# Chapter-II
# Monsoon-2004: Onset, Advancement and Circulation Features

## 2.1. Introduction

Monsoon constitutes the economic lifeline of India. The need to provide accurate weather forecast during monsoon season is arising from a variety of user interests. Agriculture is one such highly weather sensitive sector where weather forecasts have a high stake. It is, therefore, essential that we are in a position to provide forecasts of arrival of monsoon which is so eagerly awaited by all and sundry after the blazing heat of the summer. Monsoon does not mean wet weather throughout the monsoon season. We have periods of dry and wet spells caused by distinct flow pattern epochs.

The initiation of the cross equatorial flow off the Somalia coast of Africa during May in response to the heating over the South Asian continent marks the beginning of the summer monsoon evolution process over the Arabian sea. The onset of monsoon over the South Kerala coast is manifested as a consequence of significant changes of atmospheric circulation, cloudiness etc and evolves gradually over the Arabian Sea. Long term records of onset over Kerala suggest that the event is more or less regular and its normal onset date of arrival over Kerla is 1 June with standard deviation of about eight days.

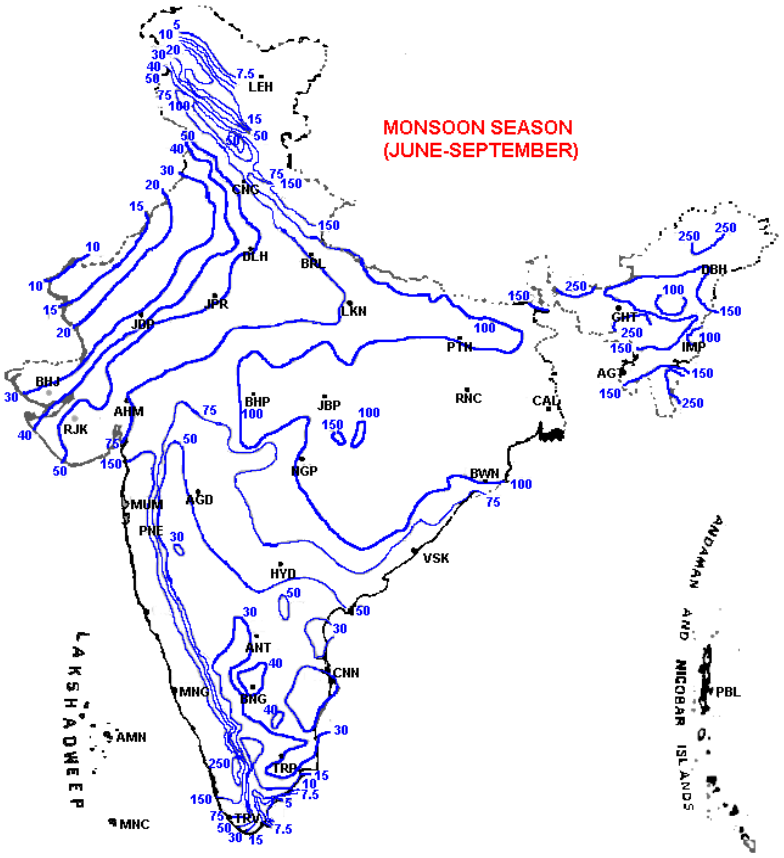



**Fig 2.1**

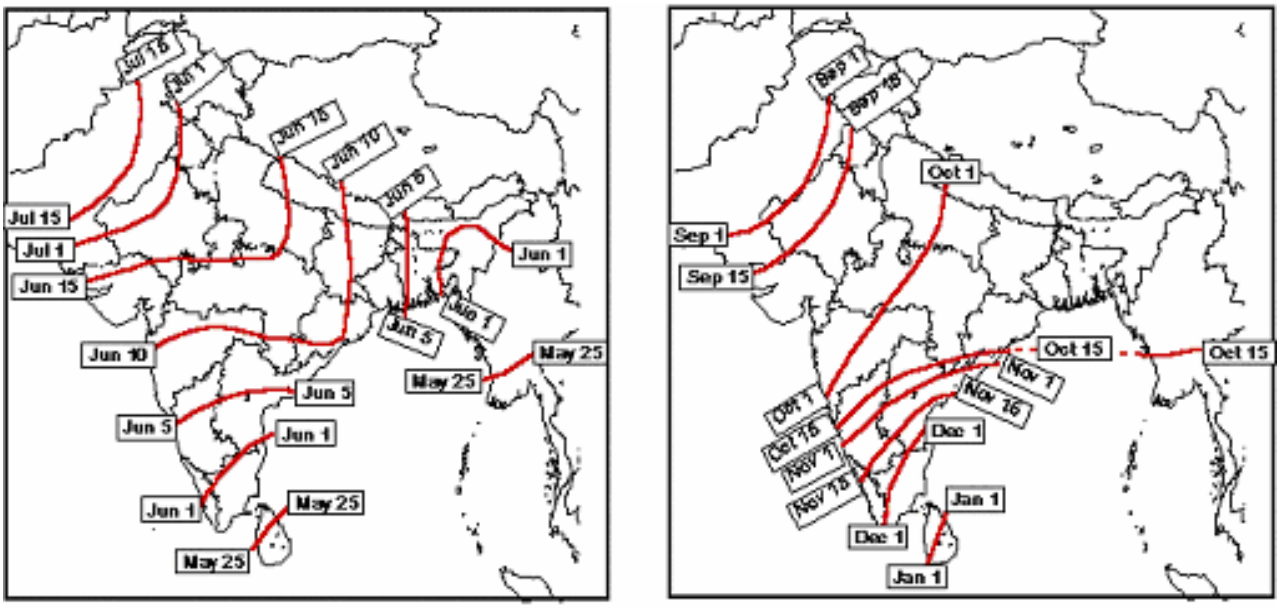
## 2.2 Onset of monsoon

The problem of onset of monsoon has been reviewed by many workers. Though it has been studied extensively over the years, particularly by making use of the enormous data collected through the scientific ventures, the precise definition of onset of southwest monsoon has still remained a debatable point. The climatological dates of onset of monsoon were fixed by India Meteorological Department on the basis of sharp increase in pentad rainfall and circulation. Normal (climatological) date of onset of monsoon over southern parts of Kerala is June 1. During individual years the date of onset over Kerala varies widely: the earliest on records 11 May (in 1918) and the most delayed was 18 June (in 1972), the Standard Deviation (S.D.) in the dates of onset of monsoon over Kerala is 8 days.

The onset of monsoon occurs during the early part of May over Myanmar and during early June over southwestern India. We present some recent findings related to the onset issues. Very rapid cooling of the Arabian sea (far east of the regions of coastal upwelling) is observed soon after the onset of the strong southwesterly monsoonal winds. Typically, the onset of the Indian summer monsoon is characterized by the development of a trough of low or a system of higher intensity which is normally called the onset vortex.

The Mascarene high and the monsoon trough over northeast India are two of the major elements of the summer monsoon. The pressure difference between the Mascarene high and the monsoon trough is in fact a measure of the differential heating that drives the monsoon. The drive of monsoon can be measured by kinetic energy of the 850 hPa winds over the Central Arabian Sea. Surges in the strength of monsoon flow over Central Arabian Sea is an important parameter to be monitored in short range forecasting of the activity of monsoon including its onset over India.

Onset of Indian summer monsoon is sudden in most of cases and the onset phase is associated with some kind of transient disturbances. Once the monsoon sets, it further progress takes place due to the rain bearing system like monsoon trough, lows, depression, mid-tropospheric cyclones etc. These synoptic scale systems are considered as perturbations embedded in the basic monsoon current. A late or weak start to the monsoon season and extended break in monsoon rains could seriously impact the rainfed crops. Also, if the southwest monsoon withdraws from the region earlier than expected, late sown crops may suffer during the filling stages from lack of moisture. Conversely, a late withdrawal, if accompanied with late season rain, could be detrimental to maturing crops




Average onset dates

Average withdrawal dates

**Fig 2.2** Average monsoon onset and withdrawal dates

## 2.3 Components of Monsoon Circulation responsible for various vagaries of monsoon rains

### *2.3.1 Monsoon trough and heat low*

The monsoon trough extends from heat low over Pakistan, eastwards towards the head Bay of Bengal and further towards the west pacific across southeast Asia. The entire low pressure system is almost east-west oriented with a semi-permanent well marked heat low over north Pakistan. Monsoon trough is a major semi-permanent feature of the monsoon circulation and has a great control on the monsoon rainfall activity in the sub-continent and southeast Asia. The trough oscillates north and south. An intense trough in its normal position provides well distributed rainfall over India. Shifting of the trough northwards, shifts the rainfall belt towards north. In India this situation is referred to as the break monsoon condition. In a very active phase there are a number of vortices (low/ depression/ cyclone) embedded in the monsoon trough enhancing the rainfall in the region. The knowledge of the conditions leading to such an active situation is, therefore, helpful in the prediction of rainfall. On the other hand generally meridional flow in the upper troposphere in the northeastern hemisphere with trough-ridge pattern or with the presence of blocking high over the Caspian Sea or over East Asia are the indicators of movements of monsoon trough towards the north giving rise to break monsoon conditions in India.

### *2.3.2 Monsoon Lows and Depressions*

The monsoon lows and depressions are the principal rain bearing systems of the south west monsoon period over India. Substantial amounts of rainfall are generated by the westward passage of monsoon depressions forming in the Bay. These are low pressure areas having wind speeds between 17 and 33 knots in their circulation. On the average 2 depressions form in each of the monsoon months (June-September). However, year to year variation in their number is quite large. Those that form in early June are responsible for the advance of the southwest monsoon, and are not strictly monsoon depressions. In July and August they usually form north of 18°N in the northwest Bay, and the site of genesis shifts in September southward in the Central Bay. These depressions usually move westnorthwest during peak months of July & August. Monsoon depressions usually develop from innocuous looking cloud systems and from diffuse pressure fields over the head Bay of Bengal. Satellite imagery shows heavy overcast mass in the southern sector with low-level cumulus clouds determining the low-level circulation centre (LLCC) to the northeast. The LLCC is often free from deep convection. The widespread and heavy rainfall in southwest sector is often accompanied with deep convection in that sector.

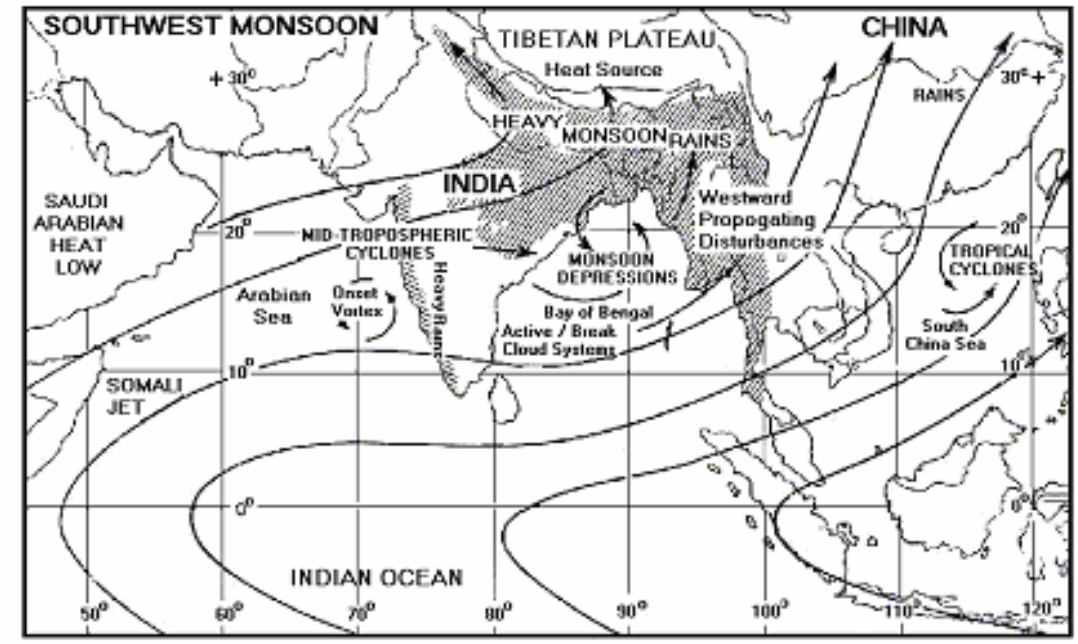



**Fig 2.3**

### *2.3.3 Tibetan High and Tropical Easterly Jet ( TEJ )*

The Tibetan High is a large warm anticyclone located at the Tibetan Plateau in the middle or upper troposphere during the summer monsoon season. Southward shift of this high from its normal position as a result of the protrusions of the mid-latitude westerlies, is seen accompanied with reduction in monsoon

activity over India and neighbourhood. A well-distributed rainfall over India is associated with well-pronounced and east-to-west oriented anticyclone over Tibet at 500 and 300 hPa levels, and a pronounced high index circulation over Siberia, Mongolia and north China. The Tibetan 'High' may sometimes shift much to the west of its usual position. In such a situation, the monsoon may extend further westward into Pakistan and in extremes cases into north Iran, though such a westward position of the Tibetan 'High' would be against its having origin in the heating effect of the Tibetan Plateau.

South of the sub-tropical ridge over Asia, the easterly flow concentrates into a jet stream with its central region passing roughly along 13.5°N at 100 hPa over the Indian sub-continent. The TEJ runs from east coast of Vietnam to the west coast of Africa. Over Africa its location is around 10°N latitude. The TEJ has been a subject of study by many Indian meteorologists. Normally the jet is at an accelerating stage from the South China Sea to south India and decelerates thereafter. The position and speed fluctuate from day to day. It has also been observed that two maxima of TEJ, one at lower latitude and the other at higher latitude (north Bay of Bengal) for period more than 2-3 days, are generally associated with the break monsoon condition.

### *2.3.4 Mid-Tropospheric Cyclones ( MTCs)*

These are upper air cyclonic circulations having the maximum intensity in middle tropospheric levels between 600 – 400 hPa. They are generally seen over the northern parts of the west coast of India. Their appearance on the surface charts is either non-existent or at best seen as trough. Observations have shown that MTCs are cold cored below 4 km and warm core above. This is consistent with the observed vorticity structure. Their horizontal length scale is 500 to 1000 Km. These systems exhibits little movement and appear to remain quasi-stationary for several days. They display usually large deep convective cloud mass in the satellite imagery.

MTCs cause active to vigorous monsoon conditions in the regions they affect. On many occasions the 24 hour rainfall may be as large as 20 cm. The other areas in the Asian monsoon regime where similar types of systems have been observed, is the South china and Indo – China region but with a lesser frequency

### *2.3.5 Off-shore troughs and Off- shore vortices*

Another class of disturbances which cause spells of heavy rain along the west coast of India are the off-shore troughs and off-shore vortices. These are small scale systems with linear dimensions of the order of 100 km in the horizontal and confined to the lower tropospheric levels in the vertical. Their presence is detected by weak easterly winds at coastal stations and off shore convection in the satellite imagery.

## 2.4 Monsoon-2004

### 2.4.1 Onset and advancement of southwest monsoon-2004

During 2004, the southwest monsoon advanced into south Andaman sea on 13th May and further covered north Andaman Sea and adjoining south Bay of Bengal on 14th May, a few days earlier than the normal date (i.e. 20th May )

During the third week of May, a cyclonic storm developed over the Bay of Bengal. It crossed Myanmar coast on 19th May without affecting weather over the eastern coast of our country. Under its influence, a strong surge of monsoon westerlies appeared over the south peninsula and this heralded the commencement of monsoon rains over Kerala coast from 18th May. Southwest monsoon which had set in over Kerala and the northeastern region about two week ahead of its normal schedule , further advanced in phases on 1, 6 and 10 June . By June 10, Southwest monsoon covered the entire peninsula .

The movement of low pressure system from Bay of Bengal to west Uttar Pradesh across the central parts of the country during mid June helped smooth advance of monsoon. Therefore, monsoon advance was rapid due to systems forming on June 16, southwest monsoon covered nearly two-third area of the country. As on 18th June , northern limit of monsoon passed through Lat. 26.0°N/ Long. 70.0°E, Udaipur, Kota, Gwalior, Mainpuri, Bareilly, Deheradun, Simla, and Jammu. There was no further progress of monsoon after 18th June.

The monsoon revived as a weak current during the first week of July with the formation of low pressure area in northwest Bay of Bengal on 1st July, which moved to central parts of Madhya Pradesh by 5th July .Subsequently a surge from Arabian Sea helped the monsoon to advance further into some more parts of Rajasthan on 4th July .The monsoon covered most area of the country outside parts of Rajasthan, Punjab and Haryana by 5th July. Northern limit of monsoon passing through Lat. 26.0°N/ Long. 70.0°E, Jodhpur, Jaipur, Delhi, Dehradun and Pathankot on 5th July. With the weakening of low pressure area, the seasonal trough once again shifted to foot hills of Himalayas causing another spell of weak monsoon over the country. After the formation of another low pressure area over northwest Bay of Bengal on 13th July, and its movement towards central parts of the country, the monsoon further advanced into the remaining parts of the country as a weak current by 18th July.

### 2.4.2 Cyclonic systems during monsoon season of 2004

A total of eight low-pressure areas viz., 3 in July, 4 in August and 1 in September and three depressions viz., 2 in June and 1 in September formed over Indian region during monsoon 2004. Month-wise summary of the low-pressure areas and depression is given in the table 2.1 below.

***Table 2.1 : Statistics of cyclonic disturbances which affected the country during monsoon months (June-September) of 2004***

| CYCLONIC DISTURBANCE | JUNE | JULY | AUGUST | SEPTEMBER | TOTAL |
|---|---|---|---|---|---|
| CYCLONIC STORM/ DEEP DEPRESSION/ DEPRESSION | 2 | 0 | 0 | 1 | 3 |
| WELL MARKED LOW/ LOW PRESSURE AREA | 0 | 3 | 4 | 1 | 8 |
| TOTAL | 2 | 3 | 4 | 2 | 11 |

**A. Depressions during Monsoon-2004**

Monsoon Depressions which normally formed over the Bay of Bengal (less frequently over the Arabian Sea) and move west-northwest-wards along Gangetic plains give copious rainfall. Normally over 6-7 such disturbances form during the whole season and their intensity rarely exceed the limit of deep depression. Some of the monsoon depressions also originate over land rather than over oceanic surface and are well known as land depression.

During monsoon season of 2004, there were two deep depressions in the month of June, one over Arabian Sea and other over the Bay of Bengal. There was formation of a land Depression in the month of September over Gangetic West Bengal.

***i. Deep Depression of 9-16 June,2004***

A well marked low pressure area which formed over the south Maharastra coast on 9th June, concentrated into depression at 0300 UTC of 10th June with center near Lat. 17.5ºN/Long. 68ºE. Moving slightly westwards it intensified into deep depression and lay centered near Lat. 17.5ºN/ Long. 67ºE at 0300 UTC of 11th June. Subsequently moving in northwesterly direction, it weakened into a depression at 1200 UTC with center near Lat. 18ºN/Long. 65.5ºE and further into a low pressure area over the same region on 15$^{th}$ June. It became less marked on 16$^{th}$ June. The system contributed good amount of rainfall over the northwest peninsula.

***ii. Deep Depression of 11-22 June,2004***

The depression which formed over the Bay of Bengal at 0300 UTC of 11$^{th}$ June with center near Lat.15.5ºN/ Long.90.0ºE was first seen as low pressure area over east central Bay and Andaman sea on evening of 10$^{th}$ June. Subsequently moving in a northwesterly direction, it intensified into a deep depression at 0300

UTC of 12th June. Moving further northwards it crossed the south Orissa coast close to Puri at 0300 UTC of 13th June. Thereafter, moving in a west-northwesterly direction, it lay closed to Phulbani at 1200 UTC of 13th June and near Sambalpur at 0300 UTC of 14th June. Moving further northwest wards, it weakened into a depression close to Raigarh at 1200 UTC of 14th June and further into a well marked low pressure area over northwest Chattisgarh and adjoining east Madhya Pradesh on 15th June. It finally became less marked over northern parts of Gangetic West Bengal and neighbourhood on 22th June.

***iii. Depression of 10-22 September,2004***

A low pressure area formed over north Bay of Bengal on 10th September .The low pressure area became well marked over the same area on 11th September. It concentrated into a depression over west Bengal and adjoining Bengladesh on 12th September. It remained practically stationary over the same area up to 15th September. It weakened into a well marked low pressure area and lay over adjoining Jharkhand on 16th September. The system further weakened as low pressure area and seen over Jharkhand on 18th September and over Chattisgarh on 19th & 20th September. The low pressure area moved slowly northwards and lay over north Madhya Pradesh and adjoining south Uttar Pradesh on 21st September. It further moved over to northern parts of West Uttar Pradesh on 22nd September. The system gave good rainfall over east central India and Uttaranchal during the third week of September.

**B. Low pressure areas during Monsoon-2004**

July 2004

Three low pressure areas formed during the month of July.

***i. Low Pressure Area of 13-17 July,2004***

A low pressure area formed over west-central and adjoining northwest Bay off north Andhra-Orissa coast on 13th July. It persisted and intensified as well marked low pressure area on 15th July. Moving in land, it lay over northern parts of Orissa and adjoining Jharkhand on 16th morning and over the northern parts of east Madhya Pradesh and adjoining Chattisgarh in the evening. It became less marked on 17th July.

***ii. Low Pressure Area of 23-25 July,2004***

Another low pressure area formed over northwest and adjoining central parts of Bay off West Bengal-Orissa coast on 23rd July. It remained active for 2 days over the area and became less marked on 25th July.

### *iii. Low Pressure Area of 28July -02 August,2004*

Third low pressure area was formed over northwest and adjoining west-central Bay off Orissa coast in the morning of 28th July. It lay over Orissa and neighborhood in the evening . It lay over Chattisgarh and adjoining east Madhya Pradesh on 29th July and over central parts of Madhya Pradesh and neighborhood on 30th July. The system further moved over north Madhya Pradesh and adjoining south Uttar Pradesh on 31st July where it persisted upto 2 August and weakened on 3rd August.

August 2004

Four low pressure areas formed during the month of August.

### *iv. Low Pressure Area of 2-7 August,2004*

A low pressure area formed over northwest Bay of Bengal off Orissa-West Bengal coast on 2nd August. It became well marked area on 3rd August. It moved westwards very slowly and lay over coastal Orissa & adjoining northwest Bay of Bengal on 4th August. It moved in west-northwesterly lay over east Madhya Pradesh and adjoining Vidarbha on 5th August . It further moved to west Madhya Pradesh and adjoining south Rajasthan on 6th August. It weakened over the same region on 7th August.

### *v. Low Pressure Area of 7-11 August,2004*

A upper air cyclonic circulation developed over Orissa and adjoining Jharkhand on 7th August and persisted on 8th August. Under its influence a low pressure area formed over Jharkhand & adjoining Chhattisgarh on 9th August, and weakened on 10th August. Its associated upper air cyclonic circulation moved over to central parts of Uttar Pradesh and over northwest Madhya Pradesh and neighbourhood on 11th August.

### *vi. Low Pressure Area of 11-18 August,2004*

A low pressure area formed over north Bay of Bengal coast on 11th August and persisted on 12th August. It slowly moved over to Orissa and adjoining west Bengal and Jharkhand on 13th August. It moved westwards over Chhattisgarh and neighborhood on 14th August. Moving west-northwest direction it lay over north Madhya Pradesh and neighbourhood and remained there up to 17th August. It weakened over northwest Madhya Pradesh and adjoining south Uttar Pradesh on 18th August.

### *vii. Low Pressure Area of 16-25 August,2004*

A low pressure area formed over north Bay of Bengal off Gangetic West Bengal - Bangladesh coast on 16th August. It moved inland and lay over Orissa and neighborhood on 17th August. It persisted over the same region on 18th and 19th August and intensified as well marked low pressure area on 20th August. It moved west-north-westward across Jharkhand, Chhatisgarh and Madhya Pradesh and lay over west Madhya Pradesh on 23rd August. It weakened into low pressure area on 24th over same area. Subsequently it moved northwestwards and lay over southwest Uttar Pradesh on 25th August.

The number of deep systems (depressions or higher intensity) during 2004 over the region was less compared to other years in past 15 years. Table-2.2 gives the statistics of number of deep systems (cyclones and depressions) during past 15 years

***Table-2.2: Statistics of depressions and cyclonic storms during monsoon seasons of 1988-2004***

| YEAR | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. OF DEP. | 4 | 4 | 4 | 4 | 3 | 1 | 2 | 2 | 1 | 5 | 3 | 4 | 2 | 1 | 1 | 2 | 3 |
| NO. OF C.S | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| TOTAL | 4 | 5 | 4 | 4 | 3 | 1 | 2 | 2 | 3 | 6 | 4 | 4 | 2 | 2 | 1 | 2 | 3 |

### 2.4.3 Strength of Monsoon Flow over Arabian Sea during Onset and Advancement phase

During 2004, the onset of monsoon over Kerala took place about a fortnight prior to normal date. Soon after the onset over Kerala and also NE States, there had been some lull in the monsoon. The advancement of monsoon over Peninsular India was more or less around normal date. Another lull in the monsoon occurred on 18 June which persisted till first week of July. Monsoon covered entire country by 18th July. It is well known that intra-seasonal monsoon variability is intimately related to the strength of low level monsoon flow over the Arabian Sea. NCMRWF's model analysed 850 hPa mean kinetic energy over Arabian sea for the period 1 June to 31 July, 2004 and 2003 is depicted in Fig 2.4, It may be seen from this figure that period of lull during 3rd week of June to 1st week of July corresponds to lower magnitude of kinetic energy (50-55 $m^2$ $sec^{-2}$). The revival of monsoon around 4th July, corresponds to slightly higher magnitude of kinetic energy (~ 70-90 $m^2$ $sec^{-2}$ ). Another important inference from this figure is that while mean kinetic energy during June 2004 is much higher compared to June 2003, the values during July 2004 are consistently lower than those in July 2003. This is mainly because of the fact that the onset of monsoon during 2003 was on 8 June, and thereafter it had slow advancement. On the other hand during 2004, monsoon had already advanced into many areas of peninsula by 1st June and further advancement took place progressively till 18th June. On the contrary,

almost entire July 2003 witnessed good monsoon activity, whereas monsoon remained in weak phase during July 2004.

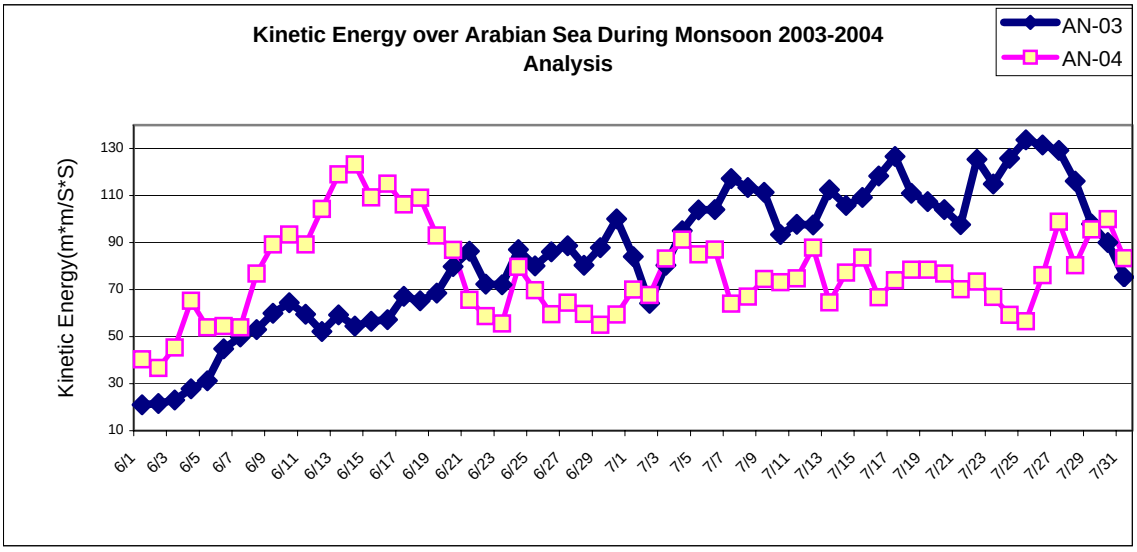



***Fig.2.4: Mean 850 hPa Kinetic Energy over Arabian Sea during Monsoon-2003 and 2004***

### 2.4.4 Mean Monthly Circulation features during Monsoon-2004

Using daily analysis from T-80 model, monthly mean wind field for different significant levels is generated for each of the four months during monsoon-2004. Isotachs of 5, 10,15 and 20 m/s are drawn and shaded with different colours. Circulation features as depicted by these charts for different months are discussed in the following paragraphs:

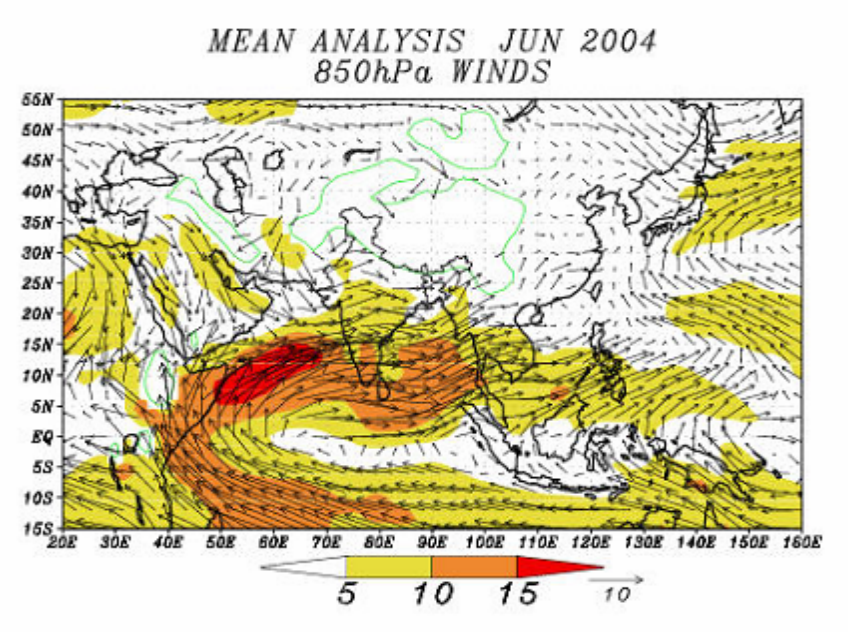
**a. June**

The 850 hPa mean wind flow for the month of June depicts strong cross-equatorial flow with maximum wind of the order of 15 m/sec off Somalia coast and central Arabaian Sea and of the order of 10m/sec over south Arabian Sea and Bay of Bengal. The interesting feature seen in this chart is the absence of seasonal monsoon trough over the gangetic plain and predominance of westerlies over the region. Similar features are seen in mean 700 hPa flow pattern, which depicts strong northwesterly to westerly winds over Ganagetic plain extending upto central parts of the country. These features clearly portrait weak monsoon circulations e.g., seasonal trough at 850 and 700 hPa levels

**b. July**

The cross-equatorial flow in the month of July,2004 as depicted by mean monthly chart, is weaker compared to that in June,2004. The areal extent of 10 m/sec winds in July is less compared to that in June particularly over Bay of Bengal. 10 year mean field for two these months (not shown) suggest that low

level jet and cross equatorial flow during July should be stronger as compared to June. Similar to June,2004 mean field, mean field of July also shows absence of seasonal monsoon trough over the gangetic plain and predominance of westerlies over the region. Mean 700 hPa flow pattern July also shows strong northwesterly to westerly winds over Ganagetic plain extending upto central parts of the country. These features confirm the observed weak monsoon conditions during July,2004.



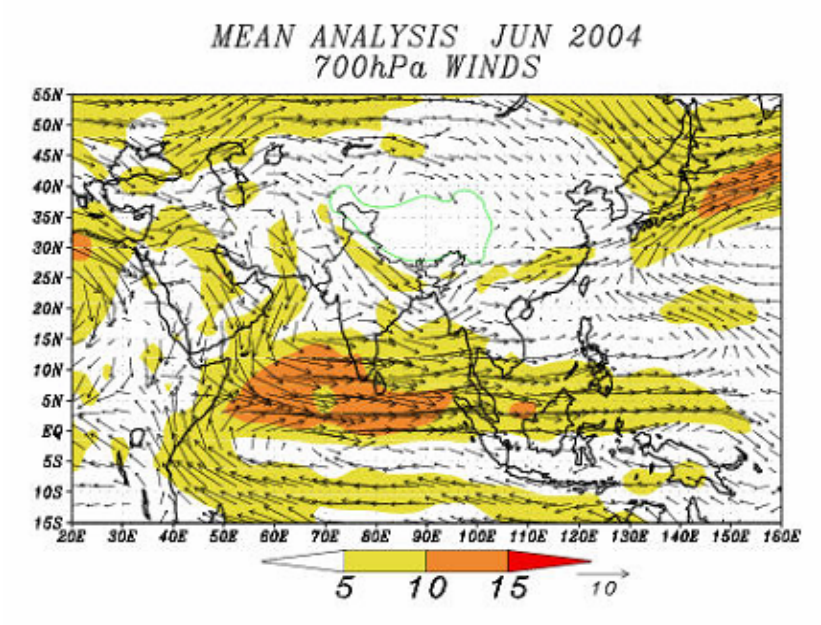




**Fig 2.5 (a) & (b)**

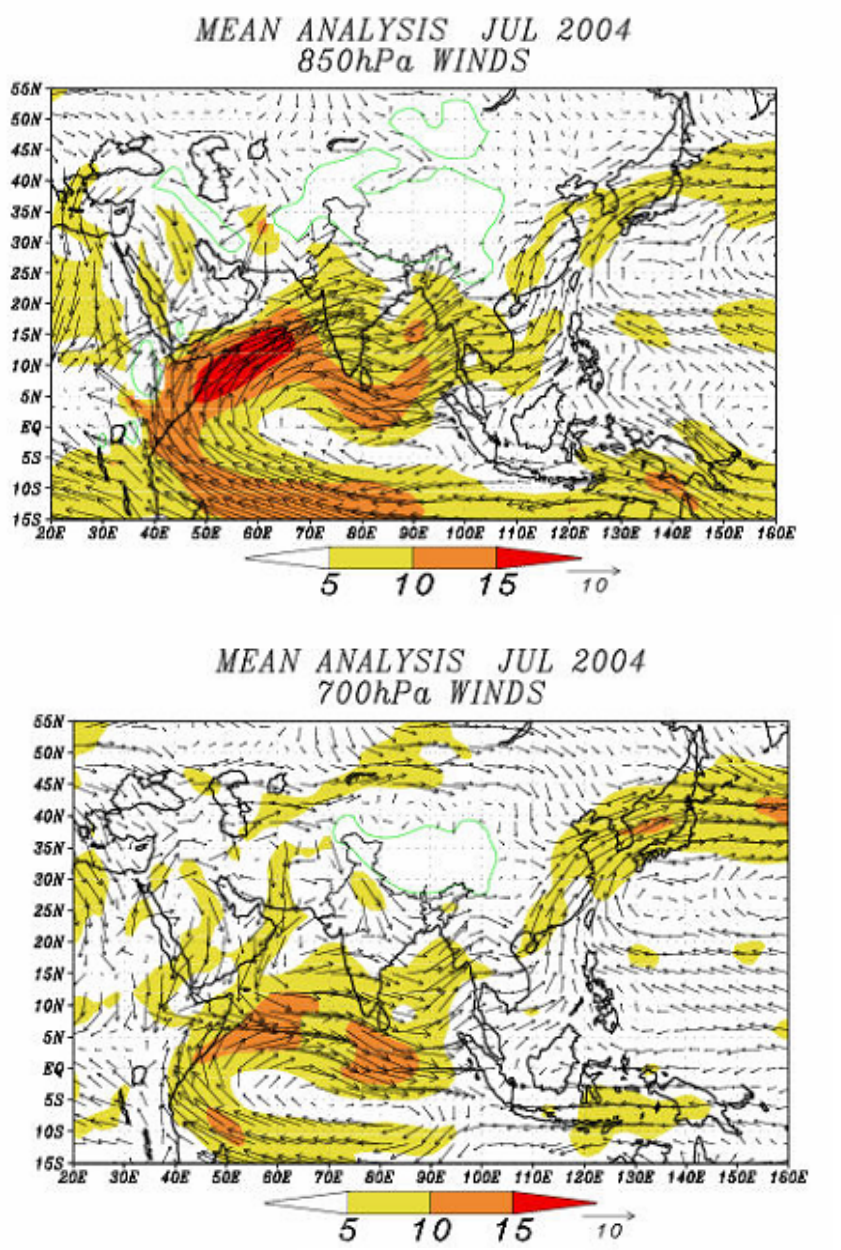



**Fig 2.5 (c) & (d)**

**c. August**

There appears to be considerable change in the mean wind fields at 850 and 700 hPa of August,2004 as compared to July,2004. The cross-equatorial flow in the month of August,2004 is stronger as compared to that in June and July,2004. The areal extent of 10 m/sec winds in August is much more as compared to that in July over Arabian Sea and Bay of Bengal. The major improvement is seen in terms of appearance of a seasonal monsoon trough over Indo-gangetic plain region at both 850 and 700 hPa levels in the month of August. These features correspond to observed active monsoon conditions during August,2004.

**d. September**

September had witnessed significant weakening of monsoon flow as evident from mean wind fields at 850 and 700 hPa of September,2004 compared to August,2004. The cross-equatorial flow in the month of September ,2004 is much weaker as compared to that in other three months viz., June, July, and August, 2004. Almost entire land area over Indian sub-continent has winds less than 5 m/sec. The areal extent of 10 m/sec winds in September is much less as compared to any other month over Arabian Sea and Bay of Bengal. The northern and central parts are dominated by westerly to northwesterly winds at 850 and 700 hPa levels. These features correspond to weak monsoon conditions during September,2004. The overall rainfall over the country was 39% below long term average rainfall during September,2004.

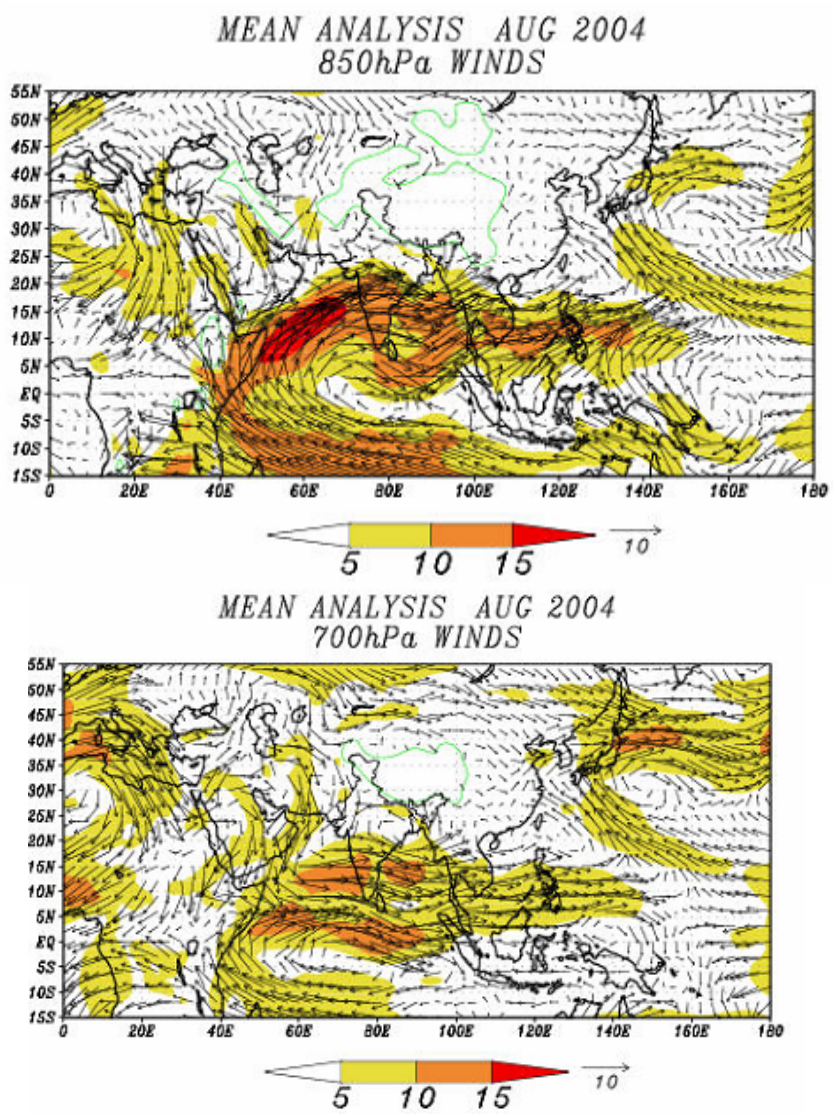
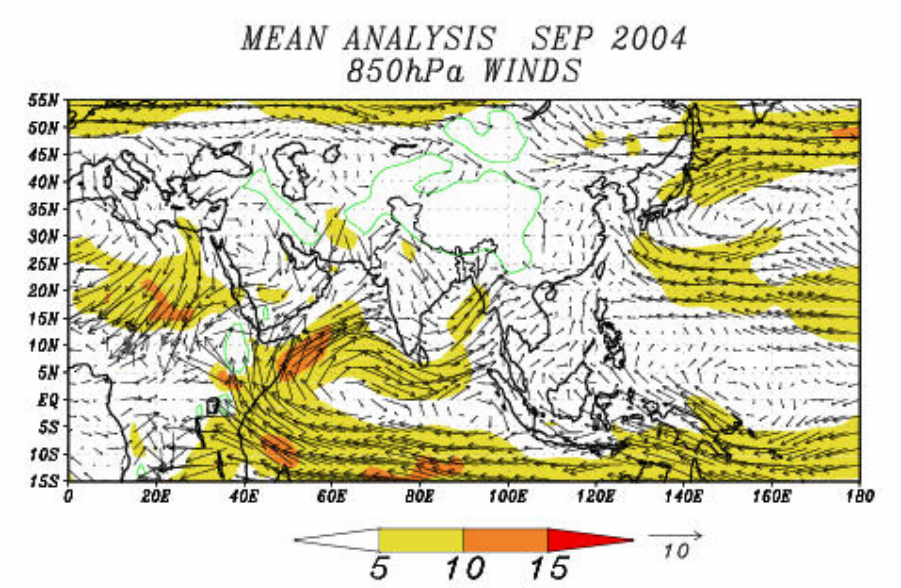



**Fig 2.5 (e) & (f)**


MEAN ANALYSIS SEP 2004
850hPa WINDS
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
0
20E
40E
60E
80E
100E
120E
140E
160E
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15
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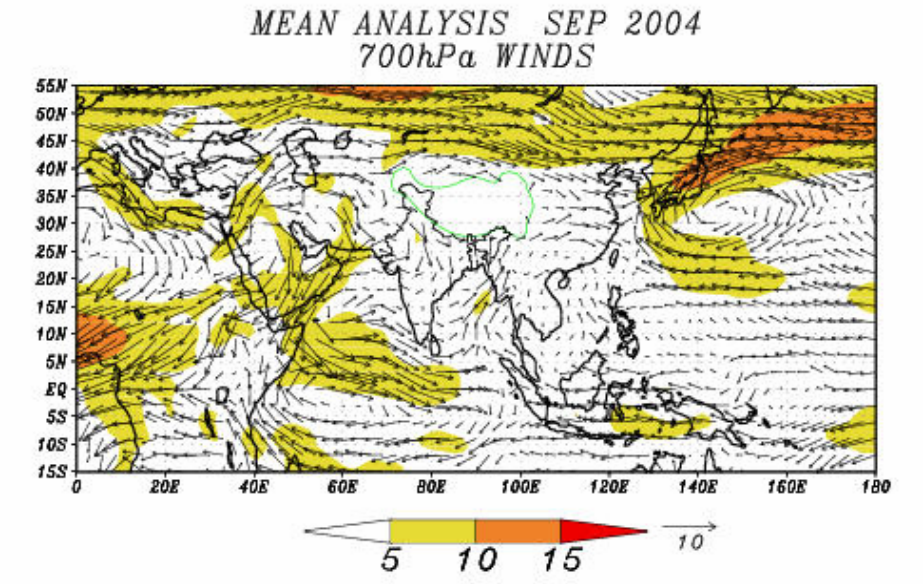
MEAN ANALYSIS SEP 2004
700hPa WINDS
55N
50N
45N
40N
35N
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25N
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5S
10S
15S
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20E
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80E
100E
120E
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160E
180
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**Fig 2.5 (g) & (h)**