MAUSAM, **63**, 3 (July 2012), 511-528

Weather in India

MONSOON SEASON (June to September 2011)†

1. Introduction

The seasonal rainfall (during June to September 2011) over the country as a whole was 102% of its Long Period Average (LPA) and thus is categorized as a normal monsoon. However, the rainfall over northeast India has been deficient. The second half of the season - especially the month of August - registered above normal rainfall, while the month of July experiencing deficient rainfall.

Four monsoon depressions formed during the season including a land depression. The monsoon depression in general did not form over their climatologically preferred area of formation *viz*., the North Bay of Bengal and formed elsewhere. Typical break condition did not occur all through the season, other than the pre-mature occurrence of break like situations, during 2-3 July when the monsoon was yet to cover the entire country.

The El–Nino neutral conditions changed over to La-Nina conditions during the second half of the season due to the re-emergence of the La-Nina conditions over equatorial Pacific. Weak positive Indian Ocean Dipole pattern was present over the equatorial Indian Ocean during the second half of the season.

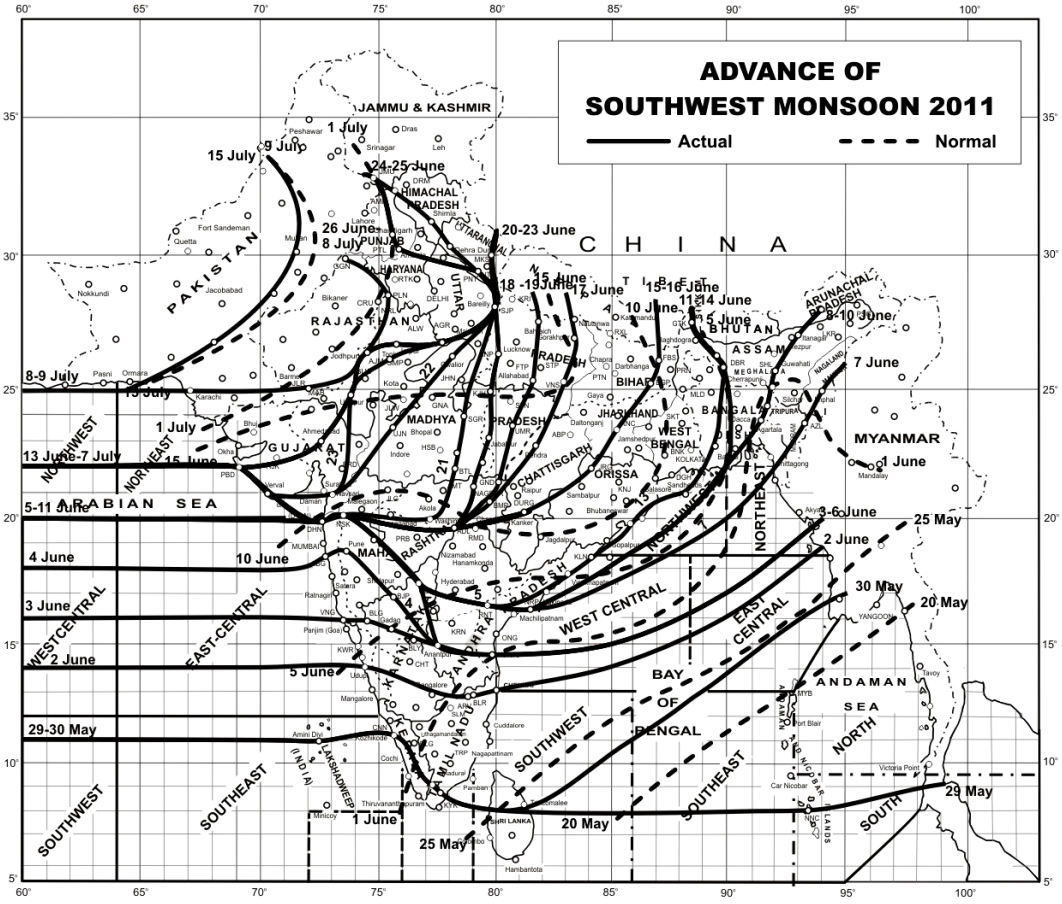

Fig. 1. Isochrones of advance of southwest monsoon - 2011

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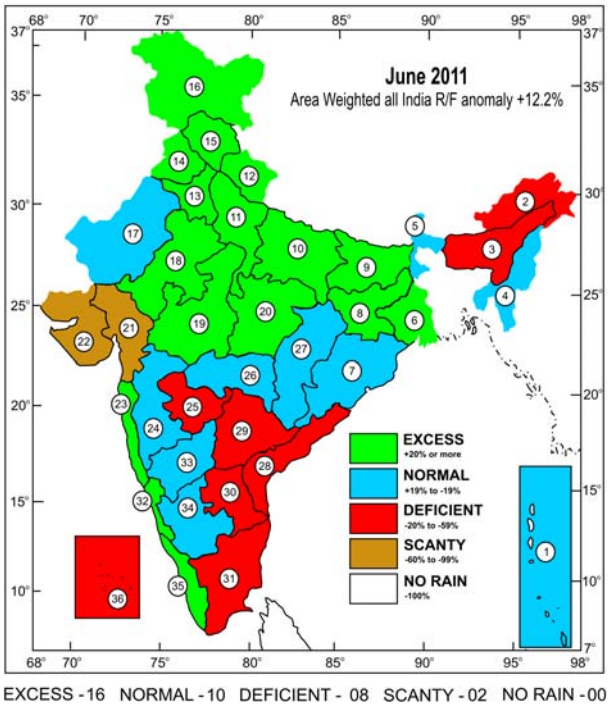

Fig. 2. Rainfall for the month of June 2011 as percentage departure from normal. 36 Sub-divisions are indicated by numbers on the map & bold letters in legend below. The rainfall anomaly values for these sub-divisions are indicated below :

1	–5	**7**	1	**13**	61	**19**	112	**25**	–51	**31**	–23
2	–33	**8**	67	**14**	123	**20**	136	**26**	–14	**32**	23
3	–36	**9**	38	**15**	48	**21**	–88	**27**	6	**33**	–13
4	–17	**10**	59	**16**	57	**22**	–72	**28**	–27	**34**	17
5	–11	**11**	137	**17**	–13	**23**	20	**29**	–41	**35**	22
6	75	**12**	57	**18**	142	**24**	–11	**30**	–24	**36**	–53

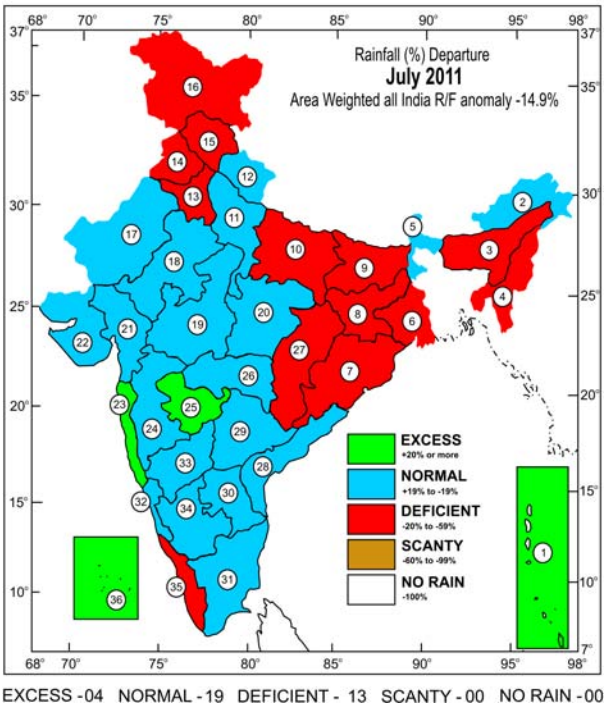

Fig. 3. Rainfall for the month of July 2011 as percentage departure from normal. 36 Sub-divisions are indicated by numbers on the map & bold letters in legend below. The rainfall anomaly values for these sub-divisions are indicated below :

1	41	**7**	–40	**13**	–53	**19**	6	**25**	29	**31**	–6
2	3	**8**	–52	**14**	–54	**20**	–9	**26**	–19	**32**	0
3	–28	**9**	–25	**15**	–46	**21**	–19	**27**	–28	**33**	4
4	–37	**10**	–28	**16**	–36	**22**	7	**28**	4	**34**	–12
5	–2	**11**	–10	**17**	–9	**23**	29	**29**	10	**35**	–26
6	–32	**12**	6	**18**	–13	**24**	1	**30**	16	**36**	22

2. Various aspects of southwest monsoon – 2011

2.1. *Onset and advance*

Fig. 1 shows the isochrones of advance of monsoon over the country .

The monsoon set in over Kerala on 29th May, 3 days prior to the normal date of 1st June. Due to strengthening of the cross-equatorial flow over Arabian Sea and the northward movement of a vortex in the form of an upper air cyclonic circulation along the trough off the west coast, the monsoon further advanced rapidly and covered entire Kerala, Tamil Nadu and Goa, most parts of Karnataka and some parts of Maharashtra and south Andhra Pradesh by 5th June. However, the organization of this vortex into a low pressure area and its further intensification and stagnation over the east central Arabian Sea during the period from 6th-10th June, caused a short lived hiatus in the advance of the monsoon along the west coast. In the mean time, the convection over the Bay of Bengal strengthened and with the formation of a low pressure area of short life span over the northwest Bay of Bengal, the eastern branch of the monsoon advanced over some more parts of Bay of Bengal and northeastern states, with a delay of nearly 5 days with respect to the respective normal dates.

Thereafter, formation of a Depression over the Arabian Sea on 11th June and a cyclonic circulation over the North Bay of Bengal caused the monsoon to further advance over some more parts of Arabian Sea, parts of Saurashtra and most parts of the Bay of Bengal and parts of coastal Andhra Pradesh and coastal Orissa on 13th June.

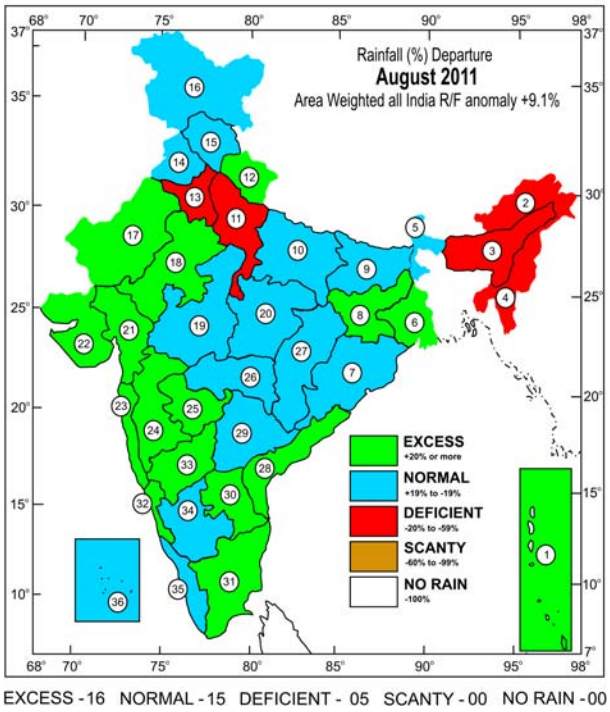

Fig. 4. Rainfall for the month of August 2011 as percentage departure from normal. 36 Sub-divisions are indicated by numbers on the map & bold letters in legend below. The rainfall anomaly values for these sub-divisions are indicated below :

1	27	**7**	–7	**13**	–35	**19**	13	**25**	23	**31**	31
2	–37	**8**	23	**14**	–5	**20**	–16	**26**	3	**32**	26
3	–22	**9**	3	**15**	14	**21**	64	**27**	0	**33**	23
4	–27	**10**	–12	**16**	1	**22**	128	**28**	26	**34**	14
5	–8	**11**	–22	**17**	86	**23**	28	**29**	5	**35**	18
6	43	**12**	32	**18**	36	**24**	28	**30**	59	**36**	17

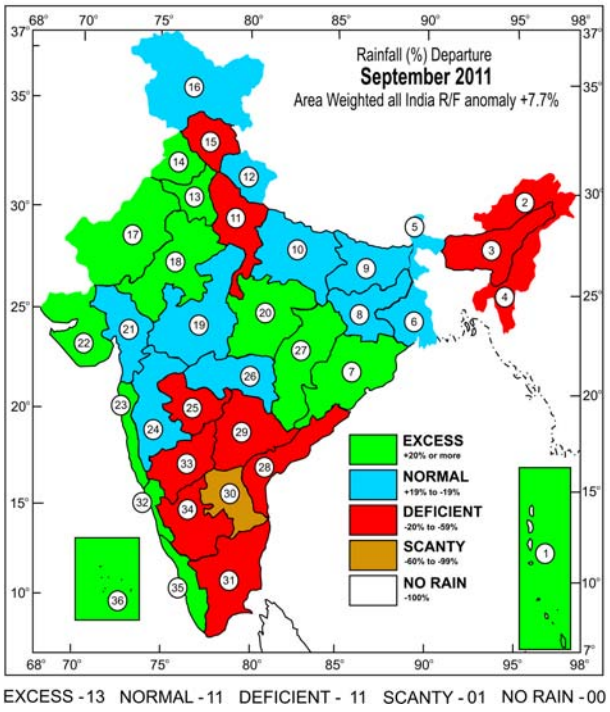

Fig. 5. Rainfall for the month of September 2011 as percentage departure from normal. 36 Sub-divisions are indicated by numbers on the map & bold letters in legend below. The rainfall anomaly values for these sub-divisions are indicated below :

1	78	**7**	49	**13**	43	**19**	3	**25**	–45	**31**	–26
2	–29	**8**	16	**14**	25	**20**	27	**26**	10	**32**	99
3	–35	**9**	19	**15**	–25	**21**	1	**27**	78	**33**	–59
4	–27	**10**	–11	**16**	18	**22**	180	**28**	–41	**34**	–28
5	–8	**11**	–35	**17**	182	**23**	37	**29**	–48	**35**	60
6	4	**12**	–17	**18**	71	**24**	–6	**30**	–60	**36**	56

Subsequently, there had been a rather steady advance during 15th - 26th June in association with the formation of a Deep Depression (16th - 22nd June) over the northwest Bay of Bengal and its gradual west-northwestward movement. This synoptic situation caused the monsoon to cover most parts of the country outside western parts of Rajasthan and north Gujarat state. The weakening of the Arabian Sea branch of monsoon caused a prolonged stagnation (14th June - 7th July) of the western limb in the Northern Limit of Monsoon (NLM). During this period, on 2nd & 3rd July, the heat trough at sea level also lay close to foothills of the Himalayas. As such, there was a prolonged hiatus (27th June - 7th July) in the NLM.

With the formation of a low pressure area over south Chhattisgarh and adjoining Telangana and the organization of the off shore trough extending from south Gujarat coast to Kerala coast during 4th - 8th July, the heat trough at mean sea level shifted southwards and became more pronounced and resulted into favourable conditions for further advance of the monsoon. Thus, the southwest monsoon covered the entire country on 9th July, 6 days earlier than its normal date of 15th July.

2.2. *Monthly rainfall distribution*

Figs. 2-5 show monthwise distribution of rainfall.

The monthly rainfall for the country as a whole during June (112% of LPA), August (110%) and September (108%) were above the respective LPA. However, the rainfall during July (85% of LPA) was

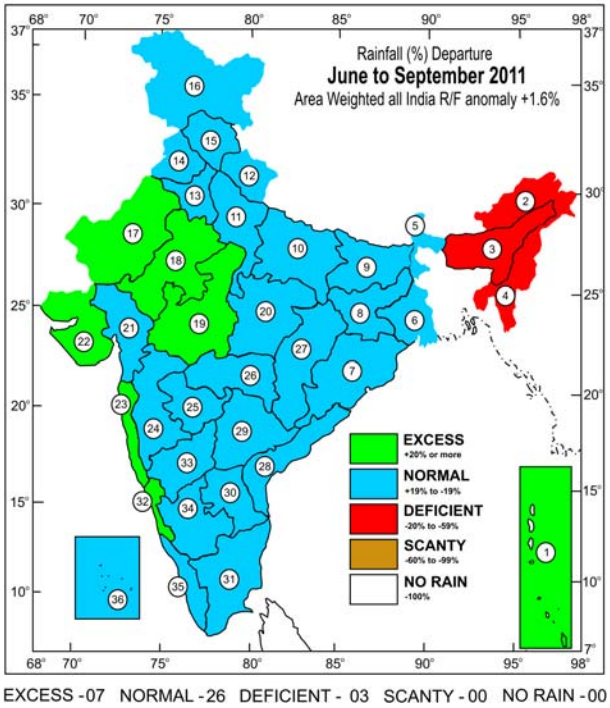

Fig. 6. Rainfall for the season as a whole (June - September) 2011 as percentage departure from normal. 36 Sub-divisions are indicated by numbers on the map & bold letters in legend below. The rainfall anomaly values for these sub-divisions are indicated below :

1	35	**7**	–4	**13**	–19	**19**	21	**25**	–7	**31**	–6
2	–22	**8**	6	**14**	–7	**20**	14	**26**	–6	**32**	22
3	–30	**9**	3	**15**	–11	**21**	0	**27**	6	**33**	–13
4	–27	**10**	–8	**16**	–3	**22**	52	**28**	–8	**34**	–3
5	–7	**11**	–6	**17**	52	**23**	28	**29**	–13	**35**	9
6	19	**12**	18	**18**	35	**24**	4	**30**	–5	**36**	2

below the LPA. A high rainfall deficiency was observed over Gujarat State due to delayed monsoon advance over northern parts of the state in June. A few sub-divisions of eastern parts of the country and Peninsular India also received deficient rainfall in the month of June. In the month of July, normal rainfall was received over most of the sub-divisions except a few sub-divisions from eastern, northeastern, northern parts of the country and Kerala, where the rainfall was deficient. Rainfall distribution over the country during August was more uniform than that during July, as the number of sub-divisions with excess and deficient rainfall during August (excess 16 & deficient 5) was more than that during July (excess 4 & deficient 13). During August, most of the sub-divisions received excess/normal rainfall except northeast India and a few sub-divisions of northern part of the country where the rainfall was deficient. During September, the northeastern parts of India continued to receive deficient rainfall. Many sub-divisions of Peninsular India and a few sub-divisions of northern India also received deficient rainfall.

2.3. *Seasonal rainfall distribution*

The meteorological sub-divisionwise seasonal rainfall distribution in terms of percentage departures from normal is given in Fig. 6. The seasonal rainfall was excess in 7, normal in 26 and deficient in the remaining 3 met. sub-divisions. No sub-division reported scanty rainfall.

2.4. *Withdrawal of southwest monsoon*

Figure 7 shows the isochrones of withdrawal of southwest Monsoon.

The withdrawal of southwest monsoon from west Rajasthan started on 23rd September, with a delay of more than three weeks with respect to the normal date of withdrawal from extreme western parts of Rajasthan (1st September). Subsequently, the monsoon withdrew from most parts of northwest India and some parts of west Uttar Pradesh on 26th September and from most parts of Uttar Pradesh, some parts of Madhya Pradesh and some more parts of Gujarat state on 28th September. On 30th September, the monsoon further withdrew from some more parts of Uttar Pradesh and Madhya Pradesh. The subsequent withdrawal of the monsoon was delayed due to the presence of various transient synoptic scale systems in the mid latitude westerly wind regime, including troughs and cyclonic circulations causing moisture incursion and rainfall over the region. The southward shifting of the upper tropospheric anticyclone caused a reduction in the rainfall activity over the east and northeastern parts from 10th October.

The tendency of delayed withdrawal of southwest Monsoon from Rajasthan is being continued since 2006. The withdrawal started from the extreme west Rajasthan on 21st, 30th, 29th, 25th and 27th September respectively in the years 2006, 2007, 2008, 2009 & 2010.

The southwest monsoon withdrew from some more parts of central and peninsular India on 11th October and from the entire northeast and eastern parts of the country on 13th October. On 24th October, it withdrew from the entire country, including south Peninsula, Bay of Bengal and Arabian Sea followed by a simultaneous commencement of northeast monsoon rains over Tamil Nadu, Kerala and adjoining areas of Andhra Pradesh and Karnataka.

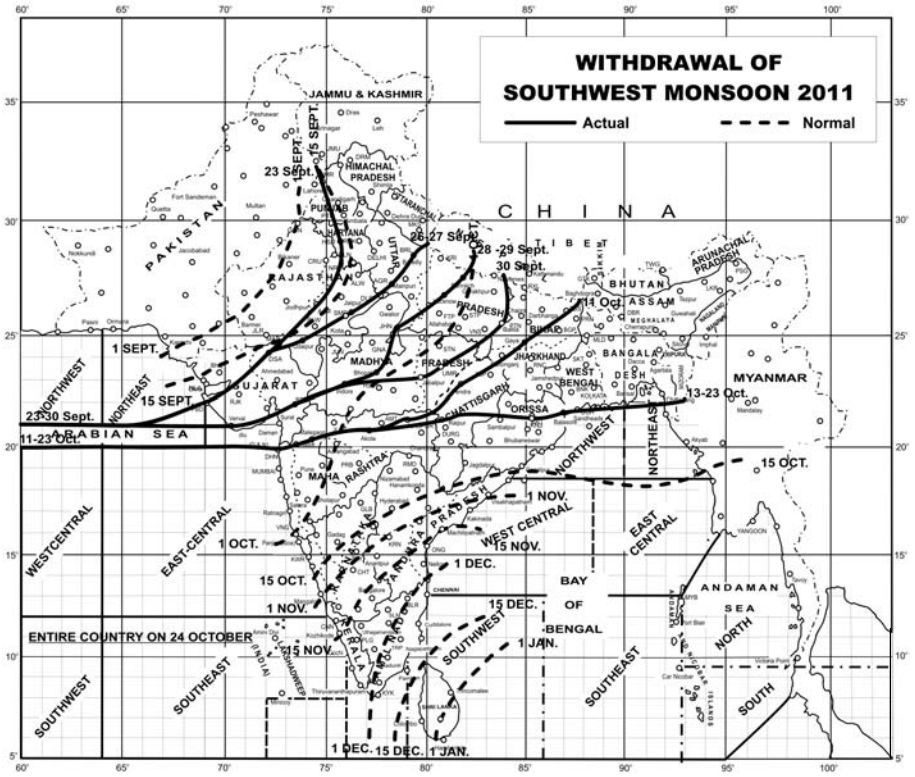

Fig. 7. Isochrones of withdrawal of southwest monsoon 2011

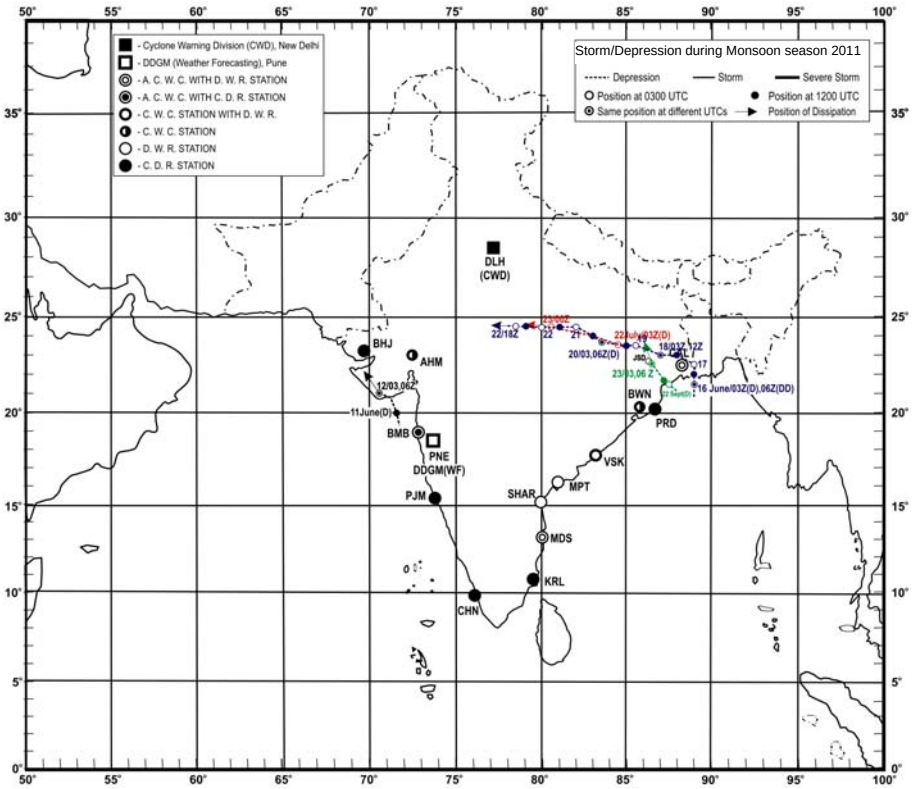

Fig. 8. Storm/depressions during southwest monsoon 2011

TABLE 1

Details of low pressure systems for the month of June 2011

S. No.	System	Duration	Place of first location	Direction of movement	Final location	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
(**A**)	*Depression*					
1.	Depression*	11 (Eve.) - 12	Northeast Arabian Sea near Lat. 20.0° N / Long.71.5° E	North-northeast	Saurashtra and adjoining northeast Arabian Sea	It was first seen as a cyclonic circulation extending between 2.1 & 4.5 kms over Lakshadweep area and neighbourhood on 31 May. Under its influence, a low Pressure area formed over the east central Arabian Sea off north Maharashtra coast from 6-7. It lay as a well marked low Pressure area from 8-11 (Mng) It became less marked on 14 June. However, the associated cyclonic circulation extended up to 4.5 kms a.s.l. lay over Saurashtra & Kutch and neighbourhood on 14 and became less marked on 15 June
2.	Deep Depression*	16 - 23	Northwest Bay of Bengal near Lat. 21.5° N / Long. 89.0° E	Northward and then west-northwest	Gangetic West Bengal and adjoining areas of Jharkhand, north Chattisgarh	It was first observed as a cyclonic circulation over north Bay of Bengal on 13. Under its influence, a low pressure area formed over north west Bengal and neighbourhood on 14 and became more marked on 15. Details are given in the text. It weakened in to low pressure area over west Madhya Pradesh on 23 and became less marked on 24 June
(**B**)	*Low pressure area/Well marked low pressure area*					
1.	Low pressure area	8 June	Northwest Bay of Bengal	Stationary	*In situ*	Became less marked on 9. It formed under the influence of cyclonic circulation extending up to mid-tropospheric levels over northwest Bay of Bengal on 7
2.	Do	29 - 30	East Uttar Pradesh and adjoining north Madhya Pradesh	Northeast	East Uttar Pradesh and neighbourhood	Less marked on 1 July. The associated cyclonic circulation extended upto mid tropospheric levels tilting southwestwards with height
(**C**)	*Upper air cyclonic circulations*					
1.	Up to lower-tropospheric levels	6 -10	Assam & Meghalaya and neighbourhood	Stationary	*In situ*	Became less marked on 11
2.	Up to mid-tropospheric levels	12 - 14	Do	Do	Do	Became less marked on 15
3.	Up to 4.5 kms a.s.l.	24 - 25	Do	Do	Do	Became less marked on 26
(**D**)	*Western disturbances and other eastward moving systems*					
(*i*)	*Western disturbances*					
1.	As an upper air cyclonic circulation (up to mid-tropospheric levels)	1 - 2	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir	Moved away on 3 June
2.	Do	12 -14	North Pakistan and neighbourhood	Do	Do	Moved away on 15 June

TABLE 1 (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
3.	As an upper air cyclonic circulation (up to mid-tropospheric levels)	19 - 21	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir	Moved away on 22 June
4.	As an upper air cyclonic circulation (up to 3.6 km a.s.l.)	26 - 28	Jammu & Kashmir and adjoining north Pakistan	Do	Do	Moved away on 29 June
5.	As an upper air cyclonic circulation (up to mid-tropospheric levels)	30 June - 3 July	Do	Do	Do	Moved away on 4 July
(*ii*)	*Eastward moving upper air cyclonic circulations*					
1.	Up to 0.9 km a.s.l.	10 -15	Central Pakistan and adjoining northwest Rajasthan	Northeast	West Uttar Pradesh and neighbourhood	Moved away on 16
2.	Up to lower tropospheric levels	20 - 23	West Rajasthan and neighbourhood	Do	Haryana and neighbourhood	Moved away on 24
3.	Do	26 June - 1 July	Punjab and neighbourhood	Do	Punjab and adjoining Haryana	Became less marked on 2 July
(*iii*)	*Troughs in westerlies*					
1.	Mid and Upper Tropospheric levels (up to 7.6 kms a.s.l.)	1 - 3	Long. 72° E to the north of Lat. 30° N	Northeast	Long. 75° E & 85° E to the north of Lat. 30° N	Moved away on 4 June
(**D**)	*East-west troughs*					
1.	Lower levels/mean sea level	9 June - 8 July	Northern plains of the country to Bay of Bengal	Oscillatory	Northern plains of the country to Bay of Bengal	Thereafter, it established as a monsoon Trough. It generally extended from north Rajasthan to Gangetic West Bengal. On a few days, western end of it shifted north to Punjab and eastern end shifted south to Orissa

3. Chief synoptic features of southwest monsoon 2011

The synoptic disturbances which affected the Indian Monsoon region during June, July, August & September are given in Tables 1 to 4 respectively.

The tracks of the depressions and deep depressions formed during the season are given in Fig. 8.

Also, there had been 10 low pressure areas / well marked low pressure areas which formed during the season. Most of them originated as upper air cyclonic circulations. Five of them formed over the land, four over the Bay of Bengal and one over the Arabian Sea. The month wise breakup of the systems is : 2 each in June, July and September and 4 in August.

The off-shore trough along various parts of the west coast persisted from 2 June - 21 September except during 19-25 June. It was quite feeble on a few days including 27 June - 4 July, 23 - 25 July, 22 - 23 August, 9 - 11 September and 19 - 21 September.

4. Extra Indian features

4.1. *Cross Equatorial Flow*

4.1.1. *Over the Arabian Sea*

The Cross Equatorial Flow along the equatorial belt (equator to 5° N / 5° S) over the Arabian Sea was stronger than normal by about 5 kts during the second week of June and third week of September. It was also stronger than normal by about 5-10 kts during first week of

TABLE 2

Details of low pressure systems for the month of July 2011

S. No.	System	Duration	Place of first location	Direction of movement	Final location	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
(**A**)	*Depression*					
1.	Land Depression*	22 -23	Northwest Jharkhand and neighbourhood	West-northwest	North Madhya Pradesh and neighbourhood	A low pressure area formed over Gangetic West Bengal and neighbourhood under the influence of cyclonic circulation. Associated cyclonic circulation extended up to 3.6 kms a.s.l. persisted over Rajasthan and neighbourhood from 24-25; over Gujarat state and neighbourhood from 26-28 and became less marked on 29
(**B**)	*Low pressure areas*					
1	Low pressure areas	6 - 7	South Chattisgarh and adjoining Telangana	Northwest	West Madhya Pradesh and neighbourhood	Less marked on 8. It formed under the influence of cyclonic circulation extending up to mid tropospheric levels over Gangetic West Bengal and neighbourhood. Associated cyclonic circulation extended up to mid tropospheric levels, which lay over northwest Madhya Pradesh and adjoining east Rajasthan on 9, west Uttar Pradesh and adjoining Haryana on 10, west Uttar Pradesh and adjoining Biar on 11 and Bihar; adjoining Jharkhand on 12 and became less marked on 13
2	Do	13 - 16	West central and adjoining northwest Bay of Bengal off Andhra Pradesh - south Orissa coast	Do	South Uttar Pradesh and adjoining north Madhya Pradesh	Became less marked on 17. Formed under the influence of cyclonic circulation extending up to 4.5 kms a.s.l. over the northwest Bay of Bengal and neighbourhood. The associated cyclonic circulation persisted over the same region on 17 & 18 and merged with cyclonic circulation over Haryana and neighbourhood on 19
(**C**)	*Upper air cyclonic circulations*					
1.	Up to 2.1 km a.s.l.	2 - 3	Assam & Meghalaya and neighbourhood	Stationary	*In situ*	Became less marked on 4
2.	Between 1.5 and 4.5 km a.s.l.	17 - 19	Gujarat region and neighbourhood	Do	Do	Less marked on 20 July
3.	Up to mid tropospheric levels	14 - 16	Assam & Meghalaya and neighbourhood	Do	Do	Less marked on 17
4.	Do	25 - 26	West central Bay of Bengal and neighbourhood	West	West central Bay of Bengal and adjoining north coastal Andhra Pradesh	Less marked on 27
5.	Between 1.5 and 5.8 km a.s.l.	29 July - 4 August	West central Bay of Bengal off south Orissa-north Andhra coast	North	Northwest Bay of Bengal and adjoining areas of Gangetic West Bengal	Less marked on 4
(**D**)	*Western Disturbances and other eastward moving systems*					
(*i*)	*Western disturbances*					
1.	As an upper air cyclonic circulation (up to 3.1 km a.s.l.)	6 - 11	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir	Moved away on 12 July

TABLE 2 (*Contd*.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
2.	As an upper air cyclonic circulation (up to mid tropospheric levels)	14 - 16	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir	Moved away on 17 July
3.	Do	17 - 21	Do	Do	Jammu & Kashmir and neighbourhood	Moved away on 22 July
4.	Do	23 - 27	Do	Do	Do	Moved away on 28 July
5.	Do	28 July - 2 August	Do	Do	Jammu & Kashmir	Moved away on 3 July
(*ii*)	*As an induced cyclonic circulations*					
1.	Upto lower tropospheric levels	15 - 21	Punjab and neighbourhood	East	East Uttar Pradesh and adjoining Bihar	Merged with the cyclonic circulation associated with the depression over northwest Jharkhand and neighbourhood on 22 July
2.	Up to 0.9 km a.s.l.	27 July - 1 August	Haryana and neighbourhood	East	East Uttar Pradesh and neighbourhood	West Uttar Pradesh and adjoining Haryana on 29 and 30; west Uttar Pradesh and neighbourhood on 31 July ; east Uttar Pradesh and neighbourhood on 1 August. Less marked on 2 August

September and by more than 10 kts during third week of July. It was weaker than normal by about 5 kts during fourth week of August and by about 5-10 kts during third week of August. Except during these periods, the cross equatorial flow along the equatorial belt was close to normal during the entire monsoon period June-September 2011.

The surface winds over the Arabian Sea to the north of 5° N were stronger than normal by about 5 kts during fourth week of June and during third & fourth weeks of September. They were also stronger than normal by about 5-10 kts during first week of September and by about 10 kts during second week of September. They were weaker than normal by about 5 kts during second & fourth weeks of July and first, second & fourth weeks of August. They were also weaker than normal by about 5-10 kts during third week of August. They were almost normal for the remaining period of the season.

4.1.2. *Over the Bay of Bengal*

The Cross Equatorial Flow along the equatorial belt (equator to 5° N / 5° S) over the Bay of Bengal was stronger than normal by about 5 kts during first week of June, fourth week of August and during first & second weeks of September. Except during these periods, the cross equatorial flow along the equatorial belt was close to normal during entire monsoon period June-September 2011.

The surface winds over the Bay of Bengal to the north of 5° N were stronger than normal by about 5 kts during fourth week of June, second, third & fourth weeks of July and second & third week of September. They were also stronger than normal by about 5-10 kts during first week of August and first & fourth weeks of September. They were almost normal for the remaining period of the season.

4.2. *Systems in West Pacific Ocean/South China Sea*

There were in all 18 low pressure systems (reaching the intensity of Tropical depression and above) in the northwest Pacific Ocean / South China Sea during June - September 2011. The month wise break-up is 3 in June, 4 each in July & August and 7 in September.

4.3. *Systems in southern hemisphere*

4.3.1. *Tropical storms/depressions*

No low pressure system (Tropical Depression, Tropical Storm or Typhoon) was reported in the Southern Hemisphere during June-September 2011.

TABLE 3

Details of low pressure systems for the month of August 2011

S. No.	System	Duration	Place of first location	Direction of movement	Final location	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
(**A**)	*Low pressure areas*					
1.	Low pressure area	8 - 11	Northwest Madhya Pradesh and neighbourhood	West	Southwest Rajasthan and adjoining Pakistan	Became less marked on 12. Formed under the influence of a cyclonic circulation extending upto mid tropospheric levels over southeast Uttar Pradesh and adjoining areas from 4-7. Associated cyclonic circulation extended up to mid tropospheric levels tilting southwards with height over southwest Rajasthan and adjoining Pakistan on 12; over south Rajasthan and neighbourhood on 13 & 14 and became less marked on 15
2.	Well marked low pressure area	11 - 17	Gangetic West Bengal	Northwest	North west Uttar Pradesh and adjoining Uttarakhand	Became less marked on 18. Associated cyclonic circulation extending upto 3.1 kms a.s.l. lay over west Uttar Pradesh and neighbourhood on 18; over southwest Uttar Pradesh and adjoining Madhya Pradesh on 19 and merged with Monsoon Trough on 20
3.	Do	29 Aug - 10 Sep	Northwest and adjoining west central Bay of Bengal off south Orissa - north Andhra Pradesh coast	Do	Pakistan and adjoining southwest Rajasthan	Bacame less marked on 11 September. Associated cyclonic circulation extending upto mid-tropospheric levels which merged with the cyclonic circulation associated with the system
4.	Low pressure area	30 Aug - 4 Sep	Northeast Arabian Sea off north Gujarat coast	Stationary	*In situ*	Formed under the influence of a cyclonic circulation extending upto mid tropospheric levels from 25-29. The associated cyclonic circulation merged with the associated cyclonic circulation of the above system
(**B**)	*Upper air cyclonic circulations*					
1.	Between 3.1 & 5.8 kms a.s.l.	1 - 3	Saurashtra & Kutch	East	Gujarat and neighbourhood	Less marked on 4
2.	Upto mid tropospheric levels	7 - 10	Gangetic West Bengal and adjoining Bangladesh	West	Gangetic West Bengal	Merged with the cyclonic circulation associated with the low Pressure area over Gangetic West Bengal on 11
3.	Upto 4.5 kms a.s.l.	17	Assam & Meghalaya and neighbourhood	Stationary	*In situ*	Less marked on 18
4.	Up to mid tropospheric levels	18 - 23	Northwest Bay of Bengal and neighbourhood	Northwest	Northwest Rajasthan and neighbourhood	Became less marked on 24
5.	Do	24 - 25	Orissa and neighbourhood	Do	North Chattisgarh and adjoining east Madhya Pradesh	Tilted southwestwards with height. Merged with monsoon trough on 26

TABLE 3 (*Contd*.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
(**C**) *Western Disturbances and other eastward moving systems*						
(*i*) *As upper air cyclonic circulations*						
1.	Up to 4.5 kms a.s.l.	4 - 9	North Pakistan and adjoining Jammu & Kashmir	Northeast	Across Jammu & Kashmir	Moved away on 10
2.	Upto mid tropospheric levels	13 -17	Do	Do	Eastern parts of Jammu & Kashmir	Moved away on 18
3.	Up to 4.5 kms a.s.l.	23- 26	North Pakistan and neighbourhood	Do	Jammu & Kashmir and neighbourhood	Moved away on 27
4.	Upto 3.6 kms a.s.l.	28 - 30	North Pakistan and adjoining Jammu & Kashmir	Do	Across Jammu & Kashmir	Moved away on 31
(*ii*) *As an induced cyclonic circulations*						
1.	Upto 1.5 kms a.s.l.	8 - 9	Punjab and adjoining north Pakistan	East	Punjab and adjoining northwest Rajasthan	Less marked on 10
2.	Upto 3.6 kms a.s.l.	24 - 25	Punjab and adjoining northwest Rajasthan	Do	West Uttar Pradesh and neighbourhood	Less marked on 26

4.3.2. *Mid-Latitude troughs*

The number of troughs in upper air westerlies affecting the Indian region which penetrated south of 30° N is 1 in June at 300 hPa level and 4 in September at 500 hPa level.

4.3.3. *Troughs in mid & upper tropospheric westerly over the south Indian Ocean*

There were 18 troughs in upper air 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 2011. The month wise break-up is 3 in June, 4 each in July and August and 7 in September.

4.3.4. *Mascarene HIGH*

The intensity of Mascarene HIGH with its mean position at 32° S / 58° E was almost equal to the normal during the monsoon period June to September 2011. It was below normal by 2.5 hPa in the month of July 2011. It was above normal by 2.0 & 0.5 hPa in the month of June & September 2011 respectively. It was equal to normal in the month of August 2011.

(*Source* : Climate Diagnostic Bulletin, NOAA, June to September 2010. Normal based on the means for the base period of 1979-1995).

5. Semi-permanent systems

5.1. *Heat low*

The heat low was established in its near normal position over Pakistan and neighbourhood around 1st June. It remained in the near normal position during June and to the northwest of its normal position on many days during July, August & September. The low started filling up from 10th September and became less marked from 16th September.

An analysis of the monthly composite patterns of surface air temperature and pressure contours (from the

TABLE 4

Details of low pressure systems for the month of September 2011

S. No.	System	Duration	Place of first location	Direction of movement	Final location	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
(**A**) *Depression*						
1.	Depression*	22 - 23 Sep	Northwest Bay of Bengal off north Orissa-West Bengal coast	Northwest	Jharkhand and neighbourhood	Became less marked on 23. Associated Upper air cyclonic circulation extended upto 3.6 kms a.s.l. over Assam & Meghalaya and neighbourhood persisted from 28 September - 4 October and became less marked on 5
(**B**) *Low pressure areas*						
1.	Low pressure area	6 - 13	Orissa and neighbourhood	West	Southeast Pakistan and adjoining southwest Rajasthan	Under the influence of cyclonic circulation extending upto mid-tropospheric levels a low pressure formed over Orissa and neighbourhood on 6; over Jharkhand and neighbourhood from7-9; over north Chattisgarh and neighbourhood on 10; over Madhya Pradesh on 11; over south Rajasthan and neighbourhood on 12;over southeast Pakistan and adjoining southwest Rajasthan on 13. It became less marked on 14
2.	Do	13 - 19	North Bay of Bengal and neighbourhood	Northwest	Sub-Himalayan West Bengal & Sikkim and adjoining Bihar	Became less marked on 20. Formed under the influence of cyclonic circulation extending upto mid-tropospheric levels over northwest Bay of Bengal and neighbourhood
(**C**) *Western disturbances and other eastward moving systems*						
(*i*) *Western disturbances*						
1.	As an upper air system (up to mid-tropospheric levels)	8 - 10	North Pakistan and adjoining Jammu & Kashmir	Northeast	Jammu & Kashmir	Moved away on 11
2.	Do	11 - 13	North Pakistan and neighbourhood	Do	Northern parts of Jammu & Kashmir	Moved away on 14
3.	Do	15 - 17	Jammu & Kashmir and adjoining north Pakistan	Do	Jammu & Kashmir	Moved away on 18
4.	Do	19 - 20	North Pakistan and adjoining Jammu & Kashmir	Do	Do	Moved away on 21
5.	Do	22 - 26	Do	East northeast	Do	Moved away on 27
(*ii*) *Troughs in westerlies*						
1.	Mid and upper troposphere (7.6 kms)	2 - 4	Along Long. 65° E to the north of Lat. 30° N	Northeast	Along Long. 74° E to the north of Lat. 30° N	Moved away northeast on 5
2.	Do (axis at 5.8 kms)	16-22	Along Long. 64° E to the north of Lat. 25° N	Do	Along Long. 90° E to the north of Lat. 23° N	Lay along Long. 66° E to the north of Lat. 25° N on 17 & 18; along Long. 68° E on 19; along Long. 72° E on 20; along Long. 77° E on 21. Moved away on 23

TABLE 4 *(Contd.)*

(1)	(2)	(3)	(4)	(5)	(6)	(7)
(**D**)	*Upper air cyclonic circulations*					
1.	Up to 1.5 kms a.s.l.	7 - 11	West Madhya Pradesh and neighbourhood	Northwest	Northeast Rajasthan and neighbourhood	Merged with monsoon trough on 12
2.	Between 2.1 & 3.6 kms a.s.l.	24 - 25	East central Arabian Sea and adjoining Maharashtra coast	North	Saurashtra & Kutch and adjoining northeast Arabian Sea	Became less marked on 26
3.	Between 1.5 & 3.1 kms a.s.l.	25 Sep - 4 Oct	Do	Stationary	*In situ*	Became less marked on 5
4.	Between 1.5 & 2.1 kms a.s.l.	30 Sep - 2 Oct	Tamil Nadu and adjoining Kerala	Quasi stationary	Tamil Nadu and neighbourhood	Became less marked on 3

∗ Details of the systems are given in the Article 'Cyclones and Depressions over north Indian Ocean during the year 2011 in the same issue.

CPC-NOAA re-analysis) during each month, around the Heat Low region normally located near Lat. 28° N / Long. 68° E, close to Jacobabad in Pakistan (figures not re-produced here) reveals that the monthly mean position of the Heat Low was located to the east of its normal position during June & July and during the near normal position during August & September. Over the Heat Low region, the Sea Level Pressure anomalies indicate the strength of Heat Low as stronger than normal during June, weaker than normal during July, normal during August and again stronger in September. However, the surface temperature anomalies are observed to be not consistent with the centres of the Heat Low. A warm anomaly had been to the north of Heat Low region during June, to the northeast during July, to the northwest during August and to the west during September.

5.2. *Axis of the monsoon trough*

An east-west oriented heat trough in the lower tropospheric levels appeared over the Gangetic Plains and persisted there during 28th May - 8th June. From 9th June onwards, it could be delineated on the mean sea level charts as well, extending up to north/east central Bay of Bengal often, until 1st July. Shifting northwards, it remained close to the foothills of the Himalayas on 2nd & 3rd July. However, subsequent to the southward shift, especially of the eastern part of it, it became more pronounced and also extended up to mid tropospheric levels during 5th - 8th July.

With the southwest Monsoon covering the entire country, it established as the monsoon trough on 9th July. Remaining in its near normal position, it extended up to mid tropospheric levels, tilting southwards with height during 13th - 19th July. During the subsequent period of July, the vertical extension was confined to lower tropospheric levels in general and another branch of the eastern end extended eastwards to the northeastern states towards the end of July. The eastern end started dipping more southwards in to the Bay of Bengal during the first week of August. It also strengthened and extended up to mid tropospheric levels during 8th - 10th August. The eastern end showed wide north-south oscillations during 11th - 17th August. It lay close to the foothills of the Himalayas on 16th and once again extended southeastwards to the east central Bay of Bengal on 17th. The western end also shifted to the north of its normal position around 17th August, in association with the northeastward drifting of a low pressure area over the region, which occurred under the influence of a western disturbance. It extended up to mid tropospheric levels, with slight southward tilt with height during 11th - 14th August and was confined to the lower tropospheric levels subsequently.

Though it regained its near normal position subsequent to the dissipation of the low pressure area during 19th - 21st August, the entire trough rapidly shifted towards north and lay close to the foothills of the

Himalayas on 22nd & 23rd August. Subsequent to the formation of low pressure areas over the Arabian Sea and the Bay of Bengal, the monsoon trough remained to the south of its normal position during the period 25th August - 14th September. Thereafter, it shifted northwards and lay close to the foothills of the Himalayas on 17th & 18th September. Further, the western end continued to remain close to the foothills of the Himalayas until the trough at sea level started getting disorganized from 23rd September, indicating the beginning of withdrawal of southwest monsoon.

5.3. *Tibetan Anticyclone/High*

The Tibetan Anticyclone (TA) was established in its near normal position at 300 & 200 hPa on 25th June. It was noticed all through the remaining period of the season.

The Kalpana as well as the METEOSAT-7 derived satellite winds were helpful often in locating the position of the anticyclone, particularly in the absence of large data gaps.

An analysis of the monthly mean characteristics of this anticyclone using the CDC / NOAA data shows that the anticyclone remained to the south/southeast of normal position during June, near normal during July & September and slightly to the west of normal position during August. However, the intensity showed wide variations as seen from the anomalous fields (Figure not shown).

5.4. *Sub-Tropical Westerly Jet (STWJ)*

STWJ started shifting northwards from the first week of June. Delhi reported 80 knots wind (305 hPa) at 1200 UTC of 14th June. Subsequently, the STWJ shifted to the north of the Himalayas. However, it made occasional re-appearances along Srinagar, Guwahati, Delhi, Gorakhpur and Ranchi latitudes during the first half of July. Towards the end of the season, it once again shifted southwards as evidenced by the 70 knots westerly wind reported over Srinagar at 192 hPa on 20th September (0000 UTC).

5.5. *Tropical Easterly Jet (TEJ)*

TEJ was established over the southern tip of Peninsular India by 9th June. The southern stations *viz*., Thiruvananthapuram, Chennai and Minicoy reported easterlies of 85 & 65 kts respectively around 200 hPa levels on 9th June. The wide latitudinal spread of the easterly jet speed winds was noticed during the whole of the season. A core wind speed of 135 kts was noted over Thiruvananthapuram on 12th July, 20th July & 9th August.

Jet speed winds were also reported over Visakhapatnam, Bhubaneswar, Hyderabad, Nagpur, Bhopal, Ranchi and Kolkata on several days during the season.

6. Monthly wind anomalies during southwest Monsoon 2011

The monthwise circulation anomaly features at lower, middle & upper tropospheric levels 850, 500 & 200 hPa during the southwest Monsoon season are discussed below.

6.1. *June wind anomaly features*

In the monthly anomaly winds, three anomalous cyclonic circulations were observed at 850 hPa level; one over the Rajasthan and neighborhood, second over east Uttar Pradesh and neighborhood and third over Gangetic West Bengal. An anomalous cyclonic circulation over Arunachal Pradesh at 850 hPa levels extending up to 700 hPa was also observed. The anomalous Anticyclone circulation was observed over south Peninsula at 850 hPa.

Anomalous cyclonic circulations were observed at 700 hPa, over Madhya Pradesh and neighborhood and also over east Madhya Pradesh adjoining Jharkhand. An anomalous cyclonic circulations were observed at 500 hPa over east Madhya Pradesh adjoining Bihar and also over Marathwada & adjoining Telangana.

During the week ending 8th June, an anomalous cyclonic circulation was observed over the east central Arabian Sea adjoining Maharashtra coast at 850 hPa level extending upto 300 hPa. An anomalous cyclonic circulation was observed over Assam & neighborhood at 850 hPa. Also, an anomalous cyclonic circulation was observed over Andaman & Nicobar Island at 850 hPa levels extending upto 700 hPa.

During the week ending 15th June, the anomalous cyclonic circulation was observed over the east central Arabian Sea off Maharashtra coast at 850 hPa extending

upto 500 hPa levels. Another anomalous cyclonic circulation was observed over the northwest Bay of Bengal off Gangetic West Bengal coast at 850 hPa extending upto 500 hPa.

In the week ending 22nd June, the anomalous cyclonic circulations were observed one over the Rajasthan & neighborhood and the other over Gangetic West Bengal & neighborhood at 850 hPa levels. Also, anomalous cyclonic circulation was observed over central India at 700 hPa extending upto 300 hPa levels.

In the week ending 29th June, an anomalous cyclonic circulation was observed over Rajasthan & neighborhood at 850 hPa extending upto 700 hPa levels. Another anomalous cyclonic circulation was observed over east Madhya Pradesh & neighborhood at 850 hPa extending upto 500 hPa levels. Also, the anomalous cyclonic circulations were observed over Assam & Meghalaya at 850 hPa extending upto 500 hPa level.

6.2. *July wind anomaly features*

In the monthly anomaly winds, the anomalous cyclonic circulation was observed over south interior Karnataka adjoining Rayalaseema at 850 hPa extending upto 700 hPa levels. An anomalous anticyclonic circulation was observed over Gangetic West Bengal & neighborhood at 850 hPa extending upto 500 hPa levels. Ridge line at 200 hPa extended along Lat. 32° N.

In the week ending 6th July, an anomalous anticyclonic circulation was observed over the entire northwest India, adjoining Gujarat & west Madhya Pradesh at 850 hPa levels. Anomalous cyclonic circulation was seen observed at 850 hPa over Arunachal Pradesh extending 700 hPa levels. Anomalous anticyclone circulations were observed over the central India at 700 hPa.

In the week ending 13th July, anomalous cyclonic circulations were observed at 850 hPa extending up to 700 hPa, one over the Assam & Meghalaya & neighborhood and another over west Madhya Pradesh and third over Marathwada adjoining Telangana.

During the week ending 20th July, anomalous cyclonic circulations were observed at 850 hPa extending up to 700 hPa levels one over the central India and second over Assam & Meghalaya & neighborhood. Ridge line at 500 hPa extended along Lat. 31° N.

During the week ending 27th July, anomalous cyclonic circulations were observed at 850 hPa level, one over the east central Arabian Sea off Maharashtra coast, second over west Madhya Pradesh and third over Chhattisgarh. Another anomalous cyclonic circulation was observed over the central India at 700 hPa level.

6.3. *August wind anomaly features*

In the monthly anomaly winds, an anomalous cyclonic circulation was observed over Konkan & Goa and neighborhood at 850 hPa extending up to 500 hPa level. Another anomalous cyclonic circulation was observed over Arunachal Pradesh at 850 hPa extending up to 500 hPa level. Also, anomalous cyclonic circulation was observed over the Maharashtra coast and adjoining Karnataka coast at 700 hPa, extending up to 500 hPa.

During the week ending 3rd August, an anomalous cyclonic circulation was observed over the west central Bay off coastal Andhra Pradesh at 850 hPa level. Another anomalous cyclonic circulation was observed over the west central Bay off coastal Andhra Pradesh at 500 hPa extending up to 200 hPa level. An anomalous anticyclone circulation was observed over northeast and northwest India at 850 hPa level. Another anomalous anticyclone circulation was observed over the entire northwest & parts of central India at 700 hPa level. Also, anomalous anticyclonic circulation was observed over the northwest, central & northeast parts of India at 500 hPa level. Anomalous ridge line at 200 hPa was seen over the 30° N latitude.

During the week ending 10th August, five anomalous cyclonic circulations were observed; one over Rajasthan, second over west Madhya Pradesh & neighborhood, third over east Uttar Pradesh & neighborhood, fourth over Assam & Meghalaya and fifth over Arunachal Pradesh at 850 hPa. Another anomalous cyclonic circulation was observed over Sub-Himalayan West Bengal & Sikkim and adjoining Bihar and second over Arunachal Pradesh at 700 hPa level. Also, anomalous cyclonic circulation was observed over Gangetic West Bengal & neighborhood at 500 hPa level. Anomalous ridge was seen over 23° N at 200 hPa level.

During the week ending 17th August, an anomalous cyclonic circulation was observed over Rajasthan and adjoining west Madhya Pradesh at 850 hPa extending up to 700 hPa level. Another anomalous cyclonic circulation was observed over Sub-Himalayan West Bengal & Sikkim and neighborhood at 850 hPa, extending up to 700 hPa level.

During the week ending 24th August, an anomalous anticyclonic circulation was observed over Gangetic West Bengal & neighborhood at 850 hPa, extending up to 700 hPa level. An anomalous cyclonic circulation was observed over south Peninsula at 850 hPa.

During the week ending 31st August, an anomalous cyclonic circulation was observed over the central India at 850 hPa level. Another anomalous cyclonic circulation was observed over Vidarbha & neighborhood at 700 hPa, extending upto 500 hPa level.

6.4. *September wind anomaly features*

In the monthly anomaly winds, an anomalous cyclonic circulation was observed over west Madhya Pradesh & neighborhood at 850 hPa level. Another anomalous cyclonic circulation was observed over the Jharkhand and adjoining Gangetic West Bengal at 850 hPa extending upto 300 hPa level. An anomalous anticyclonic circulation was observed over southeast Arabian Sea at 850 hPa level**.**

During the week ending 7th September, anomalous cyclonic circulations were observed, one over east central Arabian Sea off Gujarat-Maharashtra coasts and second over Chhattisgarh & adjoining Jharkhand at 850 hPa level. Another anomalous cyclonic circulation was observed over east Rajasthan at 850 hPa level extending up to 500 hPa.

During the week ending 14th September, an anomalous cyclonic circulation was observed over Gujarat & neighborhood at 850 hPa extending up to 700 hPa level. Another anomalous cyclonic circulation was observed over the northwest Bay of Bengal off Orissa coast at 850 hPa extending up to 300 hPa level. Anomalous ridge line was seen over Lat. 30° N at 200 hPa level.

During the week ending 21st September, an anomalous cyclonic circulation was observed over Gangetic West Bengal & neighborhood at 850 hPa extending up to 300 hPa level. An anomalous anticyclonic circulation was observed over south Peninsula at 300 hPa levels.

During the week ending 28th September, an anomalous cyclonic circulation was observed over Jharkhand & neighborhood at 850 hPa extending up to 500 hPa level. Anomalous ridge line was seen over Lat. 30° N at 200 hPa level.

7. Significant temperature during the season

Severe heat wave/heat wave conditions prevailed over some parts of northwest and central India during first half of the month. The highest maximum temperature of 49.6° C was recorded in Phalodi (Rajasthan) on 7th June 2011.

8. Disastrous weather events and damage during Monsoon months

8.1. *June*

According to media reports, heavy rains, floods, lightning and landslides took a toll of 80 persons (32 in Jharkhand, 9 each in West Bengal & Kerala, 7 each in Vidarbha & Chhattisgarh, 5 each in Karnataka & Madhya Pradesh, 4 in Tamil Nadu and 2 in Assam).

Apart from the loss of life, around 10,000 hectares of agriculture land were affected, power supply got disrupted, trees were uprooted, standing crops were damaged, houses (600 partially and 30 fully) were damaged and low lying areas were flooded in Kerala. Vast areas in northeastern state Assam were inundated and standing crops were damaged. Trees were uprooted, power supply & communication got disrupted and crops and houses were damaged in Jharkhand.

8.2. *July*

According to media reports, heavy rains, floods, lightning and landslides took a toll of 153 persons (58 in Gujarat, 31 in Bihar, 16 in Jharkhand, 15 in Madhya Pradesh, 11 in West Bengal, 7 in Assam, 6 Kerala, 5 in Karnataka, 3 in Chhattisgarh and 1 in Vidarbha).

Heavy rain/floods/thunderstorm/lightning caused havoc in Gujarat with a loss of 368.40 lakhs of rupees to crops and property. In the northeastern state of Assam, 334463 people in 513 villages were affected. Standing crops were damaged, power supply and transport and communication systems were disrupted. About 20,000 hectares of crops were affected. Vast areas were inundated. Singara, Jiadhal, Brahamaputra and its tributaries were flooded. Several embankments were breached.

8.3. *August*

Heavy rains, floods, lightning and landslides took a toll of 123 lives (43 in Madhya Pradesh, 26 in Bihar, 19

each in Assam & Jharkhand, 7 in Vidarbha, 4 in Chhattisgarh, 2 in Karnataka and 1 in West Bengal).

Assam was the worst affected state during the month. About 3.25 lakh people in 335 villages in the state were affected due to floods, thunderstorm and landslide etc. Crops in near about 70,000 hectares of land were destroyed. Several trees were uprooted and roads were damaged. About 66 Pucca & 297 Kuccha houses were fully and 124 houses were partially damaged. About seventeen RCC bridges were also damaged. An extensive damage occurred to electrical appliances. Brahamaputra and its tributaries; Subansiri, Jiadhal, Singara, Brahmajan, Jiabharali and Gabharu were flooded. Chittur River was also flooded, flooding hundreds of houses in Kerala.

8.4. *September*

According to media reports, heavy rains, lightning and thunderstorm took a toll of 178 persons (73 in Sikkim, 36 in Gujarat, 24 West Bengal, 17 Jharkhand, 6 each in Assam & Chhattisgarh, 5 in Jammu & Kashmir, 4 in Kerala, 3 in Vidarbha, 2 each in Tamil Nadu & Karnataka).

In Assam, 4 people were buried in landslide. Tiyak, Doprang, Ghai, Jiadhal and Puthi rivers were flooded and inundated vast areas of agricultural land. About 19 people died in earthquake in the hilly region of West Bengal. Earthquake also damaged of more than 100 muddy houses in the area.

9. Severe floods experienced during southwest Monsoon-2011

During the southwest Monsoon season 2011, many states *viz*., Assam, Meghalaya, West Bengal, Orissa, Bihar, Uttar Pradesh, Uttarakhand, Punjab, Jammu & Kashmir, Gujarat, Maharashtra, Karnataka and Kerala experienced flood situations during various periods of the season. Incessant heavy rainfall associated with the low pressure systems as well as dis-organized convective activity in the form of scattered thunder showers were the major causes of flood.

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Appendix

Definitions of the terms given in '*Italics*'

Rainfall

Excess	- Percentage departure from normal rainfall is + 20% or more.
Normal	- Percentage departure from normal rainfall is between – 19 % to + 19 %.
Deficient	- Percentage departure from normal rainfall is between – 20 % to – 59 %.
Scanty	- Percentage departure from normal rainfall is between – 60 % to – 99 %.
Heavy rain	- Rainfall amount from 6.5 cm to 12.4 cm.
Very heavy rain	- Rainfall amount more than 12.5 cm to 24.4 cm.
Extremely heavy rainfall	- Rainfall amount more than 24.5 cm.

Monsoon activity

Active	- Average rainfall of a sub-division is more than 1½ to 4 times the normal with minimum 5 cm along the west coast and 3 cm elsewhere in at least two stations in the sub-division.
Vigorous	- Average rainfall of a sub-division is more than 4 times or more than the normal with minimum 7 cm along the west coast and 5 cm elsewhere in at least two stations in the sub-division.

Maximum/day temperatures

According to the new criteria, since 1st March 2002, Heat Wave is declared only when the maximum temperature of a station reaches at least 40 °C for plains and at least 30 °C for Hilly regions.

Severe heat wave conditions	- Departure of maximum temperature from normal is +6 °C or more for the regions were the normal maximum temperature is more than 40 °C and +7 °C or more for regions were the normal maximum temperature is 40 °C or less.

Heat wave conditions	- Departure of maximum temperature from normal is + 4 °C to + 5 °C or more for the regions where the normal maximum temperature is more than 40 °C and departure of maximum temperature from normal is + 5 °C to + 6 °C for regions where the normal maximum temperature is 40 °C or less	