 8 July)***

Gajapati, Rayagada, Jhingiritl districts of Orissa reeled under flood situation because the rivers Vamsadhara & Nagavali over flooded due to incessant heavy rains.

Damage: Incessant heavy rains claimed the lives of 33 people in Orissa. It also caused landslides and disrupted the road & rail traffic and also flight operations.

Cause: (1) A Deep Depression (2 – 5 July) over the Bay which crossed Orissa coast between Porbandar & Chandbali on 2, moved westnorthwestwards and weakened over south Rajasthan and adjoining west Madhya Pradesh.

### ***Mumbai (3 – 6 July)***

Mithi river over flowed because of heavy monsoon rains, flooding various districts of Maharashtra including Mumbai.

Damage: 9 people died. It also caused landslides and disrupted road & rail traffic and also flight operations.

Causes: (1) Western end of the seasonal east-west trough at sea level shifted much to the south and passed through south Rajasthan and central parts of Madhya Pradesh, subsequent to the westward movement of the Depression (2 – 5 July).

(2) The offshore trough at sea level extended from south Gujarat to Kerala coasts throughout the week (week ending 5-7-06) with a steep pressure gradient along the west coast.

(3) An upper air cyclonic circulation over Gujarat region and adjoining Madhya Maharashtra on 3 & 4 July which merged in the cyclonic circulation associated with Depression (2 – 5 July) on 5.

### ***Gujarat (4 – 7 July)***

Damage: Heavy rains led to the death of 24 persons.

Causes: An upper air cyclonic circulation lay over Saurashtra & Kutch and neighbourhood on 28 June which persisted over the northeast Arabian Sea and adjoining Gujarat state till 1 July and later merged with the associated cyclonic circulation of Depression (2 – 5 July)

### ***Jammu & Kashmir (24 July – 22 August)***

Heavy rains caused overflowing of Jhelum & Chenab rivers.

Damage: Monsoonal rain caused floods and landslides leaving 15 dead, 800 evacuated, 20 villages inundated and 22 bridges damaged. Heavy rains disrupted road/ rail traffic in Rajasthan.

Causes: Six Upper cyclonic circulations in westerlies moved away northeastwards during the periods mentioned below: (a) 21 – 25 July (b) 25 – 28 July (c) 1 – 7 August (d) 6 – 11 August and (e) 10 – 21 August.

### ***Gujarat, Maharashtra, Madhya Pradesh and Rajasthan (28 July – 12 September)***

Surat, Ahmedabad, Pune, Nagpur, Bhopal, Ujjain, Udaipur, Barmer are some of the districts in Gujarat, Maharashtra, Madhya Pradesh and Rajasthan respectively that reeled under flood situation.

Damage: Gujarat (101), Maharashtra (330) and Rajasthan (138) people lost their lives, 1500 villages and towns submerged. Unusual rainfall in Thar desert -200 year record (549 mm rain between August 16 & 25). Thousands of hectares of crops destroyed. 75,000 farm animals dead. Estimated losses about 450 million dollars. More than 100 dead & tens of thousands displaced in Barmer district. Madhya Pradesh: on August 14, Bhopal received the heaviest rain in 30 years. More than 1.05 lakh people were affected and 600 heads of cattle and poultry perished. More than 70,000 people were evacuated from parts of Gujarat on 7 as the water levels in all the rivers (including Narmada) and dams crossed the danger mark.

Causes: (1) Monsoon trough was south of its normal position by 3-4°

(2) A well marked low pressure area over north Bay on 28 July moved westnorthwestwards through Jharkhand, Orissa, Chattisgarh, northwest Madhya Pradesh on 30. It was over west Rajasthan on 1 August and became less marked on 2.

(3) An upper air cyclonic circulation lay over west Madhya Pradesh and neighbourhood on 29 and merged with the cyclonic circulation associated with the above low pressure area over west Madhya Pradesh and adjoining Rajasthan and Gujarat region.

(4) A Deep Depression (2 – 5 August) which crossed south Orissa coast and weakened into a well marked low pressure area over Vidarbha and southwest Madhya Pradesh on 6. It lay as low pressure area over north west Madhya Pradesh and adjoining east Rajasthan on 8 and weakened over southeast Rajasthan and neighbourhood on 12.

(5) A Depression (16 – 18 August) over the northwest Bay moved in a westnorthwesterly direction and lay near Champa on 17 morning, near Bhopal on 18 and

weakened as low pressure area over southeast Rajasthan and adjoining northwest Madhya Pradesh.

(6) A Depression (12 August) crossed Orissa coast close to Balasore & weakened into well marked low pressure area over Chattisgarh and neighbourhood on 13, as a low pressure area over west Madhya Pradesh and adjoining southeast Rajasthan on 15 & 16. It lay over Saurashtra & Kutch and adjoining northeast Arabian Sea from 17 to 19 and became less marked.

(7) A well marked low pressure area over north Bay and adjoining coastal areas of Gangetic West Bengal and Orissa on 22 was quasi-stationary and became less marked over Jharkhand and adjoining Chattisgarh on 24.

(8) A Depression (29 Aug. – 1 Sept.) crossed Orissa coast near Paradip, moved in NW/WNW direction and lay close to sagar on 31 Aug. It then moved in NNW direction and lay close to Sawai Madhopur on 1 Sept. It weakened thereafter into low pressure area.

(9) A Depression (3– 4 September) over the north Bay moved westnorthwestwards, crossed coast close to Chandabali and weakened into a well marked low pressure area over north Chattisgarh and adjoining east Madhya Pradesh on 5 and over west Madhya Pradesh and neighbourhood on 6. It lay as a low pressure area over southwest Rajasthan and neighbourhood on 7 & 8 and merged with the heat low.

#### ***Orissa, Andhra Pradesh and Chattisgarh (1 – 10 September)***

Mahanadi, Godavari, Sabri and many other rivers were flooded due to incessant very heavy to extremely heavy rain.

Damage : 106 dead in Andhra Pradesh. More than 200 villages in Andhra Pradesh were submerged with Godavari river in spate. 70 dead in Orissa, 500000 affected, 2 million homeless, 27 of 30 districts in the state hit by flooding. Also heavy rains disrupted the traffic in Orissa. In Chattisgarh 8 persons died and 100 were reported missing.

Causes : Same as above.

#### ***Uttar Pradesh (29 Aug. – 4 Sept.)***

River Rapti, Ghagra and Sarayu were flooded because rivers in Nepal over flooded due to monsoonal rains.

Damage: 42 dead, 100 villages were flooded and over 10,000 affected.

Causes: The monsoon trough at sea level shifted gradually to the north & generally remained north of the normal position towards the later part of the week (week ending 23 August). The western end of monsoon trough remained to the north of the normal position till 29 August. This also led to heavy to very heavy rain over east Uttar Pradesh on 26, 27 & 29.

#### ***Punjab and Jammu & Kashmir (31 Aug. – 11 Sept.)***

Jhelum, Sutlej, Lidder, Chenab, Tawi rivers were flooded due to incessant rains and unseasonal snowfall.

Damage: Floods and landslides left 19 dead, 200 villages inundated, 92,724 hectare field submerged in Jammu & Kashmir. Also 15,000 people were affected by flooding. Valley remained cut off due to landslides on highways. Torrential rains and flash flood claimed 20 lives in Punjab, 200 villages inundated.

Cause: (1) The remnant of the Depression (29 August – 1 September) lay over Punjab & neighbourhood on 3 September as a low pressure area.

(2) A trough in mid & upper tropospheric westerlies with its axis at 9.5 km a.s.l. extended along Long.70° E to the north of 25° N during 3 to 5 September.

(3) Western end of monsoon trough north of its normal position.

(4) On 7 & 8 September eastern end of monsoon trough was near the foothills of Himalayas.

(5) Two upper air cyclonic circulations extending upto mid tropospheric levels moved away northeastward across northern parts of Jammu & Kashmir during 7 – 12.

### ***Andhra Pradesh, West Bengal and Bihar (18 Sept. – 5 Oct)***

Mouths of Ganges in Sunderbans delta; Haldi river, Godavari & Krishna and their tributaries over flowed.

Damage : Andhra Pradesh:- 31 dead, 5000 evacuated, 200 villages inundated in Karimnagar district. Very heavy rains lashed Telangana from 17 to 20 September. West Bengal:- 50 dead in Sunderbans region, 300 injured. 30,000 mud houses destroyed. The heaviest rains in 23 years left large parts of Kolkata city under water. 2000 evacuated from the city. (Heavy to very heavy rains from 20 – 26 September).

Bihar:-33 dead, 25 bridges washed away due to heavy to very heavy rains from 23 – 25 September.

Cause : (1) A Land Depression (21 – 23 September) close to Jamshedpur on 21 moved northwestward and was near Ranchi on 22. It lay as low pressure area from 24 – 26 over Bihar and neighbourhood.

(2) An upper air cyclonic circulation between 2.1 & 5.8 km a.s.l. lay over west central Bay off south Andhra – north Tamil Nadu coasts during 26 – 27.

(3) A low pressure area over the west central Bay on 15 moved over to north coastal Andhra Pradesh and adjoining south coastal Orissa on 18 and became less marked over coastal Andhra Pradesh and adjoining Chattisgarh on 18. But the associated upper air cyclonic circulation extended upto mid tropospheric levels on 19.

(4) A Depression (28 – 29 September) crossed coast close to Gopalpur on 29 September. It moved westwards and weakened into a well marked low pressure area over south Chattisgarh and neighbourhood. Associated cyclonic circulation extended up to mid tropospheric levels over Marathwada and adjoining Telangana tilting southwards with height on 2 October.

Table – 2.1

Positions of Semi-permanent systems for the years 2000 to 2006

	2001	2002	2003	2004	2005	2006
<b>1) Monsoon Trough</b>	Established on 3 July Less marked on 20 September.	Monsoon trough got established on 15 August and Less marked on 16 September.	Established on 5 July. Less marked on 16 Sept. No Breaks.	Established on 18 July. Less marked in the last week of Sept. Breaks during 22-23 June & 26 Aug.-8 Sep.	Established on 30 June Less marked on 2 September Break-like situation during 10-12 & 28-31 Aug.	Established on 24 July Got diffused in later part of the Sept., gradually Break-like situation during 6 to 13 September
<b>2) Heat Low</b>	Appeared on 23 May , seen till the end of September. Lowest pressure 987.0 hPa	Appeared on 29 May , seen till the end of September. Lowest pressure 988.0 hPa	Appeared on 22 May, seen till 15 Sept. Lowest Pressure 986.0 hPa	Appeared on 15 May, seen till 20 Sept. Lowest Pressure 990.0 hPa	Appeared 4 June seen till 8 Sept. Lowest pressure 988 hPa	Appeared on 23 May, seen till 4 Sept. Lowest Pressure 985 hPa
<b>3) T. A.</b>	Established on 12 June. Not seen in last week of August. Less marked on 13 Sept	Established on 11 July. Not seen in July at 500 hPa. Less marked on 12 Sept	Established on 15 June. Not seen at 500 hPa during June and first half of July. Less marked on 14 Sept.	Established on 13 June. Not seen at 500 hPa during many of the days Less marked on 19 Sept.	Established on 26 June Less marked 27 Sept.	Established on 7 June. Not seen at 500 & 300 hPa on most of the days during June. In July. Less marked from 10 September onwards.

<b>4) TEJ</b>	Seen from 24 May, till 15 September. Maximum wind speed 150 kts. at HYD at 115 hPa on 21 July.	Seen from 7 June, till end of September. Maximum wind speed 105 kts. at 137 hPa over Chennai on 18 June.	Seen from 9 May to 25 Sept. Maximum wind speed 125 kts at 116 hPa over Minicoy on 25 July.	Seen from 10 May to 30 Sept. Maximum wind speed 180 kts at 118 hPa over Minicoy on 22 June.	Seen from 6 June Maximum wind speed 110 kts : over Thiruvanant hapuram on 31 July and at 100 hPa on 8 July at over Chennai.	Seen from 11 May to 4 October. Maximum wind speed 100 kts at 128 hPa on 1 July over TRV and over Minicoy on 25 July & 31 Aug. at 202 & 200 hPa respectively
<b>5) STWJ</b>	Seen over north India during last week of May and reappeared in last week of Sept.	Seen over north India during first week of June and reappeared in last week of Sept.	Seen over Srinagar on 5 June. Re-appeared on 1 Oct.	Seen over Srinagar on 23 June. Re-appeared during the first week of Oct.	Seen over Srinagar upto 22 June. It then shifted northwards and made casual re-appearances over many stations	Seen over Srinagar and Delhi latitudes upto 11 June. It then shifted northwards thereafter, made casual re-appearances. It was seen over Delhi and Srinagar from 29 September onwards.

TABLE – 2.2

## Details of low pressure systems for the month of June 2006

Sr. No.	System	Duration	Place of first location	Direction of movement	Final location	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>I</i>	<b>Low Pressure areas</b>					
1.	Low pressure area	6 – 8	North Bay and adjoining Gangetic West Bengal	Northwest	Jharkhand and neighbourhood	It was seen as an upper air cyclonic circulation extending upto mid tropospheric levels over the north Bay on 4 & 5. The low pressure area rapidly moved inland and became less marked on 9. The associated upper air cyclonic circulation became less marked on 10.
<i>II</i>	<b>Upper air cyclonic circulations</b>					
1.	Upto mid tropospheric levels	29 May – 3 June	East central Arabian Sea off Karnataka coast.	North	northwest Madhya Pradesh and adjoining east Rajasthan	Caused the rapid advance of monsoon along the west coast and also extremely heavy rainfalls along the west coast .
2.	Between 3.6 & 5.8 km a.s.l.	10 – 12	Rayalaseema and neighbourhood	Stationary	<i>in situ</i>	Became less marked on 13.
3.	Between 1.5 & 3.1 km a.s.l.	14 – 20	West central Bay off south Andhra coast	South	Southwest Bay off Tamil Nadu coast	Became less marked on 21.

4.	Upto 3.6 km a.s.l.	14	West Uttar Pradesh and neighbourhood	Stationary	<i>in situ</i>	Became less marked on 15.
5.	Between 3.1 & 4.5 km a.s.l.	15 – 18	North Maharashtra – south Gujarat coast.	Quasi-stationary	<i>in situ</i>	Became less marked on 19.
6.	Upto mid tropospheric levels	20 – 27	North Andaman Sea and neighbourhood.	West	Northeast Arabian Sea	Moved away westwards on 28.
7.	Between 3.6 & 7.6 km. a.s.l.	28 June – 4 July	Saurashtra & Kutch	Quasi-stationary	Gujarat region and adjoining Madhya Maharashtra	Tilted southwestwards with height. It merged with the circulation associated with the Depression on 5.
8.	Upto lower tropospheric levels	22 – 25	Vidarbha and adjoining west Madhya Pradesh	Northwest	Southwest Rajasthan and adjoining Gujarat	Became less marked on 26.
9.	Between 1.5 & 4.5 km. a.s.l.	25 – 27	Bihar and adjoining east Uttar Pradesh	West	West Uttar Pradesh and adjoining areas.	Became less marked on 28.
<b>III</b>	<b>Systems in westerlies</b>					
1.	Upper air cyclonic circulation upto mid tropospheric levels	2 – 5	north Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir and adjoining Punjab.	Moved away on 6.

2.	<i>do</i>	6 – 8	<i>do</i>	<i>do</i>	Jammu & Kashmir	Moved away on 9.
3.	Upper air cyclonic circulation upto lower tropospheric levels	27 May – 2 June	Northwest Rajasthan	East	West Uttar Pradesh and neighbourhood	Became less marked on 3.
4.	Trough in the lower levels.	10 – 13	Sub-Himalayan West Bengal & Sikkim to north Bay	<i>Quasi-Stationary</i>	<i>In situ</i>	Became less marked on 14.
5.	Trough in mid & upper tropospheric levels	10 – 13	Along Long. 68° E, north of Lat. 25° N.	Northeast	Along Long. 70° E, north of Lat. 30° N.	Became less marked on 14.
6.	Upper air cyclonic circulation upto mid tropospheric levels	11 – 20	North Pakistan and adjoining Jammu & Kashmir	<i>do</i>	Jammu & Kashmir and neighbourhood.	Moved away northeastwards on 21.
7.	Upper air cyclonic circulation upto lower tropospheric levels	15 – 18	Punjab and neighbourhood	<i>Quasi-Stationary</i>	<i>In situ</i>	Became less marked on 19.
8.	Upper air cyclonic circulation between 1.5 & 5.8 km a.s.l.	20 – 22	Northwest Rajasthan and adjoining Haryana.	Eastnortheast	East Rajasthan and neighbourhood	Became less marked on 23.
9.	Upper air cyclonic circulation upto mid tropospheric levels	21 – 27	North Pakistan and adjoining Jammu & Kashmir	Northeast	Northern parts of Jammu & Kashmir	Moved away on 27.
10.	<i>do</i>	27 June – 4 July	Northeast Afghanistan and adjoining north Pakistan.	Northeast	Jammu & Kashmir	Moved away on 5 July.

**TABLE – 2.3**

**Details of low pressure systems for the month of July 2006**

<b>Sr. No.</b>	<b>System</b>	<b>Duration</b>	<b>Place of first location</b>	<b>Direction of movement</b>	<b>Final location</b>	<b>Remarks</b>
<b>(1)</b>	<b>(2)</b>	<b>(3)</b>	<b>(4)</b>	<b>(5)</b>	<b>(6)</b>	<b>(7)</b>
<b>I</b>	<b><i>Depression</i></b>					
1.	Deep Depression	2 – 4	North Bay, near Lat. 20.5° N/ Long.89.0° E	West	West Madhya Pradesh close to Betul	It was first seen as an upper air cyclonic circulation over west central Bay off Andhra coast during 26 – 28. Details are given in the text.
<b>II</b>	<b><i>Low pressure areas</i></b>					
1.	Low pressure area	11 – 13	Gangetic West Bengal and neighbourhood	<i>Quasi-Stationary</i>	Gangetic West Bengal and adjoining Jharkhand	Formed under the influence of an upper air cyclonic circulation. It became less marked on 14.
2.	Low pressure area	15 – 17	North Bay and adjoining Bangladesh and Gangetic West Bengal	Westnorthwest	Chattisgarh and adjoining Jharkhand	Though became less marked on 18, the associated upper air cyclonic circulation persisted over east Madhya Pradesh and neighbourhood upto 21.

3.	Low pressure area	20 – 23	Gangetic West Bengal and neighbourhood	Northwest	Northwest Madhya Pradesh and adjoining east Rajasthan	Formed under the influence of an upper air cyclonic circulation. Became less marked on 24.
4.	Well marked low pressure area	27 July – 1 August	North Bay	Northwest	West Rajasthan	Was well marked from 28 – 30 July.
<b>III</b>	<b><i>Upper air cyclonic circulations</i></b>					
1.	Upto 3.1 km a.s.l.	16 – 17	West Uttar Pradesh and adjoining Uttaranchal	<i>Stationary</i>	<i>in situ</i>	Became less marked on 18.
2.	Upto mid tropospheric levels	18 – 21	East central Arabian Sea off north Maharashtra – south Gujarat coasts.	<i>Quasi-stationary</i>	Saurashtra & Kutch and neighbourhood	Became less marked on 22.
3.	Between 1.5 & 3.6 km a.s.l.	19	Haryana and neighbourhood	<i>do</i>	<i>do</i>	Became less marked on 20.
4.	Between 1.5 & 4.5 km a.s.l.	25 – 26	Jharkhand and neighbourhood	<i>Sationary</i>	<i>in situ</i>	Became less marked on 27.
5.	Upto 3.1 km a.s.l.	24 – 29	East Uttar Pradesh and neighbourhood	Westnorthwest	Central parts of Rajasthan	Became less marked on 30.

6.	Upto mid tropospheric levels	30 – 31	west Madhya Pradesh and adjoining east Rajasthan and Gujarat region	Quasi-stationary	-	Merged with the low pressure area over west Madhya Pradesh and neighbourhood on 31.
7.	Upto mid tropospheric levels	31	Northwest Bay and neighbourhood	-	-	Later on caused the formation of the Deep Depression, details of which are given in the month of August.
<b>IV</b>	<b>Systems in westerlies</b>					
1.	Cyclonic circulation upto 4.5 km a.s.l.	5 – 7	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir and neighbourhood	Moved away on 8.
2.	<i>do</i>	9 – 12	<i>do</i>	<i>do</i>	<i>do</i>	Moved away on 13.
3.	Cyclonic circulation between 0.9 & 3.1 km a.s.l.	10 – 13	West Rajasthan and neighbourhood	Eastnortheast	Central parts of Uttar Pradesh	Became less marked on 14.
4.	Cyclonic circulation upto 4.5 km a.s.l.	13 – 18	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir and neighbourhood	Moved away on 19.
5.	<i>do</i>	19 – 20	<i>do</i>	<i>do</i>	Northern parts of Jammu & Kashmir	Moved away on 21.
6.	<i>do</i>	21 – 24	Northeast Afghanistan and adjoining north Pakistan.	<i>do</i>	<i>do</i>	Moved away on 25.
7.	<i>do</i>	25 – 27	Jammu & Kashmir and neighbourhood	<i>do</i>	<i>do</i>	Moved away on 28.
8.	<i>do</i>	29 – 30	Northern parts of Jammu & Kashmir	<i>do</i>	<i>do</i>	Moved away on 31.

**TABLE -2.4**

**Details of low pressure systems for the month of August 2006**

<b>Sr. No.</b>	<b>Systems</b>	<b>Duration</b>	<b>Place of first location</b>	<b>Direction of movement</b>	<b>Final Location</b>	<b>Remarks</b>
(1)	(2)	(3)	(4)	(5)	(6)	(7)
<b>I</b>	<b>Depressions</b>					
1.	Deep Depression	2 – 5	Northwest Bay (near Lat. 20.5° N/ Long. 87.5° E)	Westsouthwest, west and northwest	Vidarbha and adjoining southwest Madhya Pradesh	Crossed south Orissa coast between Puri and Gopalpur at 0300 UTC of 3. Details are given in the text.
2.	Depression	12	North Bay(near Lat. 21.0° N/ Long. 88.0° E)	West	Chattisgarh and neighbourhood	Crossed Orissa coast close to Balasore around 1500 UTC. Details are given in the text.
3.	Depression	16 – 18	North Bay (near Lat. 20.5° N/ Long. 88.0° E)	Westnorthwest	Northwest Madhya Pradesh and adjoining east Rajasthan.	Crossed north Orissa coast close to Chandbali around 1430 UTC of 16. Details are given in the text.

4.	Depression	29 Aug. – 1 Sept.	Northwest Bay (near Lat. 20.5° N/ Long. 87.5° E)	Westnorthwest and northwest	East Rajasthan and adjoining northwest Madhya Pradesh.	Crossed Orissa coast near Paradip around noon of 29.
<b>II    <i>Low pressure areas</i></b>						
1.	Well marked low pressure area	21 – 24	North Bay	West	Jharkhand and adjoining Chattisgarh	Became less marked on 25. The associated upper air cyclonic circulation persisted over Jharkhand and adjoining Bihar upto 27.
<b>III    <i>Upper air cyclonic circulations</i></b>						
1.	Between 2.1 & 5.8 km a.s.l.	29 – 30	Southwest Rajasthan and adjoining Gujarat region.	<i>Quasi- stationary</i>	<i>in situ</i>	Became less marked on 31.

<b>IV</b>	<b>Systems in westerlies</b>					
1.	Cyclonic circulation upto mid tropospheric levels	7 – 10	North Pakistan and adjoining Jammu & Kashmir	Northeast	Northern parts of Jammu & Kashmir	Moved away on 11.
2.	Cyclonic circulation upto mid tropospheric levels	10 – 16	North Pakistan and adjoining Jammu & Kashmir	Northeast	Northern parts of Jammu & Kashmir	Moved away on 17.
3.	<i>do</i>	18 – 20	<i>do</i>	<i>do</i>	<i>do</i>	Moved away on 21.
4.	<i>do</i>	21 – 27	<i>do</i>	<i>do</i>	<i>do</i>	Moved away on 28.
5.	<i>do</i>	25 – 27	<i>do</i>	<i>do</i>	<i>do</i>	Moved away on 28.
6.	<i>do</i>	28 – 30	<i>do</i>	<i>do</i>	<i>do</i>	Moved away on 31.

**TABLE -2.5**

**Details of low pressure systems for the month of September 2006**

<b>Sr. No.</b>	<b>System</b>	<b>Duration</b>	<b>Place of first location</b>	<b>Direction of movement</b>	<b>Final Location</b>	<b>Remarks</b>
<b>(1)</b>	<b>(2)</b>	<b>(3)</b>	<b>(4)</b>	<b>(5)</b>	<b>(6)</b>	<b>(7)</b>
<b>I</b>	<b>Cyclonic Storms</b>					
1.	Severe Cyclonic Storm	21 – 24	East central and adjoining northeast Arabian Sea	North	Northeast and adjoining east central Arabian Sea.	Weakened insitu. Details are given in text.
<b>II</b>	<b>Depressions</b>					
1.	Depression	3 – 4	Northwest Bay (near Lat. 20.5° N/ Long. 88.5° E)	Westnorthwest and northwest	North Chattisgarh and adjoining east Madhya Pradesh	Crossed Orissa coast close to Chandbali around 0100 UTC of 4. Details are given in the text.
2.	do	21 – 23	Jharkhand (Close to Jamshedpur)	Northwest and then northeast	Bihar and neighbourhood	Details are given in the text
3.	do	28 – 29	East central & adjoining northwest Bay (near Lat. 18.0° N/ Long. 89.0° E)	Northwest and west	South Chattisgarh and neighbourhood	Crossed Orissa coast close to Gopalpur around 1200 UTC of 29. Details are given in the text.

<b>III</b>	<b>Low pressure areas</b>					
1.	Low pressure area	15 – 18	West central Bay	West	Coastal Andhra Pradesh and adjoining Chattisgarh	Formed as an upper air cyclonic circulation over west central Bay off south Andhra- north Tamil Nadu coasts during 12 – 14
<b>IV</b>	<b>Upper air cyclonic circulations</b>					
1.	Upto mid tropospheric levels	14 – 17	North Andaman Sea and adjoining Tenasserim coast.	Quasi-stationary	<i>in situ</i>	Became less marked on 18.
2.	Between 2.1 & 5.8 km a.s.l.	26 Evening – 27	West central Bay off south Andhra – North Tamil Nadu coasts.	do	do	Became less marked on 28
<b>V</b>	<b>Systems in westerlies</b>					
1.	Trough in mid and upper tropospheric levels	3 – 5	Long. 70° E, north of Lat. 25° N.	Quasi-stationary	<i>in situ</i>	Became less marked on 6
2.	Trough in the lower levels	7 – 13	Sub-Himalayan West Bengal & Sikkim to northwest Bay	do	do	Became less marked on 14.

3.	Cyclonic circulation upto 4.5 km a.s.l.	7 – 9	North Pakistan	Northeast	Northern parts of Jammu & Kashmir	Moved away on 10.
4.	do	10 – 11	North Pakistan and adjoining Jammu & Kashmir	do	Jammu & Kashmir and neighbourhood	Moved away on 12.
5.	Trough in mid and upper tropospheric levels	21 – 26	Long. 67° E, to the north of Lat. 25° N	Eastnortheast	Long. 73° E	Became less marked on 27.
6.	Cyclonic circulation upto mid tropospheric levels	23 – 25	North Pakistan and adjoining Jammu & Kashmir.	Northeast	Northern parts of Jammu & Kashmir	Moved away on 26.

**Table – 2.6**  
**Summary of the synoptic disturbances during June-September 2006**

<b>Sr. No</b>	<b>Disturbances</b>	<b>Jun.</b>	<b>Jul.</b>	<b>Aug</b>	<b>Sept</b>	<b>Total</b>
1	Monsoon Disturbances					
	a) Cyclonic Storms (Depressions)	-	-(1)	-(4)	1(3)	<b>1(8)</b>
	b) Well-marked lows/low pressure areas	1	4	1	1	<b>7</b>
2	Cyclonic circulations (including embedded and induced cyclonic circulations)	9	7	1	2	<b>19</b>
3	Off-shore troughs	Observed between 27 May to 25 September except during 19 & 20 June, 30 & 31 August and 3 – 11 September				
4	Low level troughs	1	-	-	1	<b>2</b>
5	Troughs (Mid and upper tropospheric levels)	1	-	-	2	<b>3</b>
6	Eastward moving cyclonic circulations/western disturbances	8	8	6	3	<b>25</b>

**Table – 2.7**  
**Duration (in number of days) of low pressure systems during June-September 2006**

Number of days of C S, Depression, Well marked low pressure areas (WML), Low pressure areas (LOPAR) and Cyclonic circulation (CYCIR) during June to Sept. 2006

<b>Month</b>	<b>C S &amp; Depression</b>	<b>WML &amp; Lopars</b>	<b>Cycirs</b>	<b>Total</b>
June	-	3	93	<b>96</b>
July	3	15	46	<b>64</b>
August	9	4	29	<b>42</b>
September	11	4	14	<b>29</b>
<b>Total</b>	<b>23</b>	<b>26</b>	<b>182</b>	<b>231</b>

**Table – 2.8**  
**Number of systems and duration 2001 – 2006**

	2001		2002		2003		2004		2005		2006	
	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days
<b>1) Storms :</b>												
Jun.	–	–	–	–	–	–	–	–	–	–	–	–
Jul.	–	–	–	–	–	–	–	–	–	–	–	–
Aug.	–	–	–	–	–	–	–	–	–	–	–	–
Sept.	1	4	–	–	–	–	–	–	1	5	1	4
<b>Total (1)</b>	<b>1</b>	<b>4</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>1</b>	<b>5</b>	<b>1</b>	<b>4</b>
<b>2) Depressions :</b>												
Jun.	1	2	–	–	–	–	2	8	2	10	–	–
Jul.	–	–	–	–	1	4	–	–	1	3	1	3
Aug.	–	–	–	–	1	2	–	–	–	–	4	9
Sept.	–	–	–	–	–	–	2	5	2	9	3	7
<b>Total (2)</b>	<b>1</b>	<b>2</b>	<b>–</b>	<b>–</b>	<b>2</b>	<b>6</b>	<b>4</b>	<b>13</b>	<b>5</b>	<b>22</b>	<b>8</b>	<b>19</b>
<b>3) Low pressure areas :</b>												
Jun.	1	1	1	9	1	5	–	–	1	2	1	3
Jul.	2	15	2	7	4	10	4	17	2	9	4	15
Aug.	5	19	4	18	3	14	4	26	1	2	1	4
Sept.	2	10	3	15	4	22	–	–	2	9	1	4
<b>Total (3)</b>	<b>10</b>	<b>45</b>	<b>10</b>	<b>49</b>	<b>12</b>	<b>51</b>	<b>8</b>	<b>43</b>	<b>6</b>	<b>22</b>	<b>7</b>	<b>26</b>
<b>4) Cyclonic Circulations :</b>												
Jun.	13	71	7	30	6	32	4	22	5	45	9	48
Jul.	14	50	3	10	7	30	8	30	3	16	7	18
Aug.	11	94	7	21	3	26	3	35	9	58	1	2
Sept.	13	58	4	16	8	52	7	32	1	11	2	6
<b>Total (4)</b>	<b>51</b>	<b>273</b>	<b>21</b>	<b>77</b>	<b>24</b>	<b>140</b>	<b>22</b>	<b>119</b>	<b>18</b>	<b>130</b>	<b>19</b>	<b>74</b>
<b>5) Western Disturbances :</b>												
Jun.	–	–	8	34	7	32	6	35	5	32	8	45
Jul.	1	1	7	41	7	29	12	40	8	35	8	28
Aug.	–	–	9	33	10	37	8	26	6	24	6	27
Sept.	–	–	9	38	6	38	7	31	9	39	3	8
<b>Total</b>	<b>1</b>	<b>1</b>	<b>33</b>	<b>146</b>	<b>30</b>	<b>136</b>	<b>33</b>	<b>132</b>	<b>28</b>	<b>130</b>	<b>25</b>	<b>108</b>



# Monsoon<sup>2006</sup> A Report

## Chapter – 3

### **Rainfall Statistics**

*In this Chapter, details of rainfall distribution (daily, weekly, monthly and seasonal) during the season are discussed.*

The 2006 south-west monsoon rainfall over the country as a whole was normal. However, it was not well distributed over space and time. Due to the early onset and initial rapid advancement of monsoon, rainfall activity during the last week of May and first week of June was above normal. However, monsoon was subdued for the next two weeks due to a prolonged hiatus in advance of monsoon. After a long hiatus of about 15 days, monsoon again revived during the third week of June. It remained active till the first week of July. However, monsoon again became subdued during the next two weeks of July. During the last week of July, monsoon revived again and this time remained active for unusually long period. Monsoon was active over the country on most days of August and September, thus improving the overall monsoon performance over the country

For the country as a whole, seasonal rainfall at the end of southwest monsoon season was 100% of its Long Period Average (LPA) value. The long period average (LPA) value of southwest monsoon rainfall calculated with the data of the period, 1941-1990 is 89 cm.

During the season, out of 36 meteorological subdivisions, 6 subdivisions received excess rainfall, 21 received normal rainfall and the remaining 9 subdivisions received deficient rainfall (Fig.3.1). Moderate drought conditions (rainfall deficiency of 26% to 50%) prevailed over four sub-divisions viz. Arunachal Pradesh (-29%), Assam and Meghalaya (-38%), West Uttar Pradesh(-43%) and Haryana, Chandigarh, Delhi(-38%) (Fig 3.1). Out of 533 meteorological districts for which data are available, 60% of the meteorological districts

received excess/normal rainfall and the remaining 40 % received deficient/scanty rainfall during the season. 130 districts (25%) experienced moderate drought and 35 districts (6%) experienced severe drought conditions at the end of the season.

Per cent of districts with excess/ normal and deficient/ scanty rainfall for the years 2001- 2006 are given in the table.

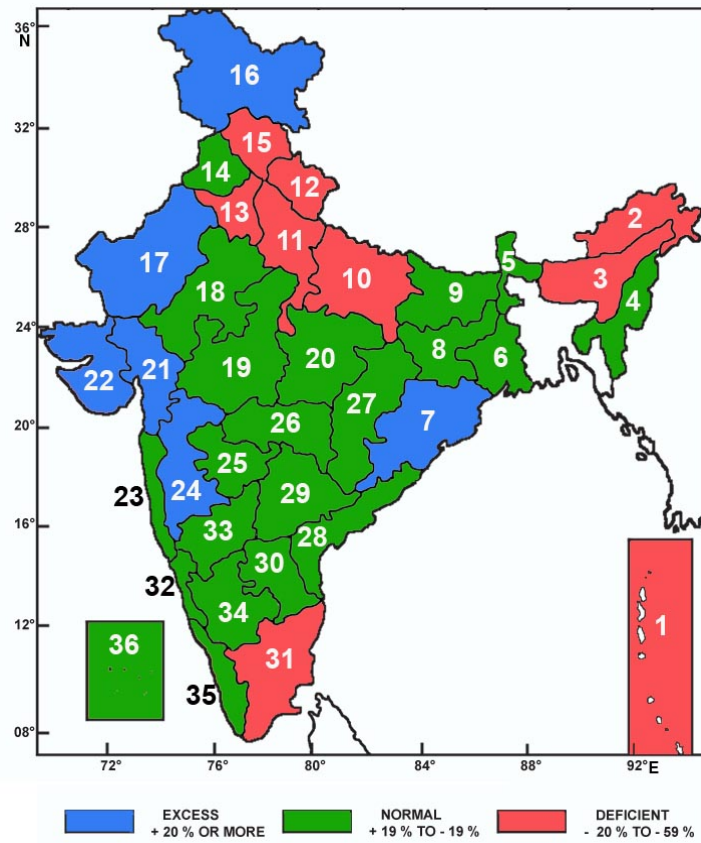
Year	Excess/Normal	Deficient/Scanty
2001	68	32
2002	39	61
2003	75	25
2004	56	44
2005	72	28
2006	60	40

Seasonal (June to September) rainfall departure, calculated using station wise rainfall data is shown in Fig. 3.2. The long period average is based on 1951-2003. Seasonal rainfall was above normal over the extreme northern (Jammu & Kashmir), eastern and central parts of the country and north and southwest peninsula. It was below normal over most of northern and northeastern parts of India. Over Gujarat region, western Maharashtra, west Madhya Pradesh, Orissa and Jharkhand the positive rainfall anomalies exceeded 40 cm. Over parts of Uttar Pradesh, Uttaranchal, Haryana, Chandigarh, Delhi, east Madhya Pradesh and extreme northeastern parts of the country, negative rainfall anomalies exceeded 20 cm.

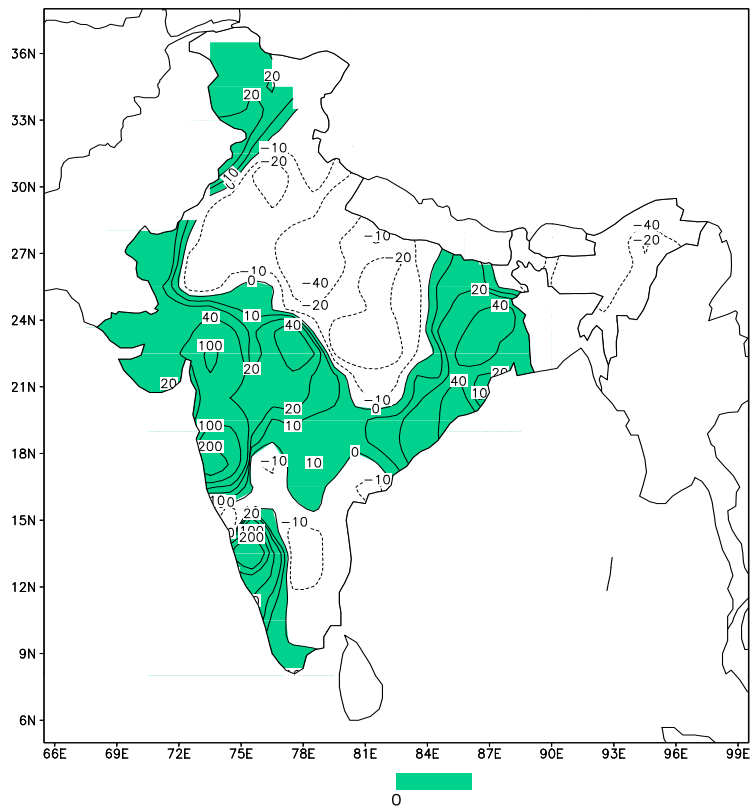
Figure 3.3 shows number of deficient sub divisions during the last ten years. It may be seen that although seasonal rainfall in 2006 for the country as a whole was normal, as many as nine sub divisions received deficient rainfall. Similarly Figure 3.4 shows percentage of districts affected by the moderate or severe drought condition during last ten years, it may be observed that in 2006, as many as 31% of districts were affected by moderate to excess drought conditions. In 2005, only 20% of districts were affected by moderate or severe drought conditions.

### Monthly rainfall distribution

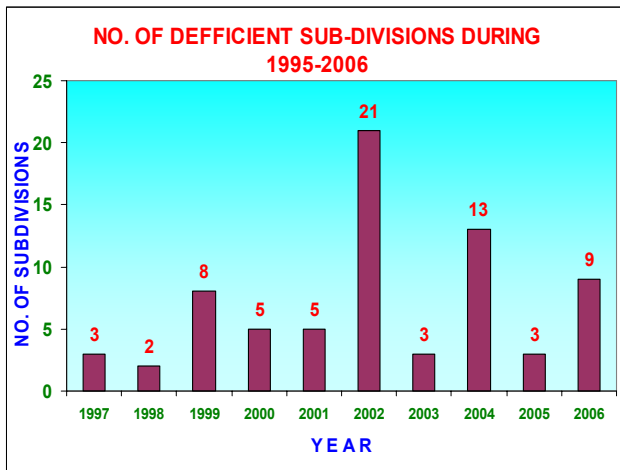
During June, rainfall activity was much above normal in the first week, especially over the western parts of India. However, monsoon was subdued in the next two weeks before again reviving during the last week of the month. Parts of peninsula and some extreme northern region received good amount of rainfall. For June 2006, rainfall for the country as a whole was **87% of its Long Period Average (LPA)** value. During the month, out of 36 meteorological subdivisions, 9 received excess rainfall, 15 received normal rainfall, 10 received deficient rainfall and 2 subdivisions received scanty rainfall (Fig3.5a).



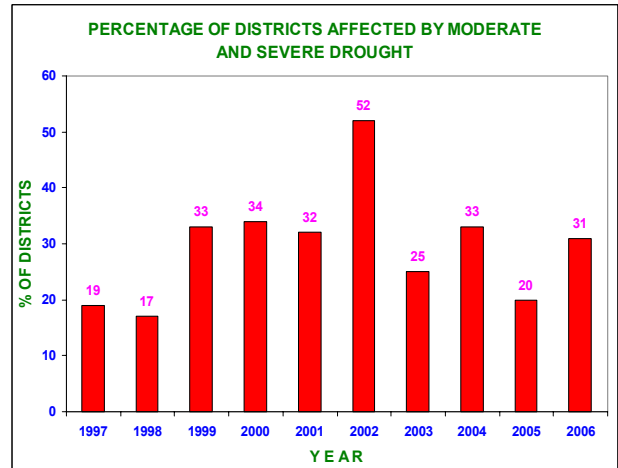
**Fig. 3.1 : Sub-Division wise seasonal rainfall (percentage departures)**



**Fig. 3.2 : Seasonal (June-Sept) rainfall anomaly (cm)  
Calculated using stationwise rainfall data**



**Fig 3.3: Number of deficient sub-divisions during the last 10 years**



**Fig 3.4: Per cent of districts affected by moderate and severe drought**

During July, rainfall activity during the month was normal. It was above normal over the central and northern parts of the country. However, it was subdued over the south peninsula and extreme northeastern parts of the country. For July 2006, rainfall for the country as a whole was 98 % of its Long Period Average (LPA) value. During the month, out of 36 meteorological subdivisions, 5 received excess rainfall, 17 received normal rainfall, 13 received deficient rainfall and 1 subdivision (Tamil Nadu) received scanty rainfall (Fig3.5b).

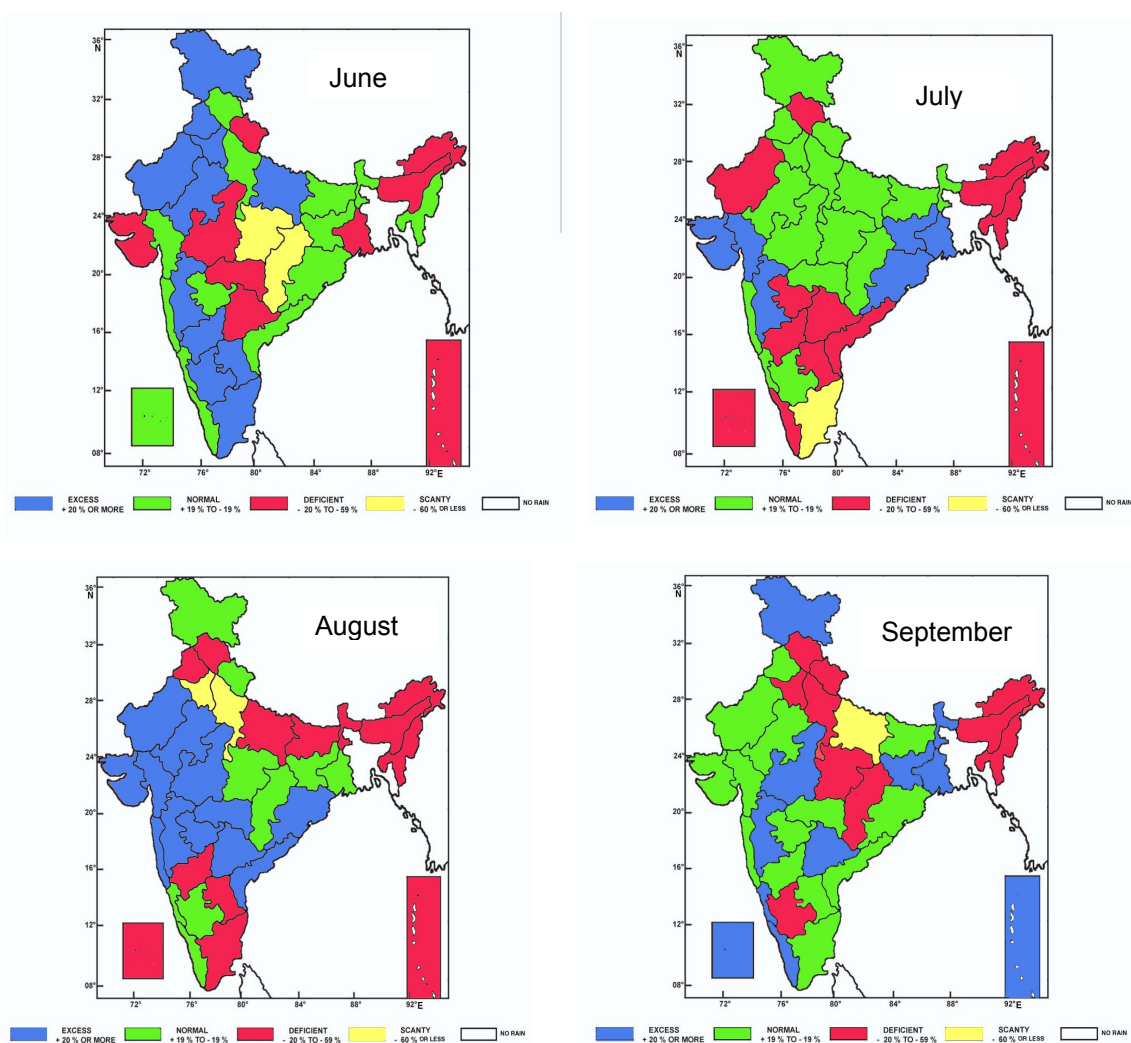
During August, rainfall activity over the country as a whole was above normal. It was above normal over the central and northwestern parts of the country. However, rainfall activity was subdued over the south peninsula, northern and northeastern parts of the country. For August 2006, rainfall for the country as a whole was 107 % of its Long Period Average (LPA) value. During the month, out of 36 meteorological subdivisions, 13 received excess rainfall, 9 received normal rainfall, 14 received deficient rainfall and 2 subdivisions (West Uttar Pradesh and Haryana, Chandigarh & Delhi) received scanty rainfall (Fig 3.5c).

During September, monsoon activity over the country as a whole was normal. It was above normal over parts of peninsula, islands, west central and extreme northern parts of the country. However, it was subdued over east central, northern and extreme northeastern parts of the country. For September 2006, rainfall for the country as a whole was 102% of its Long Period Average (LPA) value. During the month, out of 36 meteorological subdivisions, 13 received excess rainfall, 14 received normal rainfall, 8 received deficient rainfall and 1 subdivision (East Uttar Pradesh) received scanty rainfall (Fig. 3.5d).

Seasonal and monthly rainfall statistics for 2006 season are given in Table 3.1.

The following table gives the respective number of sub divisions having excess, normal, deficient and scanty rainfall during the 2006 monsoon seasons.

Month	Excess	Normal	Deficient	Scanty
June	11	14	9	2
July	6	16	13	1
August	12	9	13	2
September	13	14	8	1

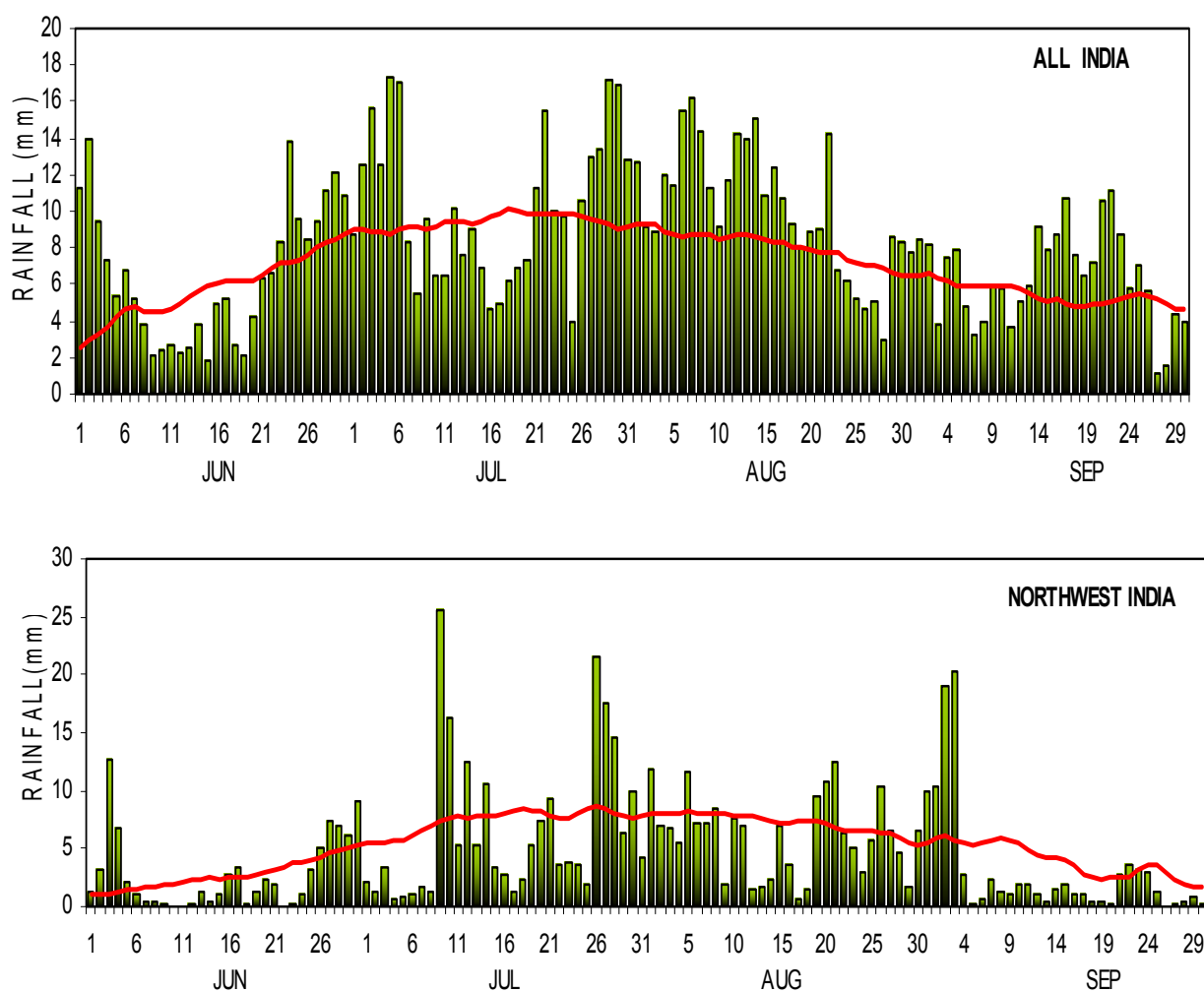


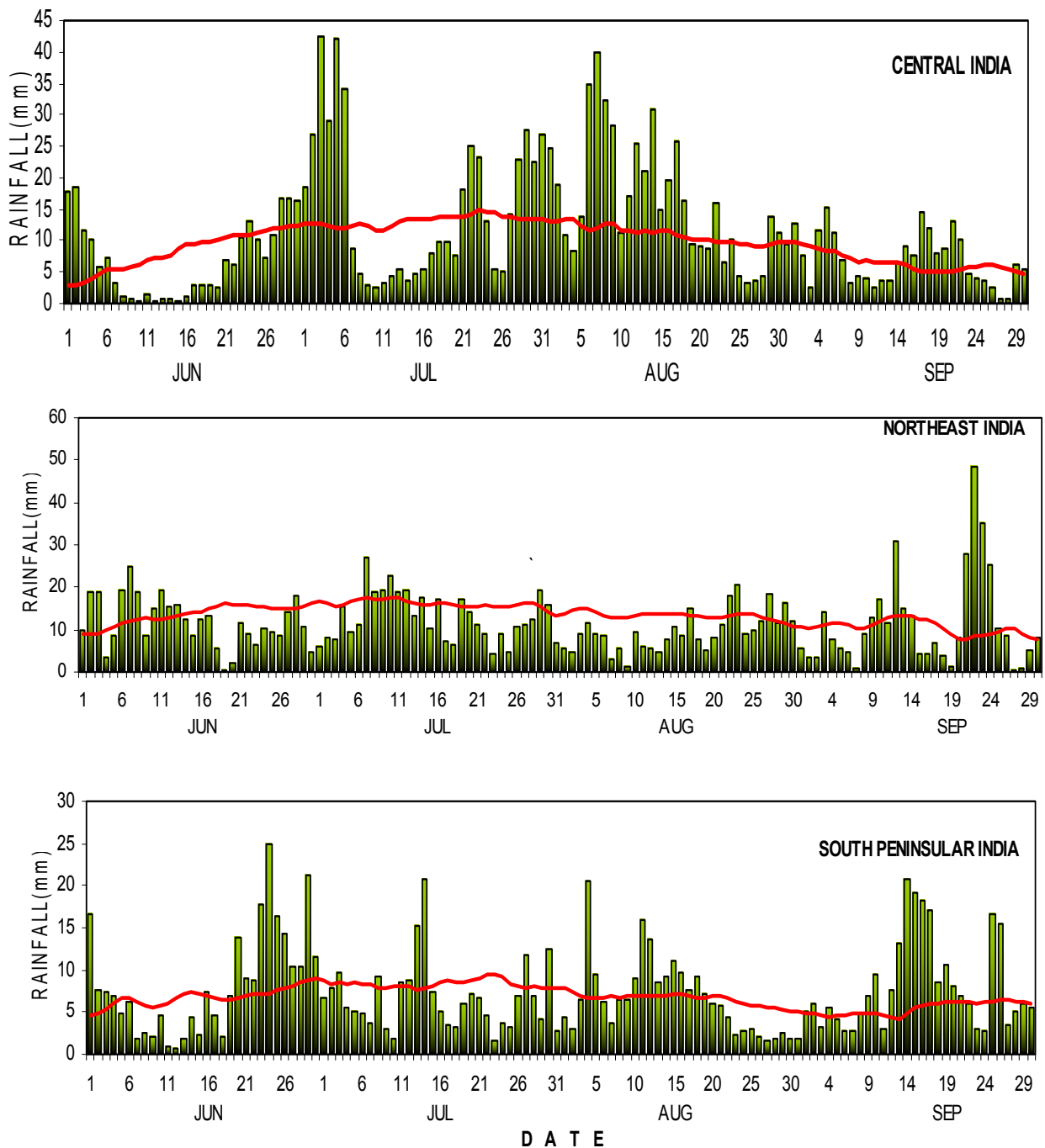
**Fig. 3.5 (a-d): Monthly sub division wise rainfall distribution in percent departure for June, July, August and September 2006**

## Daily rainfall distribution

Area weighted daily percentage rainfall departure for the country as a whole and for four homogeneous regions for the period 1 June to 30 September are shown in Fig 3.6. All India daily rainfall was above normal on many days of the season. It was continuously above normal from 23 June to 6 July, 26 July to 22 Aug. (except on 2 & 3 Aug.), 13 Sep. to 26 September. However, it was below normal at a stretch from 8 to 22 June and again on many occasions in the 2<sup>nd</sup> and 3<sup>rd</sup> week of July (from 13 July to 20 July).

Over Central and south peninsular regions, daily rainfall was above normal on a number of days viz. in the fourth week of June and first week of July, and in August and September months. Over the NW region, daily rainfall was below normal on many days of June and at a stretch from 4<sup>th</sup> Sept. to 20<sup>th</sup> September. Over the northeast India, it was below normal on many days in all the four months except in September when it was above normal on a number of days.





**Fig.3.6 : Daily mean rainfall (mm) averaged over the plains (vertical lines) and its long term average (1951-2003) (continuous line) for the country as a whole and the four homogenous regions during the season.**

### Weekly rainfall distribution

Area weighted weekly cumulative percentage rainfall departure for the country as a whole and for four homogeneous regions (NW India, NE India, Central India, and South Peninsula) for the period 1 June to 30 September are shown in Fig. 3.7.

Cumulative seasonal rainfall percentage departures for the country as a whole, after the first week of above normal rainfall activity, were continuously negative. Monsoon after the first week of June was generally subdued throughout the country till 26 July. The cumulative rainfall departure as on 26 July was -14%. However, the good monsoon spells during the first half of August helped to improve the over all performance of the monsoon. However, during the season the cumulative rainfall always remained below normal. The cumulative rainfall departure at the end of season was 0%.

Over NW region cumulative weekly rainfall percentage departure was very high (166%) in the first week of June and remained positive in the next week also. However, cumulative rainfall percentage departure was negative in all the subsequent weeks of the season. At the end of season, rainfall departure was -6%. Over central India, cumulative weekly rainfall percentage departure was very high (133%) in the first week of June and was slightly positive in the next week also. In the next two weeks it was large negative and became positive in the week ending 5 July. Again cumulative rainfall was negative during next three weeks, became positive in the week ending 2 August and remained positive in the remaining weeks of the season. At the end of season, rainfall departure was +16%. Over south peninsula, cumulative weekly rainfall percentage departure was negative in almost all the weeks of the season except for the week ending 5 July. It was large negative during second and third week of June, for week ending 26 July and 2 August. Again, during the last week of August and the first two weeks of September, cumulative rainfall departure was substantially negative. At the end of season, rainfall departure was - 5%. Over NE region, cumulative weekly rainfall percentage departure, except for the first two weeks of June, was negative during all the weeks of the season. At the end of season, rainfall departure was -17%.

Week by week and cumulative weekly rainfall departures for each of the 36 meteorological sub-divisions from 1 June to 30 September are shown in Fig.3.7 and Fig. 3.8 respectively. Rainfall was normal or excess on most of weeks (more than 50% of the weeks) over Gangetic West Bengal, sub Himalayan West Bengal & Sikkim, Orissa, Jammu & Kashmir, west & east Rajasthan, Gujrat, Saurashtra & Kutch, Konkan & Gao, Madhya Maharashtra, Telangana, Chatisgarh and coastal Karnataka sub-divisions. Similarly, cumulative weekly percentage rainfall departure was normal or excess on most of weeks over all meteorological sub divisions of Eastern & Central India, northern Peninsula, Gujrat, Rajasthan, West coast, Karnataka and Kerala.

S.NO.	MET.SUBDIVISION	WEEK ENDINGS																
		7-Jun	14-Jun	21-Jun	28-Jun	5-Jul	12-Jul	19-Jul	26-Jul	2-Aug	9-Aug	16-Aug	23-Aug	30-Aug	6-Sep	13-Sep	20-Sep	27-Sep
1	A & N ISLANDS	Deficient	Deficient	Excess	Normal	Deficient	Normal	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
2	ARUNACHAL PRADESH	Normal	Normal	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
3	ASSAM & MEGHALAYA	Deficient	Normal	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal
4	NAG.,MANI.,MIZO.,TRIPURA	Excess	Excess	Deficient	Normal	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Excess
5	S.H.W.B.&SIKKIM	Normal	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal
6	GANGATIC W.B.	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Excess
7	ORISSA	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
8	JHARKHAND	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
9	BIHAR	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
10	EAST U.P.	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
11	WEST U.P.	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
12	UTTARANCHAL	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
13	HAR., CHANDI., DELHI	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
14	PUNJAB	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
15	HIMACHAL PRADESH	Normal	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
16	JAMMU & KASHMIR	Excess	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
17	WEST RAJASTHAN	Normal	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
18	EAST RAJASTHAN	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
19	WEST M.P.	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
20	EAST M.P.	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
21	GUJARAT REGION	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
22	SAURASHTRA & KUTCH	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
23	KONKAN & GOA	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
24	MADHYA M'RASHTRA	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
25	MARATHAWADA	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
26	VIDARBHA	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
27	CHATTISGARH	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
28	COASTAL A.P.	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
29	TELANGANA	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
30	RAYALASEEMA	Normal	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
31	TAMIL NADU	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
32	COASTAL KARNATAKA	Excess	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
33	N.I.KARNATAKA	Normal	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
34	S.I.KARNATAKA	Excess	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
35	KERALA	Normal	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal
36	LAKSHADWEEP	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Normal	Deficient	Deficient	Normal



**Fig. 3.7 : Sub-division wise weekly rainfall**

S.NO.	MET.SUBDIVISION	WEEK ENDINGS																	
		7-Jun	14-Jun	21-Jun	28-Jun	5-Jul	12-Jul	19-Jul	26-Jul	2-Aug	9-Aug	16-Aug	23-Aug	30-Aug	6-Sep	13-Sep	20-Sep	27-Sep	30-Sep
1	A & N ISLANDS																		
2	ARUNACHAL PRADESH																		
3	ASSAM & MEGHALAYA																		
4	NAG., MANI., MIZO., TRIPURA																		
5	S.H.W.B.&SIKKIM																		
6	GANGATIC W.B.																		
7	ORISSA																		
8	JHARKHAND																		
9	BIHAR																		
10	EAST U.P.																		
11	WEST U.P.																		
12	UTTARANCHAL																		
13	HAR., CHANDI., DELHI																		
14	PUNJAB																		
15	HIMACHAL PRADESH																		
16	JAMMU & KASHMIR																		
17	WEST RAJASTHAN																		
18	EAST RAJASTHAN																		
19	WEST M.P.																		
20	EAST M.P.																		
21	GUJARAT REGION																		
22	SAURASHTRA & KUTCH																		
23	KONKAN & GOA																		
24	MADHYA M'RASHTRA																		
25	MARATHAWADA																		
26	VIDARBHA																		
27	CHATTISGARH																		
28	COASTAL A.P.																		
29	TELANGANA																		
30	RAYALASEEMA																		
31	TAMIL NADU																		
32	COASTAL KARNATAKA																		
33	N.I.KARNATAKA																		
34	S.I.KARNATAKA																		
35	KERALA																		
36	LAKSHADWEEP																		



**Fig. 3.8 : Sub-division wise cumulative weekly rainfall**

**Table – 3.1**  
**Rainfall (mm) for each month and season as a whole (June – September 2006)**

S No.	Meteorological Sub-Division	JUNE-06			JULY-06			AUGUST-06			SEPTEMBER-06			SEASONAL-06		
		Actual (mm)	Normal (mm)	Dep. %	Actual (mm)	Normal (mm)	Dep. %	Actual (mm)	Normal (mm)	Dep. %	Actual (mm)	Normal (mm)	Dep. %	Actual (mm)	Normal (mm)	Dep. %
1	ANDAMAN & NICOBAR ISLANDS	367.4	482.0	-24	187.3	419.0	-55	219.7	415.8	-47	550.3	438.4	26	1324.7	1755.2	-25
2	ARUNACHAL PRADESH	350.9	493.7	-29	417.5	595.5	-30	228.3	388.1	-41	309.1	357.6	-14	1305.8	1834.9	-29
3	ASSAM & MEGHALAYA	389.3	567.1	-30	335.5	563.6	-40	190.6	434.1	-56	243.7	320.6	-24	1169.2	1885.9	-38
4	N. M. M. T.	341.0	361.1	-6	273.6	345.2	-21	178.8	308.5	-42	219.6	226.2	-3	1012.9	1240.9	-18
5	WEST BENGAL & SIKKIM	419.0	495.8	-15	507.2	602.1	-16	313.2	469.7	-33	467	387.7	20	1706.4	1955.4	-13
6	GANGETIC WEST BENGAL	191.9	239.7	-20	466.9	314.6	48	313.4	312.4	0	371	269.7	38	1343.3	1136.3	18
7	ORISSA	177.0	206.1	-14	468.8	344.6	36	645.0	364.8	77	278.5	249.4	12	1569.3	1164.9	35
8	JHARKHAND	179.4	191.9	-7	438.2	335.7	31	280.5	323.8	-13	319.8	241.1	33	1217.9	1092.5	11
9	BIHAR	177.7	173.1	3	298.1	344.6	-13	154.0	295.5	-48	283	226.1	25	912.7	1039.2	-12
10	EAST U.P.	135.8	105.3	29	335.4	309.2	8	163.8	301.3	-46	68.8	197.8	-65	703.8	913.6	-23
11	WEST U.P.	60.3	68.6	-12	244.8	268.4	-9	71.9	286.2	-75	61.2	149.6	-59	438.2	772.8	-43
12	UTTARANCHAL	111.7	163.9	-32	417.3	425.5	-2	349.9	426.3	-18	99.3	207.5	-52	978.2	1223.1	-20
13	HARYANA	54.9	43.1	27	147.6	170.5	-13	35.8	167.9	-79	52.3	88.6	-41	290.6	470	-38
14	PUNJAB	59.1	41.6	42	172.0	189.2	-9	106.7	168.7	-37	98.7	102.3	-4	436.6	501.8	-13
15	HIMACHAL PRADESH	84.7	89.9	-6	219.6	288.1	-24	206.9	261.6	-21	79.4	134	-41	590.6	773.7	-24
16	JAMMU & KASHMIR	77.7	58.5	33	189.8	186.0	2	207.1	173.8	19	205.8	95.2	116	680.3	513.6	32
17	WEST RAJASTHAN	36.0	27.0	33	60.1	101.7	-41	202.9	98.6	117	34.3	40.5	-15	333.3	262.8	27
18	EAST RAJASTHAN	76.6	61.2	25	204.1	224.3	-9	319.7	232.9	37	87.2	105.2	-17	687.6	623.6	10
19	WEST M.P.	78.7	108.1	-27	302.9	304.5	-1	465.8	315.0	48	218.2	176.7	23	1065.6	904.3	18
20	EAST M.P.	55.8	143.6	-61	425.0	371.0	15	339.7	382.0	-11	82.5	200.7	-59	903	1097.4	-18
21	GUJARAT	120.7	122.6	-2	575.9	360.6	60	614.7	290.8	111	137.5	159.6	-14	1448.8	933.6	55
22	SAURASHTRA & KUTCH	64.4	81.0	-20	368.7	194.9	89	196.0	138.2	42	70.7	71.6	-1	699.8	485.7	44
23	KONKAN & GOA	612.8	674.5	-9	1065.5	1069.0	0	919.9	711.7	29	389.4	346.8	12	2987.6	2802.1	7
24	MADHYA MAHARASHTRA	184.6	134.3	37	340.2	238.2	43	364.3	176.3	107	214.5	151.3	42	1103.5	700.1	58
25	MARATHWADA	122.3	144.0	-15	123.1	192.2	-36	289.6	194.0	49	212.5	174.1	22	747.4	704.3	6
26	VIDARABHA	109.2	167.4	-35	360.0	328.5	10	415.0	300.4	38	194.9	180	8	1079	976.2	11
27	CHATTISGARH	74.8	188.6	-60	383.5	394.4	-3	438.6	391.2	12	177.6	231.6	-23	1074.6	1205.8	-11
28	COASTAL A.P.	114.6	99.5	15	92.4	159.7	-42	184.4	153.8	20	184.2	162.2	14	575.6	575.2	0
	TELANGANA	103.6	135.5	-24	146.5	242.4	-40	290.8	218.0	33	289.1	171.4	69	830	767.3	8
30	RAYALASEEMA	94.2	60.1	57	43.5	91.1	-52	46.6	97.3	-52	136.5	132.4	3	320.8	380.9	-16
31	TAMILNADU	53.2	41.6	28	19.9	70.7	-72	66.3	90.1	-26	109	113.2	-4	248.4	315.6	-21
32	COASTAL KARNATAKA	802.1	901.3	-11	1036.2	1188.0	-13	801.4	786.6	5	459.8	318	45	3099.5	3173.9	-2
33	NORTH INTERIOR KARNATAKA	124.1	98.3	26	92.3	126.4	-27	79.8	113.2	-29	134.9	153.1	-12	431	490.9	-12
34	SOUTH INTERIOR KARNATAKA	170.0	132.4	28	192.8	225.5	-15	137.5	164.1	-16	106.7	137.3	-22	607	659.3	-8
35	KERALA	577.1	678.0	-15	569.4	758.0	-25	396.4	447.3	-11	481.2	259.7	85	2024.2	2143	-6
36	LAKSHADWEEP	286.5	325.6	-12	172.6	282.3	-39	150.7	212.9	-29	318.2	164.4	94	928	985.2	-6

# Monsoon<sup>2006</sup> A Report

## Chapter – 4

### **Global and Regional Circulation Anomalies**

*In this Chapter, regional and global anomalies of SST and circulation are discussed.*

#### **4.1 Sea Surface Temperature Anomalies**

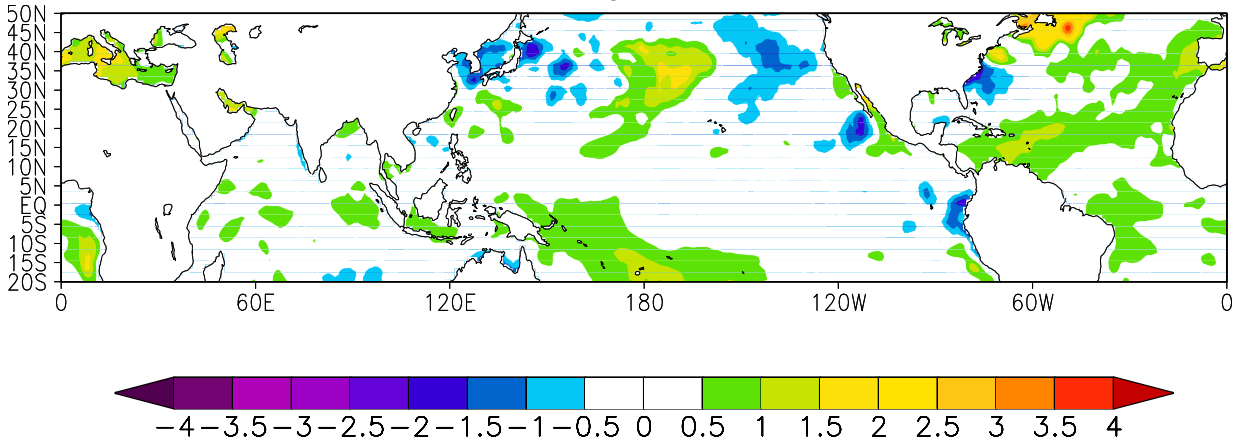
Monthly anomalies of sea surface temperature (SST) for the period May to September are shown in Fig. 4.1.

In May 2006, small positive sea surface temperature anomalies were observed over the parts of the equatorial Indian Ocean (South Bay of Bengal) and equatorial west Pacific Ocean. During June, positive sea surface temperature anomalies over the equatorial Indian Ocean extended into Arabian Sea also. The positive SST anomalies over the equatorial Pacific persisted. During July, positive SST anomalies over the equatorial Indian Ocean disappeared. However, positive anomalies started developing over the equatorial central Pacific Ocean, which increased in spatial extent and intensity during August and September, leading to moderate El Nino conditions. The time evolution of SST anomalies over the Nino regions is shown in Fig.4.2. By the end of September, SST anomalies over Nino 3, Nino-3.4 and Nino-4 regions crossed the Nino threshold of  $0.5^{\circ}\text{C}$ . A moderate El Nino event was established across the tropical Pacific basin and is expected to continue until at least the first quarter of 2007 (<http://www.wmo.int/web/press>).

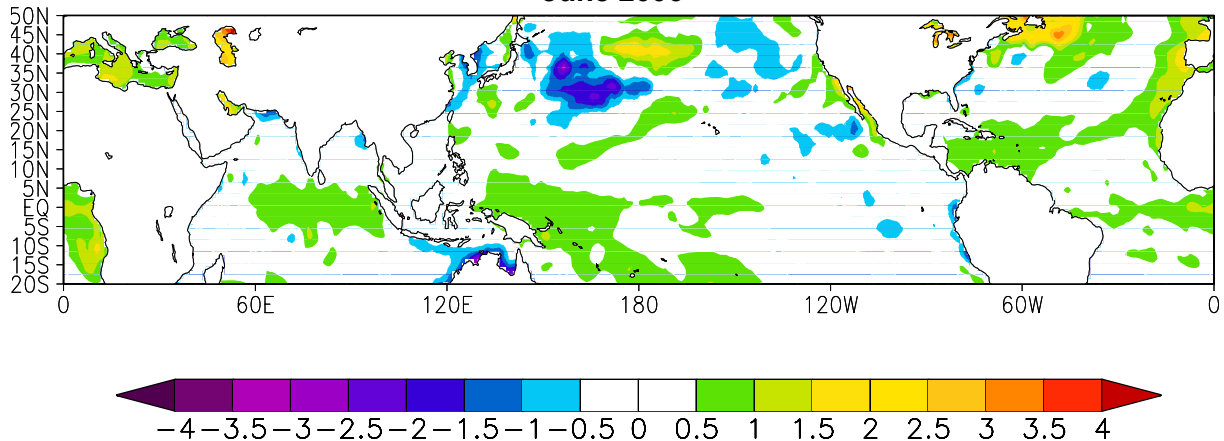
During August, positive SST anomalies persisted over the equatorial Indian Ocean also. Another interesting aspect was the development of negative (positive) SST anomalies

over the equatorial east (west) Indian Ocean. In September, positive SST anomalies over the equatorial Pacific and negative SST anomalies over the east equatorial Indian Ocean were strengthened. Positive SST anomalies also appeared over the west equatorial Indian Ocean, suggesting the development of a positive Indian Ocean Dipole event (Saji et al. 1999, Webster et al. 1999), which will be further discussed later in this section.

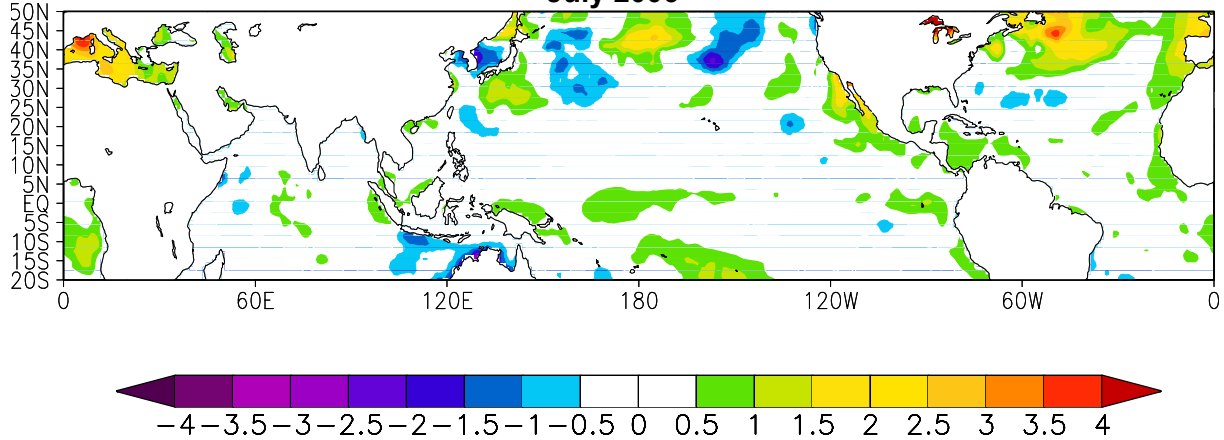
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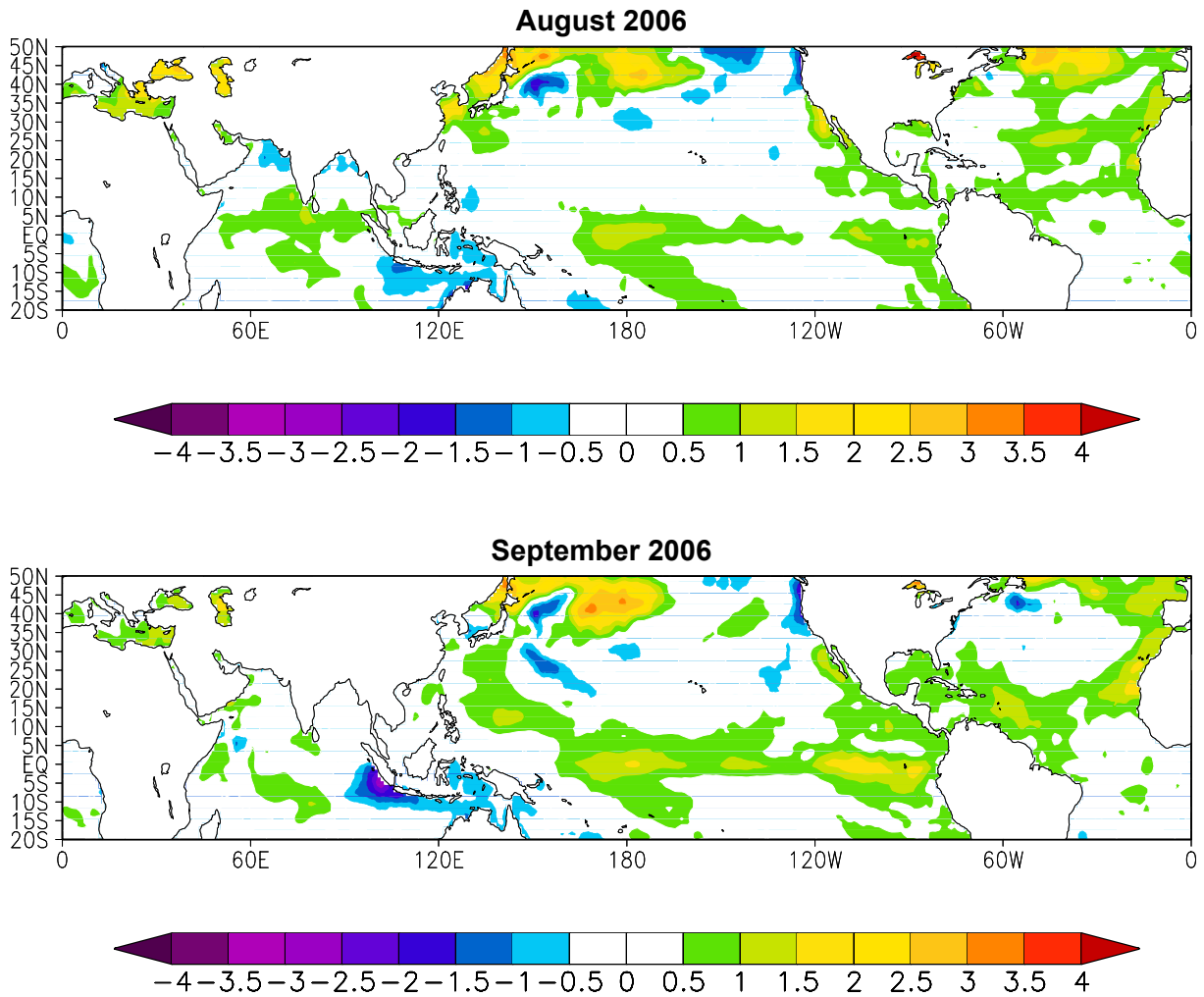


**June 2006**

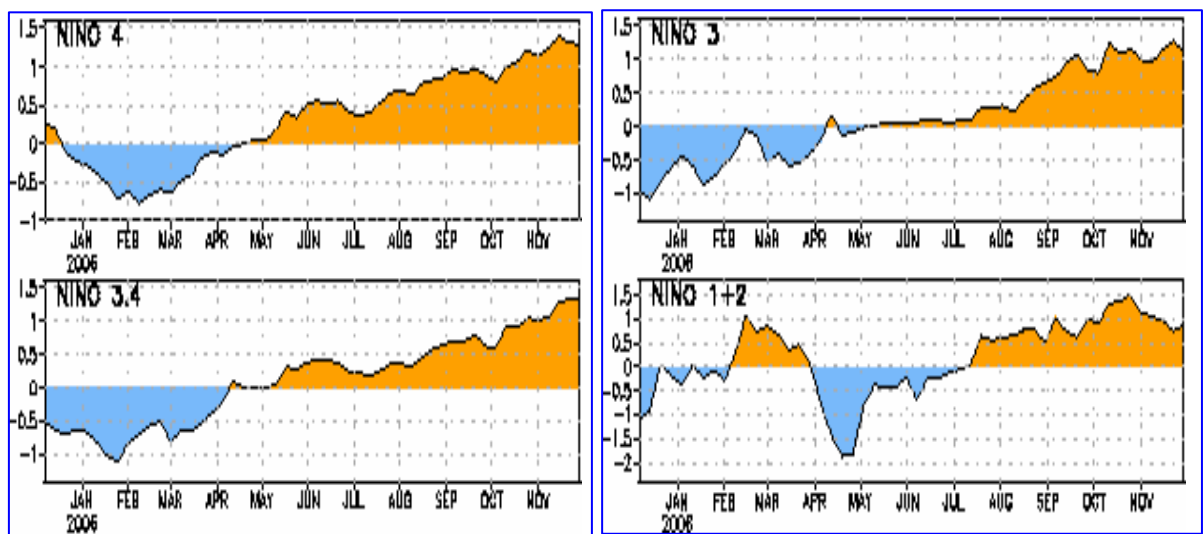


**July 2006**





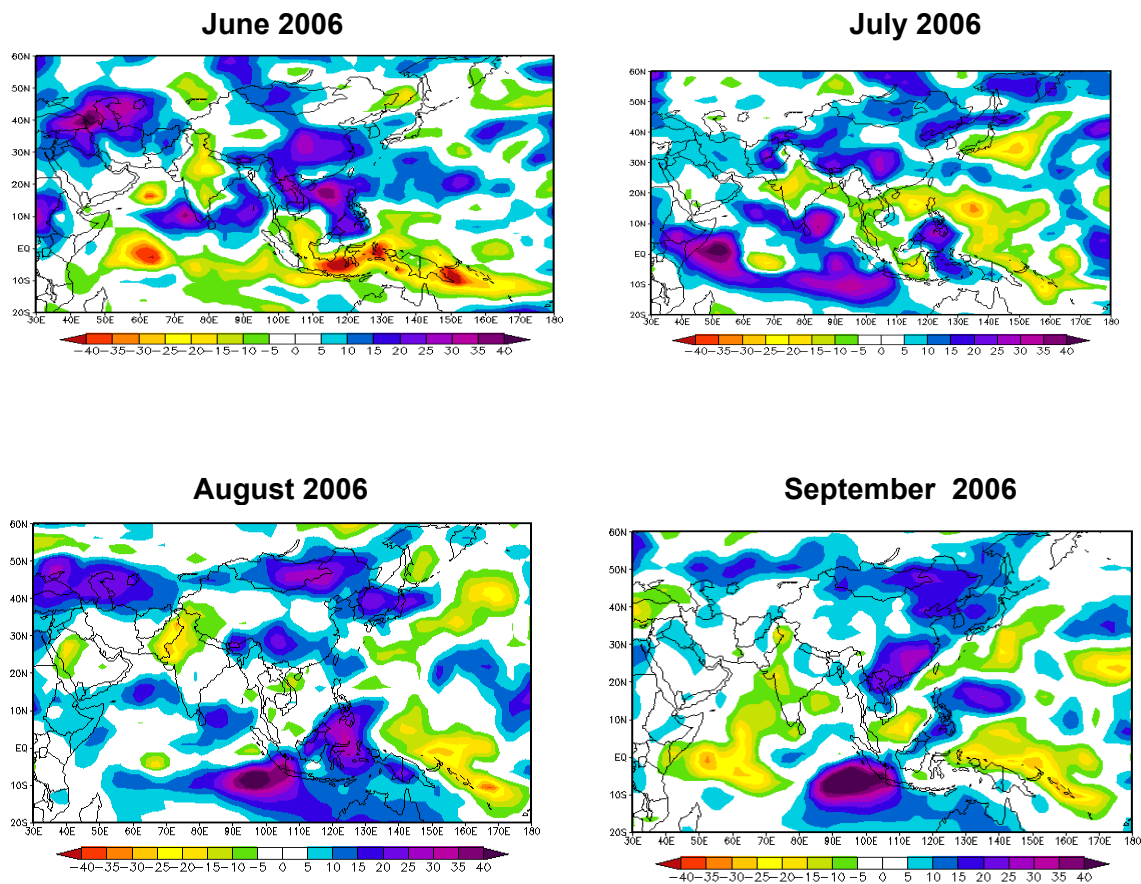
**Fig. 4.1 : SST Anomalies from May to September 2006**



**Fig. 4.2 : SST anomalies over the Nino regions (Source: CPC, NOAA)**

## 4.2 OLR anomalies

Outgoing Long Wave Radiation (OLR) anomalies during June to September months are shown in Fig. 4.3. In June, negative OLR anomalies were observed over the Central Arabian Sea, parts of northern peninsula, central, northwest and northern regions. However, positive anomalies were observed over the Bay of Bengal, north eastern regions, southern Arabian Sea and adjoining south Peninsula. During July, negative OLR anomalies (enhanced convection) were observed over Gujarat, north Maharashtra and Central India including Orissa and West Bengal. Positive OLR anomalies (suppressed convection) were observed over the equatorial and central Arabian Sea and Bay of Bengal. During August, negative OLR anomalies were observed over the Northwest region and positive OLR anomalies were observed over the Arabian Sea and south Bay of Bengal and the eastern region. During September, negative OLR anomalies were observed along the western parts of India and equatorial west Indian Ocean. Over the east equatorial Indian Ocean, positive OLR anomalies indicating suppressed convection were observed.



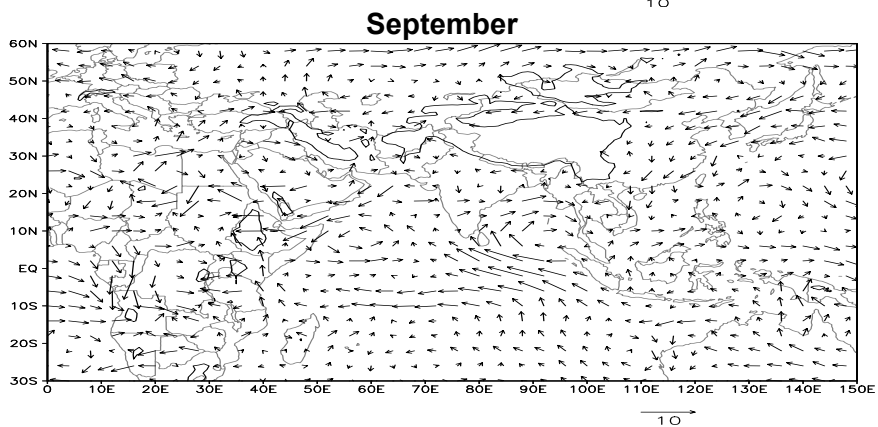
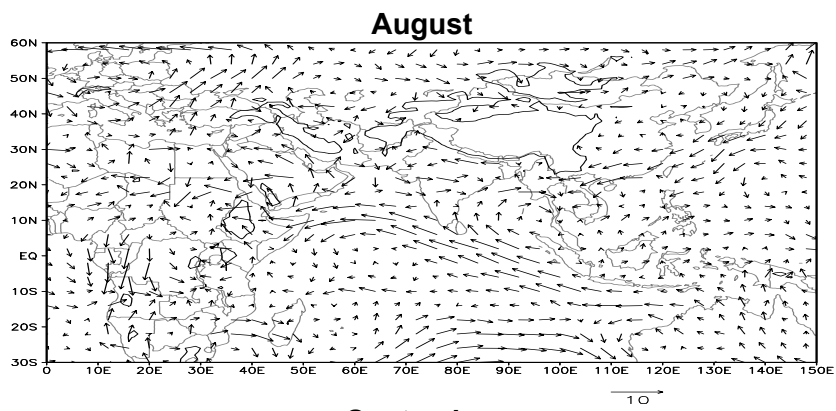
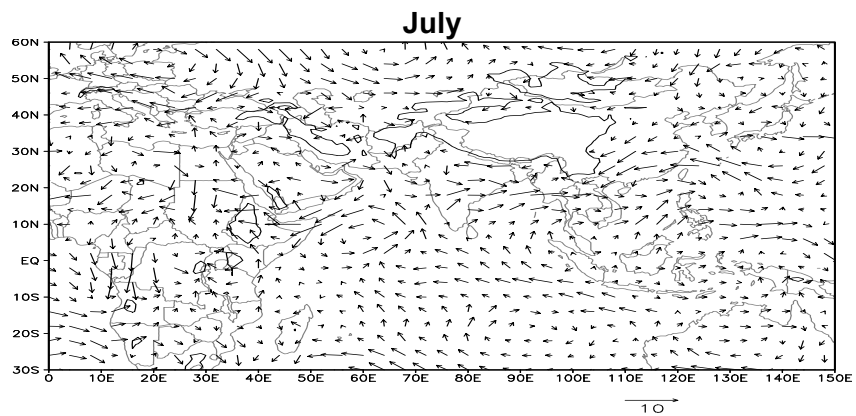
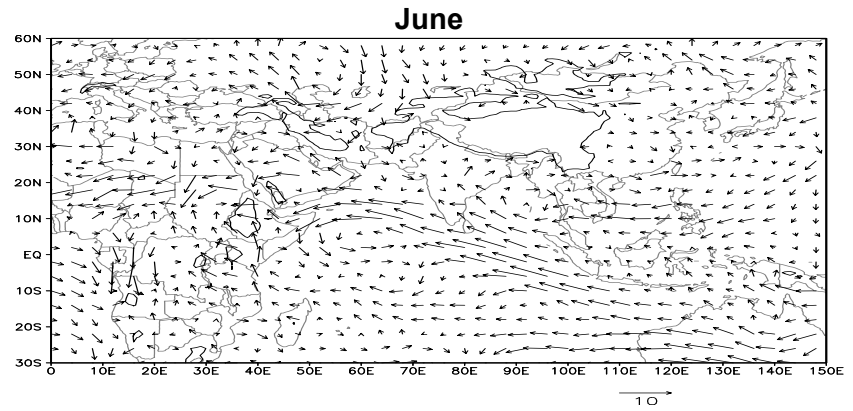
**Fig. 4.3 : OLR anomalies during June to September 2006**

### **4.3 Lower and Upper Tropospheric circulation anomalies**

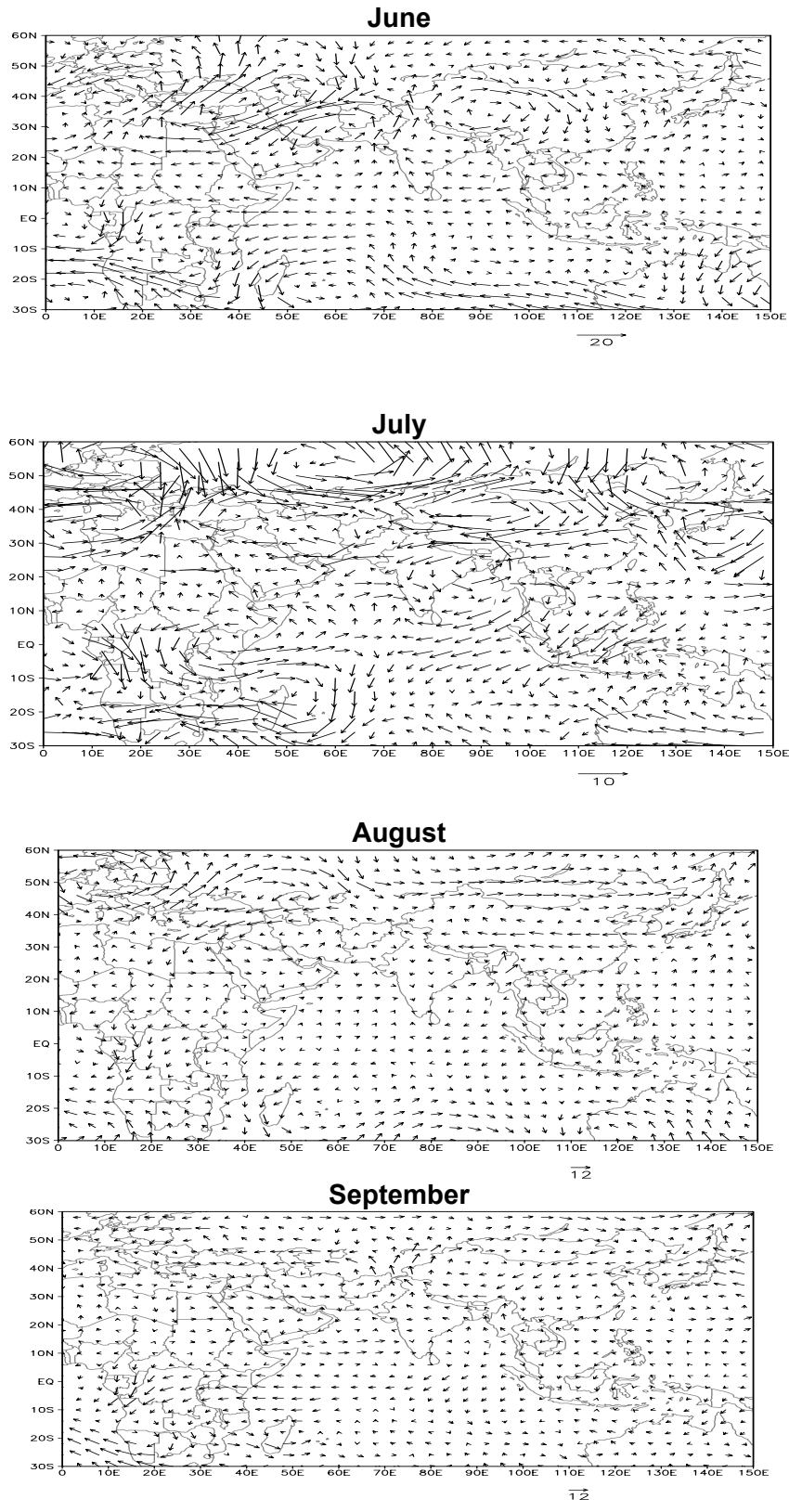
Circulation anomalies at 850 hPa during June to September months are shown in Fig 4.4 and same for 200 hPa are shown in Fig 4.5. In June 2006, at 850 hPa level, an anomalous anticyclonic circulation was observed over eastern, northeastern parts of India and adjoining Bay of Bengal. This anomalous circulation extended up to 200 hPa level with a marked northward shift. At 850 level, anomalous easterlies were observed over the peninsular region, the south Arabian Sea and the equatorial East Indian Ocean indicating weaker monsoon activity. In July 2006, at 850 hPa level, a large anomalous cyclonic circulation over the central and eastern parts of the country and adjoining Bay of Bengal was observed. This anomalous circulation extended up to 200 hPa level also. At the same level, an anomalous cyclonic circulation over the southwest Arabian sea and neighborhood was also observed. At the 200 hPa level, Tibetan anticyclone was stronger than normal.

In August 2006, at 850 hPa level, an anomalous east west trough across the central parts of the country was observed suggesting active monsoon conditions over the central parts. An anomalous anticyclonic circulation was also observed over the east central Bay of Bengal. At 200 hPa level, easterlies, stronger than the normal were observed around the equator. In September 2006, at 850 hPa level, two anomalous cyclonic circulations, one each over the southwest Arabian sea and north Bay of Bengal and adjoining east-central India were observed. At 200 hPa level, anomalous anticyclonic circulation over the eastern Tibetan region suggesting stronger than normal Tibetan high was observed. The circulation anomalies averaged over the whole season (June-September) are shown in Fig. 4.6.

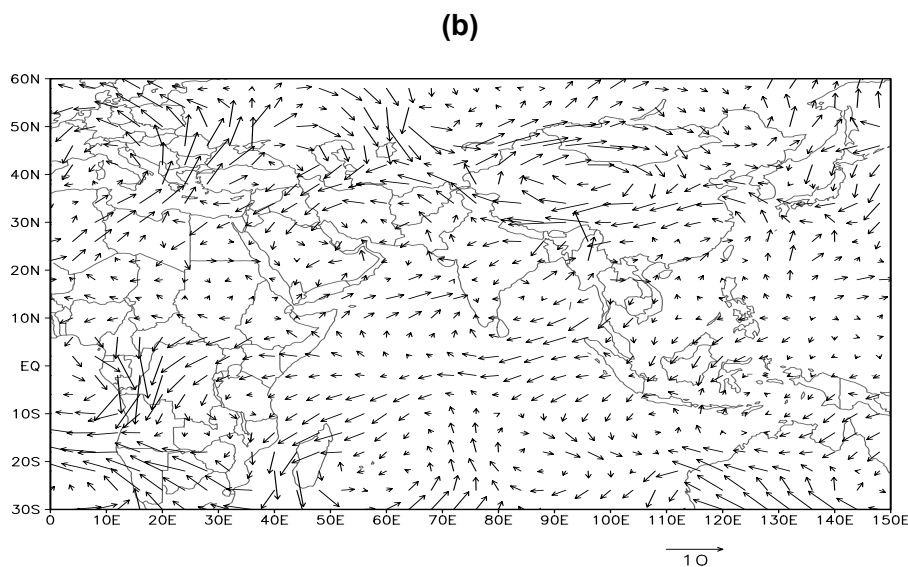
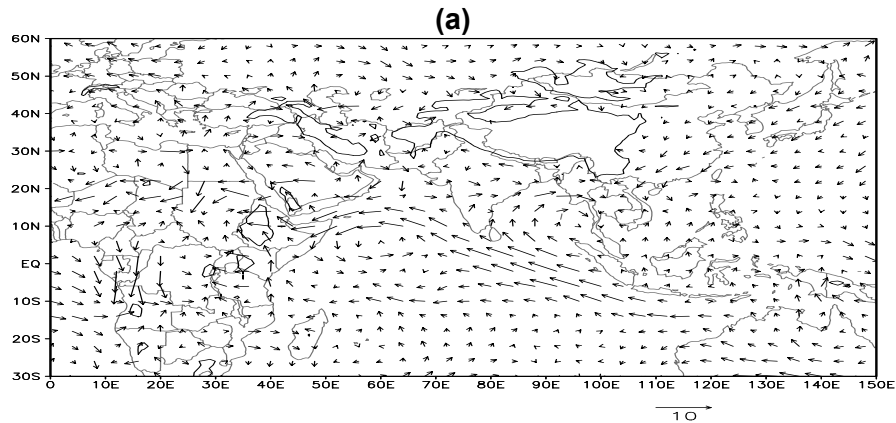
At 850 hPa level, an anomalous east-west trough over the central parts of the country was observed. An anomalous cyclonic circulation over the southwest Arabian Sea and an anomalous anticyclonic circulation over the east central Bay of Bengal were also observed. At 200 hPa level, an anomalous anticyclonic circulation was observed over the eastern Tibet and adjoining areas suggesting stronger than normal Tibetan anticyclone.



**Fig. 4.4 : Wind anomalies at 850 hPa during June to September**



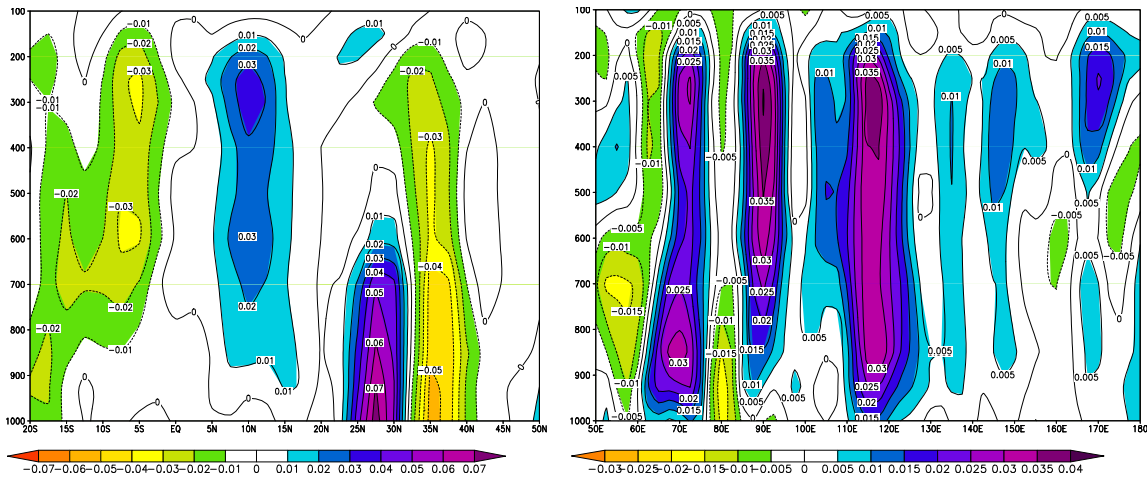
**Fig. 4.5 : Wind anomalies at 200 hPa during June to September**



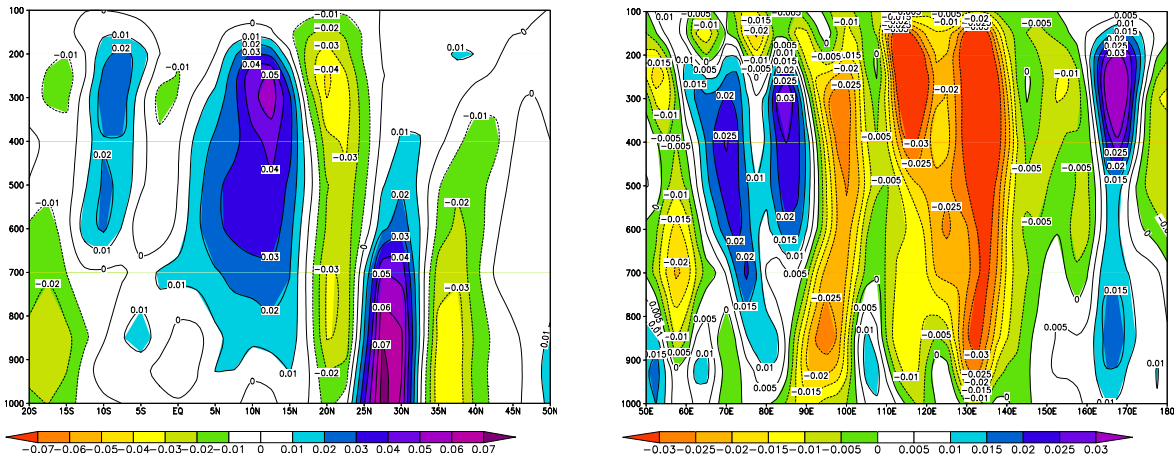
**Fig. 4.6 : Wind anomalies at (a) 850 hPa (b) 200 hPa during the monsoon season (June to September 2006)**

#### **4.4 Vertical circulation anomalies**

To examine the vertical circulation anomalies, Vertical cross sections of vertical velocity ( $\omega$  Pa/second) for June to September months were prepared and shown in Fig. 4.7 to 4.10. These diagrams show the Latitude-Height cross section averaged over longitudes  $70^{\circ}\text{E}$  to  $90^{\circ}\text{E}$  and the Longitude-Height cross section averaged over  $10^{\circ}\text{N}$  to  $20^{\circ}\text{N}$ , respectively.

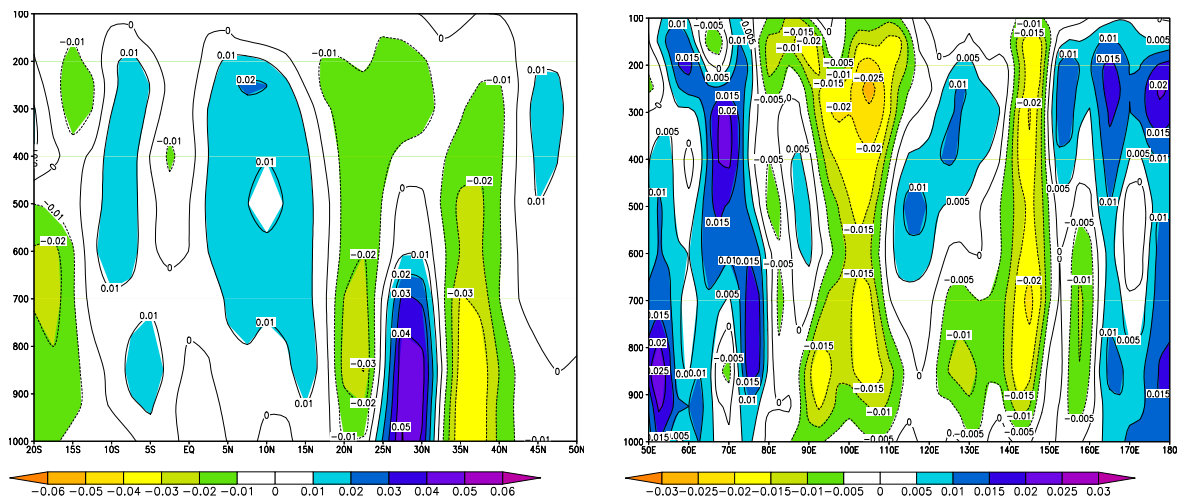


**Fig. 4.7 : Vertical cross section of Omega in June 2006**  
**a) Latitude-Height b) Longitude-height**

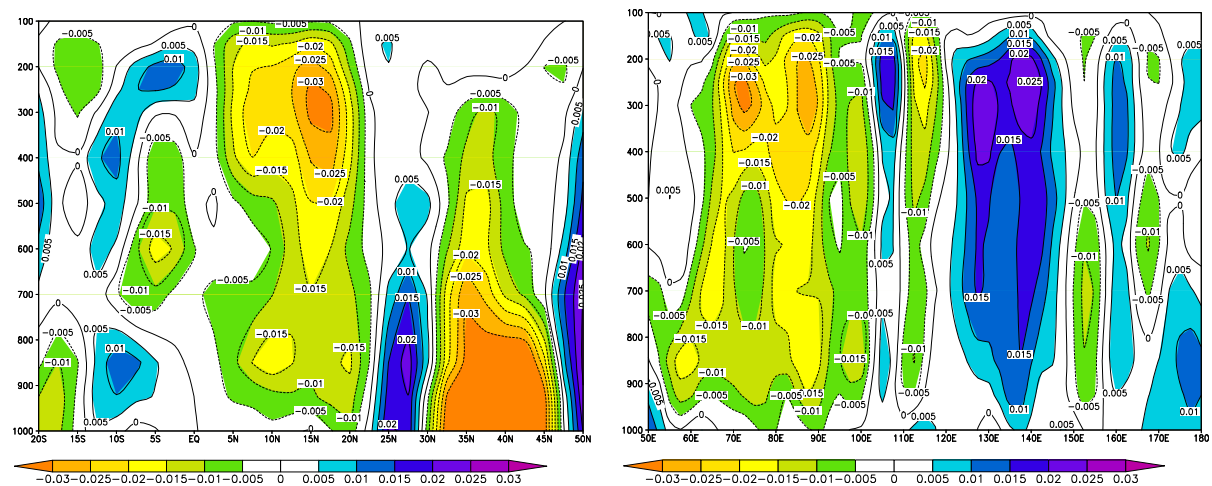


**Fig. 4.8 : Vertical cross section of Omega (vertical velocity) in July 2006**  
**a) Latitude-Height b) Longitude-height**

Fig. 4.7 (a) shows north south circulation with ascending branch around 35-40<sup>0</sup>N and descending branch over the Indian region. Negative values of omega (positive vertical velocity) over the south Indian Ocean, indicating active southern hemisphere equatorial trough (SHET) were also observed. Fig. 4.7(b) shows rising motion around 75<sup>0</sup>-80<sup>0</sup>E which may be the cause for enhanced rainfall over the region. Fig. 4.8(a) shows rising motion (enhanced convection) around 18<sup>0</sup>N to 23<sup>0</sup>N and over the south and central Bay of Bengal in July.



**Fig.4.9 : Vertical cross section of Omega in August 2006**  
**a) Latitude-Height b) Longitude-height**



**Fig.4.10 : Vertical cross section of Omega in September 2006**  
**a) Latitude-Height b) Longitude-height**

Fig. 4.9 (a) and (b) also show the ascending motion and enhanced convection over the central India, the central Bay of Bengal and over the extreme western Pacific Ocean. Fig. 4.10 (a) shows the ascending motion over the peninsular, central and north of 28°E and northeastern regions. Fig. 4.10(b) shows the ascending motion over the south and central Arabian Sea adjoining peninsula and the western Bay of Bengal.

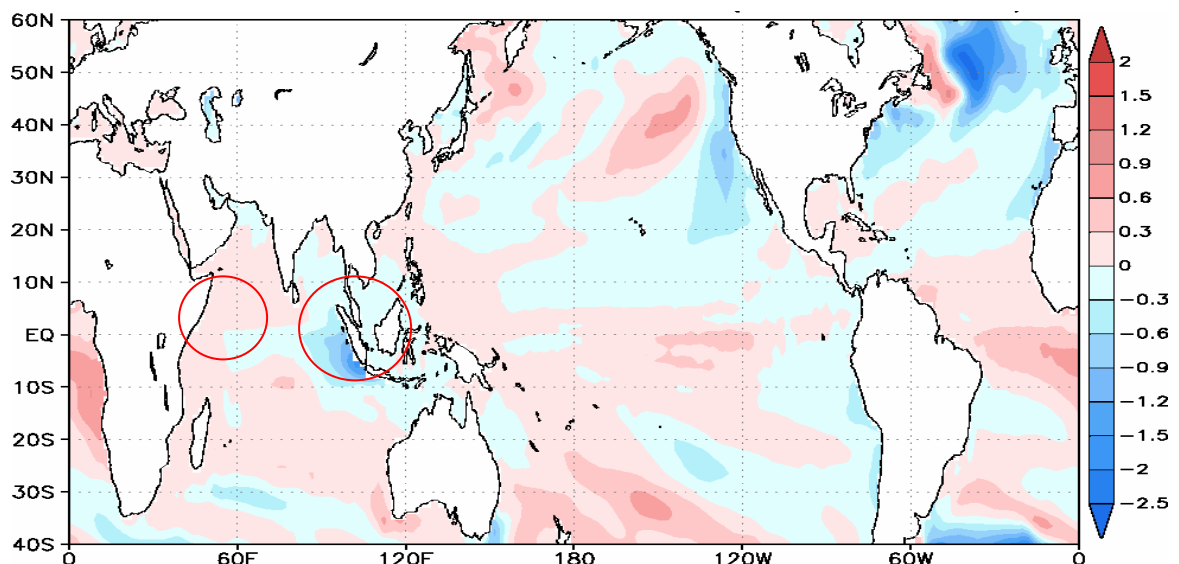
#### 4.5 Development of the Indian Ocean Dipole Event

Indian Ocean Dipole (IOD) phenomenon is one of the manifestations of the tropical air-sea interaction which form an area of active research over the Indian Ocean domain during recent time (Saji et al. 1999, Webster et al. 1999, Behera et al 1999, Yamagata et al

2002). IOD is characterized by the anomalous cooling of Sea Surface Temperature (SST) in the south eastern equatorial Indian Ocean and anomalous warming of SST over the western equatorial Indian Ocean. The Dipole Mode Index (DMI) is defined as SST anomaly difference between tropical western Indian Ocean ( $50^{\circ}$ - $70^{\circ}$ E,  $10^{\circ}$ S- $10^{\circ}$ N) and the Southeastern Indian Ocean ( $90^{\circ}$ E- $110^{\circ}$ E,  $10^{\circ}$ S-equator). Whenever DMI is positive, the phenomenon is referred as positive IOD and whenever DMI is negative it is known as negative IOD. It has been shown that IOD events have impact on rainfall in the Indian Summer Monsoon Rainfall [ISMR] (Behera et al, 1999, Ashok et al. 2001, Gadgil et al. 2004) and the Northeast monsoon rainfall over south Peninsular India (Kripalani and Pankaj Kumar, 2004).

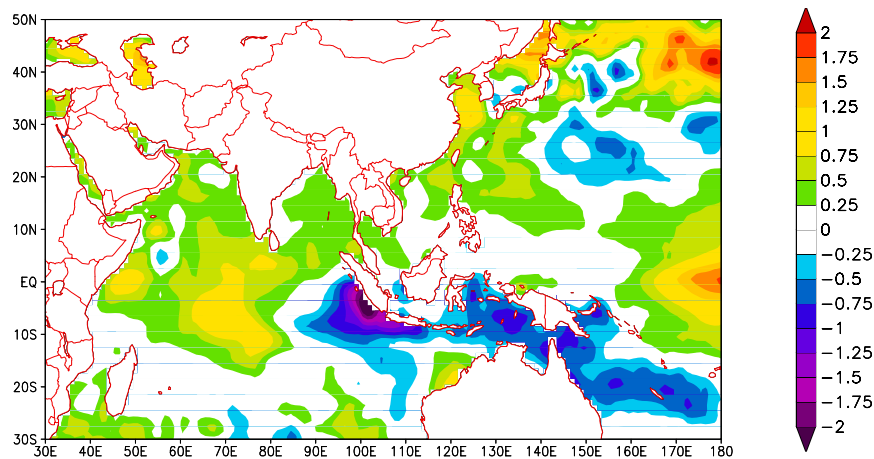
Frontier Research Center for Global Change (FRCGC) Climate Variations Research Program of Japan Agency for Marine-Earth Science and Technology in November 2005 predicted the development of positive IOD using a coupled Ocean-atmosphere model (SINTEX-F1). This is for the first time the IOD event is predicted using a general circulation model (see <http://www.jamstec.go.jp/frsgc/research/d1/iod/> for more details). Through reproduction experiments of past IOD events it is understood that the IOD events are usually predictable 4 months prior to an event. But predictions much earlier have become possible now after the world's first successful prediction of the IOD by the Research Group.

Fig. 4.11 shows the prediction of SST anomalies over Indian Ocean by the model SINTEX-F1 for the initial condition of February 2006.

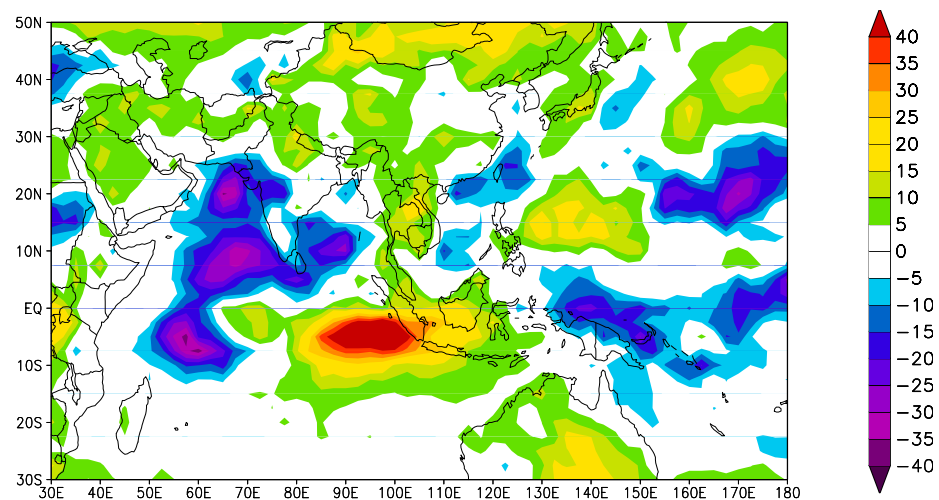


**Fig. 4.11 : SST Anomaly predictions for Sept-Oct-Nov 2006 by SINTEX –F1 based on the initial conditions of 1 February 2006**

Fig.4.12 and Fig 4.13 show the observed SST and OLR anomalies during the Sept-Oct-Nov 2006 period respectively, which suggest positive IOD type features with positive (negative) SST anomalies over west (east) equatorial Indian Ocean. However, the ongoing warming episode (El Nino) over the equatorial Pacific may be also responsible for the observed SST anomalies over the equatorial Indian Ocean, especially the negative anomalies over the east Indian Ocean.



**Fig. 4.12 : SST anomalies during SON 2006**



**Fig. 4.13 : OLR anomalies during SON 2006**

Whether the revived monsoon activity over the central parts of India during the second half of the season is due to this development of SST anomalies over the equatorial Indian Ocean is an open question, which needs to be examined further. Ashok et al. (2001) had suggested that the impact of the equatorial Indian Ocean SST anomalies associated with the positive dipole events is mostly seen during the second half, especially in September.

# Monsoon<sup>2006</sup> A Report

## Chapter – 5

### **Performance of Operational NWP Models in Short and Medium Range Time scales**

*In this chapter performance of operational NWP models (IMD and NCMRWF) in short and medium range time models during the monsoon 2006 season is discussed.*

#### **5.1 Introduction**

India Meteorological Department has been preparing short range forecasts using two regional models, Limited Area Model (LAM) and MM5 Model. The MM5 model at IMD is run at the horizontal resolution of 45 km with 23 sigma levels in the vertical and the integration is carried up to 72 hours over a single domain covering the area between lat. 30 ° S to 45 ° N long 25 ° E to 125 ° E (RSMC domain). Initial and boundary conditions are obtained from the NCEP Global Forecast System readily available on the Internet at the resolution of 1 ° x1 ° lat./long. The boundary conditions are updated at every six hours interval. The LAM is integrated up to 48 hours at the horizontal resolution of 0.75 ° x0.75 ° lat/long with 16 sigma levels in the vertical over the same domain using the initial and boundary conditions provided by T-80 Global operational model run at NCMRWF. For the day to day weather

forecasting, IMD also makes use of NWP products prepared by some other operational NWP Centres like, NCMRWF, ECMWF, U.K. Met Office etc.

In an earlier study, Roy Bhowmik and Prasad (2001) documented the rainfall prediction skill of the LAM using the data for the period 1997 to 1999 when the model was run at the horizontal resolution of  $1^{\circ} \times 1^{\circ}$  lat./long with 12 sigma levels in the vertical. In the year 2001, the model was run at the horizontal resolution of  $1^{\circ} \times 1^{\circ}$  lat./long. with 16 sigma levels in the vertical. Since 2003, it is being run at the horizontal resolution of  $0.75^{\circ} \times 0.75^{\circ}$  lat./long with the same 16 sigma levels. In a very recent study (Roy Bhowmik et al., 2006a) showed that the model in general is able to capture three regions of climatologically heavy rainfall domains viz, Western Ghats, North-east India and along the monsoon trough, but the location and magnitude of predicted rainfall differs considerably from the actual ones. The inter-comparison of performance skill between 2001 and 2003 revealed that the performance of the model rainfall forecast deteriorated in 2003. The study (Roy Bhowmik et al. 2006a) concluded that the T-80 model of NCMRWF, not being compatible in respect of resolution, is not adequate to provide first guess and boundary conditions of the IMD operational model at the higher resolution. The rainfall performance statistics of NCMRWF T-80 model over Indian monsoon region was also documented in the recent studies (Basu, 2003; 2005).

In the following section, performance of some operational NWP models in the short range time scale during the summer monsoon of 2006 has been discussed.

## **5.2. Rainfall prediction**

The standard procedure for the model rainfall forecast verification (WMO 1992) is to compute mean error, root mean square error (RMSE) and correlation co-efficient (CC) between forecast and analyzed fields valid for the same verification time. In this study, we have computed the error statistics (mean error, RMSE, CC, skill scores) based on the daily rainfall analysis and corresponding day-1 and day-2 forecasts of LAM and MM5 for the entire data period (1 June to 30 September 2006). As stated, currently the MM5 model at IMD is run once in a day in the evening using NCEP GFS outputs (based on 00 UTC observations) as initial and boundary conditions. As such, the forecast products are available for the operational use in one-day lag. Because of this, validation of MM5 model is carried-out for 48 hours and 72 hours forecasts which coincide with the 24 hours and 48 hours forecast period of LAM. For the validation of rainfall forecasts, we assumed day-1 as 24 hours forecast for LAM and 48 hours forecast for MM5 and day-2 as 48 hours forecast for LAM and 72 hours forecast for MM5. The domain for the validation is from equator to  $40^{\circ}$  N

lat and 60 ° E to 100 ° E long. In order to get a compatible dataset (observations), objective analysis of daily rainfall is carried out at the resolution of 1 ° x1 ° lat long combining raingauge observations and INSAT derived Quantitative Precipitation Estimates (QPE). The procedure ignores QPE data for the grids where land rainfall observations are available (Roy Bhowmik et al., 2005). For the computation of error statistics, model rainfall outputs are interpolated at the uniform resolution of 1 ° x1 ° lat/long.

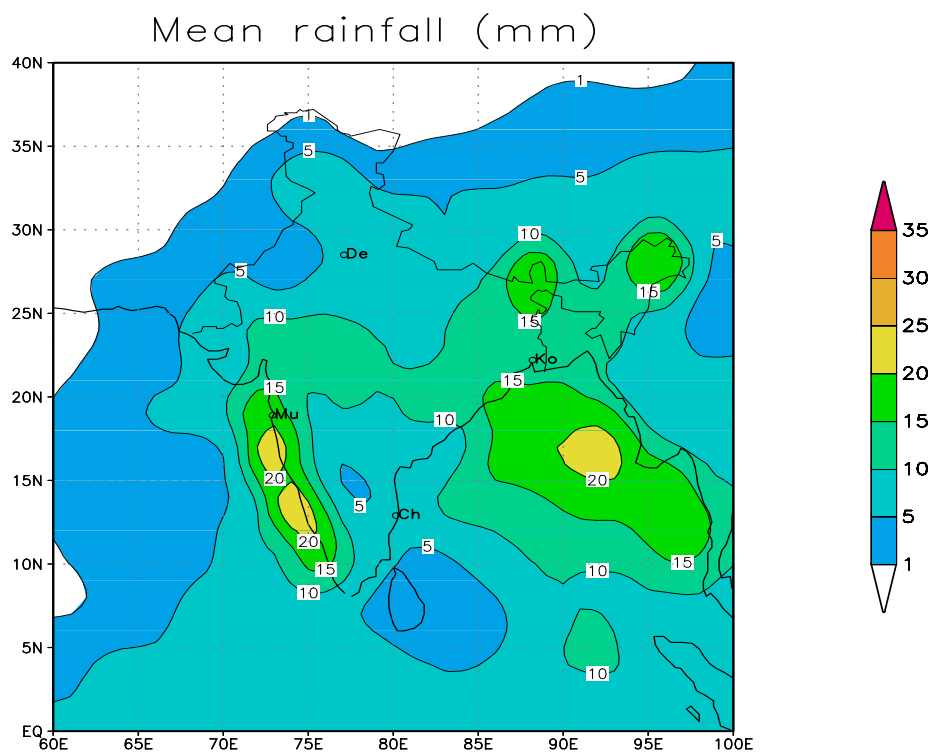
We begin with the description of seasonal mean rainfall distribution (1 June to 30 September 2006) based on daily analysis (observations) and corresponding day-1 and day-2 forecasts of LAM and MM5. Fig. 5.1 illustrates the verification map of mean rainfall for the entire 2006 monsoon season. The observed rainfall distribution shows a north-south oriented belt of heavy rainfall along the west coast between latitude 8 ° N and 20° N with two peaks (20-25 mm) centered near lat. 15° N and lat. 10° N. The sharp gradient of rainfall between the west coast heavy rain region and the rain shadow region to the east is brought out realistically in the objective analysis. Two heavy rainfall pockets (10-15 mm) are observed over the extreme northeastern parts of the country. The rainfall over the domain of monsoon trough has been 10-15 mm. The corresponding day-1 as well as day-2 forecast mean fields of LAM could reproduce north south oriented heavy rainfall along the west coast with a peak of order 10-15 mm centred at lat 15 °N. The gradient of rainfall between the west coast heavy rain region and the rain shadow region to the east is weak. Another heavy rainfall belt (15-20 mm) lies over the northeast Bay of Bengal and adjoining Myanmar areas. Over the monsoon trough region rainfall was of the order 5-10 mm. The day-2 rainfall pattern broadly remains the same where additionally another rainfall belt (5-10 mm) prevailed along the foothills of Himalayas.

The corresponding MM5 day-1 and day-2 forecast fields continue to describe a north-south oriented belt of heavy rainfall along the west coast between latitude 8° N and 20° N with a peak centered near lat. 15° N (15-20 mm). The pattern is found to be closer to the observation. The sharp gradient of rainfall between the west coast heavy rain region and the rain shadow region to the east is well simulated. Another heavy rainfall belt (20 to 25 mm) is located over the North Bay of Bengal and adjoining Myanmar areas.

Fig 5.2 presents spatial pattern of mean error (forecast –analysis) for the entire monsoon season. The mean errors of LAM, both for day-1 and day-2 show that the rainfall along the Western Ghats and adjoining sea areas, over the extreme north-eastern parts of the country, over the parts of south-east Arabian Sea and over the north Bay of Bengal is significantly under-estimated (by 10-15 mm). Rainfall over Myanmar and adjoining areas are

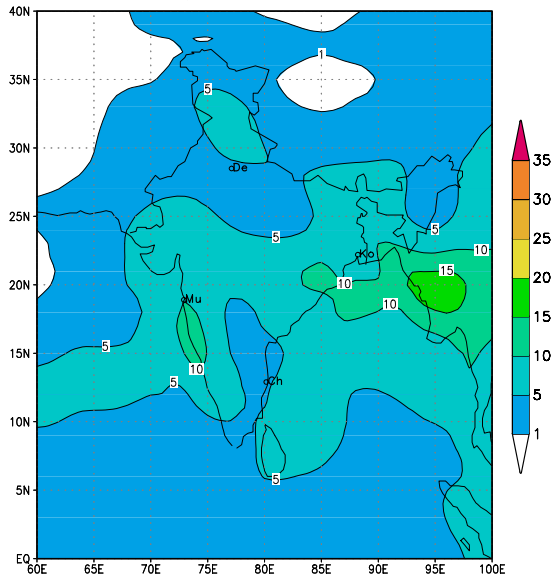
over-estimated. Otherwise, for the remaining parts of the region, the forecast is close to observation. It is interesting to note that the errors over the Western Ghats became less at day-2 forecast. The MM5 forecast for both day-1 and day-2 show underestimation of rainfall over the Western Ghats (5 to 10 mm), central and eastern parts of the country. The over-estimation of rainfall is noticed over the Myanmar areas.

Fig.5.3 presents the root mean square errors (RMSE) for day-1 and day-2 forecasts of LAM and MM5. For LAM, both day-1 and day-2 RMSE ranges between 20-30 mm along the west coast, over parts of the North Bay of Bengal, Gangetic West Bengal and in some pockets along the foothills of Himalayas. Other wise, RMSE has been of the order of 10 mm over the most parts. Similar pattern is broadly noticed in case of RMSE in MM5 day-1 and day-2 forecasts.

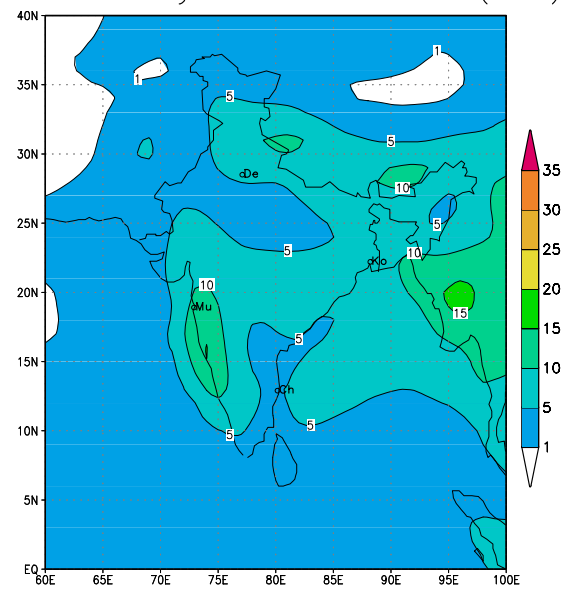


**Fig. 5.1 :Mean rainfall (mm/day) of the season (01 June to 30 September 2006) based on actual observations, LAM day-1 forecast, day-2 forecast and MM5 day-1 forecast, day-2 forecast**

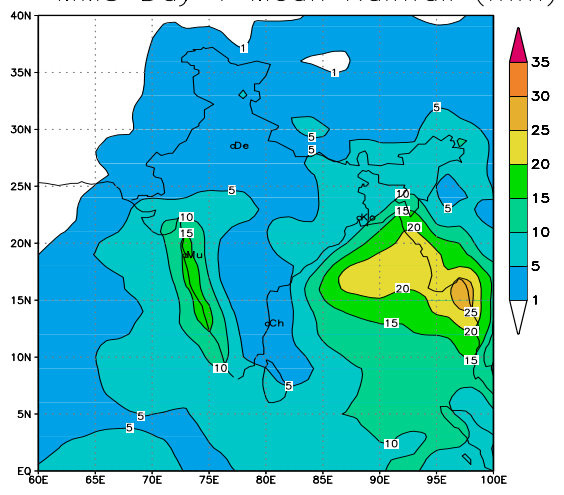
LAM Day 1 Mean Rainfall (mm)



LAM Day 2 Mean Rainfall (mm)



MM5 Day 1 Mean Rainfall (mm)



MM5 Day 2 Mean Rainfall (mm)

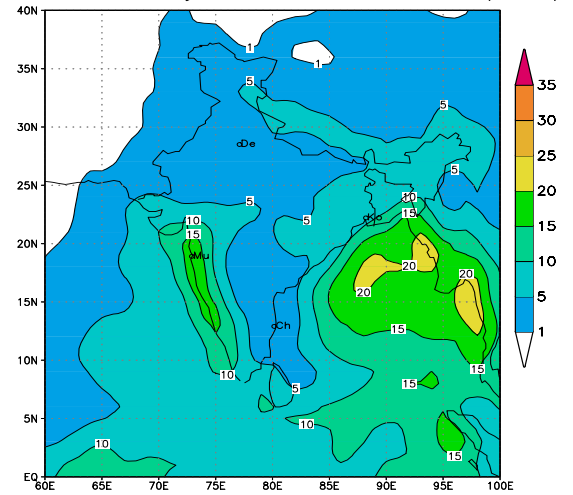
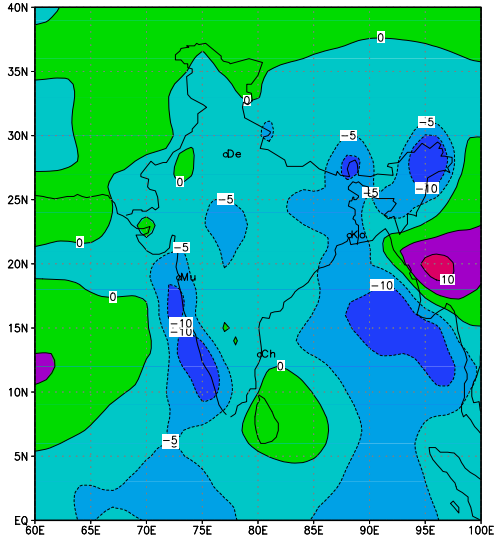
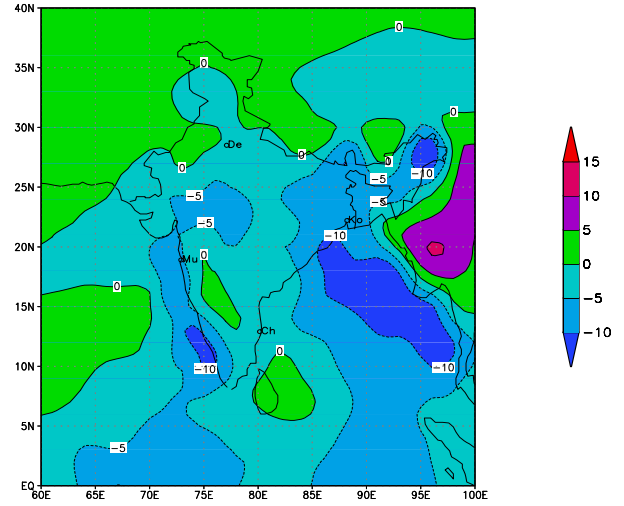


Fig. 5.1 : Continued

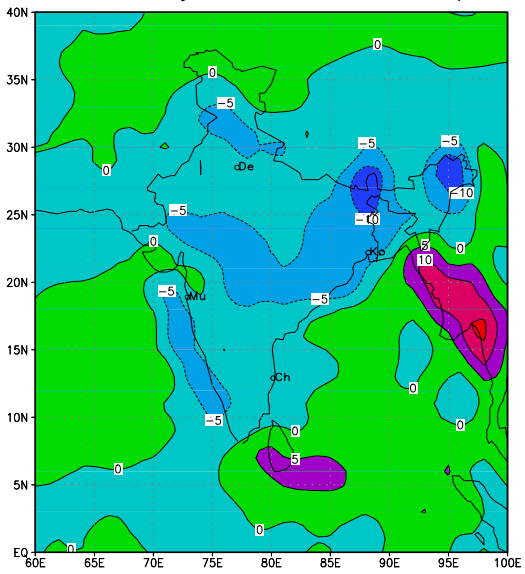
LAM Day 1 Mean Error (mm)



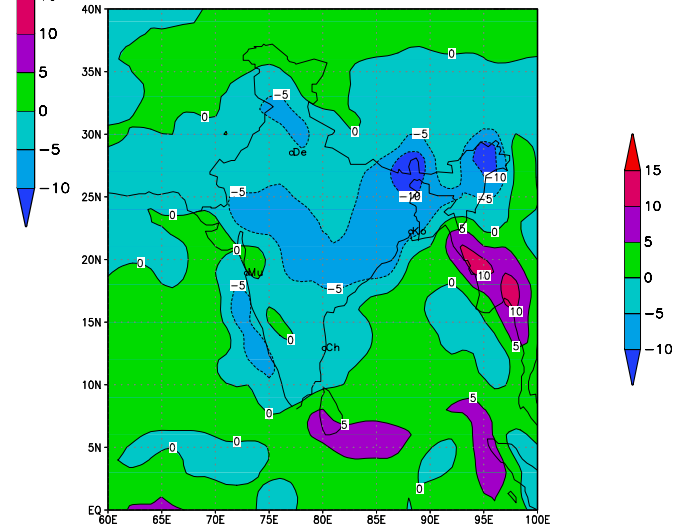
LAM Day 2 Mean Error (mm)



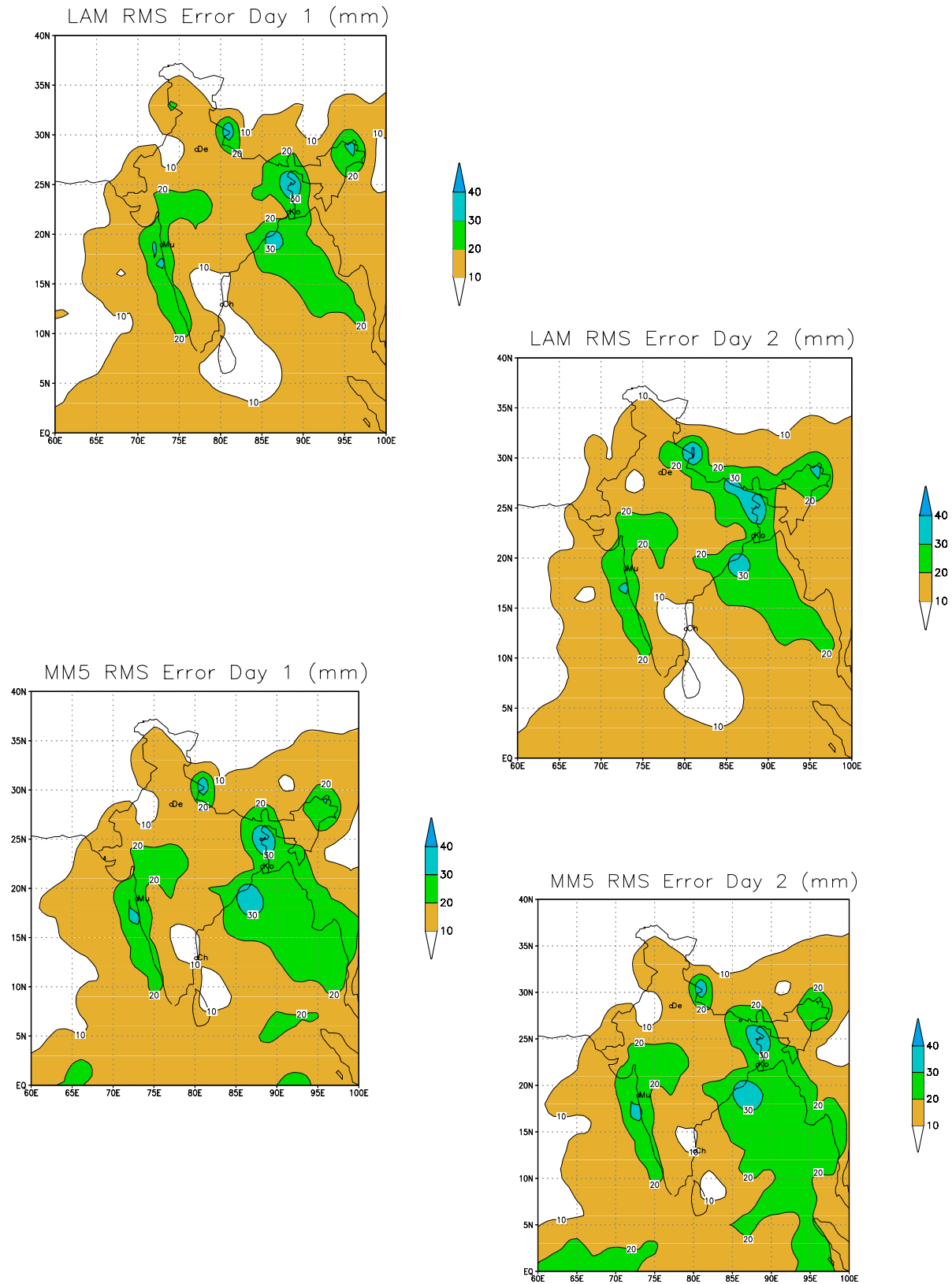
MM5 Day 1 Mean Error (mm)



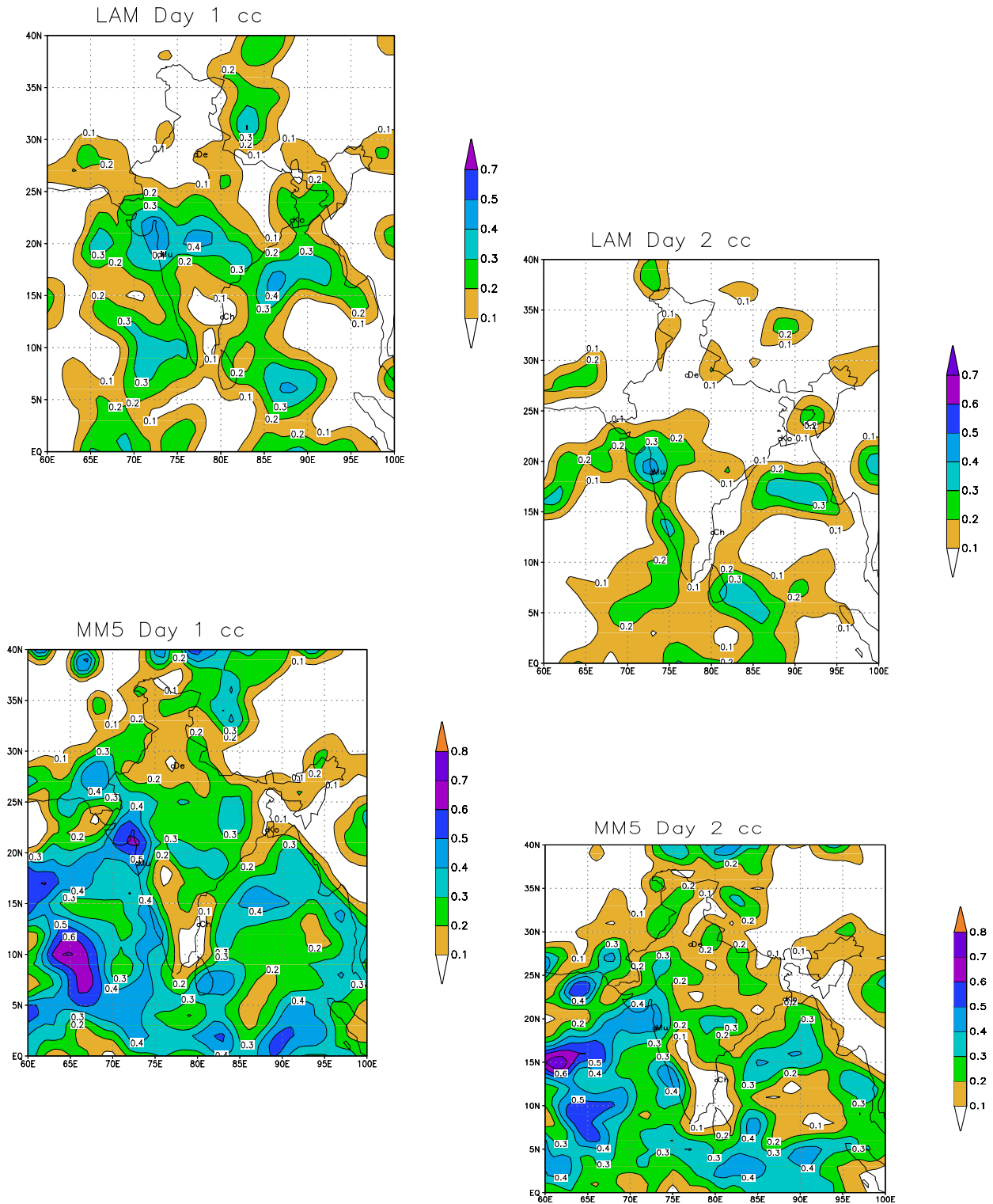
MM5 Day 2 Mean Error (mm)



**Fig. 5.2 Mean error (mm/day) of the seasonal rainfall for LAM day-1 forecast, day-2 forecast, MM5 day-1 and day-2 forecast**



**Fig. 5.3 : RMS error (mm/day) of the seasonal rainfall based LAM day-1 forecast, day-2 forecast , MM5 day-1 and day-2 forecast**



**Fig. 5.4 : Correlation Coefficient of the seasonal rainfall based LAM day-1 forecast, day-2 forecast , MM5 day-1 and day-2 forecast**

The correlation coefficient (CC) for LAM day-1 forecast (Fig 5.4) is 0.4 to 0.5 over the domain of monsoon trough, Mid Tropospheric Cyclone (MTC) and origin of monsoon low-pressure system. In the day-2 forecast, CC reduces, but the spatial pattern remains the same over these areas. The CC for the MM5 day-1 forecast has been 0.4 to 0.5 over the parts of Arabian Sea, Western Ghats, and North Bay of Bengal. The CC has been around 0.3 over some pockets over the land. The CC slightly reduces in the day-2 forecast.

The inter-comparison reveals that rainfall prediction skill of MM5 has been better and more realistic along Western Ghats and over the domain of the origin of monsoon low pressure systems (north Bay of Bengal). However, LAM shows better skill over the domain of monsoon trough.

### **5.3 Prediction of Monsoon depression - genesis and track**

During the southwest monsoon season of 2006, there have been 7 monsoon depressions which formed over the North Bay and moved across the country (the case of land depression is not considered). We examined the performance of various operational NWP models such as LAM, MM5, NCMRWF T80 and ECMWF to predict track of these systems in 24 hours and 48 hours forecast time scale. Fig 5.5 presents an inter-comparison of depression tracks based on 24 hours forecasts with reference to observed tracks. Similarly Fig. 5.6 illustrates the inter-comparison for the 48 hours forecasts.

#### ***Case 1: Deep depression of July 2-5, 2006***

The system formed as a low pressure area over the North Bay of Bengal on 30 June. It intensified into a depression on 2 July morning and deep depression in the evening. On 2 July at 0300 UTC the system was centred near lat  $20^{\circ}$  N and long  $89^{\circ}$  E, which was very close to T-80 NCMRWF forecast position. The model showed close to the actual track till the landfall and subsequently large deviation from the actual track is noticed. The forecast position of the depression based on LAM for 2 July was very much erroneous, but thereafter it agreed well with the observed track. The comparison reveals that for this system, MM5 forecast has been nearly close to the actual track. ECMWF forecast showed initially northwesterly and then westerly movement. For this system, performance of all of these models at 24 hours forecast range is found to be reasonably good.

When we compared the 48 hours forecast tracks, it reveals that MM5 persistently performed well. LAM though could predict the direction but the movement was very fast.

The forecast position by LAM for 2 July was found to be well over the land. The ECMWF showed northerly bias. T-80 forecast was very much inconsistent.

We also examined performance of the model to capture the genesis of this low pressure system. It is noticed that ECMWF, T-80 and MM5 could indicate the formation of this low pressure system 48 hours in advance.

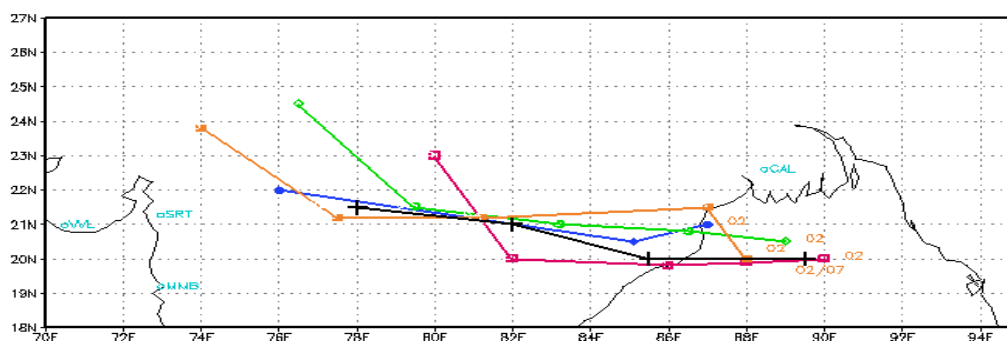
**Case 2: Deep depression of August 2-5, 2006**

The system was seen as an well marked low pressure area on 1 August morning over the northwest Bay of Bengal off north Orissa coast. Subsequently, the system concentrated into a depression and crossed Orissa coast between Puri and Gopalpur. The system initially moved in a southwesterly direction and then west-north-westerly direction. On 2 August at 0300 UTC the system was centered near lat. 20.5° N / long 87.5° E. In this case, LAM 24 hours forecast position of the system was found to be closer to the observation but forecast position largely deviated to the north from the actual track subsequently. From 3 August onwards forecasts by MM5, T-80 and ECMWF were closer to the observed track.

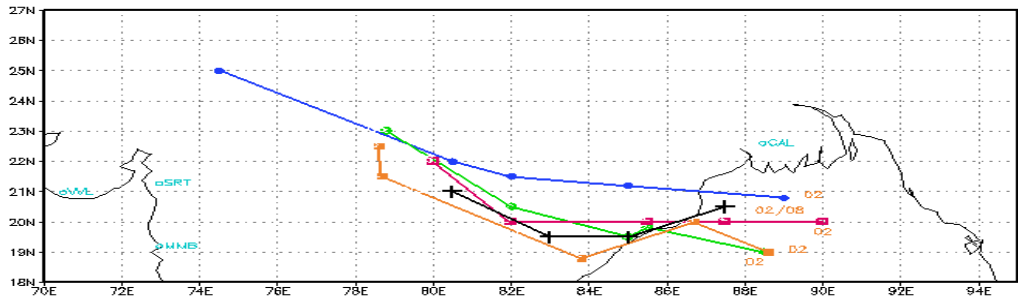
In the 48 hours forecasts, all the four models performed badly. Comparatively, ECMWF forecast track was to some extent better.

When we examined the performance of the models to capture genesis, it is noticed that in this case also ECMWF as well as MM5- could predict the formation of this system 48 hours in advance.

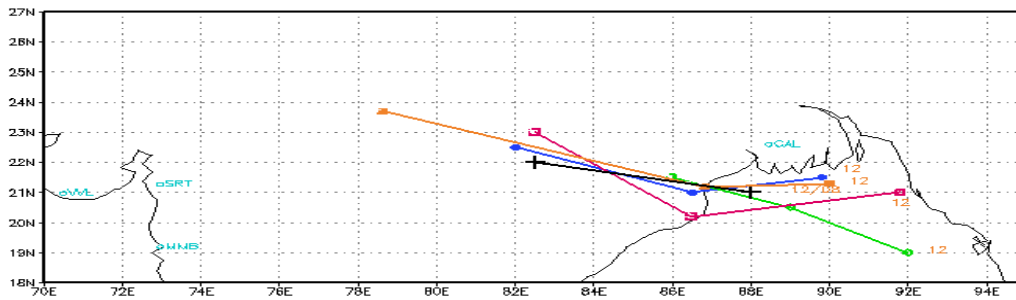
**2 July to 5 July 2006**



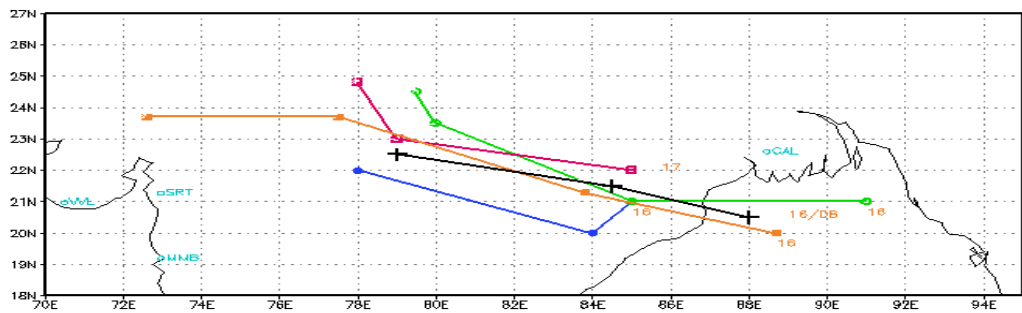
**2 August to 5 August 2006**



**12 August to 13 August 2006**

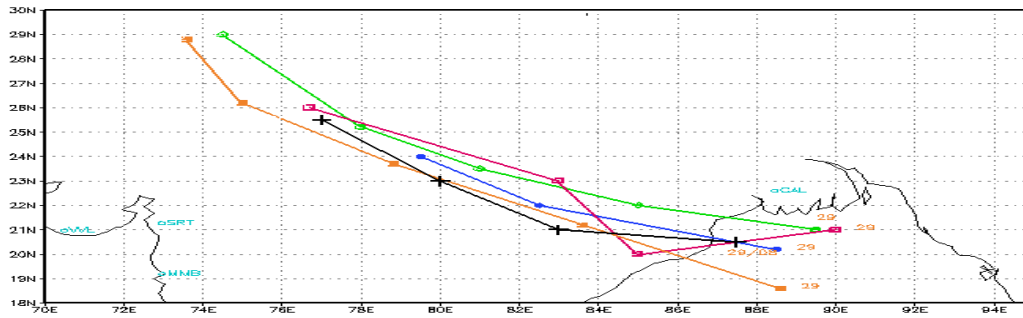


**16 August to 19 August 2006**

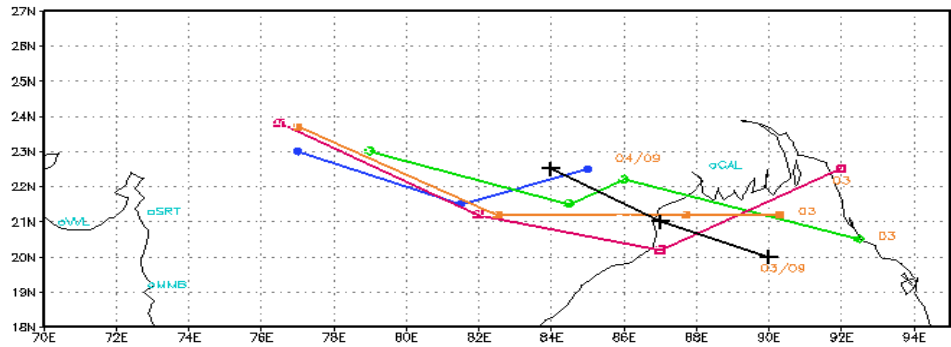


**Fig.5.5 Inter-comparison track predictions of monsoon depression based on 24 hrs forecast of LAM, MM5,T-80, ECMWF and actual observations. Solid circle in blue indicates LAM, circle in green indicates MM5, open square in red for T-80, solid square for ECMWF and + indicates actual observations**

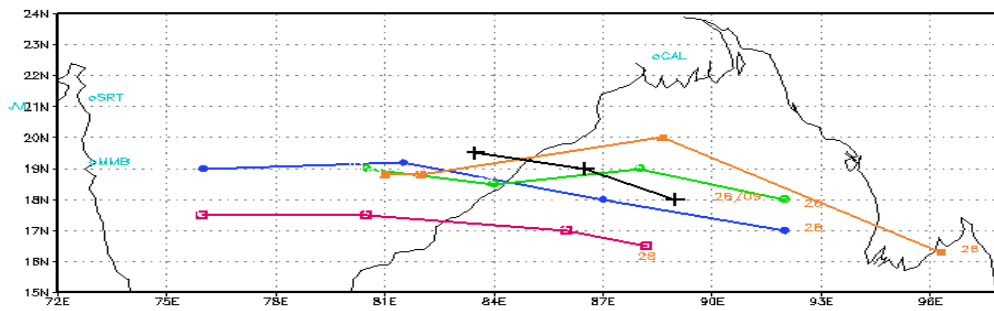
**29 August to 1 September**



**3 September to 5 September 2006**



**28 September to 30 September 2006**



**Fig.5.5 : continued**

### ***Case 3: Deep depression of August 12, 2006***

A low pressure area formed over the North Bay of Bengal off north Orissa coast on 10 August. The system concentrated into a depression in the evening. It moved west-north-westerly direction and crossed Orissa coast near Balasore. On 12 August the system was centred near lat  $21^{\circ}$  N long  $88^{\circ}$  E. The forecast track by all the models largely deviated from the actual position of the system on 12 August. However, the comparison reveals that the 24 hours forecast track by LAM and ECMWF is reasonably well matching with the observed track. ECMWF continued to show reasonably realistic track at the 48 hours forecasts also for this system.

When we examined the genesis, it is noticed that MM5 and ECMWF could predict the formation of this low pressure system 48 hours in advance, but LAM as well as T-80 failed to capture this feature.

### ***Case 4: Depression of August 16-18, 2006***

A low pressure area formed over the north Bay of Bengal off Orissa coast on 15 August, which became a depression on 16 August morning. Moving in a westerly direction, the system crossed north Orissa coast near Chandbali. On 16 August, the system was centred near lat.  $20.5^{\circ}$  N and long  $88^{\circ}$  E. In this case, only ECMWF forecast track were found to be close to the observed track. MM5 forecast position of the system for 16 August was very much away to the northeast. LAM showed system over the land on 16 August itself. The T-80 model could not capture the system on 16 August.

In the 48 hours forecast, MM5 continued to show the depression center lagging to the east on 15 August. ECMWF showed the depression center over the land on 16 August itself. The 48 hours forecast position of this system by LAM as well as by T-80 was very much erroneous.

However, in this case ECMWF, MM5 as well as T-80 could indicate the formation of the low pressure system 48 hours in advance.

### ***Case 5: Depression of August 29-September 1, 2006***

On 27 August a low pressure area formed over the North Bay of Bengal off north Orissa and West Bengal coasts. The system became a depression on 29 August, moving rapidly in a west north-west direction it crossed north Orissa coast near Paradeep. On 29 August, the depression was centered near lat  $20.5^{\circ}$  N/long  $87.5^{\circ}$  E. For this system the observed track was closer to the 24 hours forecast track of LAM. MM5 model showed a northerly bias. T-80 forecast track was found to be very erratic. The ECMWF forecast track showed slightly southerly bias.

In the 48 hours forecast also MM5 continued to show the center of the system further away to the east. The LAM forecasts showed faster movement of the system. The T-80 forecast drifted the system to the south. The forecast by ECMWF was found to be closely matching with the actual track.

In this case, only MM5 and ECMWF could capture the low pressure area in the 48 hours forecasts.

### ***Case 6: Depression of September 3- 4, 2006***

A low pressure area formed over the north Bay of Bengal off north Orissa coast, concentrated into a depression on 4 September evening. Moving west northwesterly direction it crossed north-Orissa coast near Chandbali. On 3 September, the system was centred near lat  $20^{\circ}$  N/ long  $89^{\circ}$  E. All the four models showed the center of the system largely away to the north. LAM could not capture the system on 3 September. MM5 could predict the direction correctly but it showed location of the system away to the northeast. The ECMWF forecast showed westerly movement of the system for the first 3 days.

In the 48 hours forecast, all the four models performed badly. But to some extent, forecasts by ECMWF and MM5 were better compared to other models.

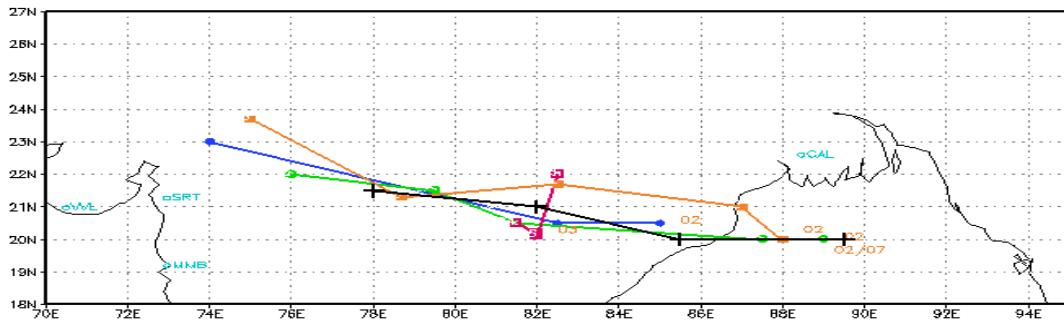
### ***Case 7: Depression of September 28- 29, 2006***

The system was seen as a low pressure area on 27 September over east central and adjoining northeast Bay of Bengal, concentrated into a depression on 28 September. Moving in a west-north westerly direction it crossed the Orissa coast near Gopalpur. On 28

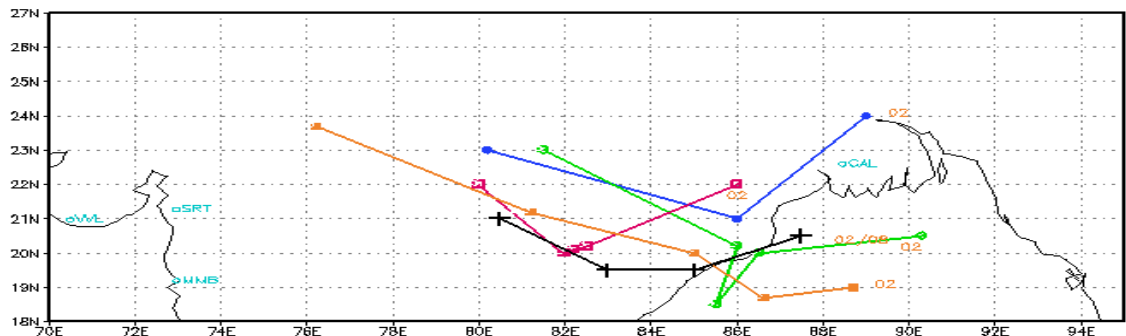
September the system was located near lat 18°N and long 88.5°E. 24 hours forecast track by LAM, MM5 and ECMWF showed location of the system away to the east. The T-80 forecast showed the system to the south. A wide range of variation is noticed in the position of the system by these models. Similar feature persisted in the 48 hours forecast also.

In this case LAM, MM5, T-80 and ECMWF could capture the formation of the system in 48 hours forecasts.

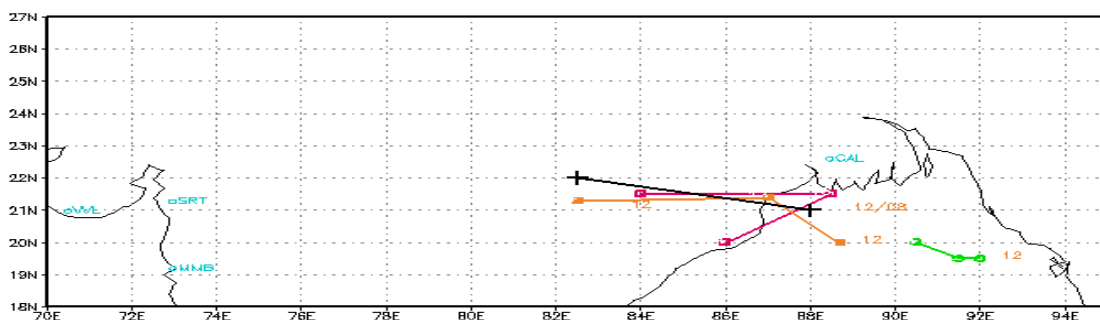
### 2 July to 5 July 2006



### 2 August to 5 August 2006

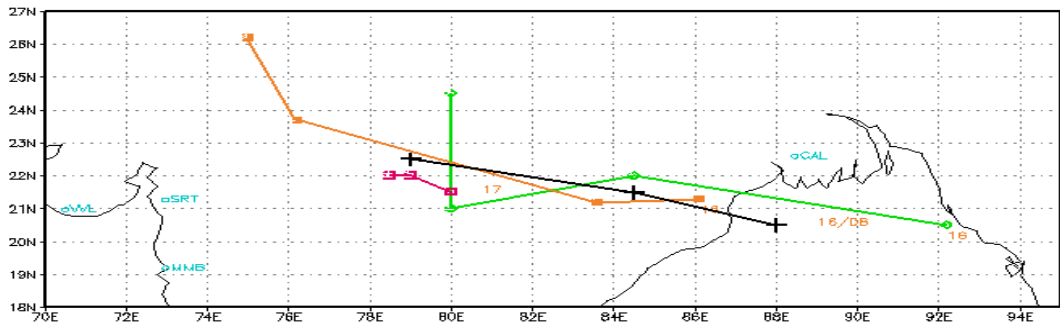


### 12 August to 13 August 2006

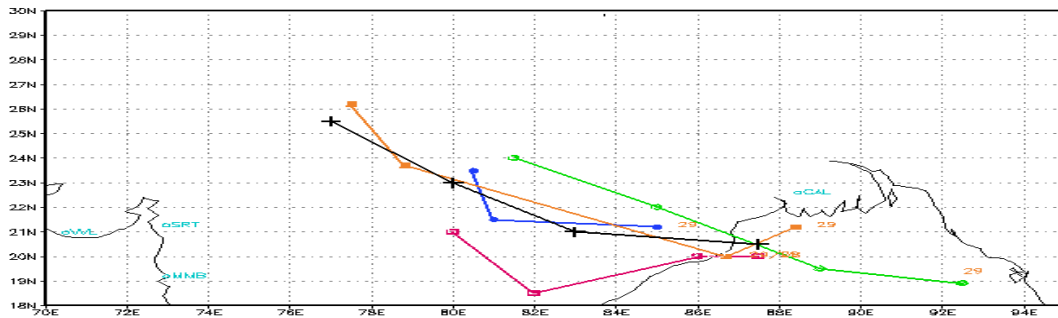


**Fig.5.6 : Inter-comparison track predictions of monsoon depression based on 48 hrs forecast of LAM, MM5,T-80, ECMWF and actual observation during July 2-5, 2006. Solid circle indicates LAM, open circle in green indicates MM5, open square in red for T-80, solid square for ECMWF and + indicates actual observations**

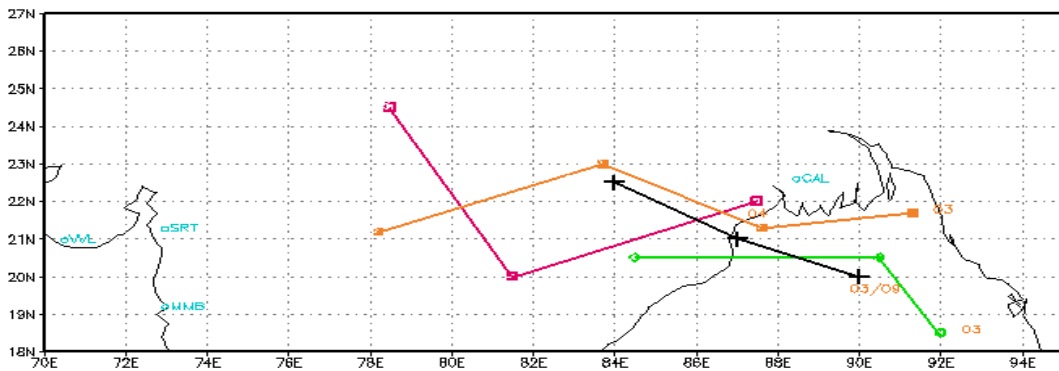
16 August to 19 August 2006



29 August to 1 September 2006



3 September to 5 September 2006



28 September to 30 September 2006

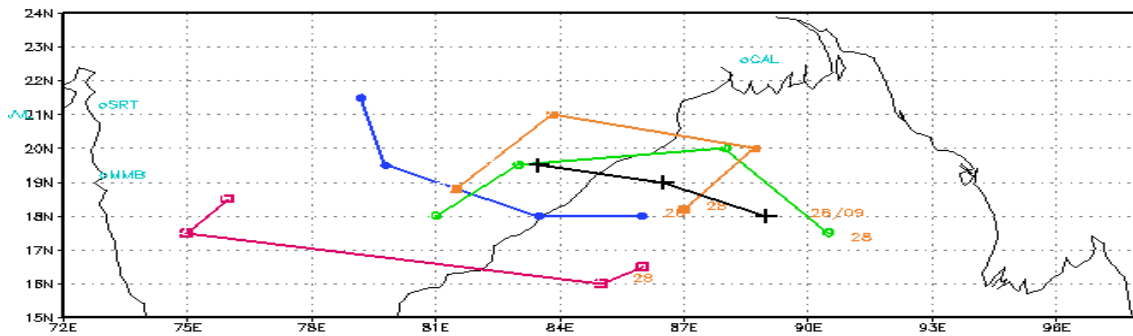


Fig.5.6 : continued

#### **5.4 Systematic Errors in the Medium Range Prediction of the Summer Monsoon Rainfall (based on inputs from NCMRWF)**

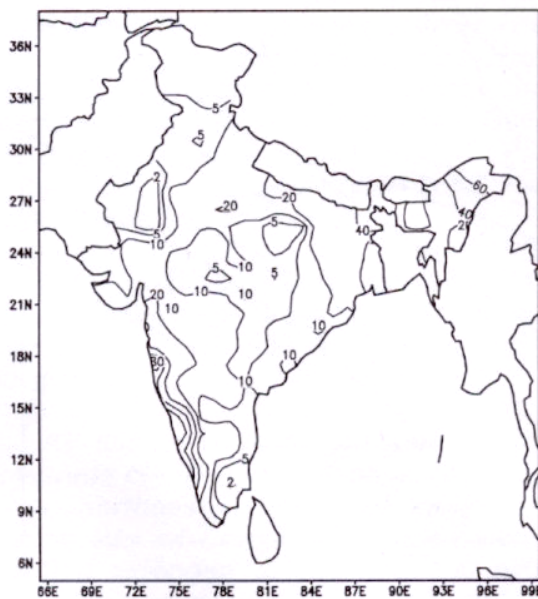
NCMRWF, Noida has been preparing operational medium range forecasts using the NCMRWF T-80 NWP model. A detailed analysis of its performance is given in the report by NCMRWF (NCMRWF, 2006). In this section, performance of rainfall prediction is discussed.

The summer monsoon rainfall over the Indian subcontinent shows spatial and temporal variability in different scales. Fig 5.7 – 5.9 (a-b) shows the monthly amount of rainfall as observed and as predicted by the model in its successive Day-5 forecasts for June, July and August respectively. The observed rainfall figures are taken from the Climate Diagnostics Bulletin of India published by the India Meteorological Department.

Although the southwest monsoon had covered most parts of the southern peninsula and north-east India by June 7<sup>th</sup>, the rainfall activity was subdued till the fourth week of June. The southern peninsula received normal to excess amount of rainfall whereas the central parts of India received deficient to scanty rainfall during June. The observations for June (Fig. 5.7a) show a maximum with amounts more than 60 cm over the west coast and north-eastern parts of India. The central part of India received less than 10 cm of rainfall. The model forecasts (Fig. 5.7b) also show a zone of maximum with rainfall amounts of 40 cm around 10° N over the west coast. The model forecasts underestimate the rainfall amounts over the northern regions of the west coast. The model forecasts show large amounts of rainfall as compared to the observations over the conventional rain shadow region on the leeward side of the Western Ghat Mountains. During the month of July, the monsoon was active over central and north-western parts of the country and subdued over the southern peninsula. The observations for July (Fig. 5.8a) show amounts of rainfall in excess of 160 cm around 18° N and 80 cm around 12° N over the west coast. The central and eastern parts of India received more than 40 cm of rainfall, which was due to the formation of a deep depression and three low pressure areas during this month. The rainfall activity was also good over Gujarat and western Maharashtra. The model forecasts (Fig. 5.8b) also show a zone of maximum with rainfall amounts of 60 cm over the west coast. The model forecasts also show rainfall maxima over the central and eastern parts of India.

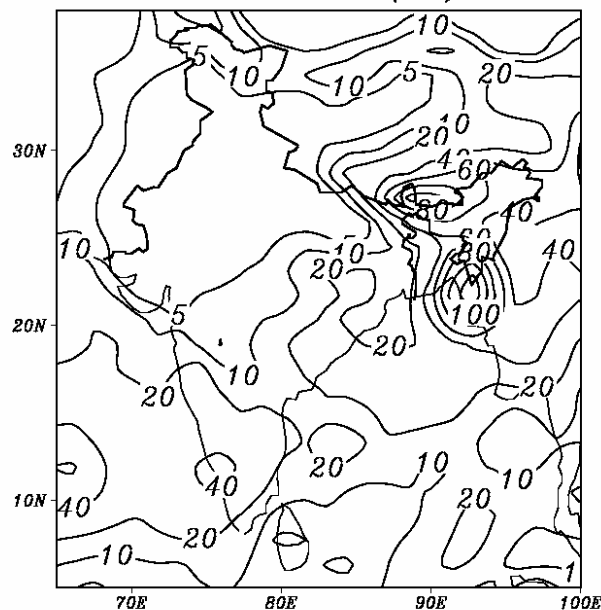
During the month of August, the monsoon was very active over the central, western and north-western parts of India. The increased rainfall activity over these regions was due to the formation and movement of four depressions during this month. The depressions had

a more westward track. The observations for August (Fig. 5.9a) show amounts of rainfall in excess of 80 cm over the west coast. The rainfall amounts over the entire central belt of India exceeded 40 cm. There were certain areas within this belt where rainfall amount exceeded 80 cm. The model forecasts (Fig. 5.9b) also show a zone of maximum with rainfall amounts of 40 cm over the west coast. The model forecasts also show amounts of rainfall in excess of 40 cm over the eastern parts of India. The large amounts of rainfall over the eastern parts of peninsular India are associated with the model forecasts errors in the lower levels which are cyclonic over this region.



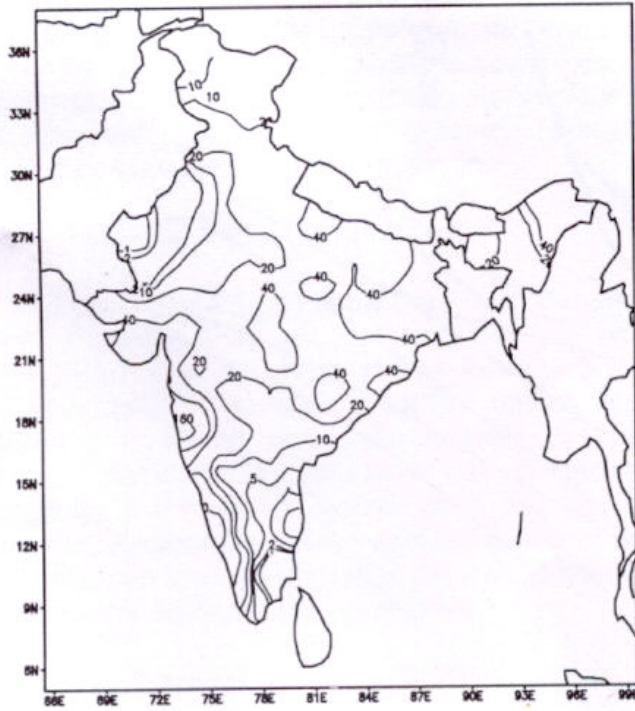
**Observed monthly rainfall  
June 2006**

*D05 FCST TOTAL PRECIP(cm) JUN 2006*



**Predicted monthly rainfall  
June 2006**

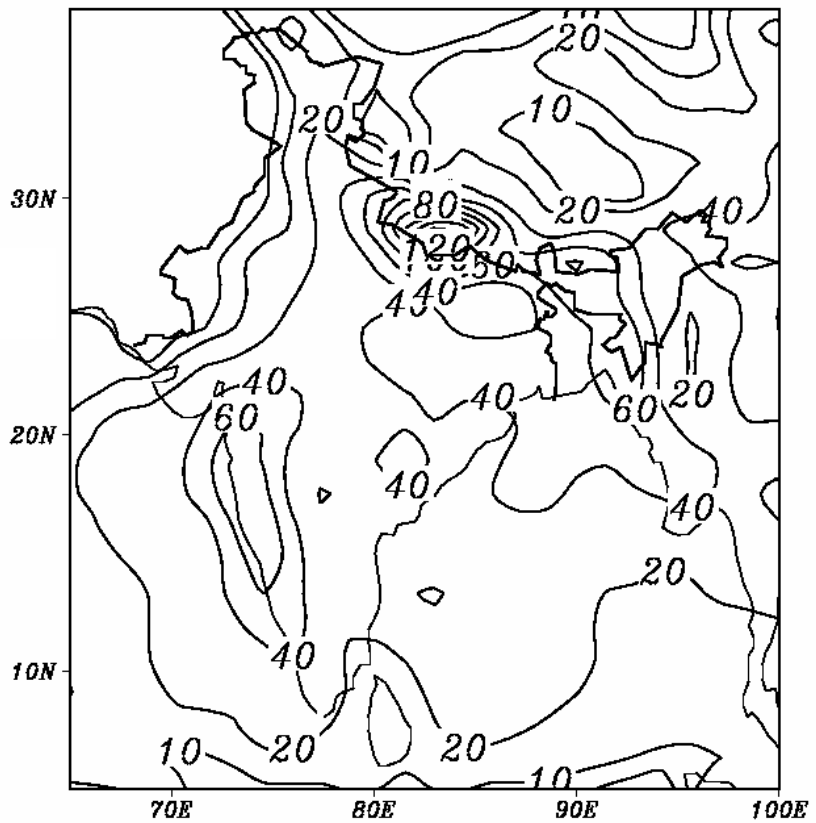
**Fig. 5.7 : Monthly amount of rainfall as observed and as predicted by the NCMRWF model in its successive Day-5 forecasts for June 2006**



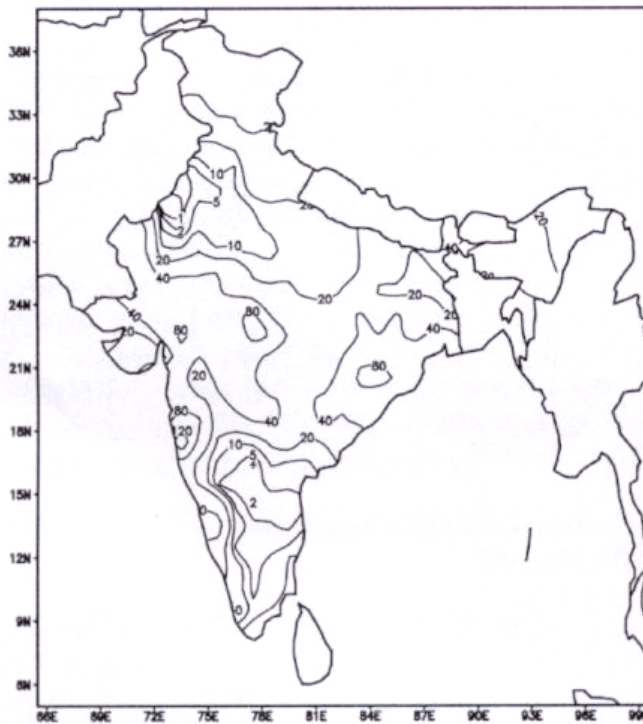
**Observed monthly rainfall  
July 2006**

**D05 FCST TOTAL PRECIP(cm) JUL 2006**

**Predicted monthly rainfall  
July 2006**

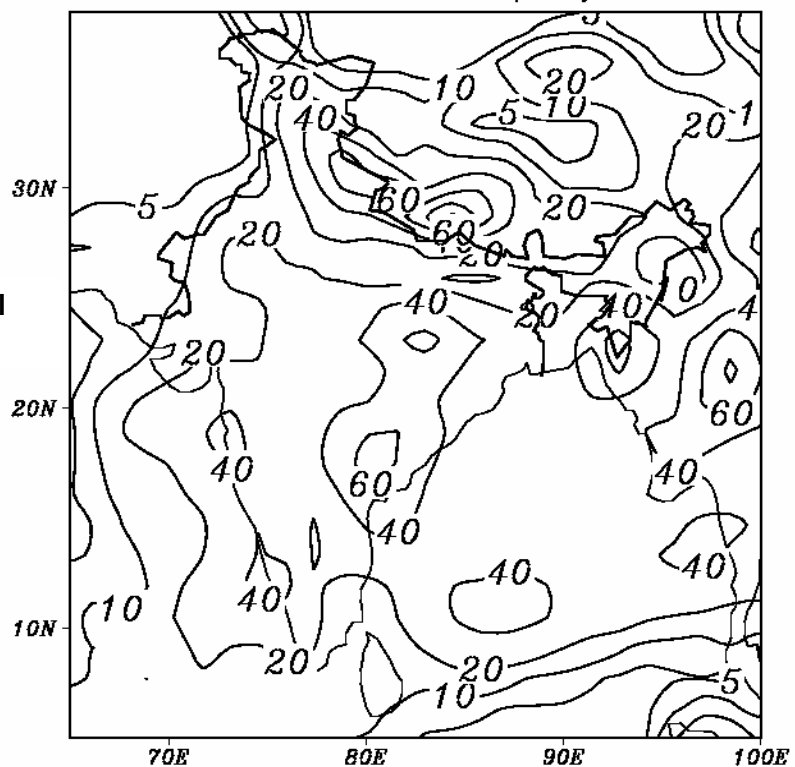


**Fig. 5.8 : Monthly amount of rainfall as observed and as predicted by the NCMRWF model in its successive Day-5 forecasts for July 2006**



**Observed monthly rainfall  
August 2006**

**D05 FCST TOTAL PRECIP(cm) AUG 2006**



**Predicted monthly rainfall  
August 2006**

**Fig. 5.9 : Monthly amount of rainfall as observed and as predicted by the NCMRWF model in its successive Day-5 forecasts for August 2006**

## 5.5 Concluding remarks

The inter-comparison of rainfall prediction skill between LAM and MM5 reveals that LAM performed better to capture rainfall over the domain of monsoon trough, whereas MM5 could produce orographic rainfall along the Western Ghats and over the north Bay of Bengal, over the domain of formation of monsoon low pressure system in a more realistic way. The pattern of the systematic errors of LAM as well as MM5 remains broadly same for the day-1 and day-2 forecasts. The skill of day-1 forecast is found slightly better compared to the day-2 forecast.

Out of the four models compared here for the prediction of genesis and track for monsoon depression, ECMWF is found to be the best one followed by MM5.

Forecasting of monsoon systems continues to be one of the difficult areas in NWP due to complex issues which involve: impact of orography, treatment of synoptic scale low pressure system, mesoscale convective systems and lack of good quality mesoscale observations, particularly over the ocean. Non-availability of high performance computing system is another limitation to go for a very high resolution non hydrostatic model. In spite of this limitation, constant efforts are being made at IMD for up gradation of NWP techniques (Hatwar et al., 2005, Rama Rao et al., 2005, Roy Bhowmik, 2003, Roy Bhowmik et al., 2005;2006b) in operational forecasting. Recently the Limited Area Model (LAM) is further modified increasing the horizontal resolution from  $0.75^{\circ} \times 0.75^{\circ}$  to  $0.5^{\circ} \times 0.5^{\circ}$  and vertical resolution from 16 sigma levels to 18 sigma levels. The code is made flexible to prepare initial and boundary conditions from the outputs of Global Forecast System (GFS) of NCEP readily available on the internet at the resolution of  $1^{\circ} \times 1^{\circ}$  lat/long and to delink the model from the T-80 (NCMRWF) inputs with which the original version of the model was tied up. The forecast period is extended from 48 hours to 72 hours. The upgraded version of the model was run in test mode during monsoon 2006. A four members multimodel ensemble technique has been implemented in test mode for rainfall prediction during monsoon 2006. The mesoscale model WRF has been implemented in the experimental mode. IMD plans to operate these modes for operational use by June 2007.

There is a further scope to improve the forecast skill through the improved data assimilation procedure at the model resolution availing latest technology in the area with optimum data ingest from dense conventional and non-conventional data sources. The observations are required to be on the mesoscale both in space and time by means of DWR, Satellites, Wind Profilers, meso network (Automatic Weather Stations), buoys and aircrafts. Four Dimensional Data Assimilation (4 DVAR) is a necessary step to obtain improved initial condition with mesoscale features. A great deal of effort is further required to develop accurate and sophisticated storm scale models (preferably at the horizontal resolution 5-10 km). One of our future priorities should be to implement a mesoscale data assimilation scheme from the optimum use of dense conventional and non-conventional observations for the improved initial analysis and more realistic mesoscale weather forecast.

Under the modernization programme, work has been in progress in IMD to acquire a High Performance Computing System, which is expected to be available at IMD in a year time. This will give thrust to the NWP activities at IMD, as IMD plans to implement advanced NWP system consisting of Global Spectral model and high resolution mesoscale data assimilation and models.

# Monsoon<sub>2006</sub> A Report

## Chapter – 6

### **Long Range Forecasts of 2006 Monsoon Rainfall**

*In this Chapter, the details of long range forecasts prepared by IMD and other institutes are discussed and the forecast performance is verified.*

Inter-annual variability of Indian monsoon rainfall has profound influence on agriculture and national economy. Even though there is no long term trend, occurrence of droughts and floods associated with the inter-annual variability of Indian monsoon affects the agriculture, water resources and financial sectors. In spite of an increase in share from the service sector to India's growth, the performance of the agricultural sector is a decisive factor to the growth of GDP of India. A significant finding of the study by Gadgil and Gadgil (2006) is the observed asymmetry in the response to monsoon variation, with magnitude of the impact of deficit rainfall on Gross Domestic Product (GDP) and Food Grain Production (FGP) being larger than the impact of surplus rainfall. The study reveals that despite a substantial decrease in the contribution of agriculture to GDP over the five decades, the impact of severe droughts has remained between 2 and 5% of GDP throughout. These aspects highlight the importance of accurate long range forecasts of monsoon rainfall.

In 2003, India Meteorological Department (IMD) introduced a two stage forecasting strategy to issue the long range forecasts to the public. Following this strategy, the forecasts for the 2006 southwest monsoon rainfall were issued in two stages. The first stage forecast was issued on 24<sup>th</sup> April, 2006. The second stage forecasts (Updated forecasts) were issued on 30<sup>th</sup> June, 2006. The first stage forecast consists of quantitative and probabilistic forecasts for the seasonal (June-September) rainfall for the country as a whole. The second stage forecast consisted of an update of the April forecast along with separate forecasts for the July monsoon rainfall for the country as a whole and that for the seasonal rainfall over four

homogeneous regions. In addition, IMD also issued an operational forecast for the monsoon onset over Kerala on 15<sup>th</sup> May.

Forecasts for the seasonal rainfall over the country as a whole were prepared using operational (8 and 10 parameter models) and newly developed statistical models. IMD has also an experimental dynamical forecasting system, implemented at its National Climate Centre, Pune. This system established in 2004 in collaboration with Indian Institute of Science, Bangalore was also used to prepare experimental forecasts for monthly and seasonal rainfall over the country as a whole. Apart from IMD, many other research institutions in India are also involved in long range forecasting research. These institutes also prepared experimental forecasts and communicated to IMD.

In this chapter, we discuss the verification of the operational forecasts issued by IMD for the monsoon rainfall and for the monsoon onset over Kerala. Various experimental forecasts prepared by IMD and other institutions in India are also presented. In addition, the details of the dynamical forecasts for the seasonal rainfall from various foreign research institutes like NCEP, ECMWF, IRI etc, are also presented.

## **6.1 Operational Forecasts for the Southwest Monsoon Rainfall**

Details of the 8 and 10 parameter operational models used to prepare operational forecasts are available in Rajeevan et al. (2004). The Power Regression (PR) technique was used for the quantitative forecasts and Linear Discriminant Analysis was used for the probabilistic forecasts. The model errors of the 8-Parameter and 10-Parameter PR models are respectively  $\pm 5\%$  &  $\pm 4\%$ . The first stage forecasts (both quantitative and probabilistic) for the seasonal (June-September) rainfall over the country as a whole was issued based on 8 parameters which need data up to March. The second stage/update forecasts for the same were based on 10 parameters including the 8 predictors used for the April forecast. Table-6.1 shows the list of 10 predictors. The last column of the Table-6.1 indicates whether the parameter was favorable (F) or unfavorable (U) for a normal monsoon. Out of the 10 parameters, 5 parameters, Eurasian snow cover, Nino 3.4 SST Tendency, East Asia Pressure, South Indian Ocean Dipole Index and Europe Pressure Gradient were unfavourable. The remaining parameters were favourable.

The model for forecasting July rainfall over the country as a whole used the following 5 parameters: Arabian Sea Surface Temperature (SST) (Jan-Feb), Nino 3.4 SST (May+June), East Asia Pressure (February + March), North Atlantic Pressure (May), and Equatorial Indian Ocean pressure (November). The model was developed using 24 years of data (1977-2000) and the model error is  $\pm 9\%$ .

Separate Multiple Regression (MR) models were used for forecasting of South-west monsoon seasonal rainfall over the 4 homogenous regions. The parameters used in the model for the four homogenous regions are given below:

**Table - 6.1: Details of predictors used in the Power Regression and Probabilistic models for the seasonal rainfall over the country as a whole.**

SN	PARAMETER	F/U
1	ARABIAN SST (JAN+FEB)	F
2	NW EUROPE MEAN TEMP (JAN)	F
3	EI-NINO 3 (JUL,AUG,SEP) PREVIOUS YEAR	F
4	SOUTH INDIAN OCEAN DIPOLE INDEX (MAR)	U
5	EAST ASIA PRESSURE (FEB+MAR)	U
6	EUROPE PRESSURE GRADIENT INDEX (JAN)	U
7	EAST-WEST 50 hPa WIND PATTERN (JAN+FEB)	F
8	EURASIAN SNOW COVER DEC (PY)	U
9	NINO 3.4 SST TENDENCY (AMJ-JFM)	U
10	SOUTH INDIAN OCEAN 850 hPa Zonal Wind (JUNE)	F

Region	Parameter	Fav/UnFav	Region	Parameter	Fav/Unfav
<b>NW India</b>	South Atlantic SLP (Jan)	<b>U</b>	<b>Central India</b>	South Indian Ocean SST (Mar)	<b>U</b>
	North Atlantic SLP (May)	<b>U</b>		East Asia Pressure (Mar)	<b>U</b>
	South Pacific SLP (May)	<b>F</b>		North Atlantic SST(Oct+Nov)	<b>U</b>
	North Atlantic SST (Jan)	<b>F</b>		North Atlantic SLP (Mar)	<b>F</b>
	East Asia Pressure (F+M)	<b>U</b>		Eq Indian Ocean SLP (Nov)	<b>F</b>
<b>South Peninsula</b>	South Indian Ocean SST(May)	<b>U</b>	<b>NE India</b>	South Atlantic SLP (Jan)	<b>U</b>
	South-east Indian Ocean SST(Oct)	<b>U</b>		North Atlantic SLP (Apr)	<b>U</b>
	South Indian Ocean SLP (Oct)	<b>U</b>		South Pacific SST (Mar)	<b>U</b>
	South Pacific SLP (Dec)	<b>U</b>		Central Pacific SST (May)	<b>U</b>
	Arabian Sea Wind (Mar)	<b>F</b>			

The Multiple Regression Models for the seasonal rainfall over the four homogenous regions have a model error of  $\pm 8\%$ .

Table-6.2 shows the details of the operational forecasts for the 2006 southwest monsoon rainfall issued by IMD and their verification. As seen in the Table-6.2, the forecasts for the July rainfall, Northwest India and south Peninsula were correct. The operational forecasts underestimated slightly the seasonal rainfall over the country as a whole and NE India. However, the forecast for the Central India was much on lower side compared to the realized rainfall.

## **6.2 Operational Forecasts for the Monsoon Onset over Kerala**

In 2005, IMD for the first time issued a long range forecast for the monsoon onset over Kerala based on an indigenously developed multiple regression model with 6 predictors. The predictors used in the model are listed in the Table-6.3. The forecast error of this statistical model is  $\pm 3$  days. Using the same model, the forecast for the 2006 monsoon onset was issued. The operational forecast of the onset date over Kerala for 2006 was 30<sup>th</sup> May. The observed onset date over Kerala was on 26 May, slightly earlier than its prediction.

## **6.3 Forecasts based on IMD's Experimental Models**

New experimental statistical models were developed for the first and second stage forecasts of seasonal rainfall over the country as a whole. To develop these models, new methods of model development period, and selection of predictors were adopted. Also, new statistical methods like Ensemble Multiple Regression (EMR) and Pursuit Projection Regression (PPR) were used to develop the new models. For the predictors, a new global data set of predictors was used. More details of these new models are available in Rajeevan et al (2006). The forecasts for the 2006 southwest monsoon rainfall based on the EMR and PPR models were 93% and 94% of LPA respectively. Experimental statistical forecasts for the seasonal rainfall over the country as a whole were also prepared using two another models; Intrinsic Mode Function (IMF) model based on only IMD rainfall series (Iyengar and Raghu Kanth 2005) and Artificial Neural Network Model. The forecast for the 2006 southwest monsoon rainfall based on these two models was 95% and 93% of LPA respectively.

In 2004, a dynamical prediction system was established at the National Climate Centre, IMD, Pune, under a collaborative research programme with the Indian Institute of Science, Bangalore. For this purpose, the seasonal forecast model (SFM) of the Experimental Climate Prediction Center (ECPC), USA was adopted. The model resolution is T63 L28. The model climatology was prepared based on data of 1979-2003. The hindcasts during 1979-2003 suggested satisfactory performance of the model over the Indian region. For preparing the predictions for 2006, persisted SSTs were used as the boundary

conditions and the forecast was computed as the average of 10 ensembles generated using initial conditions corresponding to 10 days.

Fig.6.1a shows the forecast seasonal rainfall anomaly for the 2006 SW monsoon season based on persistence SSTs in March. The Fig.6.1a indicates above normal rainfall over most parts of the country. For the second stage forecast, SST anomaly for May 2005 was assumed to persist till the end of the monsoon season. The Fig.6.1b shows the seasonal rainfall forecast based on persisted May SSTs. The forecast for the seasonal rainfall was above normal over NW India and below normal over remaining parts of India. Large negative anomalies were predicted over Bay of Bengal and adjoining NE parts of India.

#### **6.4 Forecasts from other institutes in India**

Apart from IMD, many other research institutes in India have been involved in long range forecasting research. Three institutes had communicated their experimental forecasts for the seasonal rainfall over the country as a whole to IMD prior to issuing the first stage forecast in April. Before issuing the second stage forecast in June, updated forecasts were also received. Table-6.4 shows the experimental forecasts for the 2006 southwest monsoon rainfall received from other research institutes from India. IITM Pune prepared three experimental forecasts based on statistical models.

In addition, institutes are involved in preparing experimental dynamical predictions using atmospheric general circulation models. The inferences from the dynamical predictions of IITM and CMMACS are given in Table-6.5. The extended range forecasts (monthly forecasts) prepared by SAC/NCMRWF are shown in Fig.6.2.

#### **6.5 Forecasts from Major International Climate Prediction Centres**

Many international climate prediction centers also prepare global seasonal forecasts using different dynamical models. It may be mentioned that these centers do not prepare forecasts specifically for the Indian region. NCEP, USA had supplied monthly forecasts to IMD on real time, which were also consulted while finalizing the operational forecast. The forecasts from the major climate prediction centers are shown in Fig.6.3. The inferences derived from the predictions prepared by these centers are given in Table-6.6. Among these models, the forecasts by UK Met office and NCEP CFS were more accurate. These forecasts suggested above normal rainfall over west central and NW India and below normal rainfall over NE India as observed.

**Table- 6.2: Verification of operational long range forecasts for the 2006 South-West Monsoon**

Region	Issued on	Period	Model Used	Forecast	Actual
All India	24 <sup>th</sup> April 2006	June to September	8- Parameter Models	93% of LPA $\pm$ 5%	100% of LPA
	Updated forecast 30 <sup>th</sup> June 2006		10- Parameter Models	92% of LPA $\pm$ 4%	
All India	30 <sup>th</sup> June 2006	July	5 –Parameter Multiple Regression Model	97% of LPA $\pm$ 9%	98% of LPA
North West India	30 <sup>th</sup> June 2006	June to September	Multiple Linear Regression Models	91% of LPA $\pm$ 8%	94% of LPA
North East India				94% of LPA $\pm$ 8%	83% of LPA
Central India				90% of LPA $\pm$ 8%	116% of LPA
South Peninsula				97% of LPA $\pm$ 8%	95% of LPA

**Table – 6.3: Details of predictors used for the prediction of monsoon onset**

No	Name of Predictor	Temporal Domain	Geographical Domain	C.C 1975-2000
1	SE Indian Ocean SST anomaly	JANUARY	24S-14S, 80E-100E	0.41
2	NW India Minimum Surface air Temperature	1. Deesa, 2. Rajkot 3. Guna, 4. Bikaner 5. Akola & 6. Barmer	16 <sup>th</sup> April to 15 <sup>th</sup> May	-0.63
3	Zonal Wind Anomaly at 1000hpa over Equatorial South Indian Ocean	1-15 May	10S-0, 80E-100E	0.52
4	OLR Anomaly Over Indo-China	1-15 May	17.5N-27.5N, 95E-105E	0.43
5	OLR Anomaly Over Southwest Pacific	1-15 May	30S,20S, 145E-160E	-0.54
6	Pre-Monsoon Rainfall Peak Date over South Peninsula	Pre-monsoon	(8N-13N, 74E-78E)	0.65

**Table – 6.4: Experimental Long range forecasts issued by research institutes in India**

S.No	Institute	Model	Forecast
1	Indian Institute of Tropical Meteorology (IITM) Pune	1) Regression model based On momentum flux 2) Statistical model based On Multiple Regression Analysis of global predictors 3) Statistical Model based On Global SST	91% of LPA 96% of LPA (April Forecast) 92% of LPA (June forecast) 102% of LPA
2	Indian Institute of Science Prof R.N.Iyengar	Empirical Model based On time series analysis	96% of LPA
3	Space Application Centre	Empirical Model based On Genetic Algorithm	95% of LPA

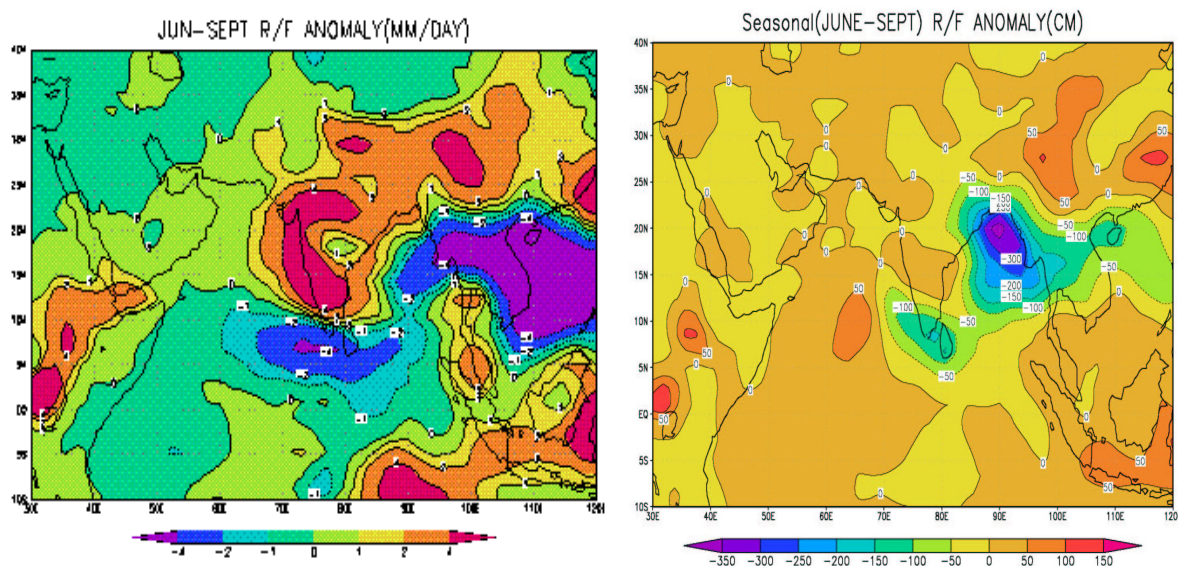
**Table- 6.5: Inferences from the dynamical predictions of IITM and CMMACS**

Institute	Inference
CMMACS Bangalore	Slightly deficient rainfall ( about 5%) over the country during June-July-August 2006
Indian Institute of Tropical Meteorology, Pune	1.5% above normal over the country during June to September.

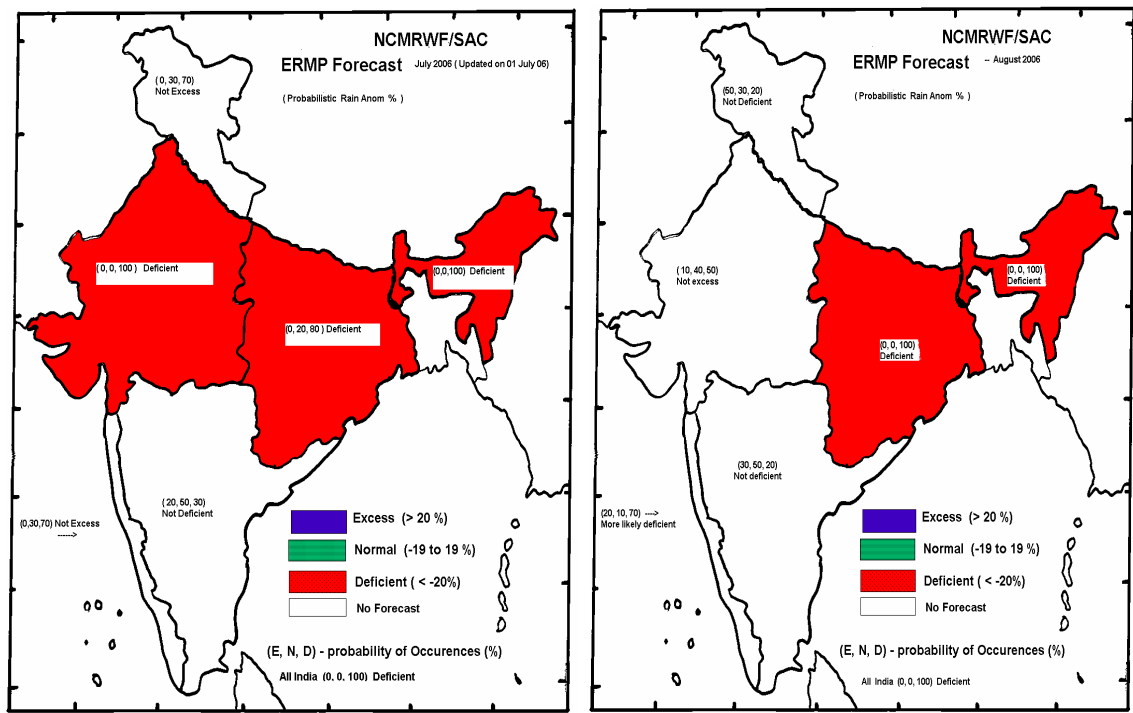
**Table- 6.6: Summary of the dynamical predictions of 2006 monsoon rainfall**

S.No	Center	Forecast Issued in	Inference for 2006 monsoon season
1	United Kingdom Meteorological Office, UK (Coupled Model)	May 2006	Over Peninsular region, rainfall conditions during JAS is more likely to be Wet over most of the parts except southern most parts where it is more likely to be wet or average. Over some parts north India, rainfall is more likely to be average and that over NE is more likely to be dry or average.
2	European Centre for Medium Range Weather Forecasts UK. (Coupled Model)	May 2006	Large negative rainfall anomaly during JJA over northwestern parts of the country and NE India. No signal elsewhere.

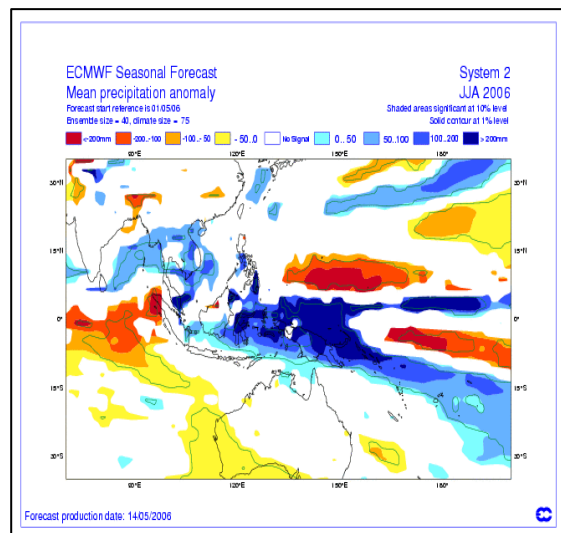
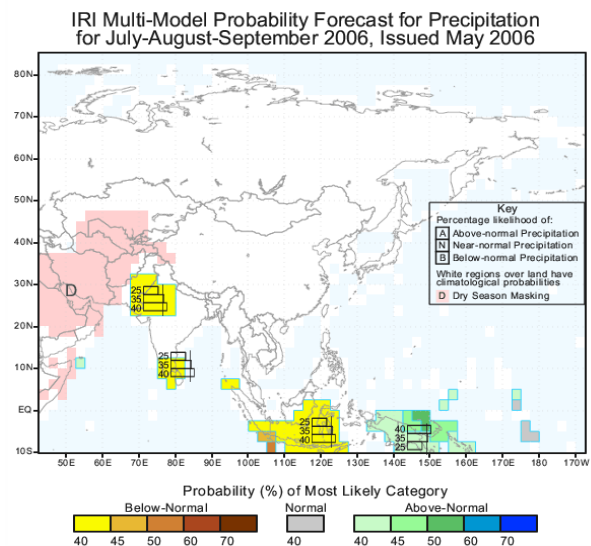
3	International Research Institute for Climate Prediction, USA (Ensemble Models)	May 2006	Climatological probability for JAS rainfall over most parts of the country except over NW India and SE India where the probability of below normal rainfall is the largest (40%).
4	National Center for Environmental Prediction, USA (Coupled Model)	May 2006	Above normal JJAS rainfall over central India and parts of NW India, northwest coast of India. Below normal rainfall over most parts of NE India.
5.	Experimental Climate Prediction Center, USA (Atmospheric Model) May SST persisted	June 2006	Negative rainfall anomaly during JAS over central India. Positive rainfall anomaly over NE region and some parts of South Peninsula.
6	NASA	June 2006	Below normal rainfall over NW India during August-September-October 2006.



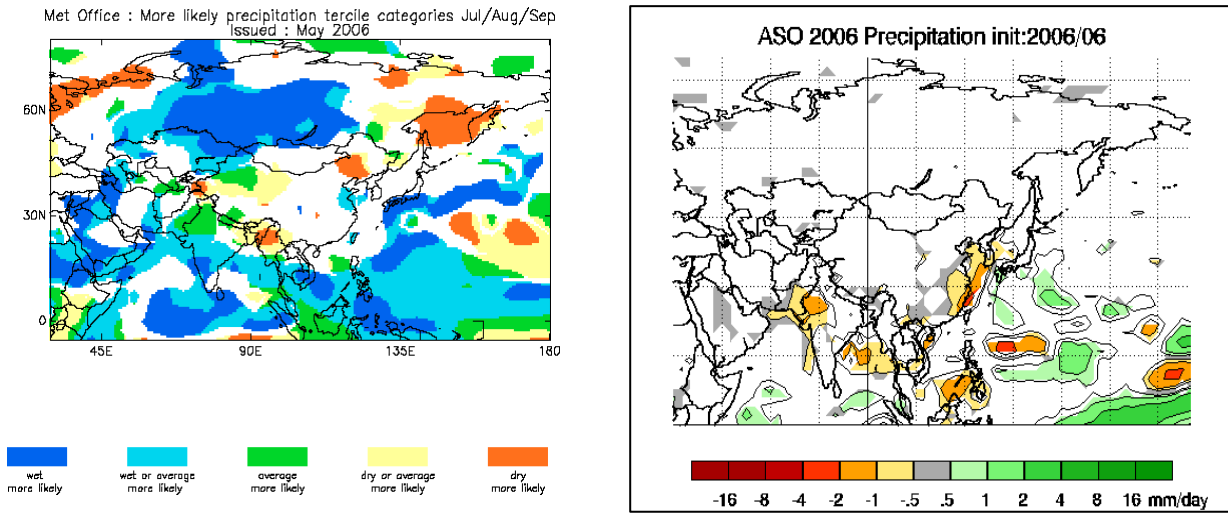
**Fig.6.1: IMD-IISc Prediction based on a) March SST b) May SST**



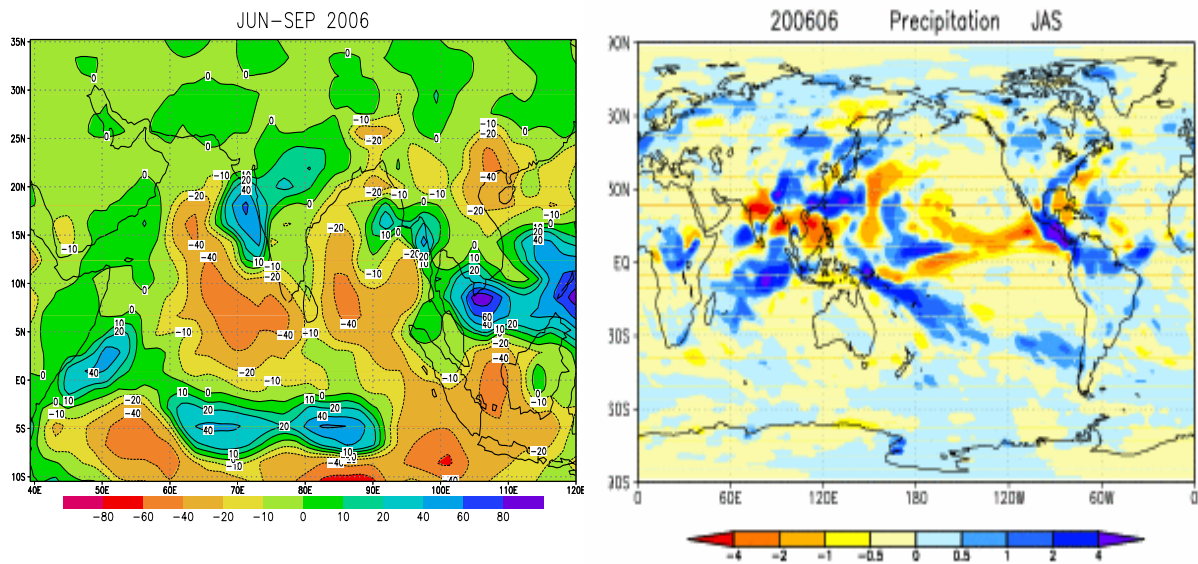
**Fig.6.2: SAC/NCMRWF Forecasts for a) July 2006 and b) August 2006**



**Fig.6.3: Dynamical Predictions a) IRI, USA for JAS period issued in May b) ECMWF, UK for JJA period issued in May**



**Fig.6.3: Dynamical Prediction c) UK Met office for JAS period issued in May  
d) NASA for ASO period in June**



**Fig.6.3: e) NCEP CFS, USA for June to Sept period issued in May  
f) ECPC, USA for JAS period issued in June**

# Monsoon<sup>2006</sup> *A Report*

## Chapter – 7

### **Conclusions**

In this report, we discussed various aspects of the 2006 south-west monsoon season. In the first chapter, the onset, advance and withdrawal phases are discussed. Monsoon arrived over Kerala almost one week before its normal date. After the first onset spell, there was a prolonged hiatus from 7-22 June in advancement of monsoon. During this period, there was enhanced convection over the equatorial Indian Ocean due to above normal sea surface temperatures. The enhanced convection over the equatorial Indian Ocean caused subsidence over the Indian sub-continent thus forcing a prolonged hiatus. In the chapter 2, semi permanent features and synoptic systems of 2006 monsoon season are discussed. An important aspect of the 2006 season was development of one severe cyclonic storm, eight depressions and seven low pressure areas. Compared to the recent few years, more number of low pressure systems developed during the season, which contributed significantly to good rainfall activity over central India, especially in August and September.

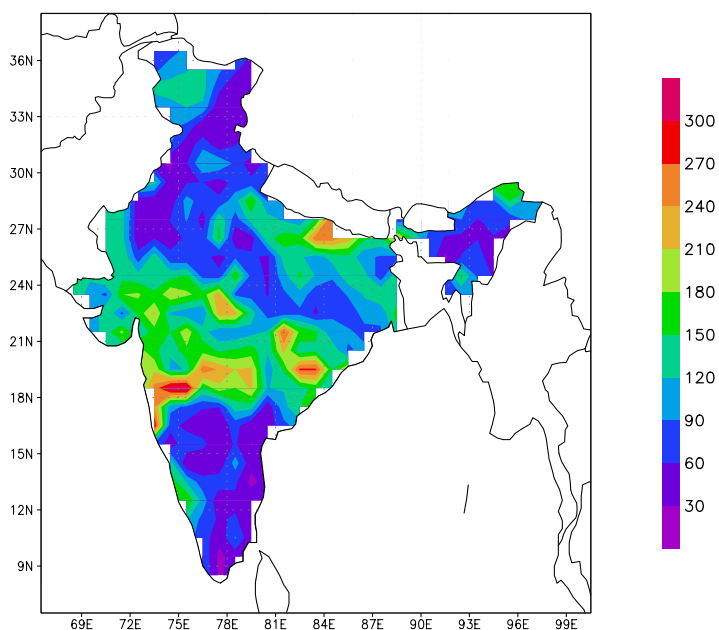
In the Chapter 3, details of rainfall distribution over the country were discussed. Southwest monsoon season (June to September) rainfall over the country as a whole was 100% of its long period average, which was on higher side of the long range forecast (93% of LPA) issued by the IMD. However, rainfall was unevenly distributed in space and time. Monsoon activity was almost subdued till the third week of July. However, the second half of the season saw a strong revival and its persistence almost during the second half. Out of 36 meteorological sub divisions, as many as 9 sub divisions received deficient rainfall. Moderate drought conditions prevailed over four sub divisions and 161 districts over the country. In the Chapter 4, the regional circulation anomalies were discussed. During the end of season, a moderate El Nino event developed over the equatorial Pacific Ocean. Over the equatorial Indian Ocean, a positive dipole event also developed, which might have triggered

the spectacular revival of monsoon during the second half of the season. In chapter 5, the details of short and medium range forecasts by the regional models (LAM, MM5) and global models (NCMRWF, ECMWF) are discussed. In the Chapter 6, details of the long range forecast for the 2005 southwest monsoon rainfall issued by IMD and other research institutes were discussed. IMD's long range forecasts for the July rainfall over the country as a whole, NW India and South Peninsula were correct.

As many as 8 depressions and one cyclonic storm formed during the season. During the recent years, frequency of monsoon depressions has shown decreasing trend. Therefore, it is pertinent to ask the question, is it the above normal activity this year a sign of reversal of the observed decreasing trends? What are the large scale thermo-dynamic and circulation features responsible for the above normal activity?

An interesting aspect during the season was enhanced rainfall activity over north Arabian Sea and adjoining Pakistan. SST anomalies over this region was above normal during the season. What caused the above normal SSTs and sustained enhanced convection over this region?

Another interesting aspect of this season was the occurrence of extreme rainfall events. At many places, many heavy rainfall events occurred, causing localized but severe flooding. In August 2006, at least 9 stations over India received record rainfall in 24 hours. This aspect was noticed in 2005 season also, which included the flooding over Mumbai on 26/27 July 2005. A recent study by Goswami et al (2006) found an increasing trend of extreme rainfall events over the Indian region during the southwest monsoon, suggesting a role of global warming in these extreme weather events. Fig. 7.1 shows the highest rainfall in 24 hours during the season occurred over  $1^{\circ} \times 1^{\circ}$  grid boxes.



**Fig. 7.1 : Highest rainfall (mm) occurrence in 24 hours during the season shown over  $1^{\circ} \times 1^{\circ}$  grid**

Salient features of the 2006 southwest monsoon season rainfall are summarized below:

- **For the country as a whole, the seasonal rainfall from 1<sup>st</sup> June to 30<sup>th</sup> September was 100% of its long period average (LPA)**
- **Seasonal rainfall over Central India was excess by 16% and it was 94% and 95% over Northwest India and South Peninsula. It was however, deficient over Northeast India by 17%.**
- **Rainfall over the country was below normal (8% of its LPA) in June. However, monsoon was near normal in July (98% of its LPA). Monsoon was slightly excess in August (107% of its LPA) and in September (102% of its LPA).**
- **Out of 36 meteorological sub divisions, southwest monsoon seasonal (June-September) rainfall was normal in 21 sub-divisions, excess in 6 and deficient in 9 sub divisions.**
- **60 % of the meteorological districts received excess/normal rainfall and the remaining 40% received deficient or scanty rainfall.**
- **Four sub divisions (Arunachal Pradesh, Assam and Meghalaya, West Uttar Pradesh and Haryana) experienced moderate drought conditions (rainfall deficiency of 25% or more) at the end of the season.**
- **Out of 533 meteorological districts, 130 experienced moderate drought and 30 districts experienced severe drought conditions at the end of the season.**

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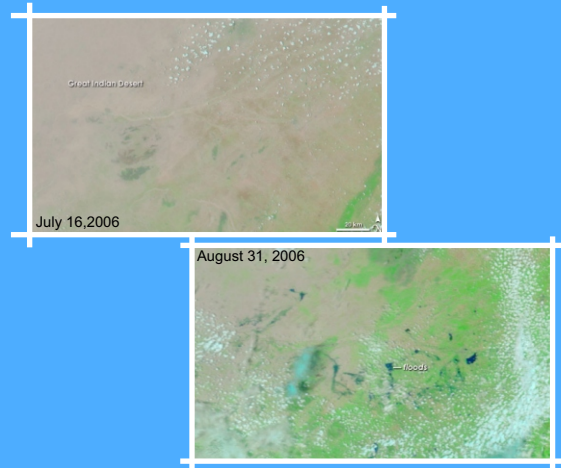
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During the second week of August heavy rains occurred in Rajasthan, the state in which the Thar desert lies. The resulting flooding was visible on August 31, when the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured the top image. Though clouds (light blue and white) partially obscure the scene, pockets of dark blue flood water appear to flow through formerly dry channels. A more wide-spread indicator of the heavy rain is the color of the landscape. In mid-July, lower image, the desert was pink-tan, with very little vegetation growing on it. By the end of August, brushes of green extended across most of the desert, indicating that plants were growing in the unusually moist conditions.

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