GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

IMD Met. Monograph:
ESSO Document No.: ESSO / IMD / SYNOPTIC MET / 01(2015)/17

Monsoon 2014

A Report

Edited by
D. S. Pai and S. C. Bhan

NATIONAL CLIMATE CENTRE

NATIONAL CLIMATE CENTRE
OFFICE OF THE
ADDITIONAL DIRECTOR GENERAL
OF METEOROLOGY (RESEARCH),PUNE

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PUNE- 411 005
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ACKNOWLEDGEMENTS

The report was prepared with the valuable inputs from various scientists and operational forecasters from various offices of India Meteorological Department (IMD). The editors express their sincere thanks to all the authors and co-authors of various chapters of this report for their whole hearted support in completing this report in time and details. As in the previous years, this report was prepared in the Office of the ADGM(R), IMD, Pune. The officers and staff of the Long Range Forecasting Section and National Climate Center provided the technical assistance. We are particularly thankful to Shri. Sikandar M. Jamadar for his technical support. We are also thankful to Shri. A.K. Jaswal, Shri. Yogesh Visale, Shri. Jayesh Shah, Shri. Randhir Jagtap and other officers & staff members of the Printing and Documentation Section for designing, type setting and printing of the report.

PREFACE

The present report on the 2014 southwest monsoon season is the 10th of such reports prepared and published by the India Meteorological Department (IMD) that brings out detailed analysis of monitoring and forecasting aspects of the southwest monsoon each year. This year, an attempt has been made to highlight extreme weather events such as very heavy rainfalls, floods, landslides etc. occurred during the season over different regions of the country. Five chapters (chapters 3 to 7) have been exclusively used for the same. In addition, a chapter (chapter 14) has been used to discuss the impact of monsoon performance on the major kharif crops in the country. Including these six chapters, the present report consists of 15 chapters in total. First two chapters discuss various features of 2014 southwest monsoon such as progress of monsoon over India, semi-permanent and transient synoptic features in the Indian monsoon region, and large scale regional and global climate anomalies associated with the season. The chapter 8 discusses spatial and temporal variability of the rainfall during the season and next 3 chapters discuss verification of operational forecasts issued by IMD for the monsoon rainfall at various time and spatial scales. Chapters 12 & 13 discuss the utility of the satellite and automatic weather station data in monitoring and prediction of the monsoon. The last chapter presents summary and conclusions of the report.

The 2014 southwest monsoon exhibited many interesting features. The monsoon onset over Kerala was delayed by 5 days but the withdrawal of monsoon from West Rajasthan was delayed by 3 weeks. The season rainfall (88% of LPA) over the country as a whole was deficient and the deficiency was distributed in all the 4 broad geographical regions of the country with lowest season rainfall over Northwest India (79% of LPA) and highest over south Peninsula. This deficiency was mainly caused by the large deficiency in rainfall till the second half of the monsoon season (deficiency of about 43% of LPA). The season also exhibited strong intraseasonal variability in associated with the Madden and Julian Oscillation (MJO) activity and near normal activity of low pressure systems formed during the season. A long break in monsoon activity was observed in the middle of the August due to the unfavourable phases of MJO activity. However, the good rainfall activity during the first half of the September helped in improving the overall rainfall situation in the country. The deficient rainfall along with strong temporal and spatial variation in the rainfall during the season had an adverse impact on the productivity and production of major kharif crops over the country except rice.

The report also presents the verification of operational forecasts at short, medium, extended and long range scales with the help of various standard skill scores. Over all this report provides useful and authentic information about the 2014 southwest monsoon season for operational forecasters, researchers and other users. I sincerely appreciate all the authors and co-authors of the various chapters of this report for their valuable contribution I also appreciate the efforts made by officers/ staff of the Office of ADGM (R), Pune in bringing out this report.

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Executive Summary

1	Document title	Monsoon 2014 A Report
2	Document type	Meteorological Monograph
3	Issue No.	ESSO Document No. : ESSO/IMD/Synoptic Met./01(2015)/17
4	Issue date	22.01.2015
5	Security Classification	Unclassified
6	Control Status	Unclassified
7	Document type	Scientific Report
8	No. of Pages	209
9	No. of Figures	147
10	No. of reference	53
11	Distribution	Unrestricted
12	Language	English
13	Editors	D. S. Pai and S. C. Bhan
14	Originating Division/Group	Long Range Forecasting Section, Office of the Additional Director General of Meteorology (Research), India Meteorological Department, Pune.
15	Reviewing and Approving Authority	Director General of Meteorology, India Meteorological Department.
16	End users	Operational Forecasters, Modelers and Researchers, Government Officials etc.
17	Abstract	This report discusses operational monitoring and forecasting aspects of the 2014 southwest monsoon. Analysis of various monsoon features, such as progress of the monsoon, semi-permanent and transient weather systems, rainfall distribution etc. have been presented. Potential regional and global climate anomaly patterns responsible for the observed rainfall features have been highlighted. The operational forecasts at various scales issued by IMD and their verification have also been discussed. The season rainfall over the country as a whole was deficient due to large deficiency in rainfall during June and first half of July. This was caused by border line El Niňo and negative Indian Ocean dipole conditions prevailed prior and early part of the monsoon season. The season also witnessed strong intra seasonal variation with a long spell of monsoon break in the middle of August caused by unfavorable phases of MJO and active monsoon spells during middle of July, early part of August and first half of September due to passage of low pressure systems along the monsoon trough region. The deficient monsoon and its intra-seasonal variability had an adverse impact on the productivity and production of major kharif crops over the country except rice.
18	Key Words	Southwest Monsoon, INSAT-3D Images, Forecast Verification, Deficient Rainfall, Satellite Imageries, Kharif Crops.

1

REGIONAL CHARACTERISTICS OF THE 2014 SOUTHWEST MONSOON

Sunitha Devi S., B.P. Yadav, Naresh Kumar, Charan Singh, P.C.S. Rao and Medha Khole

Southwest monsoon-2014exhibited strong intra-seasonal variability in terms of rainfall. Weak atmospheric circulation pattern and corresponding sluggish advance of southwest monsoon led to large rainfall deficiency in June. This chapter discusses the observed features of southwest monsoon 2014 covering various synoptic situations during the advance, mature and withdrawal phases.

1.1 Onset and Advance of Southwest Monsoon 2014

1.1.1 Arrival of Southwest Monsoon Current over the Andaman Sea

During 17th-18th May, low level cross equatorial monsoon flow was strengtheneddue to an easterly wave trough embedded in the northern hemispheric equatorial convergence zone in the form of a cyclonic circulation over south Andaman Sea and neighbourhood.It resulted in the advance of southwest monsoon over most parts of Andaman Sea and some parts of southeast Bay of Bengal on 18th May and remaining parts of Andaman Sea, some more parts of southeast Bay of Bengal and some parts of southwest and east central Bay of Bengal on 19th. Thus the southwest monsoon current reached over south Andaman Sea 2 days before the normal date of 20th May.

1.1.2 Monsoon Onset overthe Main Land

The southwest monsoon set in over Kerala on 6th June, 5 days after its normal date.

The depth of the southwesterliesup to 600 hPa was seen from 25th May onwards. The wind / Outgoing Long wave Radiation (OLR) criteria and the rainfall criterion were satisfied on 5th& 6thJune. The average wind speed at 925 hPa over the area bounded by Latitudes 5-10^{O}N and Longitudes 70-80^{O}E was 21 knots, the Satellite derived OLR value in the box confined by Lat. 5-10^{O}N, Long. 70-80^{O}E was 181.64 W/m^{-2} on 6th Juneand percentage of rainfall over the rainfall monitoring stations was 71% and 79% on 5th&6thJune respectively as evidenced from Figures 1.1&1.2 given below. Hence the onset over Kerala was declared on 6th June as per the objectively derived operational Criteria of IMD.

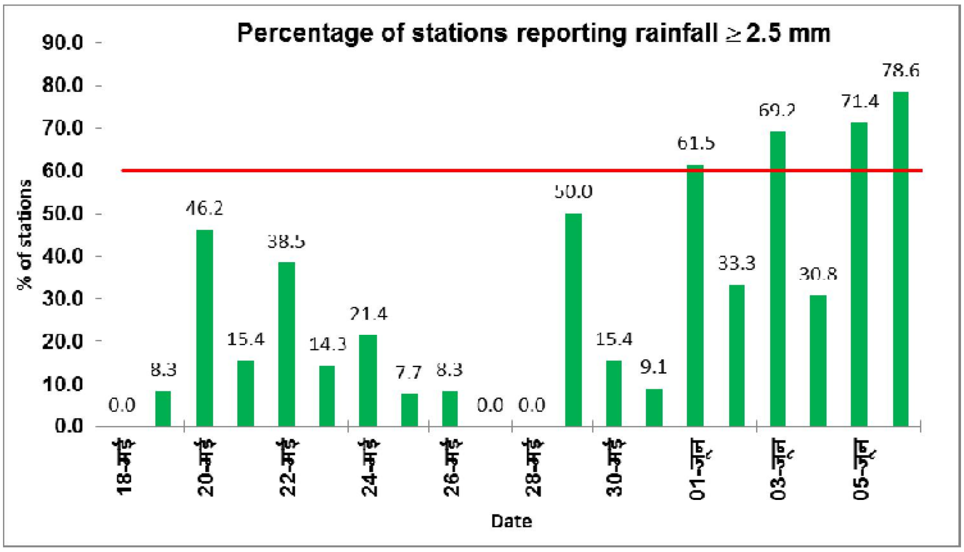

Fig.1.1: Percentage of rainy stations out of the 14 onset monitoring stations.

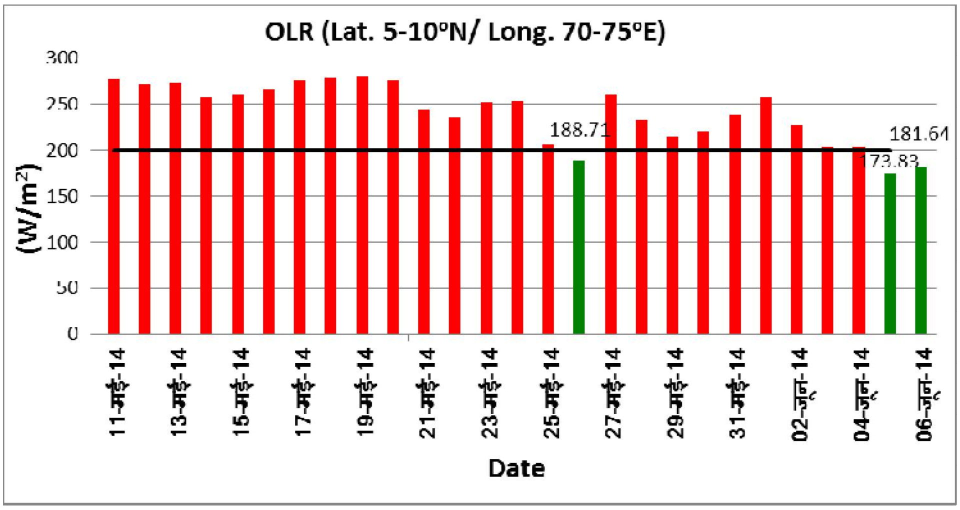

Fig.1.2: INSAT derived OLR values during 11th May-6th June.

1.1.3 Advance of Monsoon

The isochrones of advance of monsoon over the country are given Fig.1.3.

The southwest monsoon set in over Kerala on 6th June, 5 days later than its normal date of 1st June. Same day, monsoon also advanced into most parts of south Arabian Sea, some parts of Tamil Nadu, most parts of southwest Bay of Bengal and some parts of west central Bay of Bengal. Thereafter, though not rapid, it consistently advanced and by 18th June, it covered central Arabian Sea, some parts of north Arabian Sea, south Gujarat, entire Konkan & Goa, some parts of south peninsula, Odisha, Jharkhand and Bihar, entire northeastern states and most parts of Gangetic West Bengal. The Arabian Sea branch of the monsoon current was aided by the formation of a Cyclonic Storm (**Nanauk**) over the Arabian Sea. The eastward propagation of Madden Julian Oscillation (MJO) over maritime continent led to the development of convection over north Bay of Bengal and the subsequent formation of season's first low pressure area over coastal areas of Bangladesh and neighborhood on 19th June. This aided the advance of Bay of Bengal branch of the southwest monsoon over northeastern states. Subsequently it further advanced into most parts of south peninsula, east and adjoining parts of central India by 20th June.

During the last week of June, the weakening of monsoon activity caused the re-appearance of the heat wave conditions over eastern parts of peninsular India. After a hiatus of 10 days, monsoon started reviving. Subsequently, a favourable interaction of the southwest monsoon current with the mid-latitude westerlies aided the advance of southwest monsoon into the western Himalayan region and adjoining plains of northwest India. It advanced into entire Uttarakhand, Himachal Pradesh and Jammu & Kashmir, some more parts of Uttar Pradesh and some parts of Haryana (including Chandigarh) and Punjab on 1st July.

During the first week of July, the presence of anticyclone over the peninsular region resulted in below rainfall activity over parts of north, central and peninsular region. But the formation of a low pressure area over north Bay of Bengal and adjoining coastal areas of Bangla Desh and Gangetic West Bengal during (1st July–7th July), the upper air cyclonic circulations extending up to mid tropospheric levels over west Uttar Pradesh and neighbourhood during (3rd-6th July) caused further advance into some more parts of Uttar Pradesh, remaining parts of Haryana (including Delhi) and Punjab and some parts of north Rajasthan on 3rd and subsequently into most parts of Vidarbha, remaining parts of east Madhya Pradesh and Uttar Pradesh, some parts of west Madhya Pradesh and some more parts of northeast Rajasthan on 7th. Subsequent to the formation and west northwestward movement of a low pressure area (11th-16th July), an off shore trough at mean sea level extending from Gujarat coast to Kerala coast (10th-16th July) and the cyclonic circulation extending between 3.1 & 5.8 km.a.s.l. over northeast Arabian Sea during (14th-16th July) during the second week, the monsoon activity revived gradually over central India and west coast thereby causing further advance of southwest monsoon over remaining parts of central India and most parts of northwest India on 16th and remaining parts of north Arabian Sea, Saurashtra & Kutch, Gujarat Region and west Rajasthan, and thus the entire country on 17th July 2014.

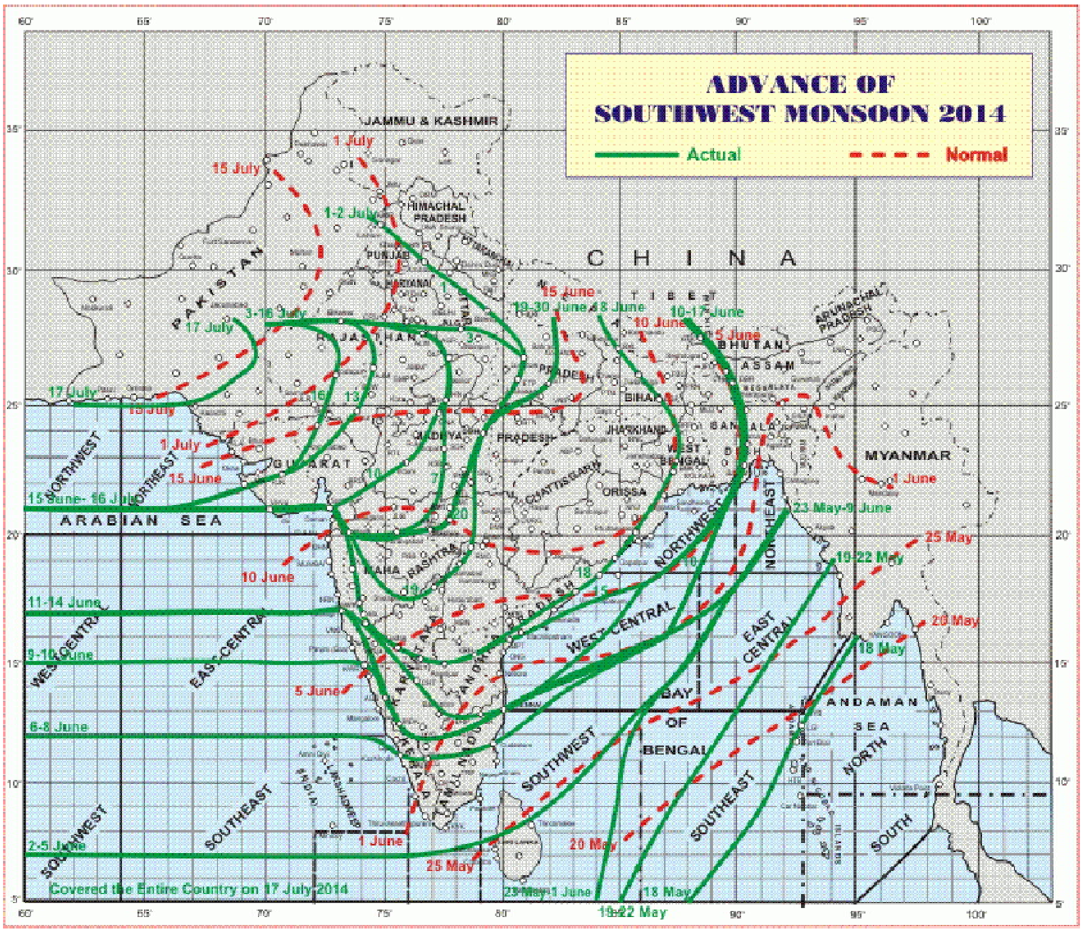

Fig.1.3: Isochrones of advance of southwest monsoon 2014.

1.2 Semi-Permanent Systems

1.2.1 Heat Low

The progressive development of a Heat Low over the sub-continent and its location over central parts of Pakistan in July is a significant factor of the establishment of monsoon. The intensity of the heat low has been correlated with monsoon activity quite often (Ramage, 1971). Departure of pressure from normal in this region and gradient of departures are taken into account. Below normal pressures in the Heat Low region and above normal pressures in the Peninsula are regarded as favouring monsoon activity over the country. Pressure gradient would then be strong over the Peninsula which is conducive to monsoon rains. The Heat Low may also strengthen when the ridge aloft weakens under the influence of westerly troughs moving further north.

This year, the continued presence of the mid-latitude circulation regime and passage of western disturbances caused weakening of the 'Heat Low' and delayed its setting. It established in its near normal position over westPakistan and neighbourhoodon6thJune.It was mostly seen in its near normal position during June, July & August and September. The Heat Low was less discernible during second fortnight of August. It became less marked in the first week of October.

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

June: 990hPa (on 14) and 991 hPa (on 20)

July: 990hPa (on 21 &29) and 991hPa (on 22, 23,30&31)

Aug: 991 hPa (on 7) and 992hPa (on 5, 8)

Sept: 998 hPa (on 5) and 999 hPa (on 1,2&8)

1.2.2 Monsoon Trough

During the season, from the Heat Low over Pakistan and neighbourhood, a trough extends southeastwards to Gangetic West Bengal. The trough line runs at surface from Ganganagar to Kolkata through Allahabad, with west to southwest winds to south and easterlies to the north of the trough line. The position of the trough line varies from day to day and has a vital bearing on the monsoon rains. Position of trough line close to the foot-hills has been referred as 'break in monsoon' when there is drastic decrease in rains over the country, though the Himalayan mountain belt experiences heavy falls which can cause floods in the rivers originating there. The trough sometimes shifts to the central parts when monsoon depressions from the North Bay move west / west northwest-wards across the country.

This year, the higher than normal mean sea level pressure anomalies over the northwestern parts of India and, presence of mid- latitude circulation regime and passage of western disturbances during end of May and first week of June delayed the establishment of an organized Heat Low. A trough at mean sea level was seen extending along Indo-Gangetic plain during18thJune–23rd June and became less marked on 24th June.It was present at mean sea level but as a shallow trough, since 26th June.With the southwest monsoon covering the entire country, this trough got established as the monsoon trough on 17th July. The axis of monsoon trough remained normal / south of its normal position during July and first half of September.It extended up to mid tropospheric levels without its characteristic tilt. It mostly remained north of its normal position /close to foot hills of Himalayas during August. The seasonal ‘Heat Low’ was less demarcated since second half of August except for first half of September, when it became noticeable. Thereafter, it became less apparent and subsequently, the axis of monsoon trough also weakened thereby becoming less delineated since 22nd September.

With the shifting of monsoon trough to the foot hills of Himalayas during the month of August, the circulation features and rainfall pattern resembled typical break like situation during 15th – 21st August.

1.2.3 Tibetan Anticyclone

The High over Tibet from 500 hPa and abovecentered near Tibet at 500 hPa and over Tibet at 300 hPa and 200 hPa, is a semi- permanent warm anticyclone. In June the axis of the anticyclonic belt is at about 25^{O}N, at 300 and 200 hPa, and near 30^{O}N only at 100 hPa, at the southern periphery of Tibet.August is similar to July, but the anticyclone is a little more to the north and slightly more intense. In September, the anticyclonic belt is near about 26^{O}N up to 200 hPa and 30^{O}N at 100 hPa. Ramaswamy (1965) pointed out that 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.

This year, the Tibetan Anticyclone got established in its near normal position at 200 hPa on 11th July. It was observed all through the remaining period of the season.Initially, It was seen to the west and then to the northeast of its normal position during July.It exhibited east-west oscillation about its normal position during first half of Augustand weakened in second half due to mid latitude intrusion and was shifted to south to southeast of its normal position. It was in its near normal position except during mid-September when it was east of its normal position.

1.2.4 Tropical Easterly Jet

South of the sub-tropical ridge over Asia, the easterly flow concentrates into jet stream centered near about the latitude of Chennai at 100 hPa in July. The jet stream runs from the east coast of Vietnam to the west coast of Africa. Normally, the jet is at an accelerating stage from the South China Sea to south India and decelerates thereafter. Consequent upper divergence is regarded as favourable for convection upstream of 70^{O}E and subsidence downstream. Position and speed fluctuate from day to day.

This year, the Tropical Easterly Jet(TEJ) got established over the southern tip of Peninsular India by 29th May with Thiruvananthapuramreporting easterlies of 66kts around 106hPa level.A wide latitudinal spread of the easterly jet speed winds was observed during July and August while during June and September; the stations over the Peninsular India only reported jet wind speeds.The highest wind speed of 125ktsat 130 hPawas reported at Thiruvananthapuram on 14thAugust.

Apart from Thiruvananthapuram, Chennai, Minicoy and AminiDivi, the Jet speed winds were reported over Visakhapatnam, Kochi, Panjim, Hyderabadand Kolkata on several days during the season.

1.2.5 Mascarene High

The onset of monsoon is associated with a sudden acceleration of winds from the southern hemisphere towards India, across the equator. The southern hemispheric circulation regime along the Indian Ocean longitudinal belt is dominated by an anticyclonic circulation, around a region of high pressurecentered at 30^{O}S/ 50^{O}E, known as Mascarene High, off the coast of Madagascar. Sikka and Gray (1981) suggested that the Mascarene High undergoes short period intensity fluctuations due to passage of extra tropical waves of the southern hemisphere. The intensification of Mascarene High strengthens the cross equatorial flow in the form of Low Level Jet and the corresponding monsoon current over the Arabian Sea.

The Mascarene HIGH with its mean position at 30.7^{O}S / 63.7^{O} E was strengthened by 1.9hPa during the monsoon period June to September. It was above normal by 1.3, 2.6, 3.7 hPa during the months of June, July and September respectively. It was almost normal in the month of August 2014.

1.2.6 Somali Low Level Jet

The lower tropospheric monsoon flow is essentially concentrated near the coast of east Africa in the form of Low Level Jet (LLJ). Fluctuations in the intensity of this LLJ takes place in association with the passage of extra-tropical westerly waves of the southern hemisphere. Strengthening of the LLJ is associated with increased monsoon activity along the west coast of India.

The below normal strength of the monsoon low level westerlies during the first 3 weeks of June, its subsequent strengtheningand short period fluctuations and weakening during the later part of the season once again are reflected in the Somali jet speed index [Fig.1.4]. This is derived as the square root of twice the domain mean Kinetic Energy of the 850 hPa horizontal wind in the region (50^{O}E - 70^{O}E, 5^{O}S - 20^{O}N) [Boos and Emanuel, (2009)].

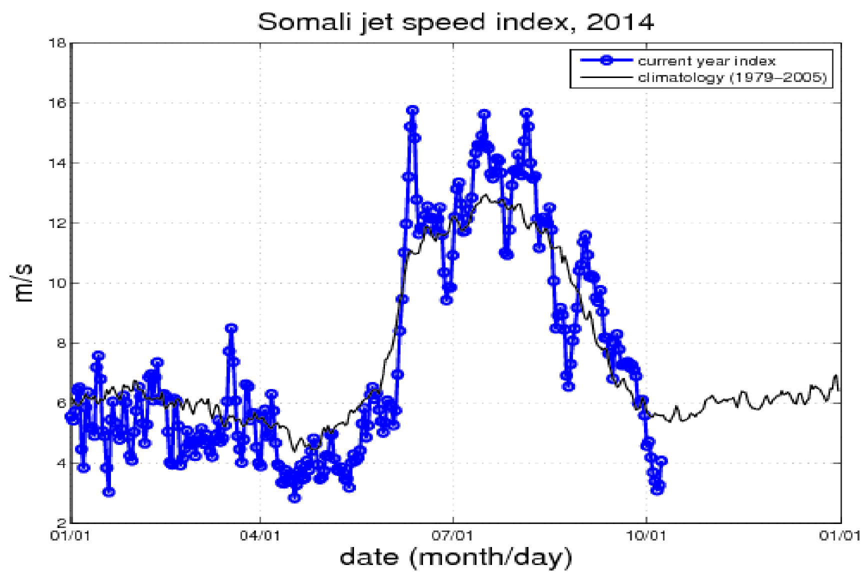

Fig.1.4: Somali jet speed index

1.3. Other Features:

1.3.1 Off-shore Trough

The off-shore trough along different parts of the west coast persisted from3rd June – 15th September except during 9th – 10th June, 23rd June – 2nd July, 26th – 27th July, 15th Aug and 18th – 24th Aug. It was quite feeble from 3rd – 5th June, 11th– 13th June, 18th June, 20th – 22nd June, 24th – 25th July, 14th Aug, 27th – 31st Aug and 7th Sept.

1.3.2 Intensity of Australian High(normally centered at 30^{O} S/ 140^{O}E)

The Australian HIGH centered at 32.9^{O}S / 135.0^{O}E was above normal by an average of about 7.0 hPa during the entire monsoon period June to September. It was above normal by 6.8, 4.3, 9.4 hPa& 7.3 hPa in the month of June, July, August and September 2014 respectively.

1.3.3 Sub-Tropical Westerly Jet

Sub-Tropical Westerly Jet (STWJ) started shifting northwards from the first week of June. Srinagar reported 60 knots wind (at 300hPa) at 00 UTC of 20th June. Subsequently, the STWJ shifted to the north of the Himalayas. However, it made occasional re-appearances along the latitude of Srinagar during July and August.In the third week of September, it once again shifted southwards as evidenced by the 69 knots westerly wind reported over Srinagar at 222hPa on 21stSept. (00 UTC).

1.4 Synoptic Disturbances over the Indian Monsoon Region

1.4.1 Storms and Depressions

One Cyclonic Storm ‘Nanauk’ andtwo Depressions formed during the season. One formed as a Deep Depression over coastal areas of Bay of Bengal and neighbourhoodand the other over Land. Based on climatological data, about 6 monsoon depressions develop over the Indian region during the SW monsoon season [June to September] with a standard deviation of about 2.5. On an average, two systems get formed during July and August and one each during June& September. The tracks of the monsoon depressions are given in Fig. 1.5 and their description below.

1.4.1.1*Cyclonic Storm ‘Nanauk’ over the Arabian Sea* (*10th – 14th June 2014)*

A cyclonic circulation extending upto mid tropospheric levels embedded in the east-west shear zone lay over east-central Arabian Sea and neighbourhood on 8th. Under its influence, a low pressure area formed over east-central and adjoining southeast Arabian Sea on 9th. It lay as a well-marked low pressure area over east central Arabian Sea on 10th with associated cyclonic circulation extending up to7.6 km.a.s.l. It concentrated into a **Depression** and lay centered near Lat. 15.5^{O}N / Long. 68.5^{O}E, about 610 kms south-west of Mumbaiand 630 kms south southwestof Veraval at 09TC of 10th. It moved northwestwards and lay centered near Lat. 16.0^{O}N / Long. 68.0^{O}E, about 620 kms southwest of Mumbai and 600 kms south southwest of Veraval at 12 UTC of

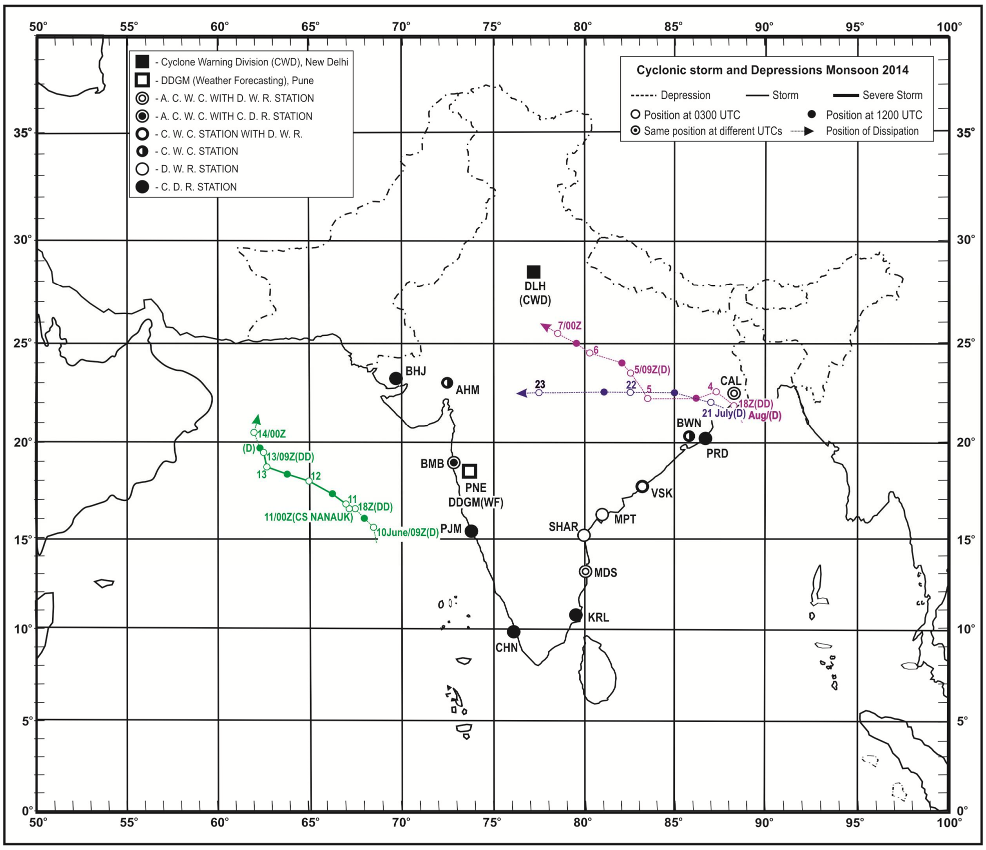

Fig.1.5: Tracks of Monsoon Depressions 2014 (Provisional)

10th. It further moved northwestwards, intensified into a **Deep Depression** and lay centered near Lat. 16.5^{O}N / Long. 67.5^{O}E, about 630 kms southwest of Mumbai and 570 kms south southwest of Veraval at 18 UTC of 10th. It further moved slowly westwards and intensified into a **Cyclonic Storm 'Nanauk'** and lay centered near Lat. 16.5^{O}N / Long. 67.2^{O}E, about 660 kms southwest of Mumbai and 590 kms south southwest of Veraval at 00 UTC 11th. It continued to move slowly northwestwards and lay centered over east central Arabian Sea near Lat. 16.7^{O}N / Long. 67.0^{O}E, about 670 kms west-southwest of Mumbai and 590 kms south southwest ofVeraval at 03 UTC of 11th.Subsequently moving west northwestwards, it laycentered at 12 UTC of 11th, near Lat. 17.3^{O}N / Long.66.2^{O}E, about 720 kms west-southwest of Mumbai and 590 kms southwest of Veraval.It further moved west north-westwards and lay centered over east central and adjoining west central Arabian Sea near Lat. 18.0^{O}N and Long. 65.0^{O}E, about 830 kms west southwest of Mumbai and 650 kms southwest of Veraval at 03 UTC of 12th. It moved west northwestwards and lay centered over west central and adjoining east central Arabian Sea, near Lat. 18.3^{O}N and Long. 63.9^{O}E, about 940 kms west southwest of Mumbai and 740 kms west southwest of Veraval at 12 UTC of 12th. It further moved northwestwards and lay centered over west central Arabian Sea, near Lat. 18.7^{O}N and Long. 62.7^{O}E, about 1080 kms west southwest of Mumbai and 850 kms west southwest of Veraval at 03 UTC of 13th. It moved north-northwestwards, weakened into a **Deep Depression** and lay centered over west central

Arabian Sea, near Lat. 19.5^{O}N and Long. 62.5^{O}E at 09 UTC of 13th. It moved north northwestwards and further weakened into a **Depression** and lay centered over west-central Arabian Sea near Lat 19.8^{O}N and Long 62.4^{O}E, about 1100 kms west northwest of Mumbai and 850 kms west southwest of Veraval at 12 UTC of 13th. It further moved northwards and lay centered over northwest and adjoining west central Arabian Sea, near Lat. 20.5^{O}N and Long. 62.0^{O}E, about 1160 kms west northwest of Mumbai and 680 kms west southwest of Veraval at 00 UTC of 14th. It moved northeastwards and weakened into a well-marked low pressure area over the same region at 03 UTC of 14th. It lay as a low pressure area over northeast and adjoining east central Arabian Sea in the early morning of 15th and became less marked in the same morning. However, the associated cyclonic circulation extending upto mid tropospheric levels lay over northeast Arabian Sea on 14th and 15th; over northeast Arabian Sea and adjoining Gujarat coast between 1.5 &3.6 km.a.s.l. on 16th. It lay over Saurashtra & Kutch and neighbourhood between 1.5 &4.5 km.a.s.l. on 17th and between 3.1 & 5.8 km.a.s.l. on 18th.

1.4.1.2 Land Depression over northeastern parts of Odisha and adjoining areas of Gangetic West Bengal(21st -23rd July 2014)

An upper air cyclonic circulation between 1.5& 5.8 km.a.s.l.lay over northeast Bay of Bengal and neighbourhood on 19th. Under its influence, a low pressure area formed over North Bay of Bengal and adjoining areas of Gangetic West Bengal and Odisha with associated cyclonic circulation extending upto 7.6 km.a.s.l. on 20th. It rapidly concentrated into a **Depression** and lay centered over northeastern parts of Odisha and adjoining areas of Gangetic West Bengal, near Lat. 22^{O}N / Long. 87^{O}E about 50 kms east of Baripada at 03 UTC of 21st. It moved west northwestwards and lay centered over south Jharkhand and neighbourhood near Lat. 22.5^{O}N / Long. 85.0^{O}E about 100 kms west southwest of Jamshedpur at 12 UTC 21st. It further moved westwards and lay centered over north Chhattisgarh and neighbourhood near Lat. 22.5^{O}N / Long. 82.5^{O}E about 50 kms southeast of Pendra at 03 UTC of 22nd and moved westwards and lay centered over east Madhya Pradesh and neighbourhood near Lat. 22.5^{O}N / Long. 81.0^{O}E about 100 kms southeast of Jabalpur at 12 UTC of 22nd. It further moved westwards and lay centered over west Madhya Pradesh and neighbourhood near Lat. 22.5^{O}N / Long. 77.5^{O}E about 50 kms southeast of Bhopal at 03 UTC of 23rd and weakened into a well-marked low pressure area over the same region by the afternoon of 23rd and persisted there in the same evening. It lay as a low pressure area over northwest Madhya Pradesh and neighbourhood on 24th, lay over southwest Rajasthan and neighbourhood in the evening and merged with the monsoon trough on 25th. However, the associated cyclonic circulation extending upto lower tropospheric levels persisted over southwest Rajasthan and neighbourhood on 23rd, over northeast Rajasthan and neighbourhood on 26th & 27th; over Punjab and adjoining north Rajasthan on 28th and over Punjab and neighbourhood on 29th & 30th.

1.4.1.3Deep Depressionover northwest Bay of Bengal and adjoiningcoastal areas of West Bengal and neighbourhood (3rd -7th August 2014)

A cyclonic circulation between 5.8 &9.5 km.a.s.l.lay over northwest Bay of Bengal and neighbourhood on 1st Aug. Under its influence, a low pressure area formed over North Bay of Bengal and neighbourhood on 2nd morning. It lay as a well-marked low pressure area over the same region on 3rd morning. It concentrated into a **Depression** and lay centered over northwest Bay of Bengal and adjoining coastal areas of West Bengal near Lat. 21.5^{O}N and Long. 88.5^{O}E about 80 km southeast of Diamond Harbour at 1200 UTC of 3rd.Moving slightly north-northwestwards it intensified into a **Deep Depression** and lay centered over coastal areas of Gangetic West Bengal near Lat. 21.9^{O}N and Long. 88.3^{O}E, about 80 kms southeastof Kolkata at 1800UTC of 3rd. It moved west northwestwards and lay centered over Gangetic West Bengal and neighbourhood at 0300UTC of 4th, near Lat. 22.5°N and Long. 87.2^{O}E close to Midnapur. Further moving west northwestwards it lay centered over Jharkhand and adjoining Gangetic West Bengal near Lat. 22.2^{O}N and Long. 86.1^{O}E about 50 kms south of Jamshedpur at 1200UTC of 4th and over north Chhattisgarh, adjoining Jharkhand and east Madhya Pradesh near Lat. 22.2^{O}N and Long. 83.5^{O}E about 100 km eastsoutheast ofAmbikapur at 0300UTC of 5th. Further moving west northwestwards, it weakened into a **Depression** and lay centered over north Chhattisgarh and adjoining east Madhya Pradesh near Lat. 23.5^{O}N and Long. 82.5^{O}E about 150 kms east of Umaria at 0900UTC of 5th and over northeast Madhya Pradesh and neighbourhood close to Sidhi near Lat. 24.0^{O}N and Long. 82.0^{O}E at 1200UTC of 5th. It further moved west northwestwards and lay centered over central parts of north Madhya Pradesh and neighbourhood about 50 kms southeast of Khajuraho, near Lat. 24.5^{O}N and Long. 80.2^{O}E at 0300UTC of 6th. It remained practically stationary and lay centered over the same region close to Nowgong near Lat. 25.0^{O}N and Long. 79.5^{O}E at 1200UTC of 6th. Moving slightly west-northwestwards it lay centered over northwest Madhya Pradesh and neighbourhood, near lat. 25.5^{O}N and Long. 78.5^{O}E, about 50 kmsoutheast of Gwalior at 0000UTC of 7th. Continuing the west northwestward movement, it weakened into a well-marked low pressure area over northwest Madhya Pradesh and neighbourhoodon 7th morning. It lay as a low pressure area over northwest Madhya Pradesh and adjoining east Rajasthan in the same evening. It merged with the monsoon trough on 8th. However, the associated cyclonic circulation extending up to mid tropospheric levels lay over northeast Rajasthan and neighbourhood on 8th & 9th, northwest Madhya Pradesh and adjoining southwest Uttar Pradesh on 10th, southwest Uttar Pradesh and neighbourhood on 11th and became less marked on 12th.

1.4.2 Low Pressure Areas/Well Marked Low Pressure Areas

During the season of SW monsoon 2014, ten low pressure areas / well marked low pressure areas formed against a normal of 6 low pressure areas per season. Most of them originated as upper air cyclonic circulations. Out of the ten low pressure areas formed during this season, 8(3 of them as well marked) formed over the Bay of Bengal, 2as well marked formed over the Arabian Sea. The month wise break up is 1 in June, 3 in July, 3 in August and 3 in September and approximate tracks are given in Fig.1.6.

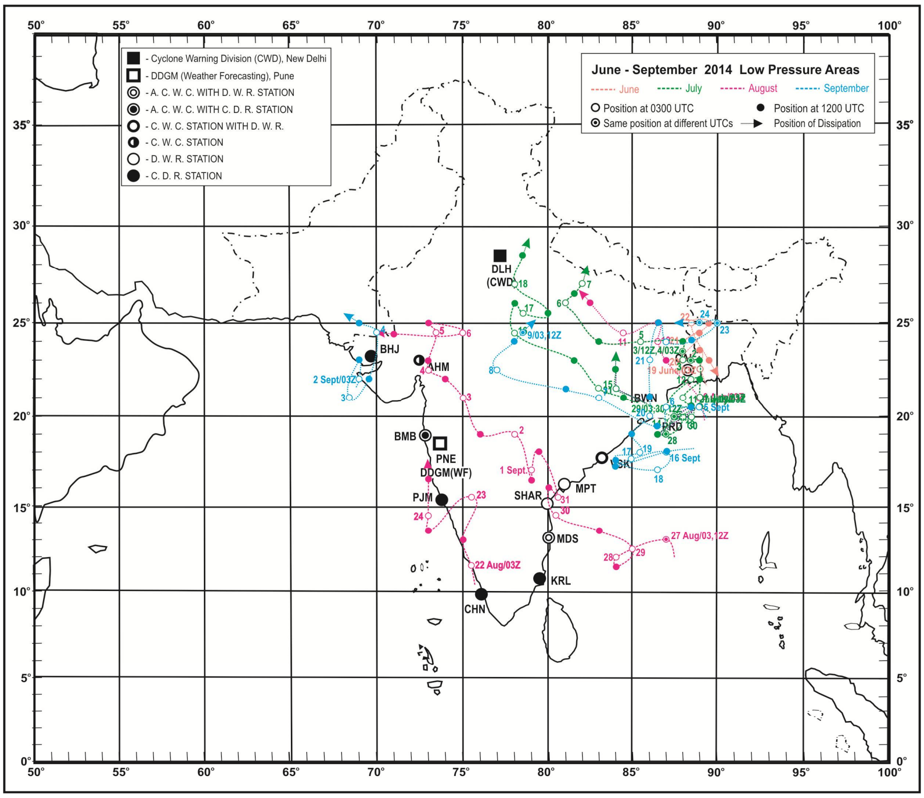

Fig.1.6:Tracks of low / well marked low pressure areas.

The first low pressure area (19th – 22nd June) formed over coastal areas of Bangladesh and neighborhood under the influence of a cyclonic circulation over northwest Bay of Bengal and neighborhood. It increased the rainfall activity over the region and thus led to the further advance of southwest monsoon over sub-divisions in the east.

The formation of second low pressure area (1st -7th July) over north Bay of Bengal and adjoining areas and its more north-northwesterly movement kept the monsoon activity over the eastern parts only. Therefore the rainfall activity all over India during the period remained subdued.

The low pressure area (9th -11th Aug.) formed over north Bay of Bengal and its northwestwards movement and dissipation, led the monsoon trough to shift towards the foot hills of the Himalayas on 13th Aug. With the formation of 2 well marked low pressure areas (23rd -24th Aug.) & (27thAug – 6thSept), one each over the Arabian Sea and Bay of Bengal, the rainfall activity over major parts of peninsular India enhanced during the last week of

August. Monsoon activity in general remained weak outside this areas and northeastern parts of the country, which received rainfall associated with the north-south trough in the lower and mid tropospheric westerlies. The formation of the well-marked low pressure area over the Bay of Bengal and its west-northwestwards movement across the central parts of India along with the formation of the low pressure area (2^{nd} -4^{th} Sept.) over Saurashtra & Kutch and adjoining northeast Arabian Sea revived the rainfall activity over central and northwest India.

The above well marked low pressure area took a more northward course from 4^{th} Sept and thereafter interacting with the trough in the mid-latitude westerlies in the lower tropospheric levels, caused heavy to very heavy rainfall resulting severe floods in Jammu & Kashmir during first week of September. The formation and movement of the third well marked low pressure area (5^{th}– 9^{th} Sept) over north Bay of Bengal off west Bengal–Bangladesh coasts helped the monsoon trough to shift southwards of its normal position and thus led to vigorous monsoon activity over north, east central and adjoining peninsular India.

In the latter half of September, a low pressure area (16^{th}-24^{th}Sept.) formed over northwest Bay of Bengal and adjoining coastal areas of Odisha and west central Bay of Bengal. Its northward movement increased the rainfall activity over eastern parts only.

1.4.3 Upper Air Cyclonic Circulations

There were 50 upper air cyclonic circulations (in lower and middle tropospheric levels) which formed during the season.

The month wise distribution of these is: 14, 13, 10 & 13 during June, July, August and September respectively.

1.4.4 Eastward Moving Cyclonic Circulations/Western Disturbances

There were 13 eastward moving systems as upper air cyclonic circulations. The month wise distribution is 4in June, 3 in July, 5 in August and 1 in September.

1.5 Significant weather events during the season

The resultant weather which affected normal life and damage to property, excluding those from the lack of timely rains are depicted in Fig. 1.7. High impact weather manifested as extremely heavy rainfall (rainfall amount ≥ 25cm during 24 hours) is also marked over the affected sub-divisions and representative amounts with their location and dates of occurrence are given in the Table along with the figure. A detailed analysis of some of these events is made in the subsequent chapters.

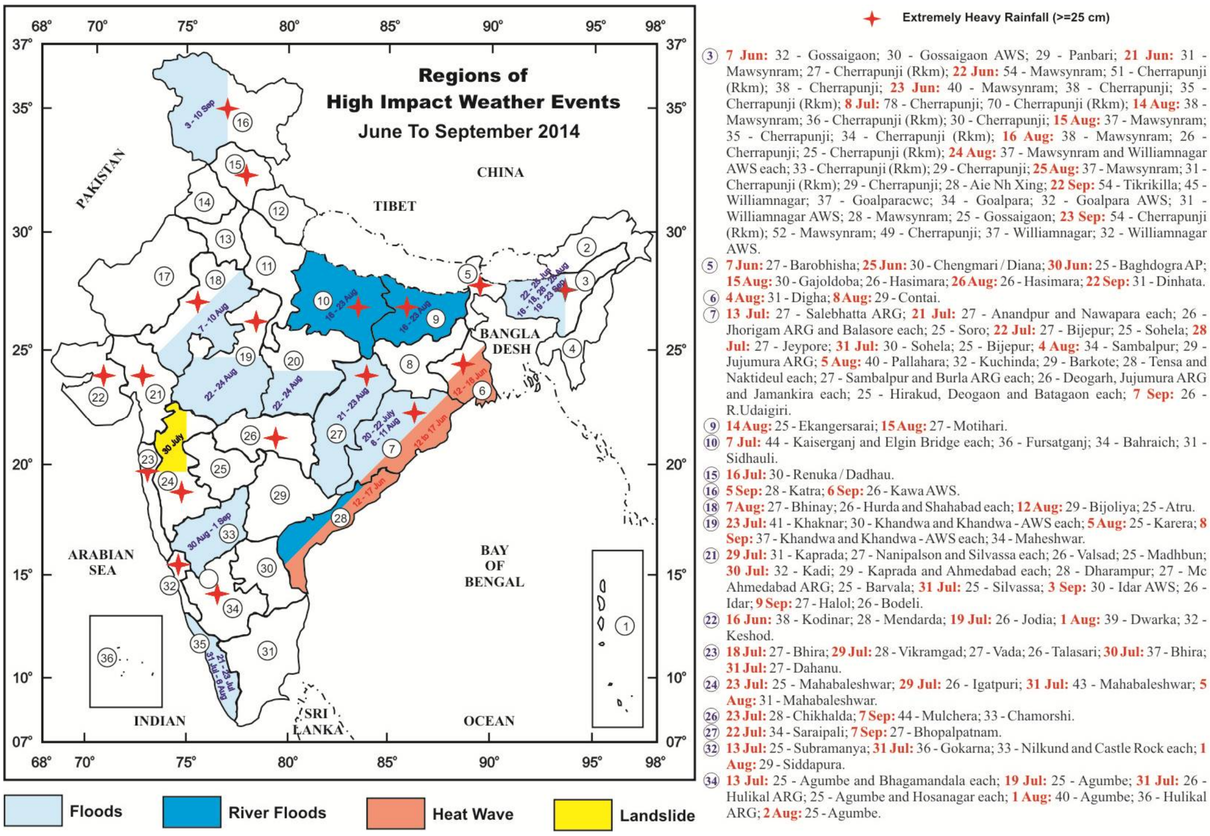

Fig.1.7: Regions affected by high impact weather events during the season

1.6 Low Pressure Systems over Other Oceanic Areas during June to September 2014.

1.5.1 Low Pressure Systems over West Pacific Ocean/ South China Sea

There was in all, 12 low-pressure systems (reaching the intensity of Tropical depression and above) over the Northwest Pacific Ocean / South China Sea during June – September 2014.

The month wise distribution low pressure systems formed over NW Pacific during the 2014 southwest monsoon is given below:

Low Pressure Systems	June	July	August	September	TOTAL
Tropical Depression (T.D.)	01	-	-	01	02
Tropical Storm (T.S.)	-	-	01	04	05
Typhoon/Super Typhoon	-	03	01	01	05
TOTAL	01	03	02	06	12

1.5.2 Low Pressure Systems over South Indian Ocean

No low pressure system (TD, TS or Typhoon) was reported in Southern Hemisphere during June- September 2014.

1.5.3 Troughs in the Mid Latitude Westerliesfrom Northern & Southern Hemispheres Affecting the Indian Monsoon

(i) Troughs in Mid &Upper tropospheric Westerly Winds from Northern Hemisphere

The month wise break up of number of troughs in the mid latitude westerlies which moved across Indian region from west to east and penetrated to the south of 30^{O}N is given below.

Atmospheric Level	June	July	August	September	Total
300 hPa	03	03	04	04	14
500 hPa	03	01	02	04	10

(ii) Troughs in Upper Air Westerly Winds, over South Indian Ocean

The troughs in upper air westerlies which moved across the South Indian Ocean from west to east, penetrated to the north of Lat.30^{O}S, in the Southern Hemisphere, during June to September 2014.

Atmospheric Level	June	July	August	September	Total
500 hPa	07	06	05	07	25
300 hPa	06	07	09	06	28

1.7 Withdrawal of the Southwest Monsoon

The isochrones of withdrawal of monsoon are given in Fig.1.8.

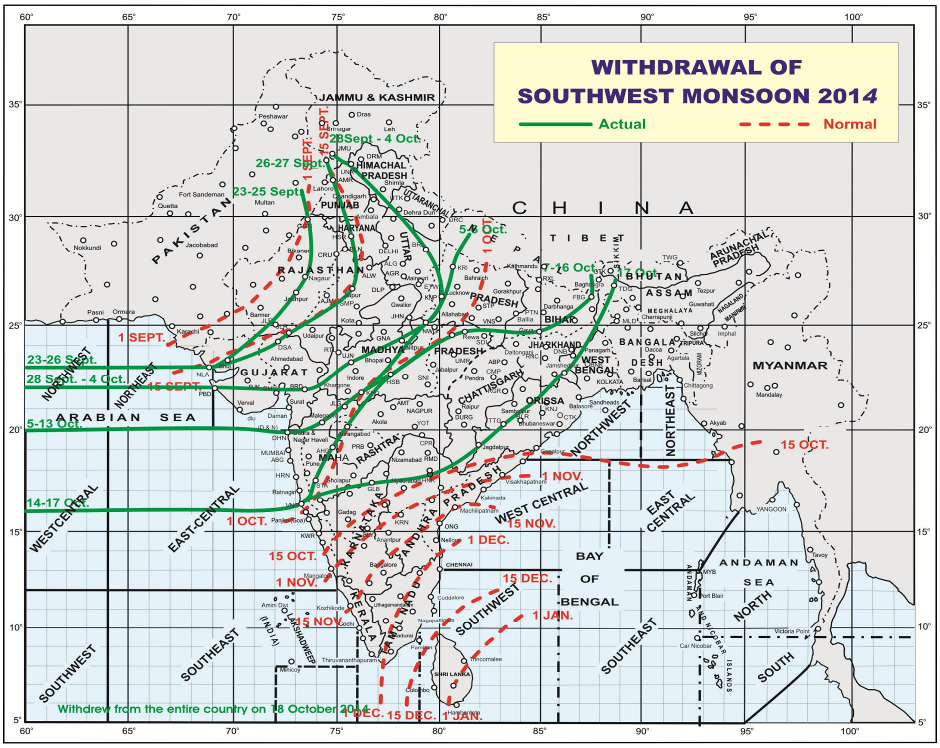

Fig.1.8: Isochrones of withdrawal of South West Monsoon 2014.

The weather over the western parts of Rajasthan remained mainly dry from 17th Sept. A change over in the lower tropospheric circulation pattern over the region from cyclonic to anti cyclonic during 16th - 17th Sept. indicated the beginning of the withdrawal of southwest monsoon from the region. Hence the withdrawal of southwest monsoon commenced from 23rd Sept. and the withdrawal line passed through Ganganagar, Nagaur, Jodhpur, Naliya, Lat. 23^{O}N/ Long. 65^{O}E and Lat.23^{O}N / Long. 60^{O}E on 23rd Sept. It withdrew from some parts of Punjab, Haryana, east Rajasthan and Gujarat Region, some more parts of Kutch area, and remaining parts of west Rajasthan and the withdrawal line passed through Amritsar, Hissar, Jaipur, Deesa, Naliya, Lat. 23^{O}N/ Long. 65^{O}E and Lat. 23^{O} N / Long. 60^{O}E on 26th Sept. It further withdrew from remaining parts of Punjab, Haryana, Chandigarh & Delhi and east Rajasthan; some parts of Jammu & Kashmir, Himachal Pradesh, east Uttar Pradesh, Madhya Pradesh and Saurashtra; most parts of west Uttar Pradesh and some more parts of Gujarat Region, Kutch and north Arabian Sea on 28^{th} Sept. By 7^{th} October, the withdrawal process completed from the remaining parts of northwest &most parts of central India. This was followed by the formation and landfall of the Very Severe Cyclonic Storm 'HUD HUD' over the Bay of Bengal during 7^{th} – 14^{th} Oct. Subsequent to its weakening and northward movement, the southwest monsoon further withdrew from some more parts of west Madhya Pradesh, most parts of Madhya Maharashtra, Konkan and some more parts of Marathwada and central Arabian Sea on 14^{th} Oct. Withdrawal from the remaining parts of the mainland and the Sea areas was completed on 17^{th}& 18^{th}, with the simultaneous commencement of northeast monsoon rains over Tamil Nadu and neighboring peninsular India on 18^{th} October.

1.8 Concluding remarks.

The season ended up with a rainfall deficiency of 12% from its Long Period Average (LPA). The rainfall deficiency of June (-42% of LPA)is comparable with that of 2009 (June-2009 reported a rainfall deficiency of -47.2%) in the recent decade. Though the onset phase was being marked with a sluggish advance and persistent heat wave conditions over major parts of the country, during the later part of the season, there had been several incidences of extremely heavy rainfall and calamitous floodsituations such as the one occurred over Jammu & Kashmir in the beginning of September. Some of the observational features are summarized below.

- Southwest monsoon current advanced over the Andaman Sea 2 days earlier than its normal data of 20^{th} May and set in over Kerala on of 6^{th} June, 5 days later than normal. The southwest monsoon covered the entire country by 17^{th} July, about 2 daysafter its normal date of 15^{th} July.

- **The withdrawal of monsoon from west Rajasthan commenced on 23rd September**delayed, compared to its normal date of 1st September. Formation and landfall of the Very Severe Cyclonic Storm 'HudHud' was the major event during the withdrawal phase.
- During the season, one Cyclonic Storm, 2 monsoon depressions and 10 monsoon low pressure areas formed.The rainfall distribution varied widely in space and time, this year.
- Break like situation developed during the latter half of August. The rainfall activity over central and northwest India revived only towards the end of August, from this prolonged subdued spell.

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2

GLOBAL AND REGIONAL CIRCULATION ANOMALIES

O. P. Sreejith, D. S. Pai and Pallavi Prabhu

In this Chapter, regional and global anomalies of sea surface temperature, outgoing long wave radiation and circulation during the 2014 southwest monsoon season are discussed and important factors responsible for the observed rainfall patterns over India during the season are identified.

2.1 Sea Surface Temperature Anomalies

2.1.1. Equatorial Pacific

Evolution of SST anomalies in the four NINO regions for one calendar year since December, 2014 is shown in the Fig.2.1. As seen the cool ENSO neutral conditions observed early this year continued till middle of March and turned to warm ENSO neutral conditions. Thereafter a warming tendency was observed throughout the equatorial Pacific till the early part of the monsoon season with SSTs over the east and central equatorial Pacific reaching to borderline El Nino conditions. However, during the middle of the monsoon season, the SSTs showed cooling tendency temporarily. From the early part of August, the SSTs over all the Nino regions except NINO1+2 showed warming tendency and by the end of December, 2014 reached to weak El Nino threshold values.

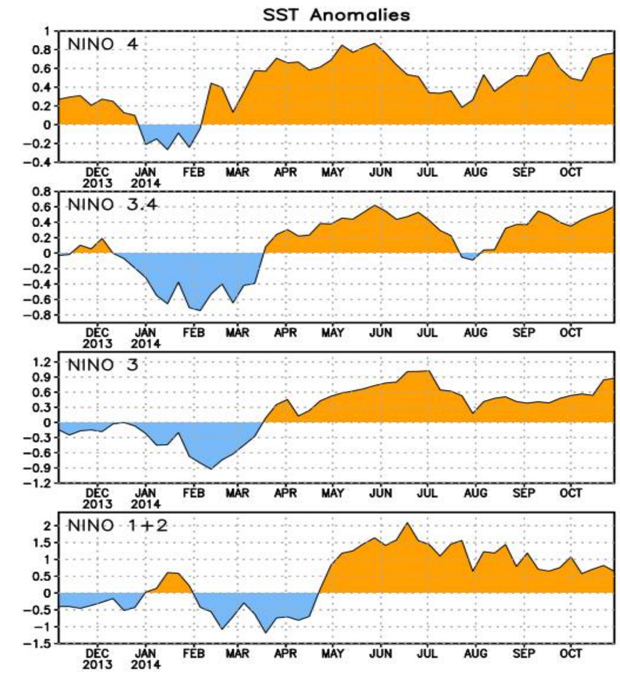


Fig.2.1: Time series of area-averaged sea surface temperature (SST) anomalies (°C) in the Niño regions [Niño-1+2 (0°-10°S, 90°W-80°W), Niño 3 (5°N-5°S, 150°W-90°W), Niño-3.4 (5°N-5°S, 170°W-120°W), Niño-4 (150ºW-160ºE and 5ºN-5ºS)]. (Source: Climate Prediction Centre).

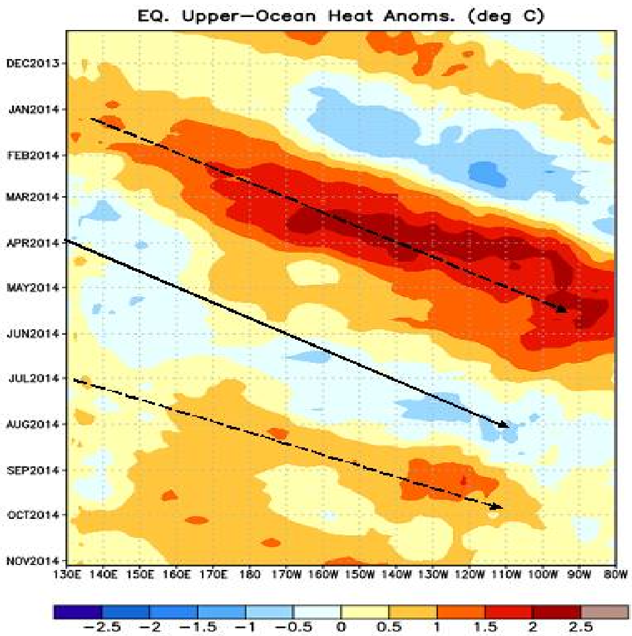


Fig 2.2: The equatorial upper-ocean heat content anomalies over equatorial Pacific. (Source: Climate Prediction Centre)

The SST anomalies in the NINO 3.4 region showed continuous increase from February and crossed the threshold value of 0.5^{O} C during later part of May. During June 2014, the SSTs in the NINO3.4 region were slightly above average (0.6^{o}C). However, during the subsequent months, it decreased suddenly and reached negative value in the month of August. The SST anomaly again started increasing and crossed the threshold value of 0.5^{o} C during end of September month. Similar SST variations are observed in all other Niño regions (NINO 1+2, NINO 3 and NINO 4). As shown in Fig.2.2 the upper (0-300m) oceanic heat content anomalies were positive in the tropical east Pacific prior to the monsoon season. It can also be noted from the Hovmoller diagram (time vs longitude) of equatorial (5^{O}S- 5^{O}N) heat content anomalies (Fig.2.2) that from January to June 2014, the heat content anomalies increased across the equatorial Pacific, partly in association with a down-welling Kelvin wave. The warm phase is indicated by dashed lines. The down-welling and warming occur in the leading portion of a Kelvin wave, and up-welling and cooling occur in the trailing portion. However propagation of a weak up-welling (cooling) started during the month of March and reached eastern pacific in the month of September.

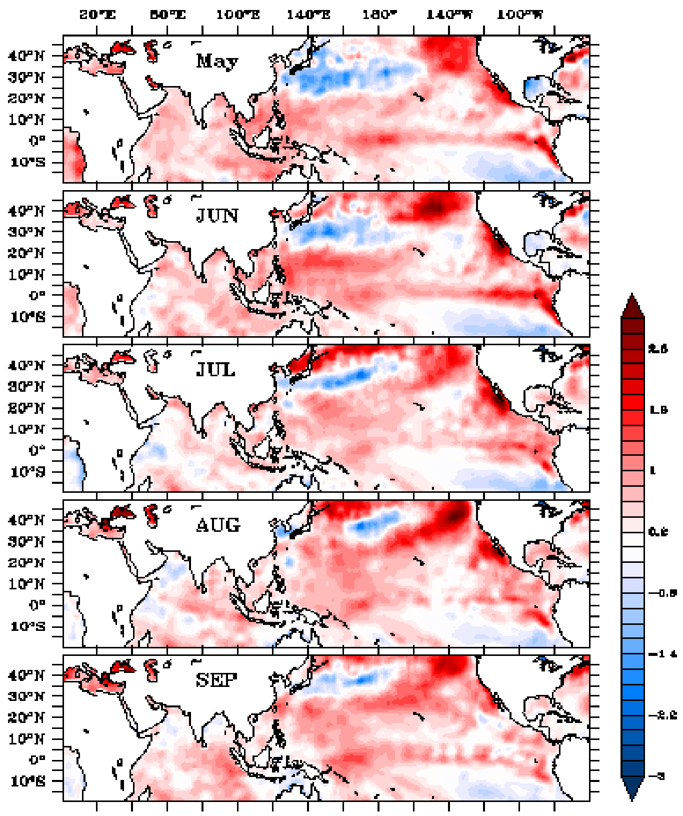


Fig. 2.3: SST anomalies in the Indo-Pacific region during a) May b) June c) July d) August e) September 2014.

Monthly anomalies of sea surface temperature (SST) for the period May to September 2014 are shown in Fig.2.3. As seen in Fig.2.3, during May, weak positive SST anomalies were observed in the eastern equatorial Pacific and extend up to central Pacific indicating ENSO neutral conditions close to border line El Niño pattern. During the monsoon season, warm SST anomalies over the extreme east equatorial pacific showed westward spreading during June and July months and developed a SST pattern close to borderline ENSO neutral/weak El Niño conditions. The magnitude of positive anomalies over some areas of equatorial east Pacific was more than 1^{0}C during the first half of the monsoon season. In the month of August, the warm SST anomalies in the eastern equatorial pacific weakened and observed a basin wide SST warming during the monsoon season and it persisted thereafter.

2.1.2 Indian Ocean

A basin wide warming of Indian Ocean was observed during the month of May and June as seen from Fig.2.3. A weak negative dipole like pattern with negative SST anomalies in the western side of the tropical Indian Ocean started appearing during the month of July. The weak negative dipole like pattern persisted during the rest of the monsoon season.

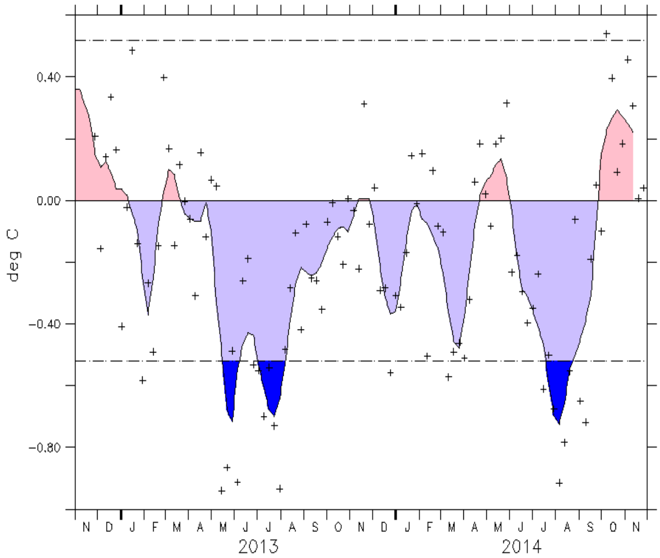


Fig. 2.4: The time series of Dipole mode Index (DMI) representing Indian Ocean Dipole Condition during 2014.(source: IOC).

The Fig.2.4 shows the time series of Dipole Mode Index (DMI) for the year 2014. The DMI represents the intensity of the IOD defined as the anomalous SST gradient between the western equatorial Indian Ocean (50^{o}E-70^{o}E and 10^{o}S-10^{o}N) and the south eastern equatorial Indian Ocean (90^{o}E-110^{o}E and 10^{o}S-0^{o}N). The negative IOD index reached above the threshold value of 0.5^{o}C in the later part of July and peaked during August. During the end of September, the IOD index returned to positive side.

2.2 OLR anomalies

Monthly spatial distribution of Outgoing Long wave Radiation (OLR) anomalies during June to September month is shown in Fig.2.5. The negative (positive) OLR anomalies indicate above (below) normal convection. One of the important features observed during the monsoon season was the positive OLR anomalies (below normal convective activity) over Indian Region. During the month of July and September OLR anomaly were positive (below normal convection) over the Indonesian maritime region associated with the border line El Niño condition. A dipole like feature observed during the month of July over south Indian Ocean with positive anomaly in the eastern side and negative anomaly (above normal convection) in the western side associated with weak negative IOD and this pattern persisted during the subsequent monsoon season.

During June, positive OLR anomalies were observed over the Indian subcontinent and Bay of Bengal and weak negative anomaly over the southern Arabian Sea and equatorial region. The magnitude of maximum positive anomaly more than 40W/m^2 is observed over the Indian region and negative anomaly more that 40W/m^2 over equatorial eastern Indian Ocean near maritime continent. The convective pattern associated with the negative IOD developed during the month of July. The negative IOD pattern weakens further during August and September and positive OLR anomaly pattern is observed over the Indian monsoon region with slight variation in the magnitude and spatial extension. Compared to June, during the subsequent months, weak positive OLR anomalies were observed over entire Indian Land mass. During the month of September improved convective activity is observed over northern Arabian Sea.

The OLR anomalies averaged for the monsoon season (June to September) are shown in the Fig.2.6. The negative IOD pattern is clearly seen in the seasonal average also. Over the Indian region, the OLR anomalies are positive except over north eastern part of the country. The positive anomalies over south India extended to Bay of Bengal where the anomalies exceed 20 W/ m^2 indicating below normal convection over the region.

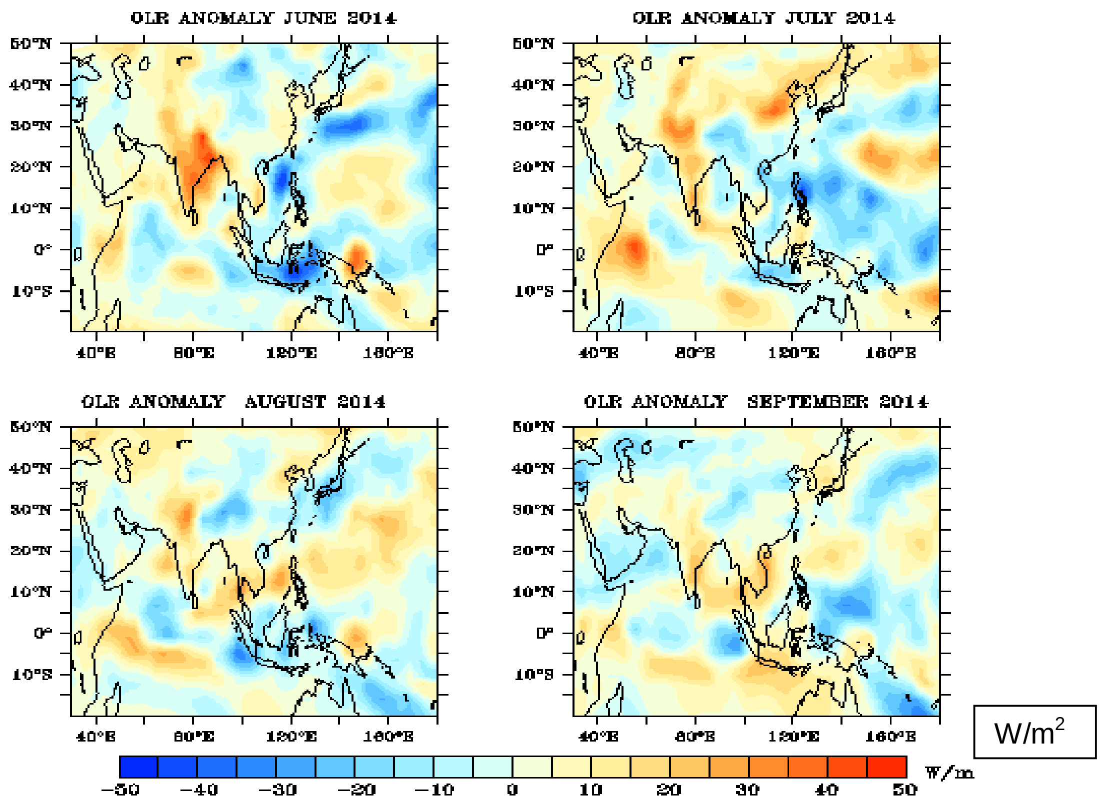


Fig. 2.5: Monthly OLR anomalies during June to September 2014.

The season averaged 850 hPa wind anomaly (vector, Fig.2.6) shows anomalous cyclonic circulation over Somali coast indicating weaker than normal lower tropospheric monsoon circulation over southern peninsular Indian and stronger than normal circulation over eastern part of ITCZ. An anomalous cyclonic circulation is seen over southwest Indian Ocean which resulted in the weakening of cross equatorial flow across Arabian Sea.

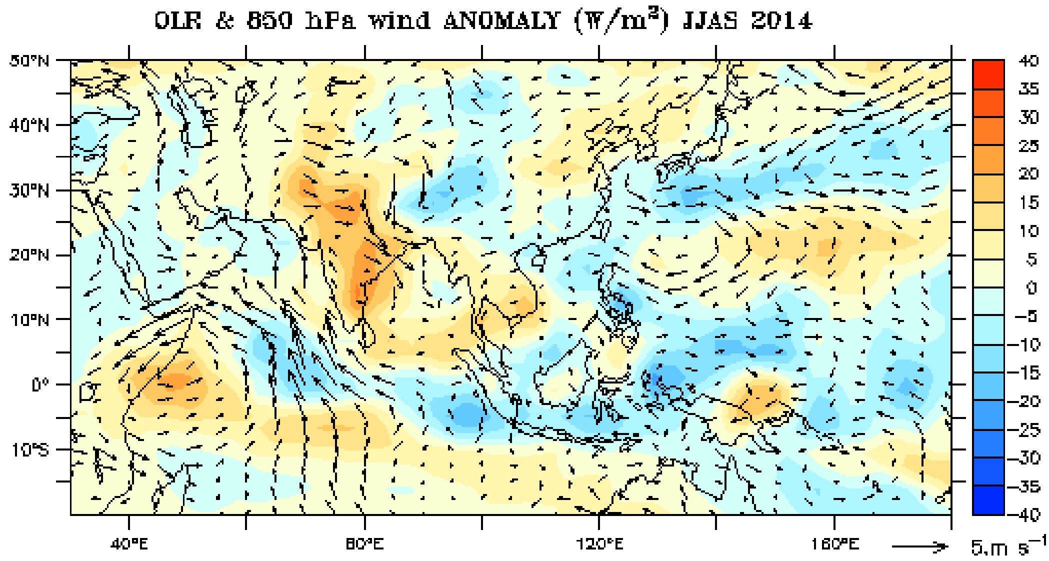


Fig. 2.6: OLR anomaly overlay with 850hPa wind during June to September 2014.

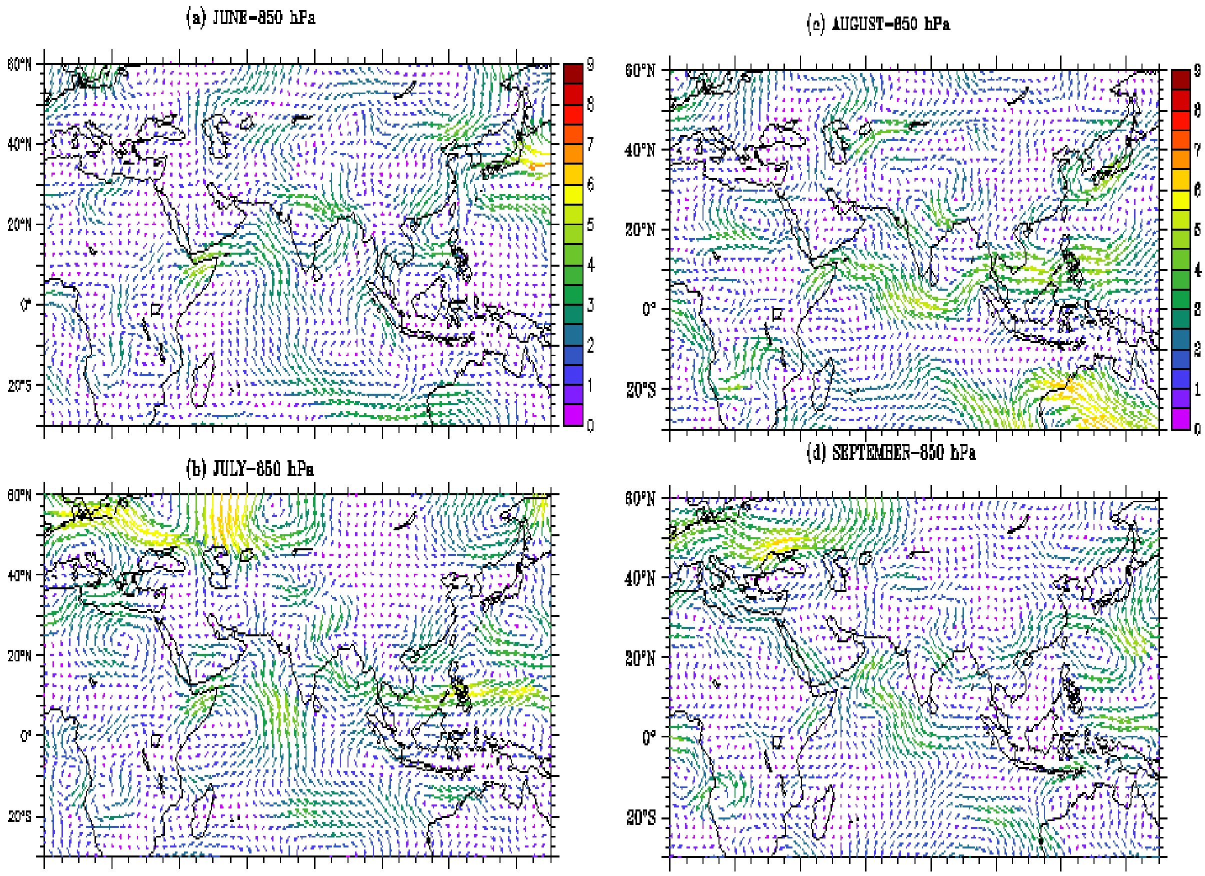


Fig 2.7: Wind Anomalies at 850 hPa during a) June b) July c) August d) September

2.3 Lower and Upper Tropospheric Circulation Anomalies

The monthly wind anomaly patterns at 850 hPa for June to September are shown in Figures 2.7a, b, c & d. During June, most significant feature is the anomalous cyclonic circulation over the southwest Arabian Sea and anomalous anticyclonic circulation over the central Indian region. This indicates a weaker monsoon flow close to Somali coast and weaker Low level Jet (LLJ) over the west coast of India. An anomalous anticyclonic circulation was also seen over the eastern equatorial Indian Ocean and neighboring land region. During July, the anomalous anticyclonic circulation over central India shifted to northwest India and Pakistan region. The anomalous cyclonic circulation over the southwest Arabian Sea weakens during July but with slightly shifted in its position and resulted in increased strength of LLJ over the west coast of India. Another anomalous cyclonic circulation is observed over the head Bay of Bengal region. The anomalous cyclonic circulation over the southwestern Arabian Sea was more pronounced during August but with slight shift in its positions. The anomalous cyclonic circulation over the head Bay of Bengal weakened and shifted northward during August. During September, anomalous cyclonic circulations over Somali coast weaken and strong LLJ were observed. In general, it can be summarized that except September, during all the other months of 2014 southwest monsoon season, the low level monsoon flow was slightly weaker than normal. Above normal cross equatorial flow was seen from the central equatorial Indian Ocean, however not entering the main land during June and August months. Particularly over south Peninsula, the wind anomalies were easterly indicating weaker than normal low level westerly.

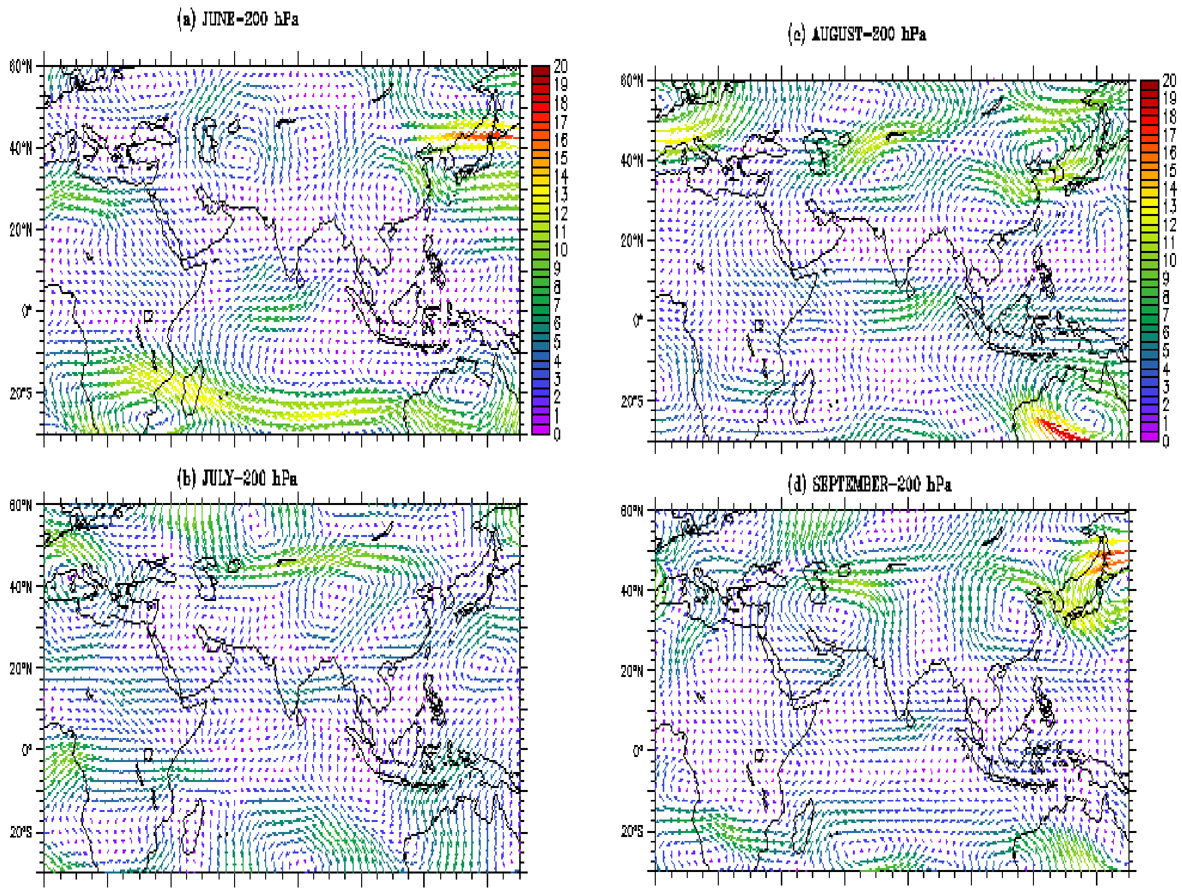
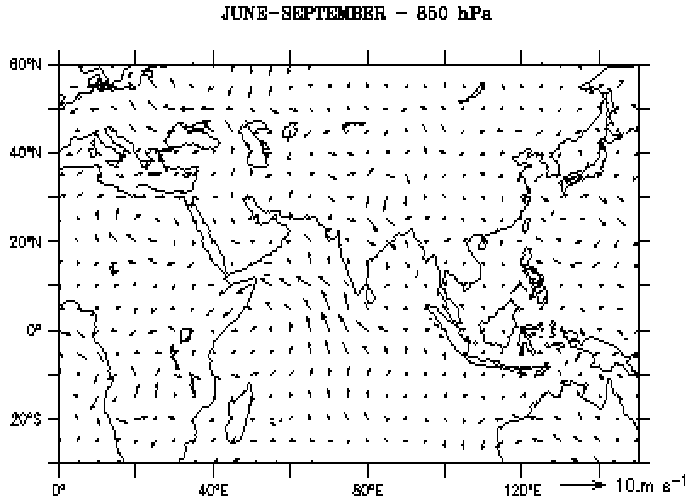


Fig 2.8: Wind Anomalies at 200 hPa during a) June b) July c) August d) September

This feature like anomalous anticyclonic circulation over south Arabian Sea near Somali coast was also visible in the wind vector anomalies averaged over the season (Fig.2.9). This resulted in weakening of cross equatorial flow along the western Indian Ocean and reduction in the rainfall activity.

The Figures 2.8a, b, c & d show wind anomalies at 200 hPa. During June, the most significant feature was an anomalous anticyclonic circulation with center located at 85^{O} E and 40^{O} N and anomalous cyclonic circulation with center located at 60^{O} E and 38^{O}N. The weak westerly anomalies indicate weak Tropical Easterly Jet Stream (TEJ). During the month of July, the anomalous anti-cyclonic circulation became cyclonic and the cyclonic circulation became anticyclonic.

During August, this anomalous anticyclonic circulation shifted further northeast wards. During September, the anomalous anticyclonic circulation weakened and was observed over north of India with center located at 60^{O} E and 38^{O} N. During all the four months, anomalous westerlies were observed over south Peninsula indicating weaker than normal tropical easterly jet stream. The season averaged 200 hPa wind vector anomalies (Fig.2.9) also clearly reveal weaker than normal Tropical Easterly Jet Stream during 2014 monsoon season.



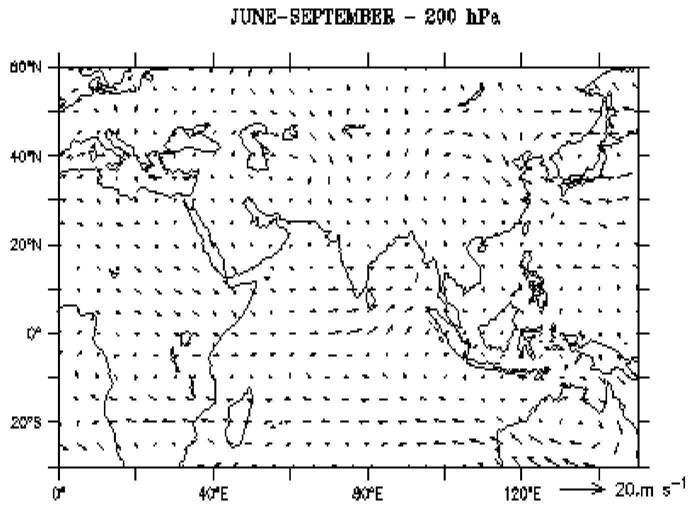


Fig. 2.9: Wind Anomalies at 850hPa and 200hPa during June to September 2014.

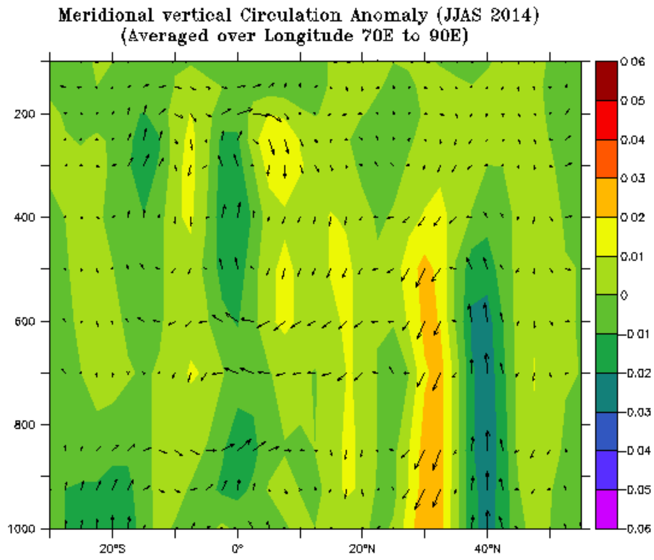


Fig.2.10. Vertical cross-section of Pressure vertical velocity overlay with Meridional vertical circulation for the monsoon season (June-September 2014). Pressure vertical velocity (Omega) are shaded. The anomalies are averaged over longitudes 70^{0}E to 90^{0} E.

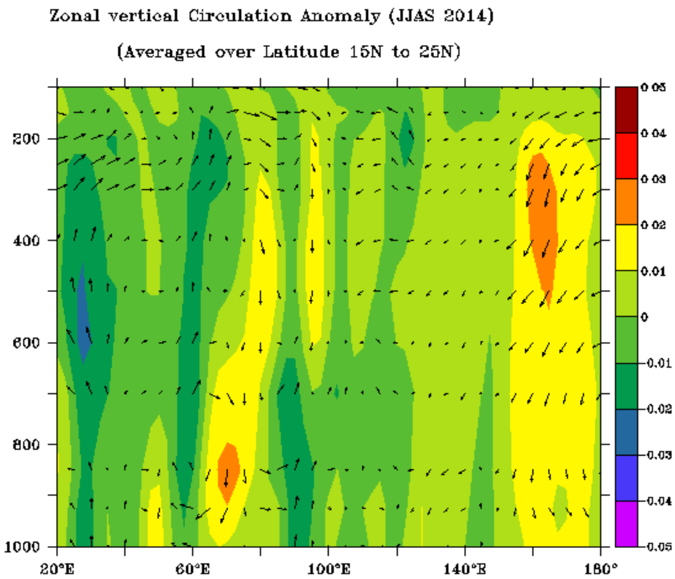


Fig.2.11. Vertical cross-section section of Pressure vertical velocity overlay with Zonal vertical circulation for the monsoon season (June-September 2014). Pressure vertical velocity (Omega) are shaded. The anomalies are averaged over latitude 15N to 25N.

2.4 Meridional and Zonal Circulation Anomalies over Indian Region

To examine the changes in the meridional circulation over Indian region during the monsoon season, latitude – height cross section of vertical velocity (omega) anomalies averaged over longitudinal zone of 70^{o}E-90^{o}E was plotted for the monsoon season (Fig.2.10). Two anomalous meridional circulation cells can be seen in the figure. Over the Indian monsoon region, a very weak anomalous meridional circulation cell with ascending branch around 22^{o}N and descending branch around 18^{o}N is observed. North of this meridional cell, there is a stronger meridional circulation cell in the mid latitude region with ascending branch over around 40^{o}N and descending branch around 30^{o}N. However there was large scale descending motion at higher level (above around 700 hPa) over the latitudinal domain, equator to about 30^{o}N. This anomalous subsidence motion over the monsoon region resulted in the below normal convective activity over Indian Region.

Fig.2.11 shows the zonal circulation over Indian region, longitude-height cross section of vertical velocity (omega) anomalies averaged over latitudes 15° N-25° N during the monsoon season. The descending motion over the Indian region prevailed during the season can be also seen in the zonal circulation. The ascending motion around 100° E indicates above normal typhoon activity over the northwest Pacific.

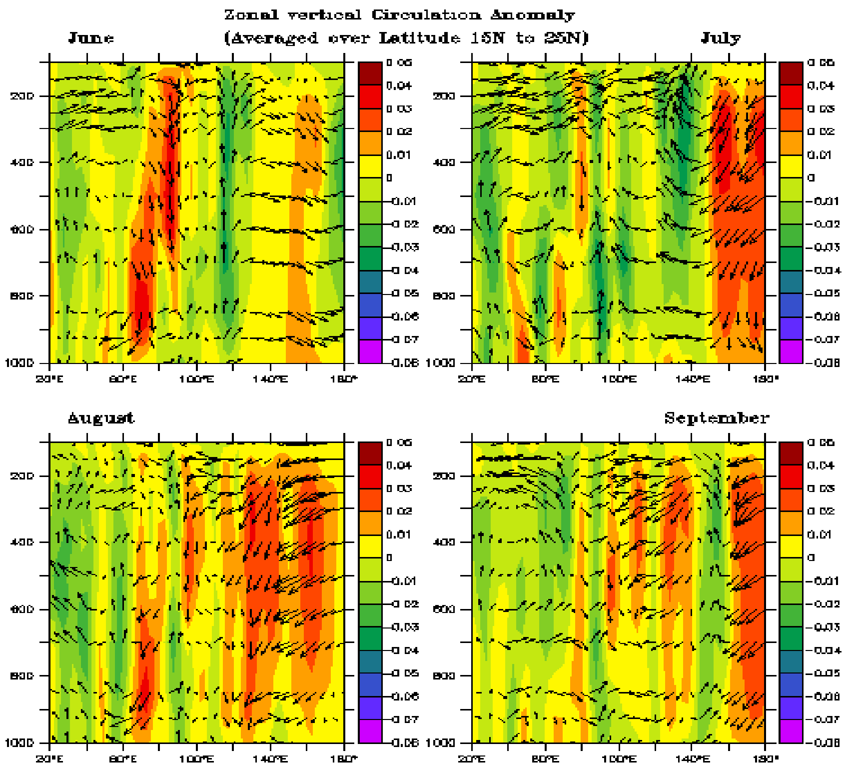


Fig 2.12: Longitude Height Circulation Cross-section and Omega during a) June and b) July c) August and September 2014. Pressure vertical velocity (Omega) is plotted using shaded areas. The anomalies are averaged over latitude 15° N to 25° N.

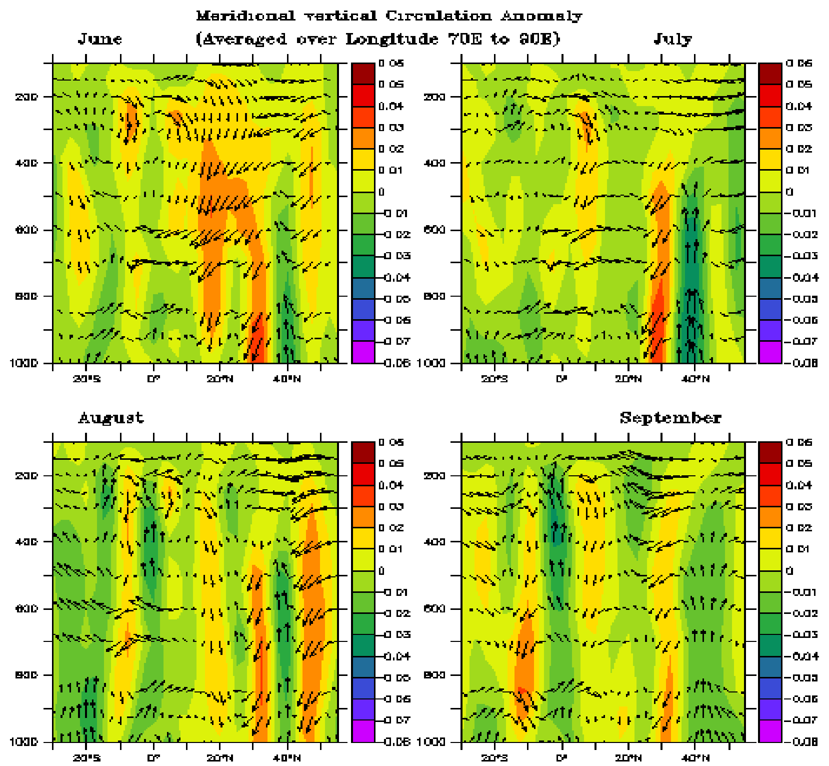


Fig. 2.13: Latitude Height Circulation Cross-section and Omega during a) June and b) July c) August and September 2014. Pressure vertical velocity (Omega) is plotted using shaded areas. The anomalies are averaged over Longitude 70°E to 90° E.

Fig.2.12 depicts the monthly zonal circulation during the season. It can be seen that during June a strong descending motion persist over the Indian region and ascending motion around 100^o E. The ascending motion shifted to 140^o E during the subsequent months.

Fig.2.13 depicts the monthly meridional circulation during the season. It can be seen that there were descending motion over Indian region throughout the monsoon season. The large scale descending motion over Indian region during June around 20^0N disappeared during July, but reappeared during the month of August. This large scale descending motion during the month of June resulted in very large deficiency in June rainfall. The strength of descending motion observed around 30^oN decrease continuously during the subsequent months.

2.5 Important global and regional features that influenced the rainfall pattern over India region

During the season, out of the total 36 meteorological subdivisions, 23 subdivisions constituting 67.3% of the total area of the country received normal season rainfall and the remaining 12 subdivisions (30% of the total area of the country) received deficient season rainfall. One subdivision (south Interior Karnataka) constituting 3% of the total area of the country received excess rainfall. The Subdivisions having positive percentage departure values are Jammu and Kashmir, Orissa, south Interior Karnataka, coastal Karnataka and Kerala.

During the monsoon season, all the months, except September rainfall was below its LPA value. The rainfall deficiency was highest during the month of June with 58% LPA value. The rainfall during July and August was below normal (90% of LPA) respectively. The second half of the season rainfall was 2% below its LPA values (90% of LPA during August and 108% during September). During July, majority of the subdivisions from central India and west peninsula received excess (3 subdivisions) or normal rainfall (17 subdivisions). The excess rainfall subdivisions are Konkan & Goa, south Interior Karnataka and Odisha. The large rainfall deficiency was observed over north and northeast India, region close to Himalayas and interior & southeast Peninsula. During August, majority of the subdivisions from Peninsula, east and northeast India received normal / excess rainfall. On the other hand, majority of the subdivisions from northwest India and neighboring central India received deficient/ scanty rainfall. During September, the rainfall activity over many parts of the country showed significant increase and 23 subdivisions received excess or normal rainfall. However, 13 subdivisions mainly from north India along the plains of Himalayan region and north peninsula received deficient rainfall.

The main observed anomaly features in the monthly and seasonal rainfall patterns can be summarized as; (i) normal seasonal rainfall was received over most parts of the country, however only 5 subdivisions have positive percentage departure (Table-8.1), (ii) The country received very large rainfall deficiency during June and above normal rainfall in September, (iii) Only one subdivision (south Interior Karnataka) received excess season rainfall.

It will be interesting to identify the global and regional forcings that were possibly responsible for the main rainfall features summarized above. During the beginning of the monsoon season 2014, an El Niño like SST warming trend was developed in the eastern Pacific and this has large impact on the Indian summer monsoon rainfall. We will first discuss the impact of this forcing. As seen in the section 2.1, the warming trend in SST anomaly started during February, and by June, the SST anomalies over NINO3.4 region crossed the threshold of 0.5°C. The cooling of SSTs over NINO3.4 started late June and continued until the SST anomaly reached negative side during the month of August. Beginning of August SSTs over NINO3.4 region again started warming and crossed threshold value during end of September. During 2014, the rainfall during the second half of the monsoon season over country as a whole was 98% of LPA and that during September was 110% of LPA. All these facts indicate that the improvement of rainfall activity during the end of the 2014 monsoon season may be due to the collapse of the borderline ENSO neutral/weak El Niño conditions over the eastern Pacific.

The observed negative rainfall anomalies over the country may also associated with the weak negative IOD over the western equatorial Indian Ocean during the monsoon season. The aspects of influence of negative IOD events on rainfall over Indian region are discussed below. A weak negative IOD was developed during June and strengthened during the subsequent months. The IOD index started to increase during the month of August and became normal at the end of season. Ashok and Saji (2007) have observed in phase association between IOD and rainfall over monsoon trough region.

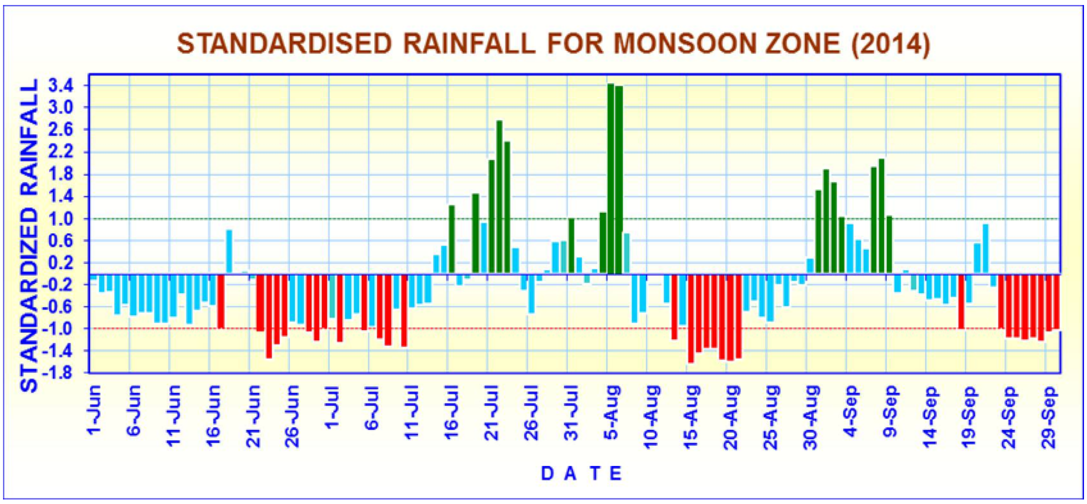


Fig.2.14: Time series of standardized rainfall anomaly for core monsoon zone for 2014 monsoon season.

There were large intra-seasonal fluctuations observed in rainfall during the season. The Fig.2.14 shows the time series of standardized rainfall anomaly over core monsoon region during 1 June to 30 September 2014. This index was proposed by Rajeevan et. al. (2008) for identifying the break and active monsoon spells. The rainfall over the core monsoon region received negative rainfall anomalies during most of the days during the monsoon season. The rainfall was generally below normal for throughout June month except few days in the middle of June. The rainfall anomaly became positive during second half of July and positive rainfall anomalies last during the first week of August. The weak monsoon activity continues up to the beginning of September. During September above normal rainfall was observed during first week and then the rainfall anomaly became negative except couple of days in the 3rd week September. Except a single day, the rainfall anomaly was on the negative side during entire June.

The large deficiency in rainfall during June and first two weeks of July may be due to strong descending motion (as seen in Fig.2.12 and Fig 2.13) over Indian region caused by the negative IOD and border line El Nino like conditions in the early part of the monsoon season.

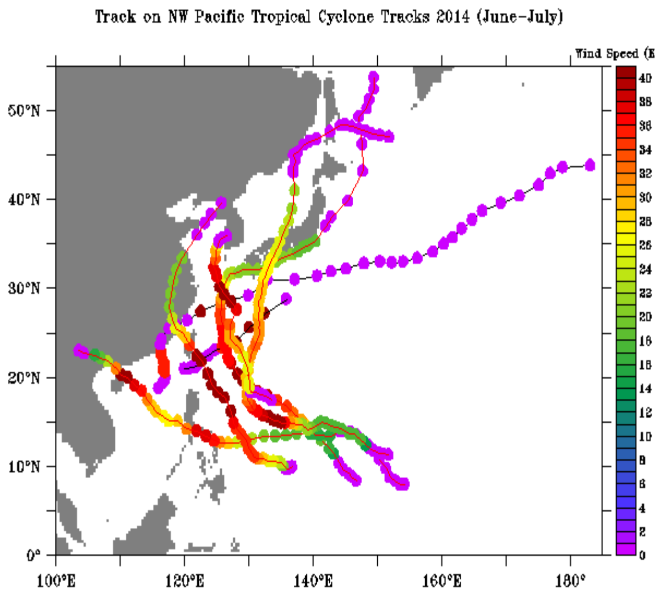


Fig 2.15: Observed tracks of the Typhoon formed over northwest Pacific during June and July month of 2014. Tracks of typhoons formed in the month of June represent in black colour and red for July. (Data Source: Best track data JMA)

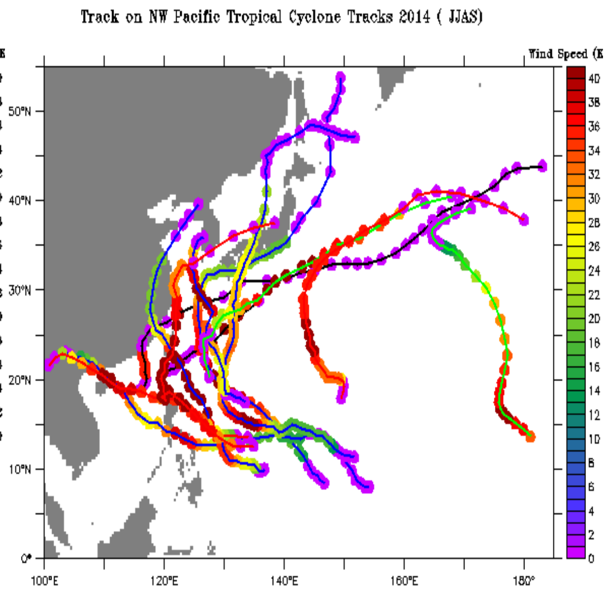


Fig 2.16: Observed tracks of the Typhoon formed over northwest Pacific during 2014 monsoon season. The typhoons formed in each month is shown in different colours, black (June), blue (July), green (August) and red (September). (Data Source: Best track data JMA)

The deficiency was also caused by the above normal convective activity over tropical west Pacific associated with the above normal Typhoon activity in the northwest Pacific as show in Fig.2.15. The tracks of typhoons formed over northwest Pacific during June to July is shown in Fig.2.15 and during the monsoon season is shown in Fig.2.16. Seven typhoons were formed during June and July together against the normal of 5.3 typhoons. In the subsequent months there were one system in August and six systems formed September, against the normal number of 5.9 and 4.8 respectively.

The active/break spells of Indian Summer Monsoon Rainfall is modulated by Madden–Julian oscillation (MJO), one of the dominant modes of tropical variability on intraseasonal time scales (Madden and Julian 1972). Previous studies have reported the significant role of MJO on intraseasonal variability of ISMR (e.g. Pai et al 2011). The two dimensional (RMM1, RMM2) phase diagram (Wheeler and Hendon (2004) daily location of the MJO during the 2014 monsoon season is shown in Fig.2.17. It is seen that in the beginning of the monsoon season MJO activity was over Indian Ocean (phase 2& 3) which then got propagated to Maritime continent (phase 4 & 5). MJO activity which was weak in the beginning of July got strengthen and moved initially over Maritime continent (phase 4 & 5) and then over Pacific Ocean (Phase 6 &7). During August, MJO activity was mostly over Indian Ocean (Phase 1 &2) and unfavourable for active monsoon conditions. The prolonged break monsoon spell in the middle of August (Fig.2.14) can be associated to the unfavourable phases of Madden Julian Oscillation (MJO). The rainfall anomaly pattern over the country in the intra seasonal scale during the monsoon season is strongly associated with the strength and phases of the MJO (Pai et al. 2011). Pai et al. (2011) observed that MJO Phases of 4, 5 and 6 are favorable for normal to active Indian summer monsoon rainfall. The good rainfall activity in the later part of the July may be associated with the favorable phase of MJO activity.

During the season, 3 Low Pressure Systems (LPS) formed over Arabian Sea and 10 LPS formed over Bay of Bengal (Figures 1.5 &1.6). One of the LPS formed over Arabian Sea developed into cyclone in June and two of the LPS formed over Bay of Bengal developed into depressions; one each during July and August. The LPS formed over the head Bay of Bengal were followed a westward path (similar to its climatology) along monsoon trough region over Indian landmass.

Fig.2.18 shows the dates of synoptic scale systems (lows in blue colour, Depressions in red and Cyclone in Orange colour) formed over North Indian Ocean during 2014 monsoon season and various MJO phase are shown in different shades of purple (phase 1 & 2) and green(phase 5 & 6). Light colour indicates amplitude is weak and dark shade indicates MJO active. It is seen that during July, LPS formation was associated with the MJO phases 5 and 6 and they had relatively longer life spans. The 3 LPS formed during August were short lived and also notice that the MJO phase during most part of August was 1 or 2. During September when the MJO was mostly weak, the life span of the low pressure systems were longer.

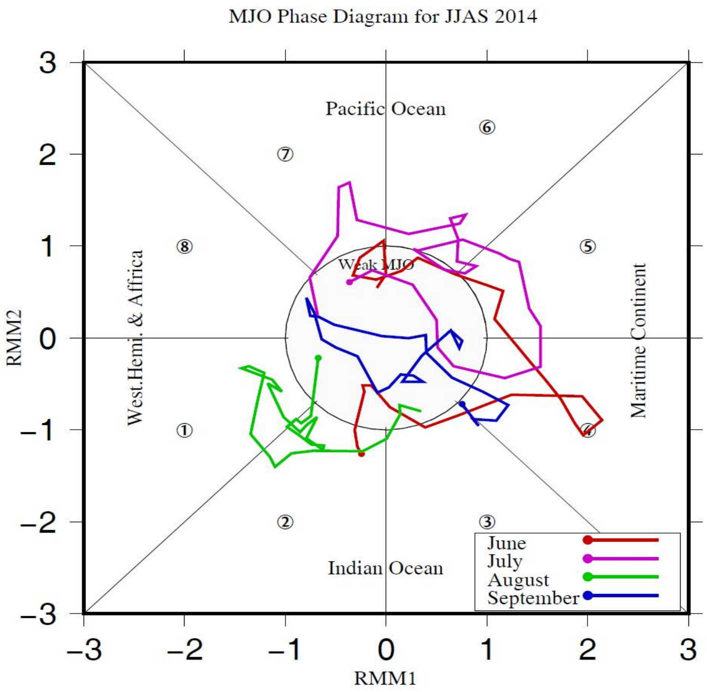


Fig. 2.17: The Phase-space diagram depicts MJO index during the 2014 monsoon season (June to September). The encircle number inside 8 sectors of the diagram represent 8 Phases of MJO in the diagram. For each of the months different colors have been used.

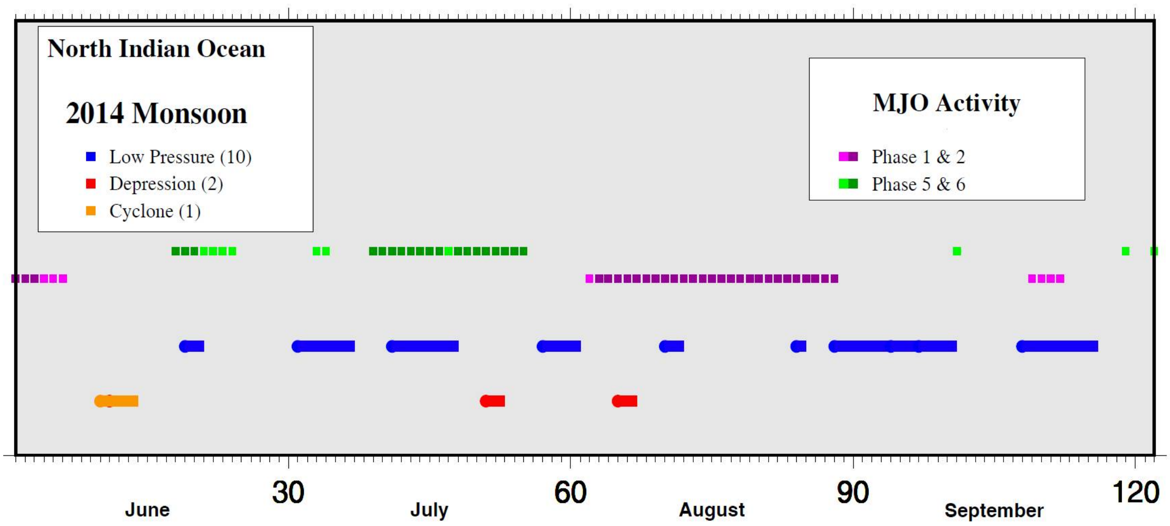


Fig 2.18: The dates of synoptic scale systems (Lows in blue colour, Depressions in Red and Cyclone in orange) formed over North Indian Ocean during 2014 monsoon season and various MJO phase are shown in different shades of purple (phase 1 &2) and green (phase 5 &6). Light colour indicates amplitude is weak and dark shade indicates MJO is active.

2.6. Conclusions

The country received near normal rainfall (94% of LPA) during the period July to September period. But due to the large rainfall deficiency in June, the 2014 season rainfall over the country as a whole (88% of LPA) ended as deficient (<90% of LPA).The deficiency in the season rainfall during 2014 was mainly caused by the large rainfall deficiency during June. This large deficiency during June was caused by the borderline like El Niño warming trend conditions prevailed in the east Pacific and associated large scale descending motion over Indian region. Another factor was negative IOD index in the Indian Ocean during the first half of the season. The deficiency in July may be caused by above normal typhoon activity in the tropical northwest pacific. The prolonged break like situation in August may be due to unfavorable phases of MJO activity. The favorable factors for good rainfall in the second half of the season were sudden cooling of SSTs in the equatorial Pacific in the middle of the monsoon season, formation of good number of synoptic scale low pressure systems and favorable MJO activity.

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3

HEAVY RAINFALL OVER JAMMU & KASHMIR DURING 3-6 SEPTEMBER, 2014 LEADING TO FLOOD CONDITION

Sonam Lotus

3.1 Introduction

The state of J&K occupies the northern most part of India and is broadly divided in three major regions, viz. Jammu, Kashmir and Ladakh. Each of these region have different climatic zones owing to its complex geographical features because of which it is home to various disastrous weather events like flood, flash flood, landslide, avalanche, cloud burst etc. Jammu regions receive over 70% rainfall during SW monsoon, and experiences disastrous weather events mostly flood and flash flood (in hilly areas) and cloud bursts on some occasions. Although Ladakh and Kashmir receive lesser monsoon rainfall but monsoon winds when interact with western disturbance/ trough(eastward moving systems) creates disastrous weather events over this region .The Leh cloud burst on 6th Aug. 2010 and this year's Flood during 1st week of Sept in Kashmir are the recent example of this interaction. During monsoon season(June to September), Jammu receives 570 mm of rainfall which is 73% of annual total where as Srinagar and Leh receives 202 mm & 43 mm of rainfall which is 29% & 40% of annual total respectively. Kashmir Valley is surrounded by mountains through which a silent river having a length of about 225 kms outfall at Salambad, Uri. (I&FC, J&K govt.). Every monsoon season leaves behind certain important facets for which it becomes known for further studies (Kamaljit et al). This year's also, it caused havoc at many places spread over many parts of India as is shown in Fig.1.7.

3.1.1 Major river systems in Kashmir

Lidder, Bringi, Vishow and Rambiara are major tributaries of the River Jhelum in South Kashmir, besides Aripath, Sandran, Veth-Vethroo. Nallahs like Tulbran, Sukhnag, Ferozpora, Sindh contribute considerable discharge to the river in central Kashmir and finally the discharge from the catchment Ningli, Erin, Mudhumati, Pohru, Khurshi, Vij and Dakil join the River Jhelum in North Kashmir .

3.1.2 History of Floods in J &K

Flood is not new in J&K. Every year, flood of various magnitudes occurs in many parts of the state. In Kashmir floods have occurred at regular intervals in the past like 1903, 1905, 1909, 1928, 1948, 1950, 1951, 1953, 1954, 1956, 1957, 1959, 1962, 1963, 1964, 1969, 1972, 1973, 1976, 1986, 1992, 1995, 1996, 2006 and 2014 (I&FC, J&K govt.). Out of all these floods, the floods of 1903 & 1959 and 2014 are considered to be the most severe and 2014 flood being the most destructive till date as the magnitude of the flood was such that rescue and relief operations was beyond the capacity of the state govt. and Army, Navy, Air force, NDRF etc. were called in for the purposes and the flood water lasted for 10-12 days.

3.2 Chief Features of Monsoon 2014 over J&K

Southwest monsoon set over entire Jammu and Kashmir on 1st July 2014 on its normal date and withdrew from the entire state during 28th-1st October 2014 , a delay of 12-15 day from its normal withdrawal date i.e. 15th Sept. For the state as a whole, the monsoon (June to September) rainfall remained above normal (+22). July and August received deficient rainfall. However, due to interaction of strong monsoon and mid-latitude system during 1st week of Sept. the state received continuous widespread rainfall with heavy to very heavy fall during 1st week of Sept (Fig.3.1) which balanced the deficient rainfall. The district level daily 24hrs accumulated rainfall from 1st to 6th Sept. 2014 is shown in Fig.3.2 (a-f).

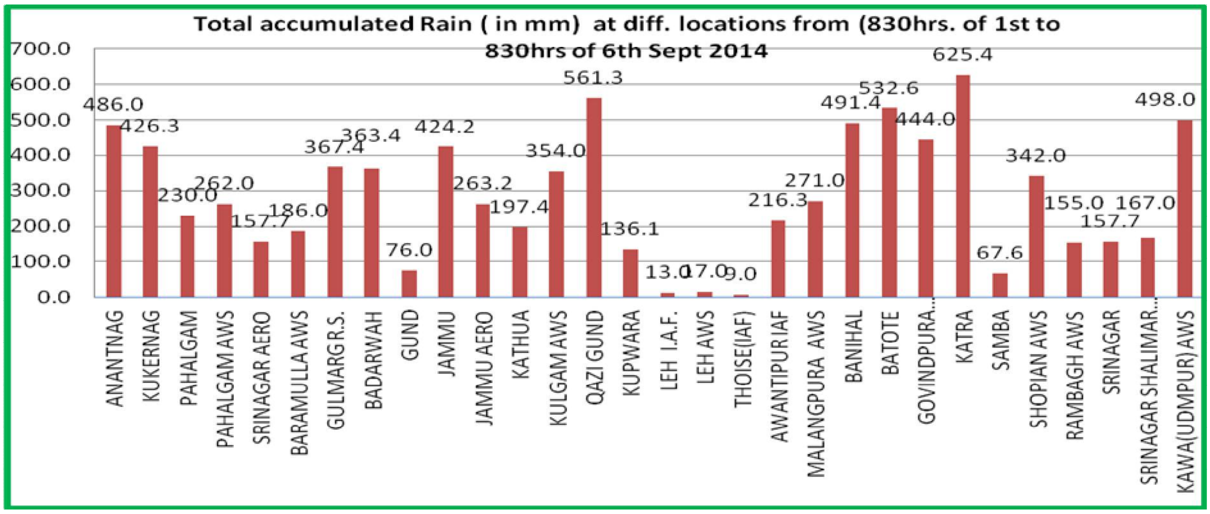


Fig.3.1: Daily rainfall from 1st to 6th Sept. 2014.

The formation of the well marked low pressure area over the Bay of Bengal and its west-northwestwards movement across the central parts of India along with the formation of the low pressure area (2nd - 4th Sept.) over Saurashtra & Kutch and adjoining northeast Arabian Sea revived the rainfall activity over central and northwest India. This well marked low pressure area took a more northward course from 4th Sept and thereafter interacted with the trough in the mid-latitude westerlies in the lower troposphere levels, caused heavy rainfall resulting in severe floods in hilly areas of Jammu (Rajouri, Doda, Kistwar, Reasi etc) and many districts of south & Central Kashmir (Shopian, Kulgam, Pulwama, Anantnag,etc.). This also resulted in the complete submergence of Srinagar city where flood water touched above 20 feet at some places as per as per official sources. As per official report of Rajya Sabha, 282 people have died 6.48 lakh hectare of crop area affected and 2.53 lakh houses have been reported damaged due to the floods, adding 61,326 cattle were also killed. The agriculture and horticulture sector, according to government sources, bore the maximum brunt of the floods in the state particularly in Kashmir. Besides, the major government departments suffered heavy infrastructure losses.

3.2.1 Rainfall Climatology of Kashmir during September

Climatologically, September is not a rainy season for Kashmir. The average monthly rainfall of Srinagar city based on data from 1901 to 2014 in Sept. is only 33mm. The highest monthly rainfall recorded in September at Srinagar is 184.8mm during 2014 thus breaking the previous records of 180.8mm in 1909 and 141.9mm in 1928. There has been only 9 years in a span of 114 years when Srinagar received monthly rainfall of over 100mm as shown in Fig.3.3.

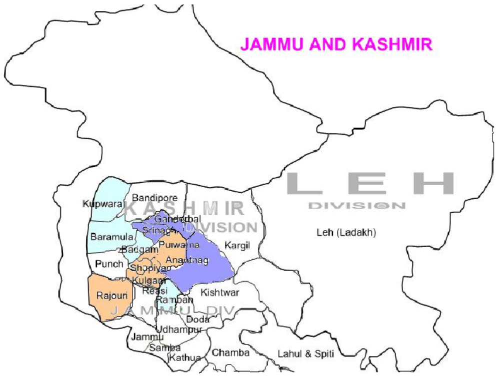


Fig. 3.2(a): 1st Sept

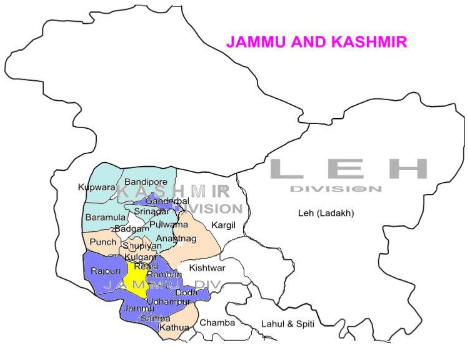


Fig. 3.2(b): 2nd Sept

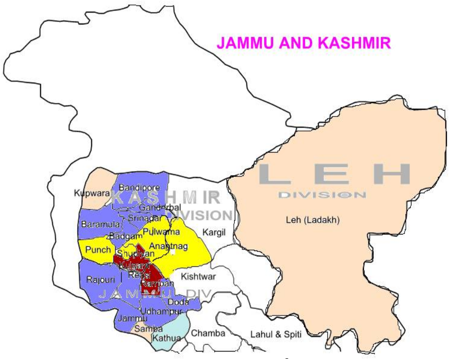


Fig. 3.2(c): 3rd Sept

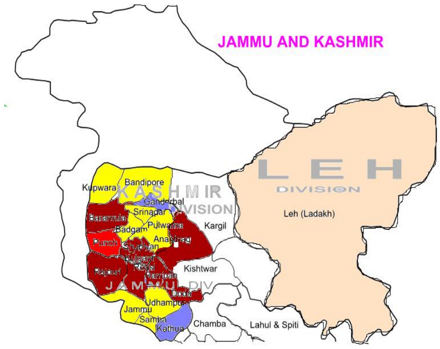


Fig. 3.2(d): 4th Sept

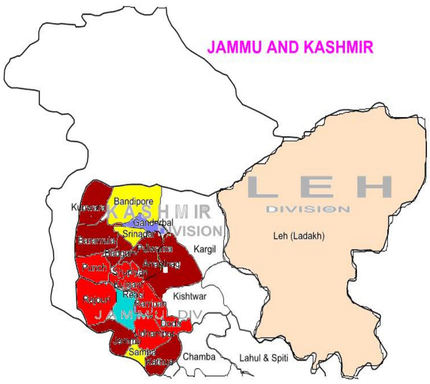


Fig.3.2(e): 5th Sept

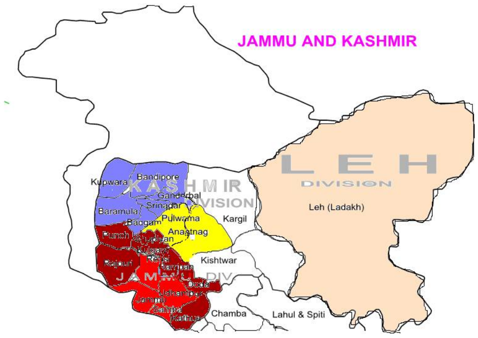


Fig. 3.2(f): 6th Sept

Colour Legends

Very Light (0.1 to 2.4 mm)	Heavy (64.5 to 124.4mm)
Very Light (2.5 to 7,.5) mm	Very Heavy (124.5 to 244.4
Moderate (7.6 to 35.5 mm)	Extremely Heavy (More than 244.5mm) 244244.5mm)244.5mm)
Rather Heavy (35.6 to 64.4mm)	

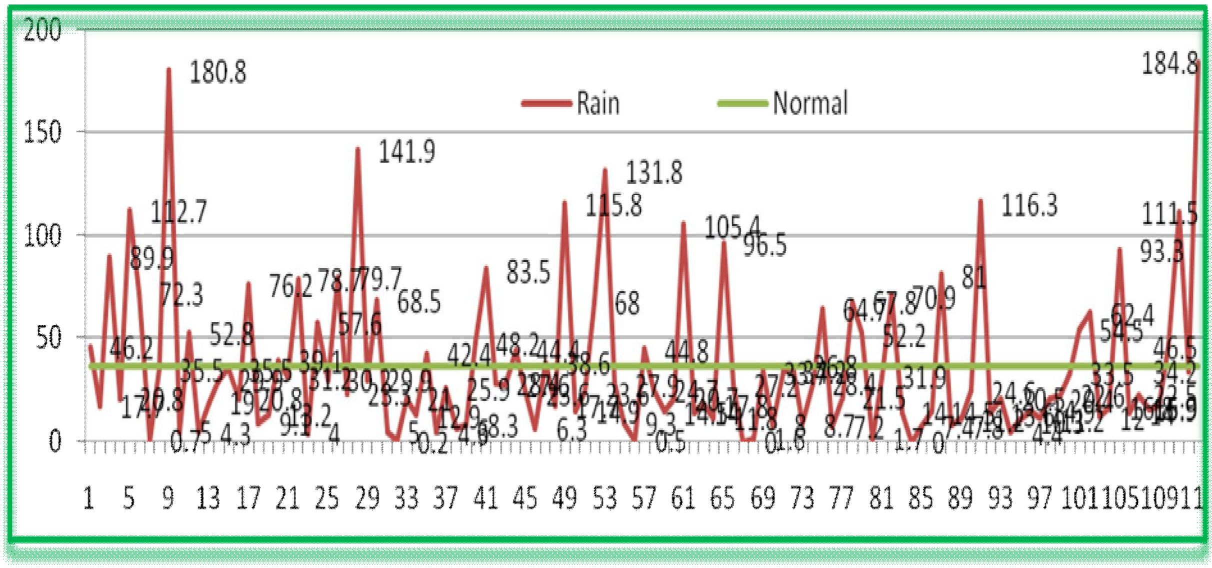


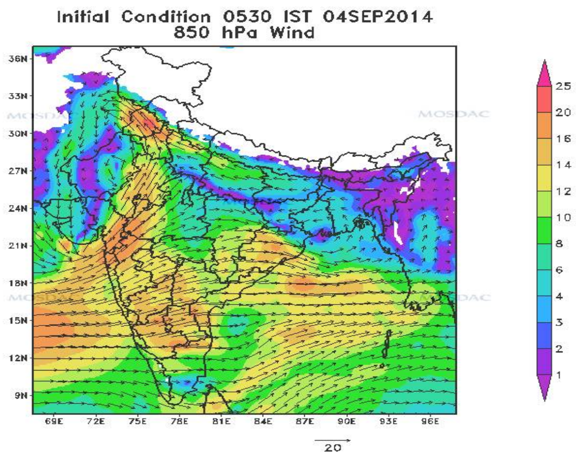
Fig.3.3. Monthly averaged rainfall of Srinagar for September (1901-2014).

3.3 Chief Synoptic Features on 3-5th Sept. 2014

On 3rd September, the southwest Monsoon has been vigorous over Jammu & Kashmir and active over Odisha, east Rajasthan, Madhya Pradesh, Gujarat Region and coastal Karnataka. A low pressure area lies over southeast Rajasthan and neighborhood. Associated cyclonic circulation extends up to 3.6 kms a.s.l. There was another low pressure area over Saurashtra & Kutch and adjoining northeast Arabian Sea and the associated cyclonic circulation extends up to mid tropospheric levels. The axis of monsoon trough at mean sea level passes through centre of low pressure area over Saurashtra & Kutch and adjoining northeast Arabian Sea, centre of low pressure area over southeast Rajasthan and neighborhood and thence southeastwards to North Andaman sea across northwest and east central Bay of Bengal. It extends up to 3.1 kms a.s.l. passing across the same region. There was an off shore trough at mean sea level from south Gujarat coast to Lakshadweep as well. There was a western disturbance as an upper air cyclonic circulation between 3.1 & 4.5 kms a.s.l. that lies over Jammu & Kashmir and neighborhood. Another fresh western disturbance as a trough in mid and upper tropospheric westerlies runs roughly along 64^{O}E to the north of 28^{O}N.

On 4th September, a low pressure area lies over west Rajasthan and neighborhood Fig. 3.4 (a-b) & Fig.3.5(a). Associated cyclonic circulation extends up to 3.1 kms a.s.l. The axis of monsoon trough at mean sea level passes through centre of low pressure area over west Rajasthan and neighborhood and thence southeastwards to east central Bay of Bengal. There was cyclonic circulation over northwest Bay of Bengal and neighborhood which extended up to mid tropospheric levels. The western disturbance as a trough in mid and upper tropospheric westerlies with its axis at 5.8 kms a.s.l. running roughly along 70^{0}E to the north of 28^{0}N was observed (Fig. 3.5(b)). There was continuous moisture feeding from the Arabian Sea as can be seen from the satellite imageries Fig. 3.6 (a) & Fig. 3.6(b).

Winds at different levels



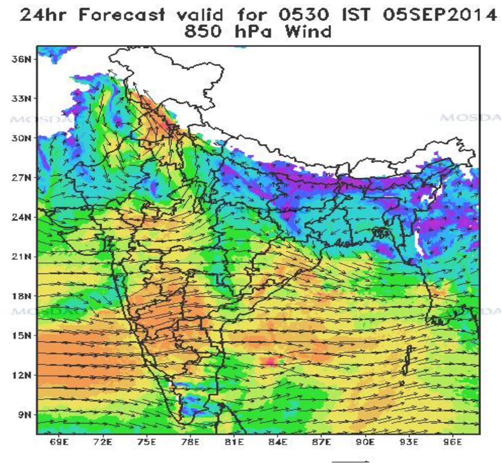
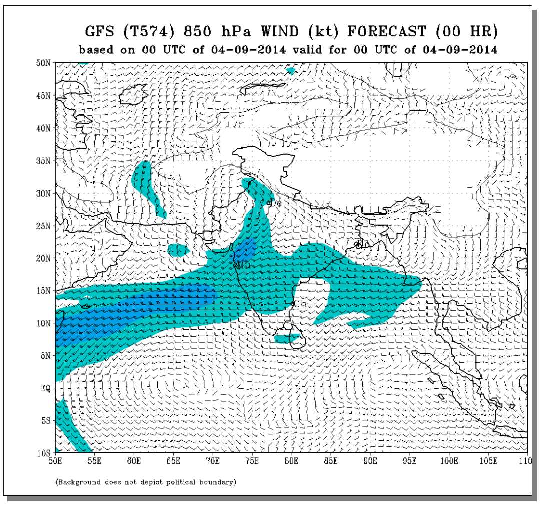


Fig.3.4(a): Wind at 850 hPa level on 4th

Fig.3.4(b) 24hr. forecast Wind at 850 hPa level



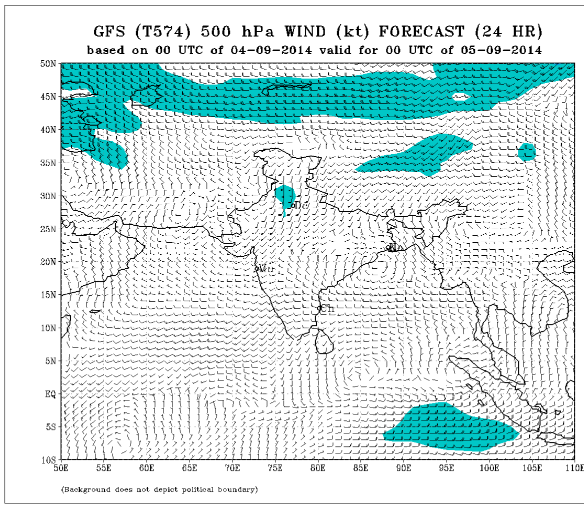


Fig.3.5(a): Low pressure area over west to the north of Lat. 28^{0} N.Rajasthan

Fig.3.5(b): Westerly Trough along Long.70^{0}E

Satellite Images at 03:15Z & 08:15Z showing moisture feeding from Arabian Sea and Bay of Bengal

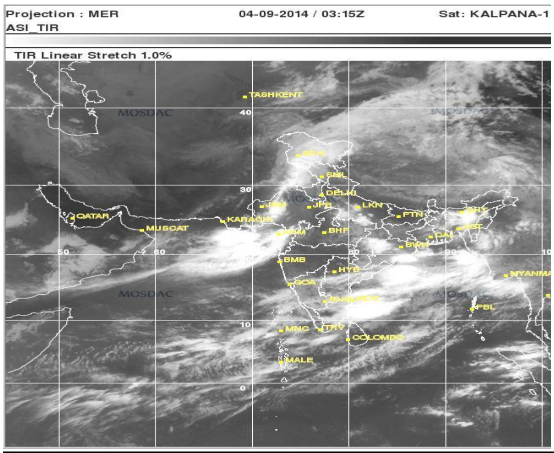


Fig. 3.6(a): Satellite Images at 03:15Z

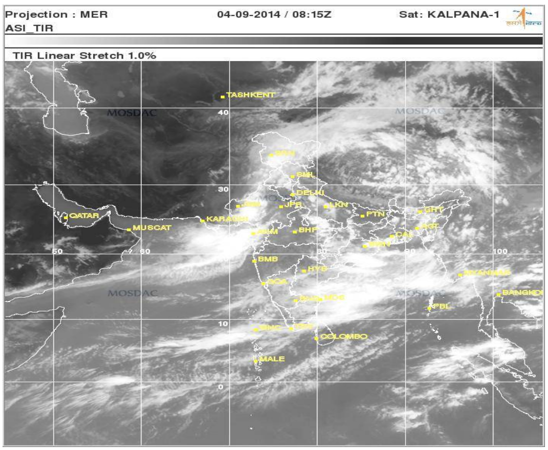


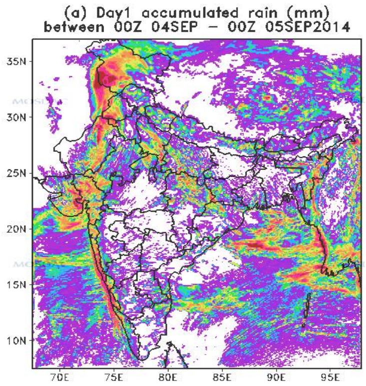
Fig.3.6(b): Satellite Images at 08:15Z

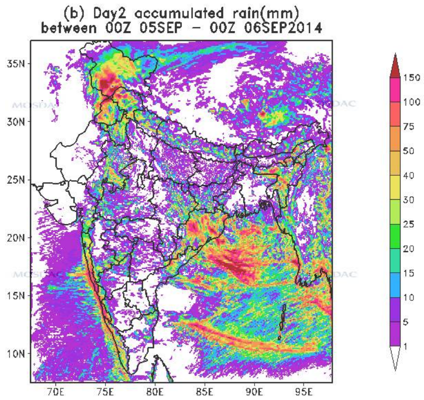
On 5th September, the southwest Monsoon has been vigorous over Punjab, Jammu & Kashmir, west Rajasthan and Gujarat State and active over Odisha, west Uttar Pradesh, Haryana, east Rajasthan, Konkan & Goa and coastal Karnataka. The low pressure area over west Rajasthan and neighborhood lies as a well-marked low pressure area over northwest Rajasthan and adjoining areas of Haryana and Punjab. Associated cyclonic circulation extends up to mid tropospheric levels. The axis of monsoon trough at mean sea level passes through the centre of well-marked low pressure area over northwest Rajasthan and neighborhood. The other low pressure area over Kutch and neighborhood has become less marked. However associated cyclonic circulation extending up to 3.1 kms a.s.l. persists over Kutch and adjoining south Pakistan. The western disturbance as a trough in mid and upper tropospheric westerlies with its axis at 5.8 kms a.s.l. runs roughly along 74^{O}E to the north of 28^{O}N.

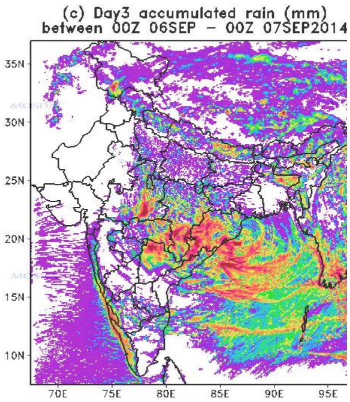
3.3.4 Weather Warning issued by MC Srinagar on 3rd Sept. 2014

A Western Disturbance over J&K and its interaction with monsoon currents over North West India is likely to affect the state from today the 3rd of Sept. (Wednesday) to 6th Sept 2014 (Saturday) with occasional gaps. Under the influence of this weather system, moderate to heavy rainfall /Thundershower and snowfall over higher reaches will occur at most places in Kashmir & Jammu divisions and at a few places in Ladakh region particularly along Srinagar-Jammu, Srinagar-Leh, and Leh-Manali Road etc. Some places may receive heavy to very heavy rain/shower during this period. This weather condition may trigger landslide and flash flood in vulnerable areas of the state. Above weather system may disrupt surface and air transport during these days.

Some NWP out puts(forecasted accumulated rain)

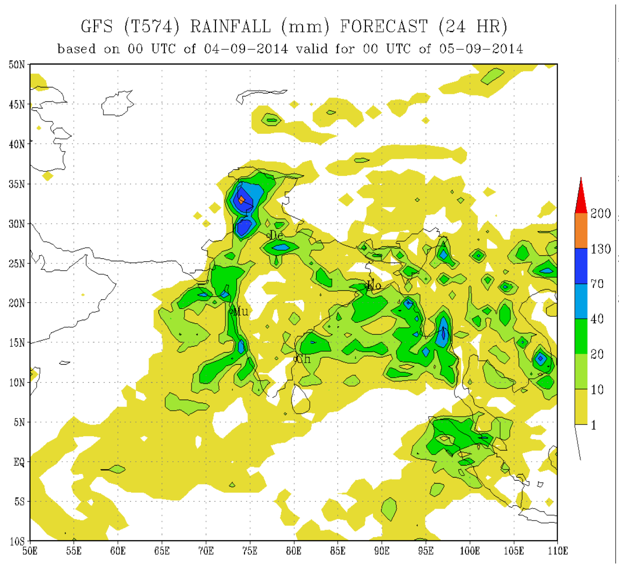






(Source: www.mosdac.gov.in)

Fig.3.7(a): Day-1 **Fig.3.7(b):** Day-2 **Fig.3.7(c):** Day-3



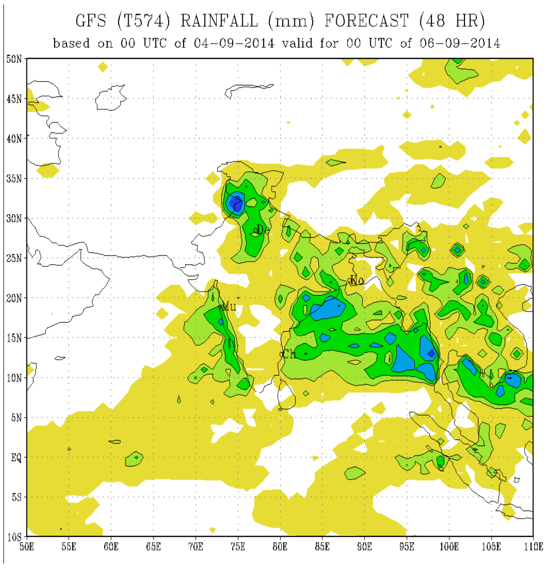


Fig. 3.8(a): Day-1 **Fig. 3.8(b):** Day-2

(Source: www.imd.gov.in)

3.4 Rainfall distribution

3.4.1 Station wise rainfall distribution

Table-3.1: Daily 24hrs rainfall in (mm) from (AWS & manual observatories) recorded at various locations of J&K measured at 03UTC / 8:30hrs IST.

Sr. No.	STATIONS	Dates September 2014						
		1	2	3	4	5	6	7
1	ANANTNAG	10.6	6.4	58.4	180.0	150.2	80.4	20.2
2	ANANTNAG AWS	7.0	6.0	57.0	-	-	-	-
3	KUKERNAG	0.6	10.5	57.7	119.4	149.5	88.6	43.3
4	PAHALGAM	33.4	3.2	40.2	58.6	47.2	47.4	24.2
5	PAHALGAM AWS	41.0	4.0	47.0	68.0	52.0	50.0	31.0
6	SRINAGAR AERO	2.2	0.0	22.4	53.9	69.6	22.8	26.2
7	BARAMULLA AWS	1.0	0.0	8.0	65.0	84.0	28.0	1.0
8	GULMARG R.S.	0.0	0.6	34.0	106.6	128.0	38.2	10.2
9	BADARWAH	0.0	13.4	29.2	81.4	138.8	100.6	0.6
10	GUND	12.6	8.2	22.6	32.6	33.6	26.8	24.6
11	JAMMU	0.0	56.2	9.0	39.3	101.4	218.3	77.0
12	JAMMU AERO	0.0	8.0	7.2	44.4	79.2	203.6	21.6
13	KATHUA	0.0	2.8	1.4	33.8	65.6	93.8	0.0
14	KULGAM AWS	1.0	7.0	49.0	82.0	138.0	77.0	48.0
15	QAZI GUND	8.2	7.3	80.4	156.7	206.0	102.7	56.1
16	KUPWARA	2.3	1.8	2.8	45.6	68.2	15.4	1.1
17	LEH I.A.F.	0.0	0.0	8.6	4.4	0.2	0.0	0.0
18	LEH AWS	0.0	0.0	11.0	0.0	0.0	0.0	0.0
19	THOISE(IAF)	0.0	0.0	0.0	9.0	11.7	14.3	0.4
20	POONCH	**00**	**5**	**51**	**161**	**138**	**55**	**6**
21	AWANTIPUR IAF	7.2	1.0	39.1	51.0	140.4	67.0	47.0
22	MALANGPURA AWS	4.0	1.0	37.0	61.0	102.0	66.0	45.0

23	RAJOURI	3.0	21.4	20.2	107.3	194.2	68.3	13.0
24	BANIHAL	0.4	15.6	93.7	106.8	188.8	86.1	53.8
25	BATOTE	0.2	31.4	67.8	102.4	207.8	123.0	38.0
26	GOVINDPURA AWS	0.0	17.0	52.0	71.0	202.0	102.0	27.0
27	KATRA	0.0	47.6	21.8	67.4	279.2	209.4	0.0
28	SAMBA	0.0	14.2	6.0	47.4	51.7	164.4	29.9
29	SHOPIAN AWS	3.0	4.0	42.0	68.0	140.0	85.0	54.0
30	RAMBAGH AWS	14.0	1.0	18.0	51.0	52.0	19.0	flood
31	SHALIMAR AGRO	14.8	0.0	26.2	53.9	49.0	21.4	21.8
32	SRINAGAR	13.6	0.4	20.0	51.8	52.4	19.5	21.1
33	SRINAGAR AGRO AWS	15.0	0.0	26.0	54.0	49.0	23.0	23.0
34	KAWA AWS	0.0	8.0	14.0	64.0	152.0	260.0	-
35	UDHAMPUR (IAF)	0.0	8.0	12.8	51.0	163.0	191.3	152.0

Heavy rain **Very heavy rain** **Extremely heavy rain**

As can be seen from the Table-3.1, light rain started from 1st Sept. and increased gradually till 2nd and from the early morning of 3rd moderate to heavy rain reported from most of the rain gauges at widespread places of Jammu & Kashmir region and the rainfall of same magnitude continued till 6th evening.

3.4.2. District wise rainfall distribution:

Table-3.2: Mean 24hrs. rainfall in (mm) from (AWS & manual observatories) recorded at various districts of J&K from 1st to 7th Sept measured at 03UTC / 8:30hrs IST.

Sr.No	DISTRICT(J&K)	Dates September 2014							
		1	2	3	4	5	6	7	Total
1	ANANTNAG	19.2	6.0	52.1	85.2	79.8	53.3	23.7	319.3
2	BADGAM	2.2	0.0	22.4	53.9	69.6	22.8	26.2	197.1
3	BARAMULA	0.5	0.3	21.0	85.8	106.0	33.1	5.6	252.3
4	DODA	0.0	13.4	29.2	81.4	138.8	100.6	0.6	364.0
5	GANDERBAL	12.6	8.2	22.6	32.6	33.6	26.8	24.6	161.0
6	JAMMU	0.0	32.1	8.1	41.9	90.3	211.0	49.3	432.6
7	KATHUA	0.0	2.8	1.4	33.8	65.6	93.8	0.0	197.4
8	KULGAM	4.6	7.2	64.7	119.4	172.0	89.9	52.1	509.7
9	KUPWARA	2.3	1.8	2.8	45.6	68.2	15.4	1.1	137.2
10	(LEH)	0.0	0.0	6.5	4.5	4.0	4.8	0.1	19.9
11	POONCH	00	5	51	161	138	55	6	416
12	PULWAMA	4.1	0.7	36.7	54.7	80.8	44.3	30.7	251.9
13	RAJOURI	3.0	21.4	20.2	107.3	194.2	68.3	13.0	427.4
14	RAMBAN	0.2	21.3	71.2	93.4	199.5	103.7	39.6	528.9
15	REASI	0.0	47.6	21.8	67.4	279.2	209.4	0.0	625.4
16	SAMBA	0.0	14.2	6.0	47.4	51.7	164.4	29.9	313.6
17	SHOPIAN AWS	3.0	4.0	42.0	68.0	140.0	85.0	54.0	396.0
18	SRINAGAR	14.4	0.4	22.6	52.7	50.6	20.7	16.5	177.7
19	UDHAMPUR	0.0	8.0	13.4	57.5	157.5	225.7	76.0	538.1

Heavy rain   Very heavy rain   extremely heavy rain

3.5 Probable Causes of Severe Flood in J&K

No doubt, the monthly rainfall this year for Sept. broke all previous record of 114 years available data of IMD, but it is not only the rainfall that led to flood and submergence of whole city of Srinagar, the centre of state's administration. Different experts have different opinion. In recent report Romshoo (2014), a glaciologist writes that the valley's flood vulnerability has worsened during last few decades as most of the wetlands that used to act as sponge during flood have been urbanized and converted into concrete landscape in the entire valley and most of the valley's wetlands and water bodies are fighting a losing battle for their survival. These wetlands have got adversely affected due to their encroachment and seasonal changes in precipitation and run off due to climate change coupled with unplanned urbanization and human greed. Apart from this, concrete structures have come up in areas which used to be the flood plains.

Rainfall started from 1st Sept and continued till 6th with most stations reporting heavy rainfall on consecutive 3 days 4-6th. This coupled with snow-melt water led to surge in water level of the main Kashmir's river Jhelum leading to flood. Some experts also say that there has been several cloud bursts at various places particularly on higher reaches of valley, but in there is no instrumental evidence to support these theories.

3.6 Conclusions

The Monsoon 2014 over J&K will be known for the severe flooding at many parts of Jammu and Kashmir region. As per official report of Rajya Sabha, 282 people have died, 6.48 lakh hectare of crop area affected and 2.53 lakh houses have been reported damaged due to the floods, adding 61,326 cattle were also killed (Daily Greater Jammu). There was flash flood in Chenab valley of Jammu region and flood at many places of Kashmir region. Both Jammu and Kashmir regions were affected by flood but the inundation was more at Kashmir valley. Of the total 282 dead, approx. 230 was in Jammu region and rest in Kashmir.

1. The floods and associated huge casualty and damage occurred over Jammu & Kashmir during 1st week of Sept., resulted from the interaction between a monsoon low and a trough in the westerlies.

2. The wind analysis at 850 hpa and 700hpa levels shows that the continued heavy rainfall were due to interaction of NWN moving monsoon currents and the eastward moving mid-latitude westerly troughs.

3. Analysis of wind anomalies from SAC's model shows continuous moisture feeding from Arabian Sea. The impending heavy rainfall was well captured by models from SAC, Ahmedabad (www.mosdac.gov.in) and that of IMD's GFS only 24 hrs in advance as can be seen from

Fig.3.7(a-c) & Fig.3.8(a-b). However, most of the NWP model could predict the severity of this event much in advance i.e. 2 and more days in advance.

Acknowledgement :

The author is thankful to the Director General of Meteorology, IMD for providing the opportunity to write this article. The author also thanks the Deputy Director General of Meteorology, RMC, New Delhi for his constant encouragement. Thanks are also due to various other organizations like, SAC (ISRO), NCMRWF, NWP division of IMD, Prof. Shakil Romshoo of Kashmir University and Sh. Javaid Ahmad, Chief Engineer Irrigation & Flood control, J&K govt. for providing valuable information. The author also duly acknowledges the help of his colleagues Mr. Latif, Mr. Ajay and Mr. Rakesh.

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4

METEOROLOGICAL ANALYIS OF SHORT SPELL FLOODS OVER ODISHA AND BIHAR DURING THE SECOND HALF OF THE 2014 SOUTHWEST MONSOON

G. C. Debnath, G. K. Das and Devendra Pradhan

This chapter discusses the meteorological analysis of three instances of floods; in Odisha during 20-22 July & 1st week of August, 2014 and in Bihar during 14-16 August 2014.

4.1. Introduction

South west monsoon is the most spectacular feature of Indian economy .Its onset, activity during the season and its withdrawal are however, subject to variations to create floods and droughts over vast parts of the country. The variability of Indian summer monsoon rainfall (ISMR) with an epochal nature has been studied by various authors namely Joseph (1976), Mooley and Parthasarathy (1984), and Parthasarathy et al. (1994). Odisha and Bihar the meteorological sub-division of eastern India are influenced by different types of weather systems during monsoon. The cyclonic disturbances develops over northwest Bay of Bengal and adjoining sea areas play a significant role in the monsoon rainfall over Orissa. But Bihar gets more rain due to movement of monsoon trough towards foot hills and movement of monsoon systems north of its normal path.

4.2 Floods in North Odisha during 20-22 July 2014

Odisha faced first flood of the season during 20-22 July in North Odisha. This flood was associated with the formation of a low pressure area over northwest Bay of Bengal and adjoining area of Gangetic West Bengal (GWB) and Odisha on 20th July 2014 which was intensified into a land depression on 21st July over northeastern parts of Odisha and adjoining GWB (Fig. 4.1 and Fig. 4.2). North Odisha received heavy to very heavy rainfall along with extremely heavy rainfall during 20-22 July 2014. Continuous heavy rainfall caused flood in Baitarani River in North Odisha. Due to this flood, as per govt. report numbers of human and livestock causalities were 12 and 38 respectively. 29479 hectares of crop was also damaged.

4.3 Floods in Odisha during 1st week of August 2014

2nd flood in Odisha occurred in Baitarani, Brahmani and tributaries of Mahanadi in the 1st week of August 2014. This flood occurred due to formation Low pressure over North West Bay of Bengal and its intensification into a deep Depression during 3-6 August 2014 (Fig. 4.4 and Fig.4.5). This system spurred the vigorous monsoon conditions over the Indo -Gangetic plains (Fig.4.6). Odisha received very heavy rainfall to extremely heavy rainfall in the rivers catchments area leading to flood in this region. Due to this flood in river catchments there is a report of 32 human casualties, 149 livestock loss and 45953 house damage. Massive damage to public infrastructure like embankments and 367691 ha of crop damage have also been reported.

4.4 Floods in Bihar during 14-15 August 2014

During southwest monsoon 2014, Bihar faced moderate flood like situation during 14-15 August 2014. This flood was associated with the break monsoon synoptic situation. The low pressure area (9-11 Aug.) formed over North Bay of Bengal and its northwestwards movement and dissipation, led the monsoon trough to shift towards the foot hills of the Himalayas on 13th Aug (Fig. 4.7 and Fig. 4.8).

Due to such synoptic condition heavy to very heavy rainfall along with extremely heavy rainfall occurred in North Bihar and Nepal (Fig. 4.9) leading to flood situation in Bagmati River and Kosi River of Bihar resulted in wide inundation of the area but no major causalities.

4.5 Conclusions

i. During 2014 monsoon short spell flood over Odisha was due to formation of low/depression and its north west movement whereas Bihar experienced flood due to shift of monsoon trough towards foot hills.

ii. Deep depression caused very heavy to extremely heavy rainfall over larger part of Odisha as compared to Depression.

iii. The wind analysis at 850 hPa level indicates that the heavy rainfall over Odisha was due to movement of depression/deep depression towards WNW direction.

iv. Heavy rainfall over Bihar was due to shifting of monsoon trough towards foot hills.

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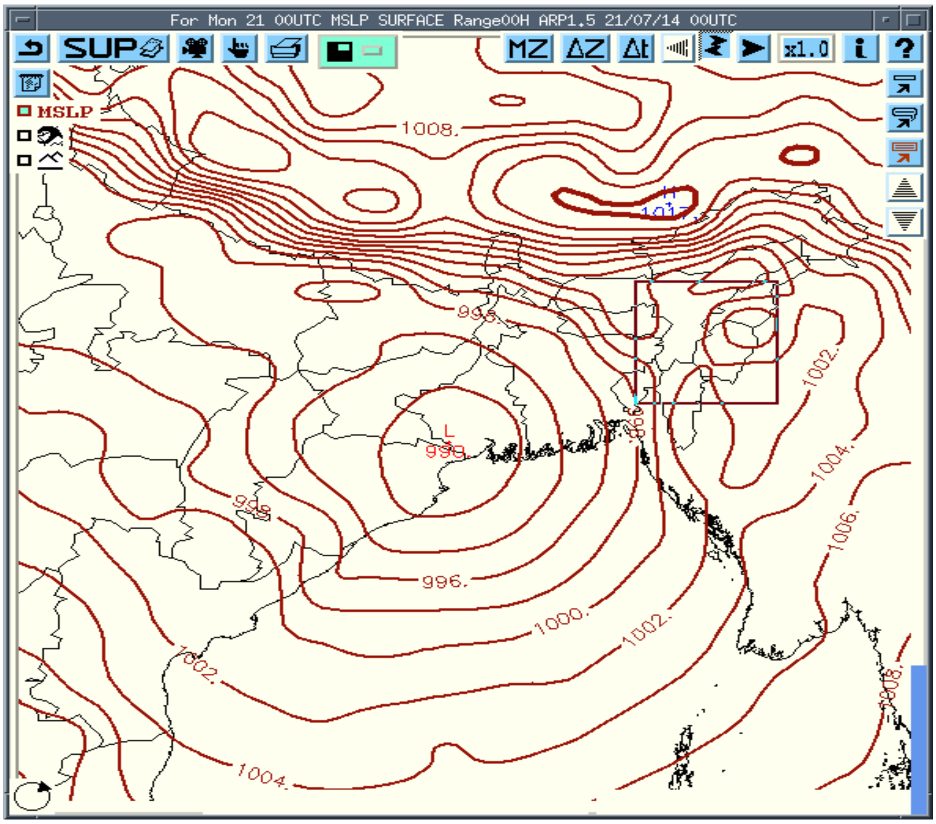


Fig. 4.1(a)

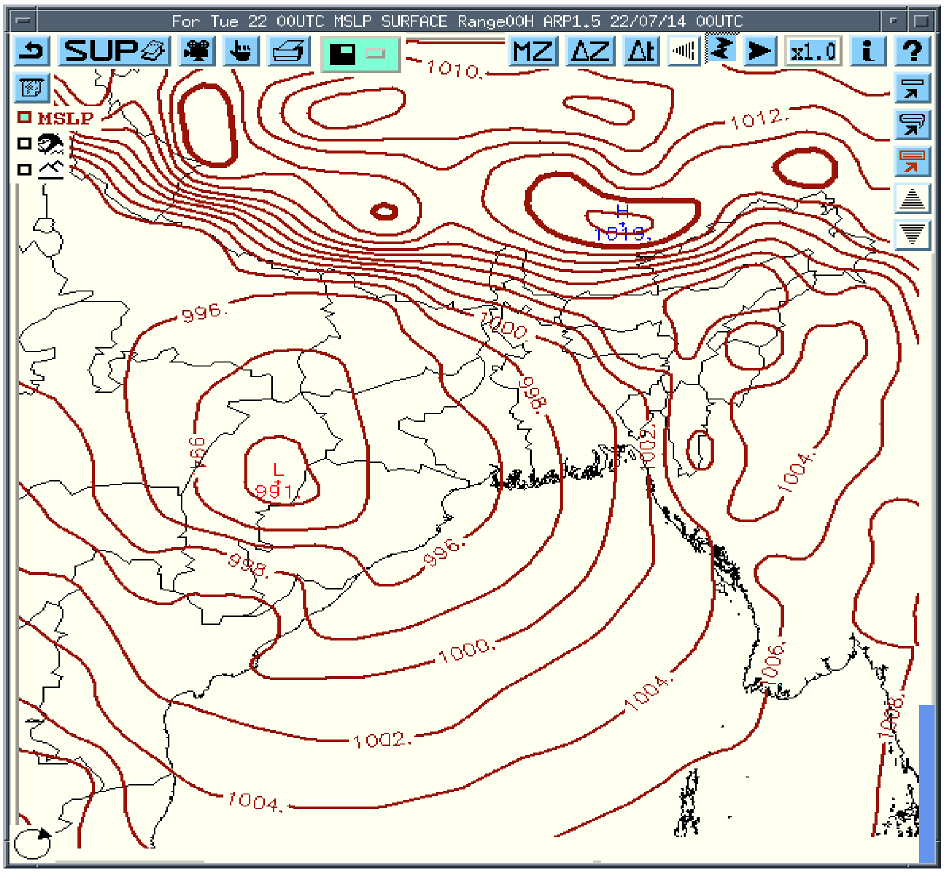


Fig. 4.1(b)

Fig. 4.1: MSLP during 21-22 July 2014.

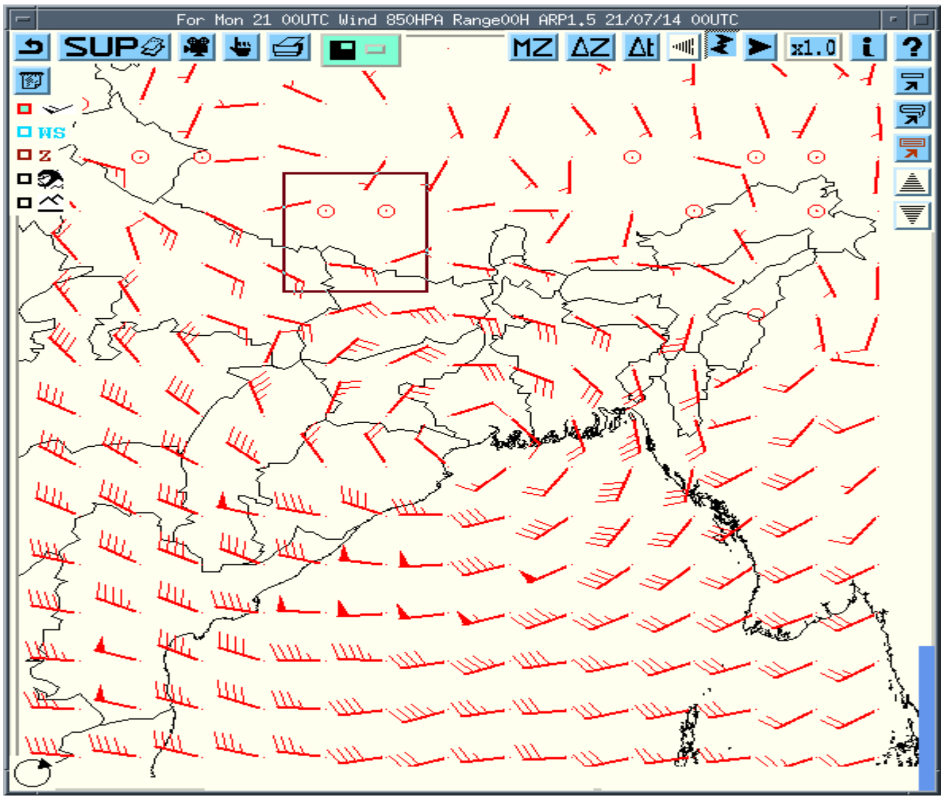


Fig.4.2(a)

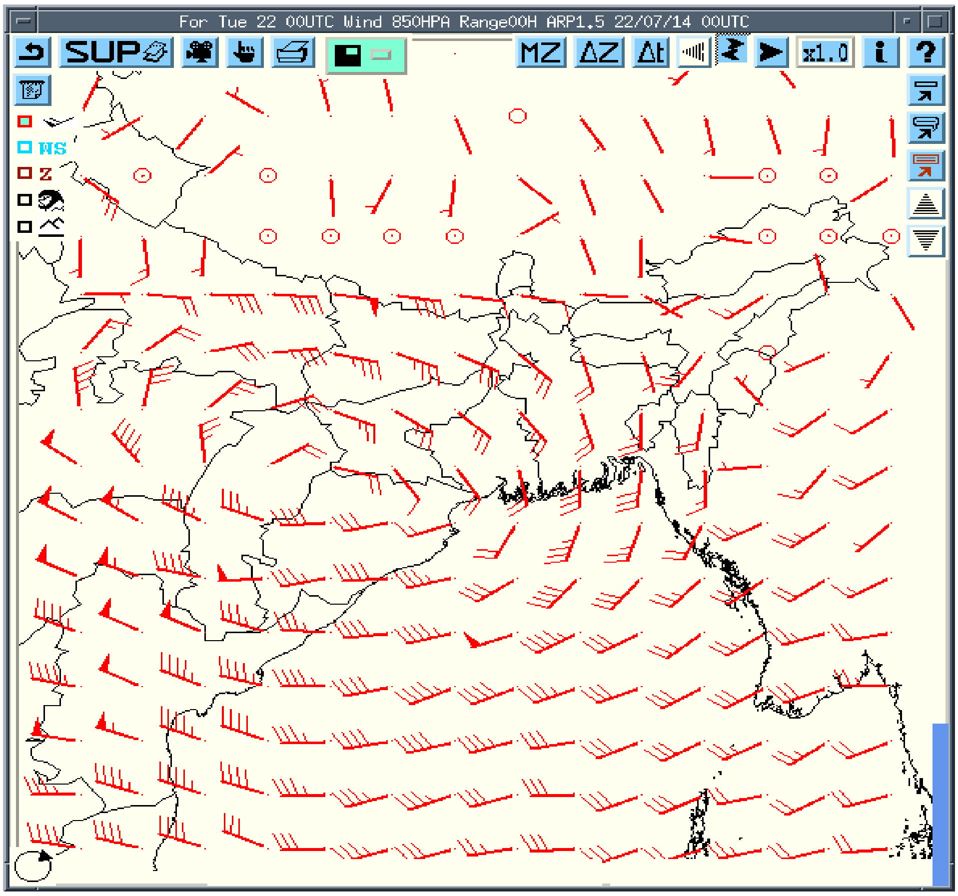


Fig. 4.2(b)

Fig.4.2: Wind at 850 hPa during 21-22 July 2014

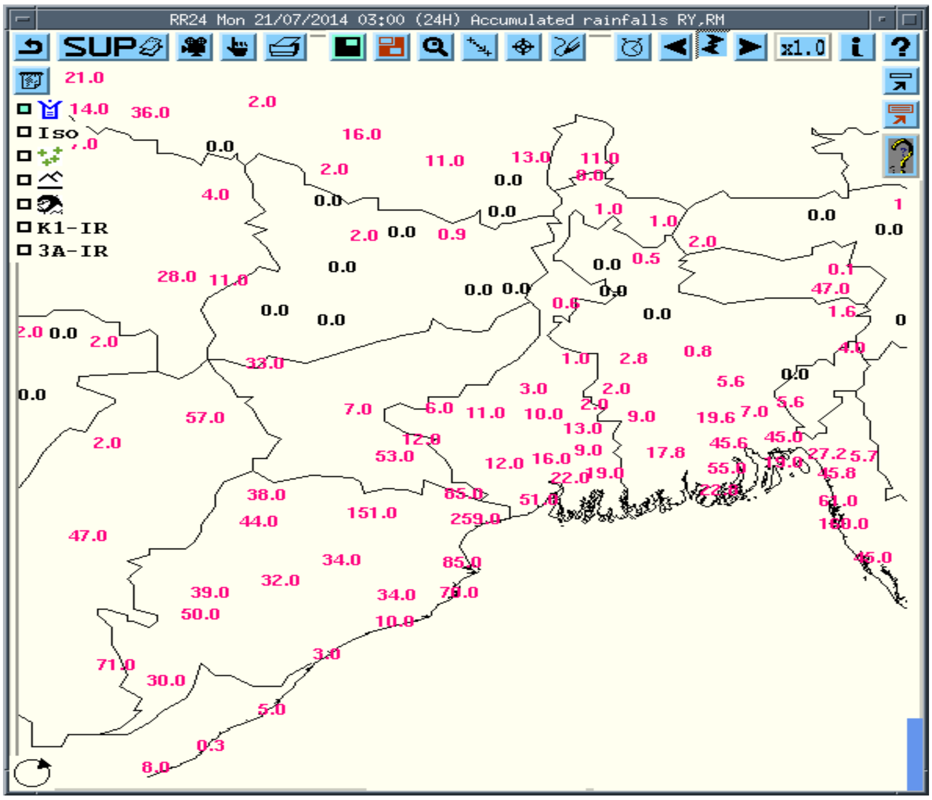


Fig. 4.3(a)

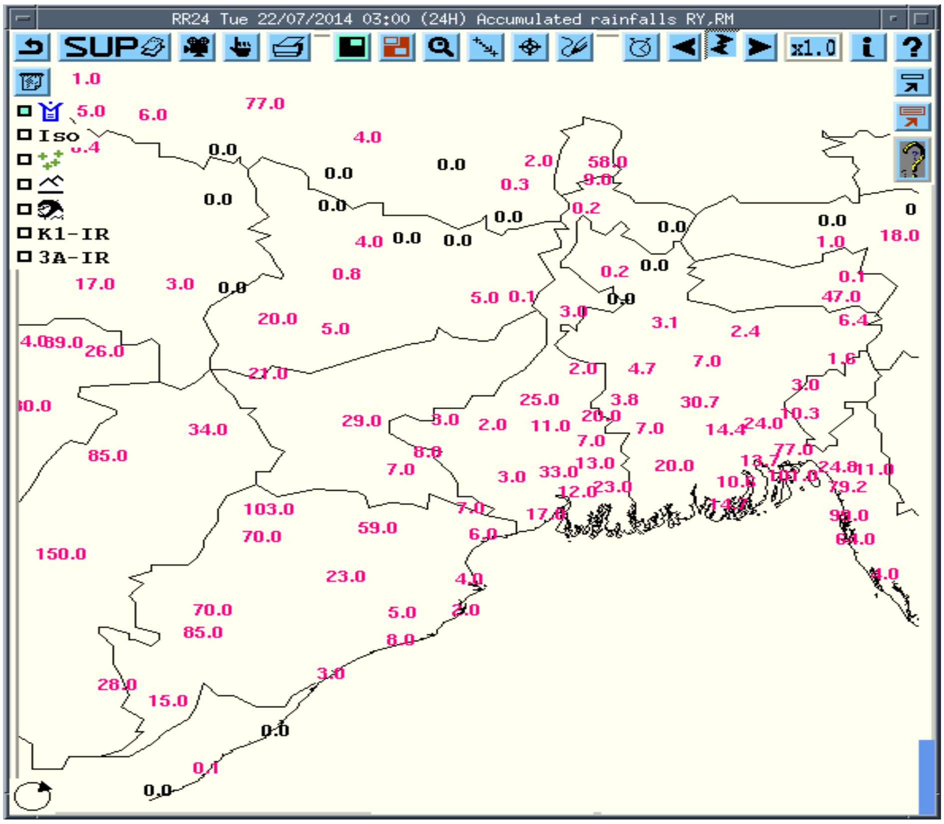


Fig. 4.3(b)

Fig. 4.3: Rainfall associated with the system during 21-22 July 2014.

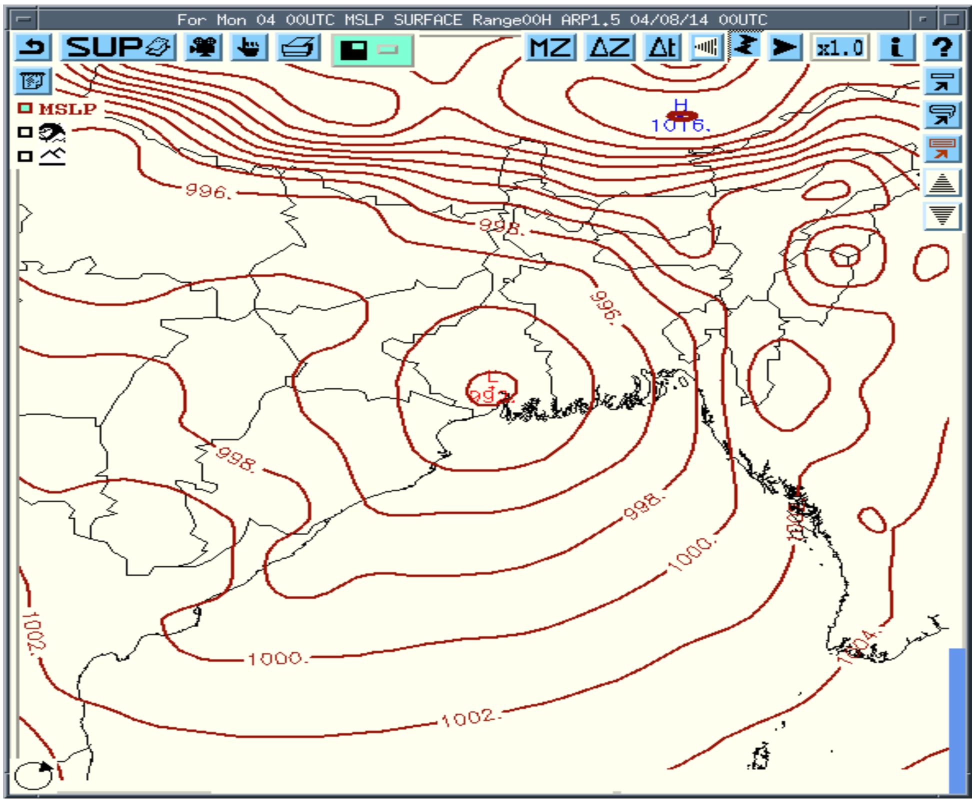


Fig. 4.4(a)

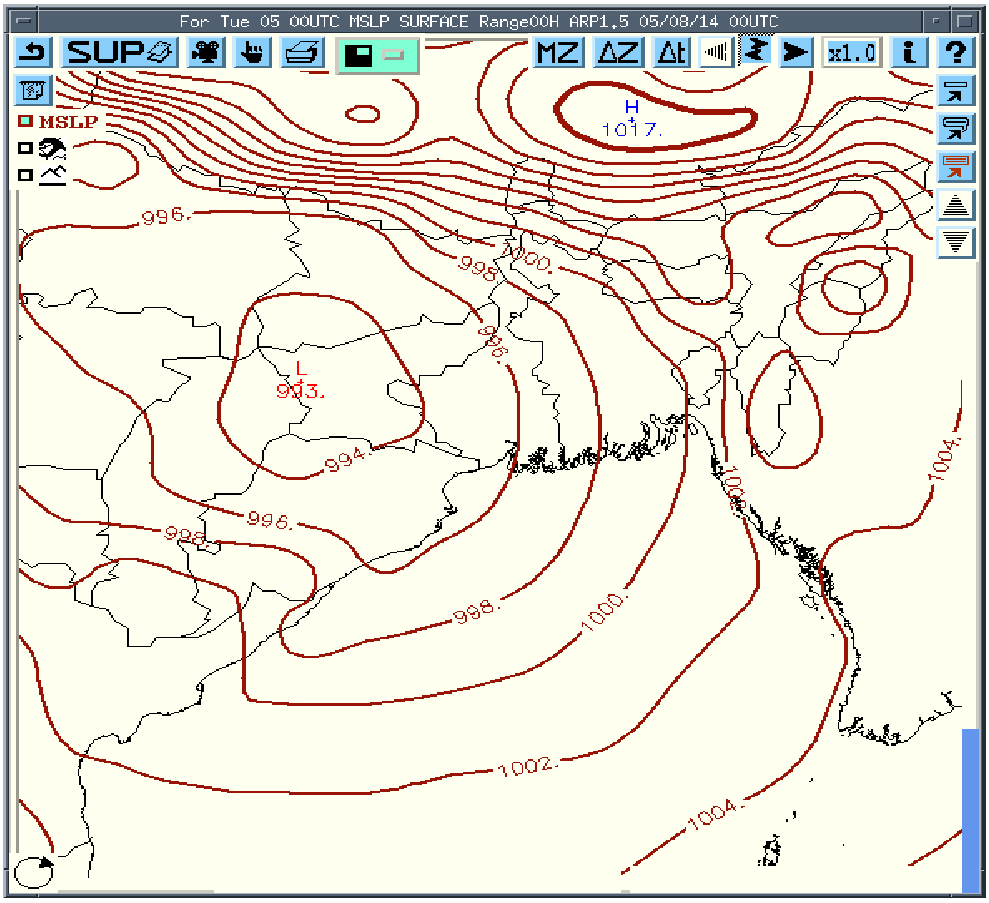


Fig. 4.4(b)

Fig. 4.4: MSLP associated with the system during 4-5August 2014.

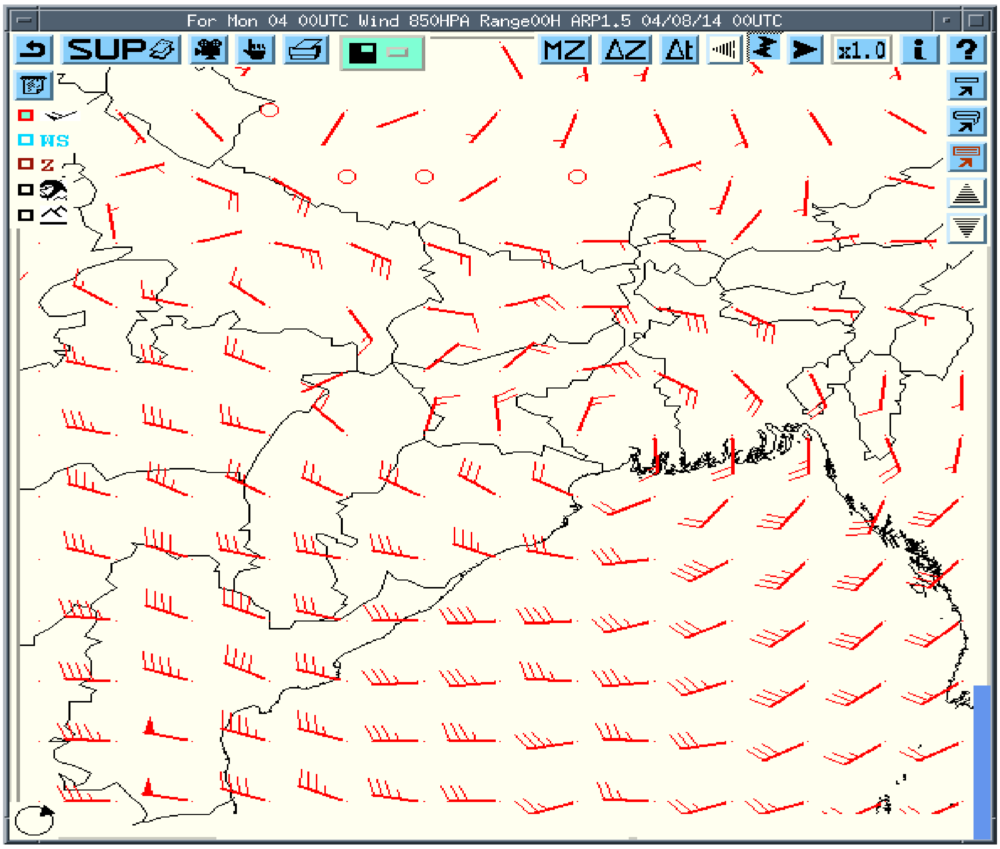


Fig. 4.5(a)

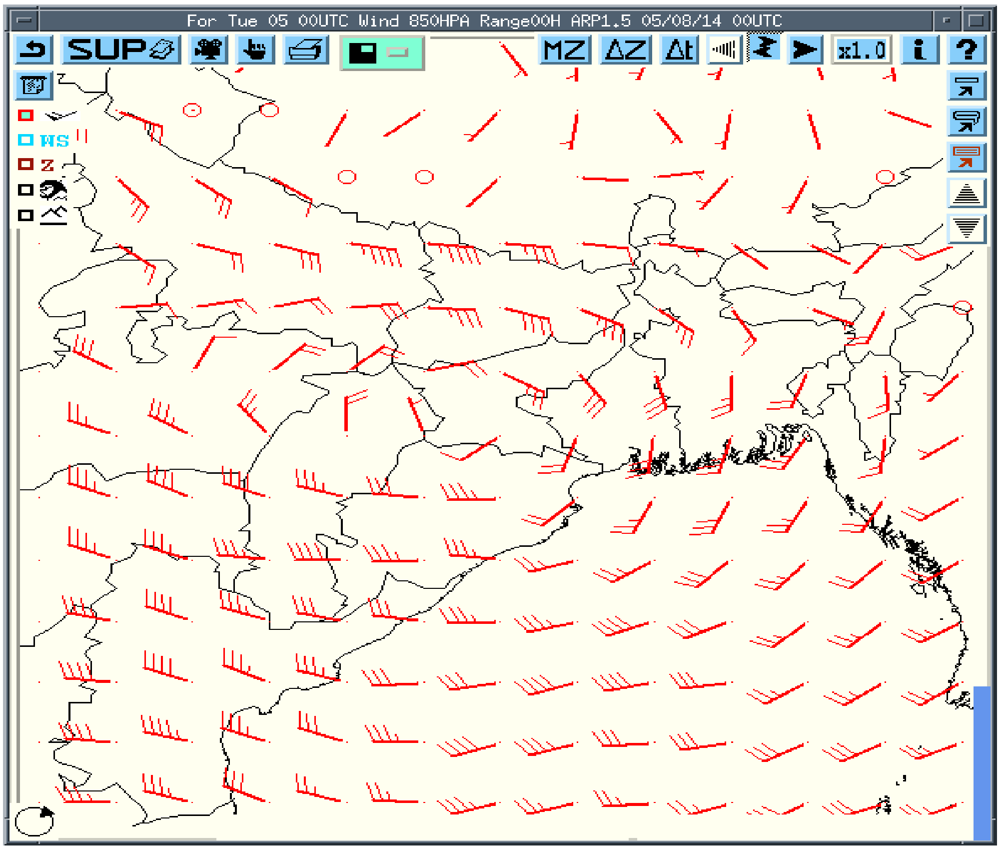


Fig. 4.5(b)

Fig. 4.5: Wind at 850 hPa associated with the system during 4-5 August 2014.

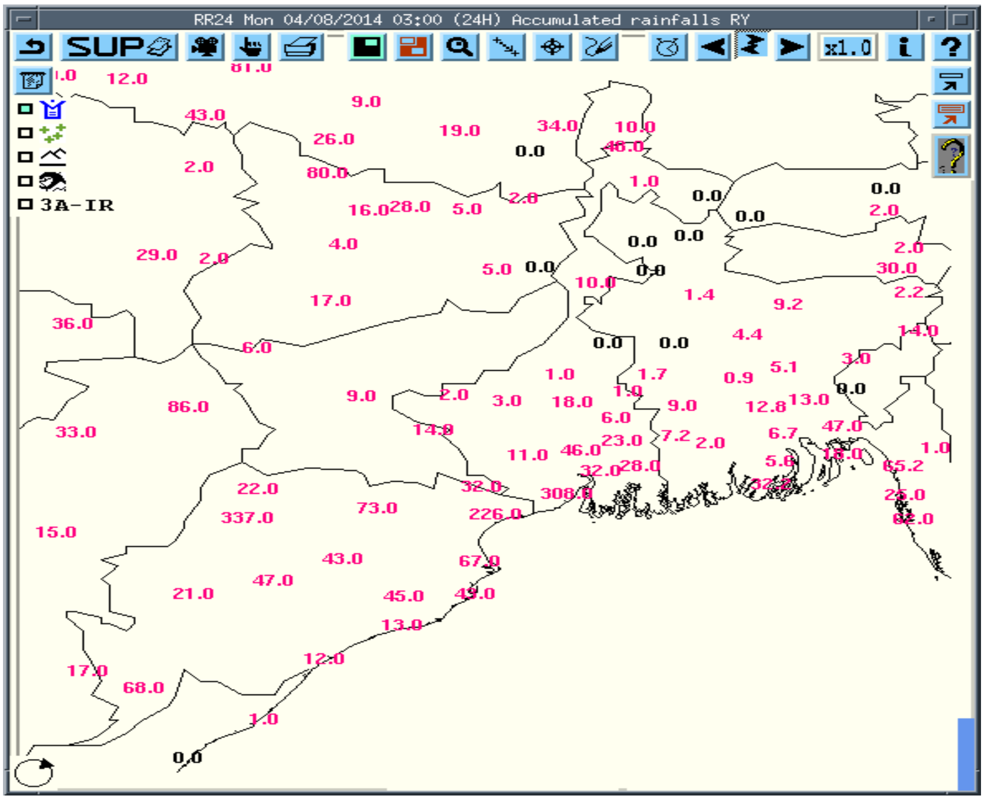


Fig. 4.6(a)

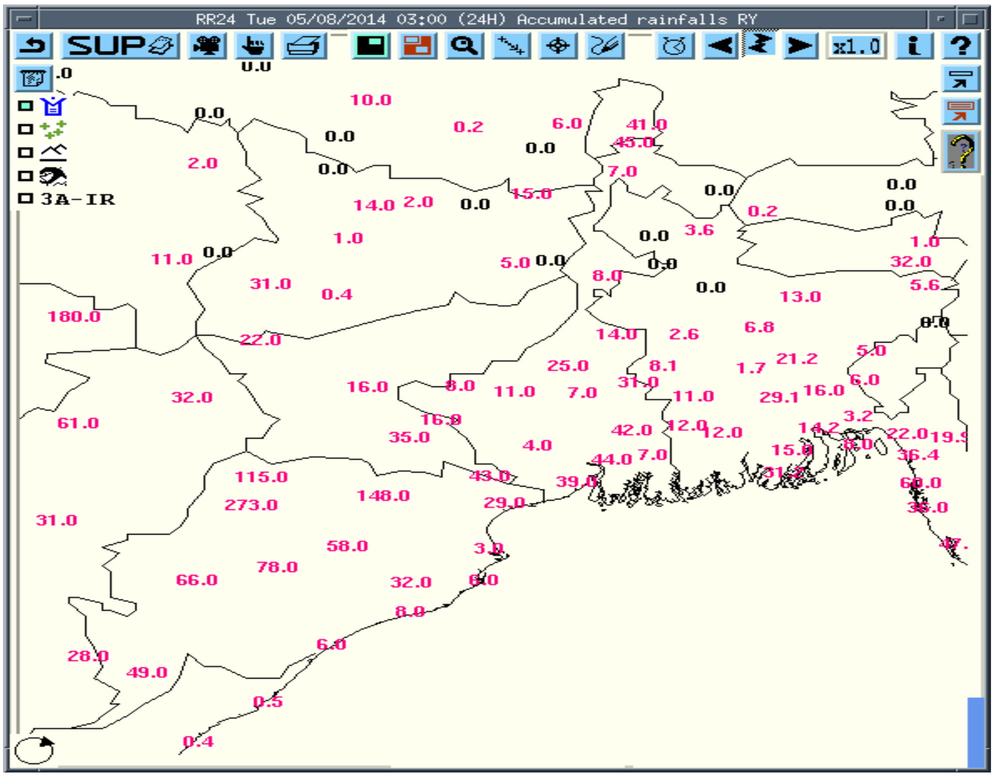


Fig. 4.6(b)

Fig. 4.6: Rainfall associated with the system during 4-5 August 2014.

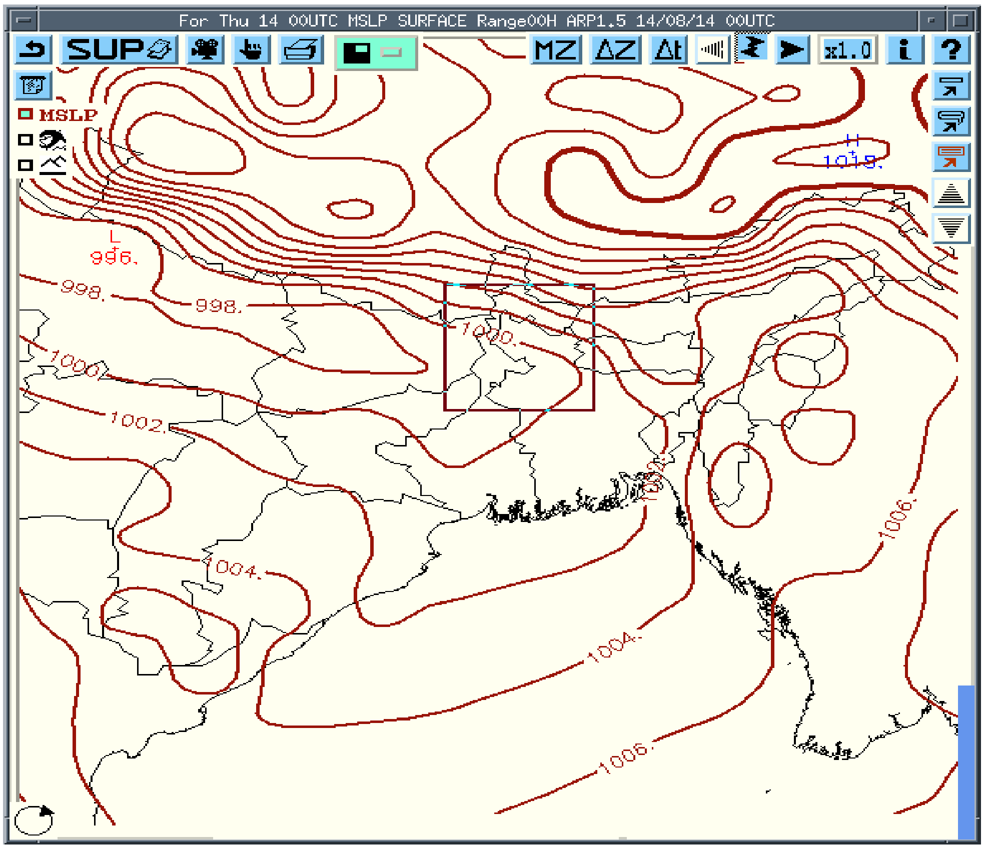


Fig. 6.7(a)

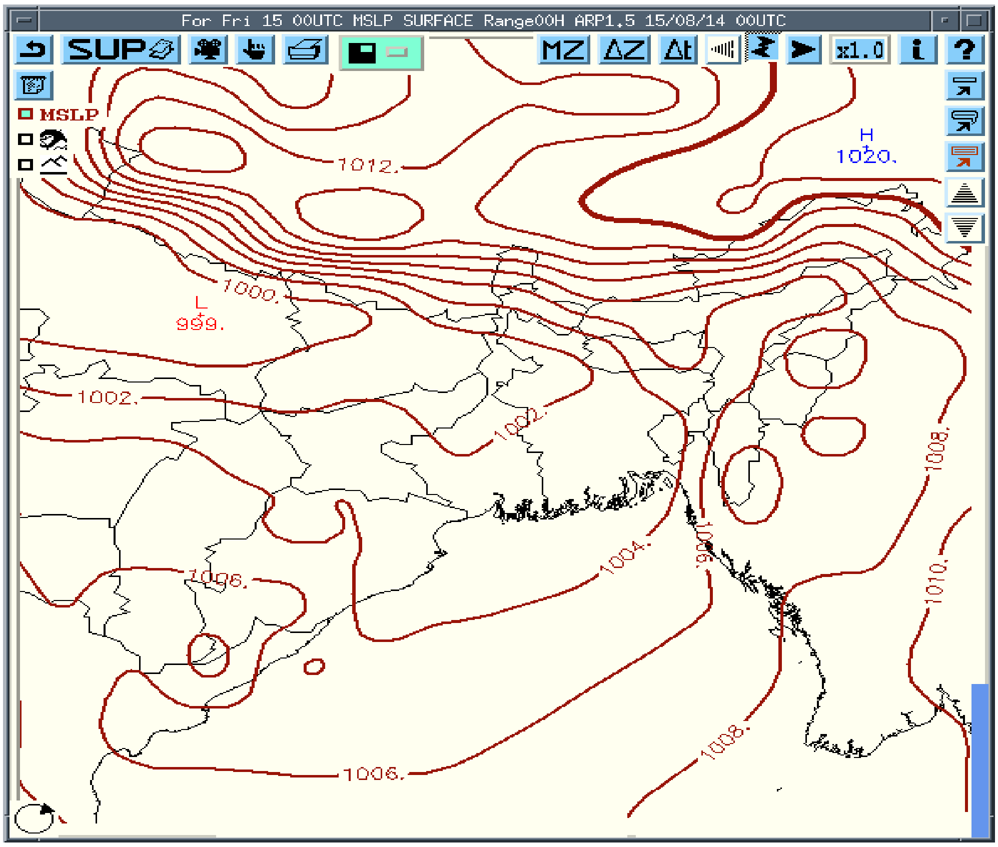


Fig. 4.7(b)

Fig. 4.7: MSLP associated with the system during 14-15 August 2014.

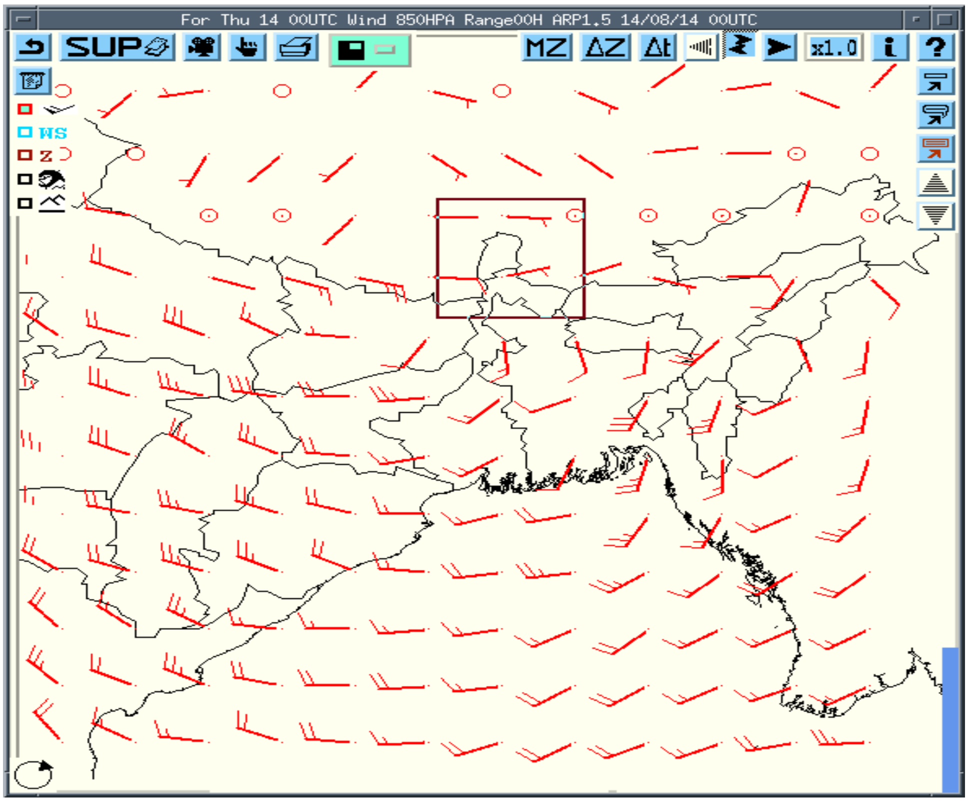


Fig. 4.8(a)

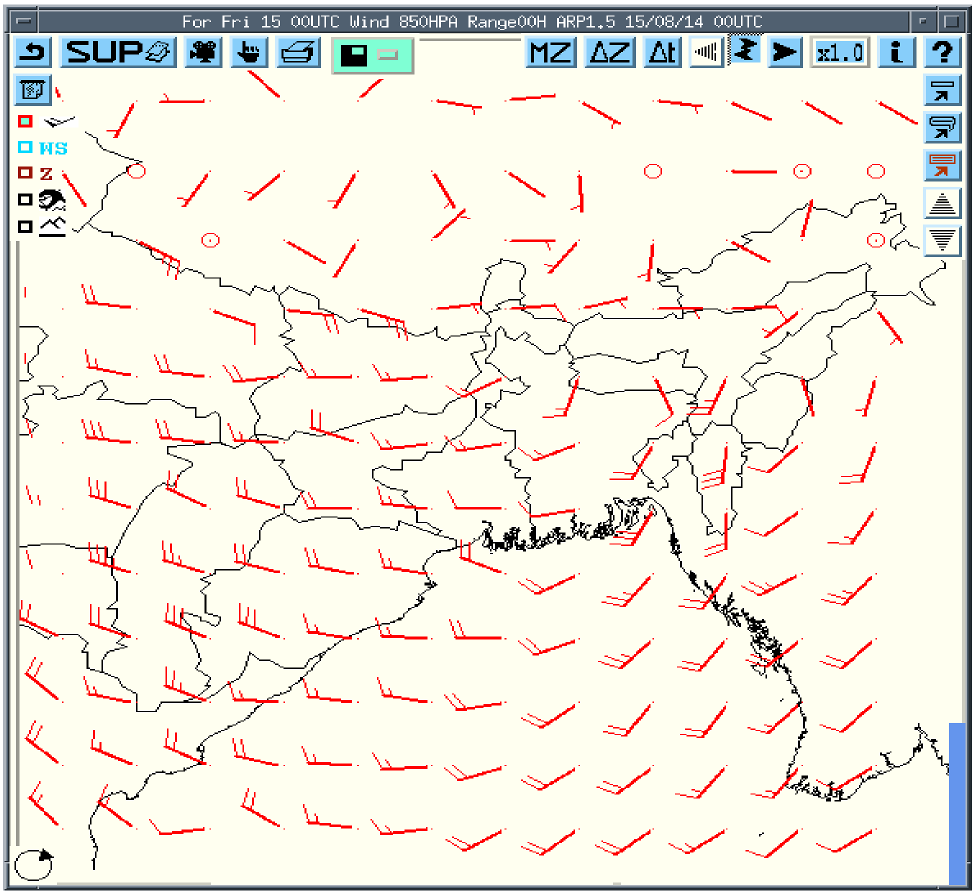


Fig. 4.8(b)

Fig. 4.8: Wind at 850 hPa associated with the system during 14-15 August 2014.

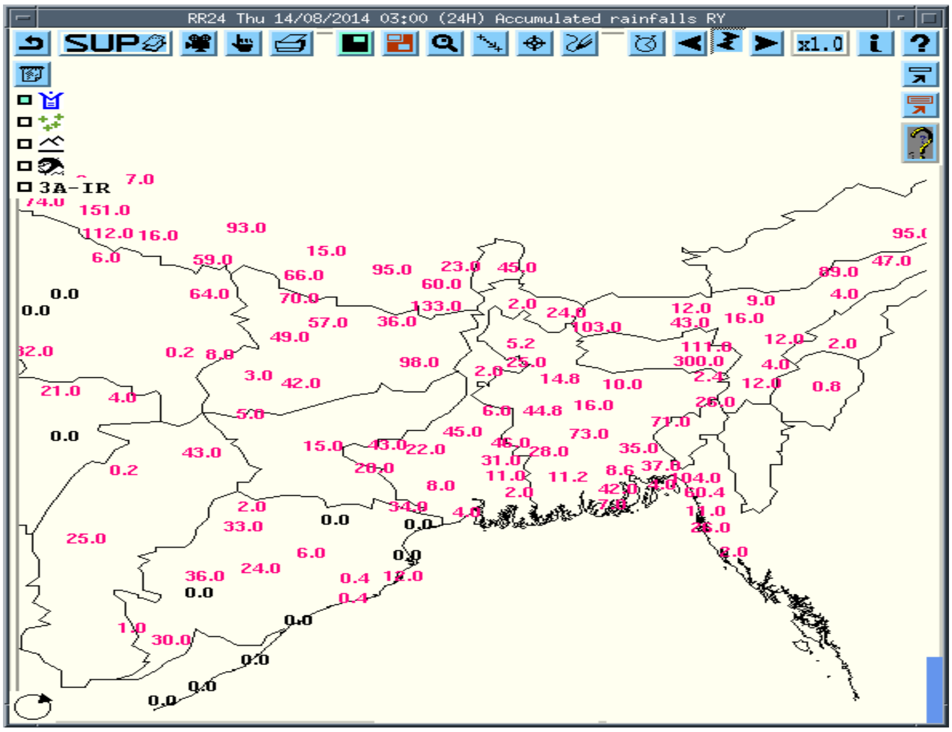


Fig. 4.9(a)

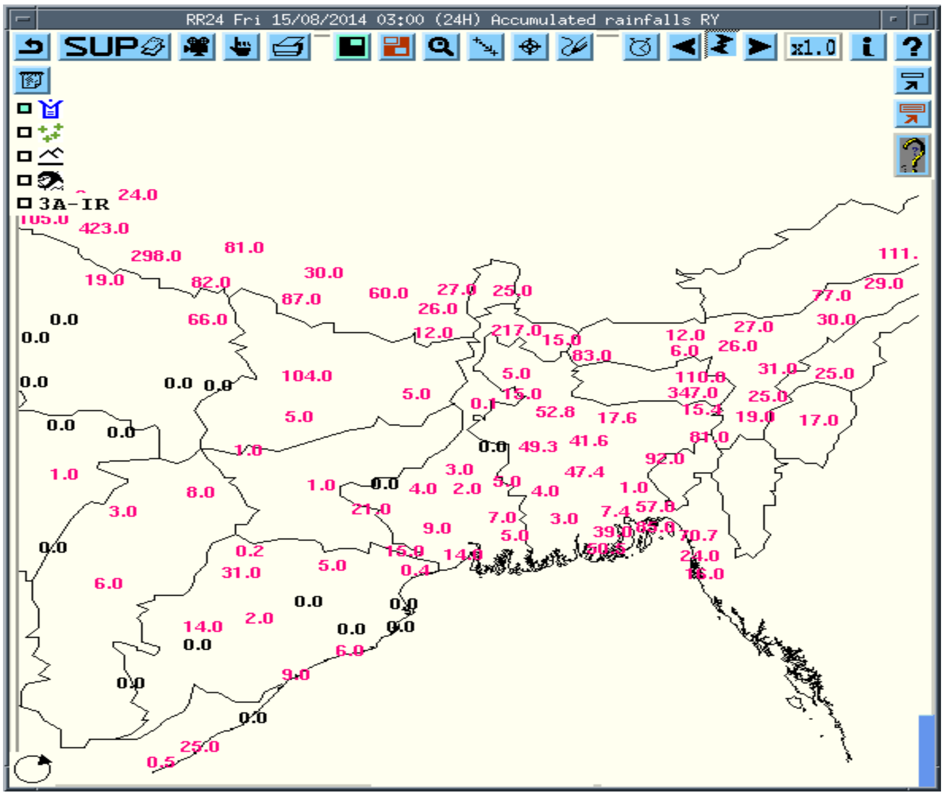


Fig. 4.9(a)

Fig. 4.9: Rainfall associated with the system during 14-15 August 2014.

5

EXCEPTIONALLY SEVERE WEATHER EVENTS DURING THE 2014 SOUTHWEST MONSOON – MAHARASHTRA STATE

K. S. Hosalikar, Shubhangi A. Bhute, S. S. Samel, P. Samant and S. B. Kadam

This chapter discusses the meteorological analysis of three incidences of extreme weather events occurred in Maharashtra during the 2014 south west monsoon season; very heavy rainfall in Pune leading to landslide in July, extremely heavy rainfall events in Gadchiroli of Vidarbha region in early September, and severe thunderstorm in Mumbai city in late September.

5.1. Introduction:

Monsoon 2014 season has left behind lesson learnt footprints over the country. As per the LRF issued the IMD season rainfall for the country as a whole was likely to be 93% of the long period average (LPA) with a model error of ±4% which was near Below normal. Monsoon 2014 was set over Kerala by 06th June 2014 and advanced over Maharashtra in Sindhudurg district of South Konkan & few parts of South Madhya Maharashtra by 11th June 2014. The monsoon further advanced at the boundary of Saurashtra, S- Gujarat, entire Konkan & some parts of Madhya Maharashtra on 15th June after four days rest by delaying five days from normal date. The Monsoon further advanced into more parts of North Madhya Maharashtra & Vidarbha on 19th June. Monsoon further advanced into more some part of North Madhya Maharashtra & Vidarbha and most part of Marathwada. Monsoon advanced gradually over northern part of Maharashtra on 7th July, after 17 days break. Monsoon covered entire Maharashtra on 10th July 2014.

Maharashtra has four meteorological sub divisions; Konkan, Madhya Maharashtra, Marathwada and Vidarbha. The rainfall varies with time and space over whole Maharashtra whose Long Period Average of Maharashtra is 1320.3 mm. There are typical synoptic situations like depressions formed over Bay of Bengal (BoB) near Orissa, offshore trough and vortices gives heavy to very heavy rainfall over Vidarbha and Konkan region. In monsoon 2014, the depressions formed over BoB have caused disaster over eastern part of Vidarbha and also Madhya Maharashtra. Under the influence of these systems Malin village, Ambegaon Taluka in Pune District, Chandrapur and Ghadchiroli District has received the heavy to very heavy rainfall within short period of time with Malin village washed out totally by landslides. Vidarbha lost its connectivity from rest of the world. During withdrawal stage Mumbai city experienced the severe thunderstorm on evening of 30th September 2014. Some of these cases are discussed in details along with synoptic situation.

5.2 Severe heavy Rainfall at Malin village, Ambegaon Taluka in Pune District Malin Landslide on 30th July 2014

5.2.1 Incident:

On 30th July 2014, a landslide occurred in the village of Malin in the Amegaon Taluka; *19°9'N and 73°41'E* of the Pune district in Maharashtra, India (Fig.5.1). The landslide, which hit early in the morning while residents were asleep, was believed to have been caused by a burst of heavy rainfall, and killed at least about 134 people. The landslide was first noticed by a bus driver who drove by the area and saw that the village had been overrun with mud and earth.

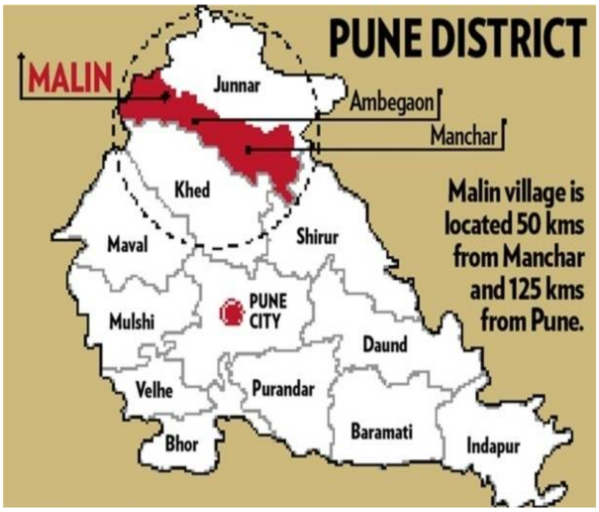


Fig.5.1: Map of Pune district showing location of Malin Village where landslide occurred on 30th July in associated with very rainfall.

5.2.2 Synoptic Situations (From 28th July to 30th July)

o An Off shore trough lay extended from North Maharashtra coast to Karnataka coast on 28th July 2014. It lay extended from Gujarat coast to Karnataka coast on 29th and it persisted on 30th July 2014.

o A low pressure area formed over Northwest Bay of Bengal and neighbourhood on 27th. It persisted on 28th and 29th. It lay as a well marked low pressure area over the same area on 30th.

o An upper air cyclonic circulation lay over Northeast Rajasthan between 1.5 km and 3.1 km above sea level on 27th.

o An upper air cyclonic circulation lay over West Madhya Pradesh and neighbourhood extended up to 3.1 km above sea level on 30th.

o An intense convection over Maharashtra was observed on 30th 00 IST (Fig.5.2A). The WRF rainfall forecast over west coast and some parts of Madhya Maharashtra shown in Fig.5.2B.

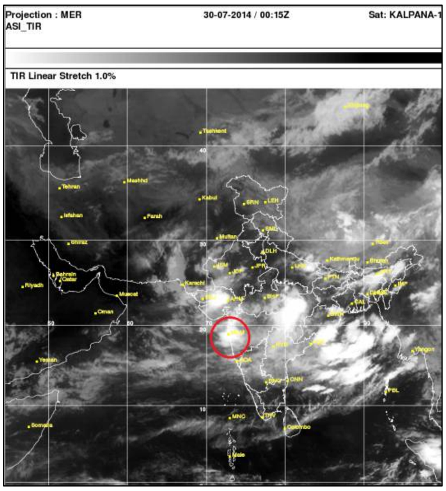


Fig.5.2A: Satellite Picture on - 30 July 2014

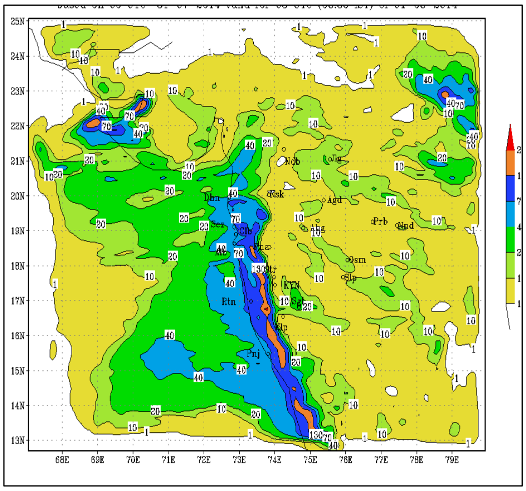


Fig.5.2B WRF precipitation forecast for – 30th July 2014.

This region is nestled in the northern Western Ghats which receives heavy rainfall in the monsoons. The region was receiving particularly very heavy rainfall in the week between 25th to 31st July as shown in Fig.5.2C. Cumulative rainfall in the week as recorded was more than **600 mm**, most of it was during 29th - 30th July. In fact on the 29th July, the region including Malin was **shown purple in 24 hr rainfall map, which signifies the highest range of rainfall, exceeding 175 mm.** The region was experiencing heavy to very heavy rainfall till Aug 1, 2014 also. Frequency of such high intensity rainfall events is predicted to increase, making these areas even more vulnerable to disasters like landslide

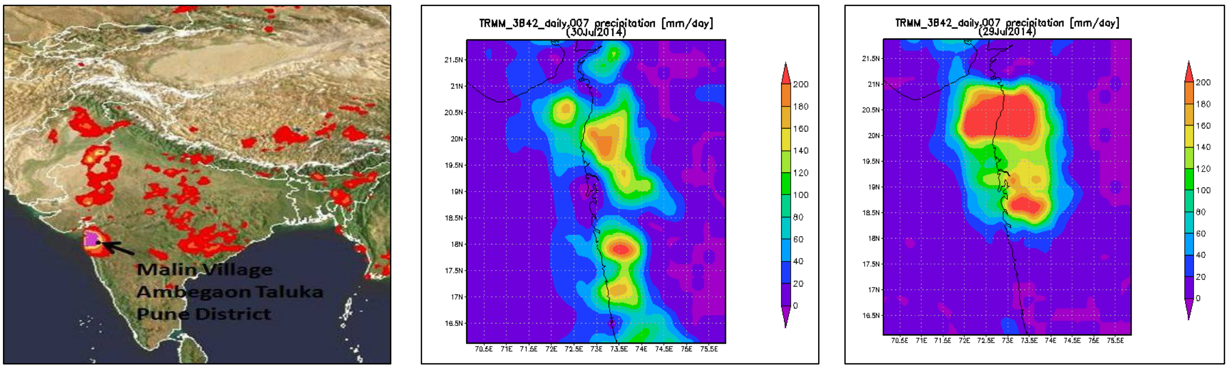


Fig.5.2C: Heavy rainfall in the TRMM cumulative rainfall for last week of July 2014.

5.2.3 Observational Data:

Rainfall records (in mm) of ORG's near Malin, District-Pune are illustrated below.

Date	Dimbe 25 Km	Manchar 35Km	Kalamb 35 Km	Ghodegaon 25Km	Pargaon 45 Km
28.07.2014	5.0	4.0	2.0	3.0	0.0
29.07.2014	26.0	13.0	15.0	16.0	0.7
30.07.2014	108.0	51.0	54.0	62.0	47.2
31.07.2014	49.0	10.0	36.0	40.0	6.2
01.08.2014	57.0	32.0	23.0	27.0	3.9

5.2.4 Cause of Impact:

The landslides were caused by heavy rainfall that had begun the previous day, with the village receiving 10.8 cm (4 in) of rain on 29 July and the downpour continuing throughout the following day. The environmental destruction that resulted in the landslide is believed to have had more than one cause. Once cause cited as contributing to the landslide was deforestation in the area Fig.5.2D(1). Another reason was changing agricultural practices – villagers had recently shifted from cultivation of rice and finger millet to wheat, which required leveling of steep areas, which contributed to instability of the hills. Also the construction of the nearby Dimbhe Dam ten years ago was considered as a possible reason. The instability of the hillsides was due to the construction activities, which are often done without careful analysis of environmental consequences.

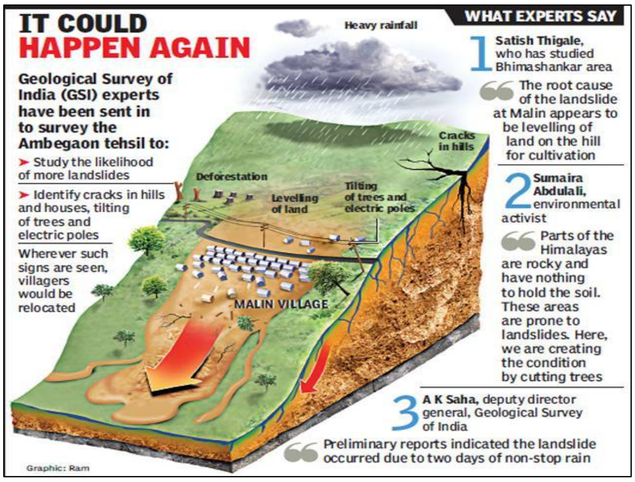


Fig.5.2D(1-3): Malin Landslide scenario after the incidence.

5.2.5 Media Covarage:

In the tragedy at a tiny village of Malin in Ambegaon, Maharashtra, as per reports, around 40 houses are under huge debris created by a landslide that occurred early in the morning on the 30th July 2014 Fig.5.2D(2-3). The death toll till now was reported to be 44 with 150-300 missing as per different estimates. Unfortunately, the chances of survival of the missing are dim as per the Chief of Rescue operations.

5.3 Historical Rain at the Mulchera of Gadchiroli in Vidarbha on 7th Sept 2014

5.3.1 Incident:

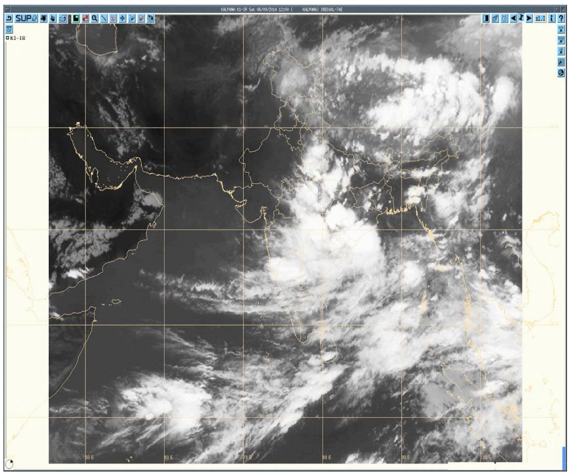
Gadchiroli District is situated in the southeastern corner of Maharashtra, and is bounded by Chandrapur District to the west, Gondia District to the north, Chhatisgarh state to the east, and Telangana state to the south and southwest. Gadchiroli is located at 20.10°N 80.0°E. It has an average elevation of 217 meters (715 feet). Mulchera in Gadchiroli recorded exceptional heavy rainfall of 435.6 mm on 7th Sept, 2014, causing a huge disconnection of the place from neighboring villages.

5.3.2 Synoptic Situations Supported by Charts:

- The Fig.5.3A shows that the convective clouds were observed over Vidarbha and neighborhood area on 6th Sept. 2014.

- A well marked low pressure associated with an upper air cyclonic circulation was located over coastal North Bay of Bengal, Odissa & Chhattisgarh on 12 UTC of 6th Sept. 2014. Fig5.3B.
- Fig.5.3C and Fig.5.3D indicate upper air wind charts for 925 and 500 hPa levels.

Under the influence of above well marked low pressure, the fairly wide spread heavy to Very Heavy with isolated extremely heavy rain occurred in the districts of Gadchiroli & Chandrapur under Vidarbha division on 7th Sept. 2014 and same is seen from TRMM 24 Hrs precipitation accumulation forecast over Vidarbha region on 7th July 2014; Fig.5.3E



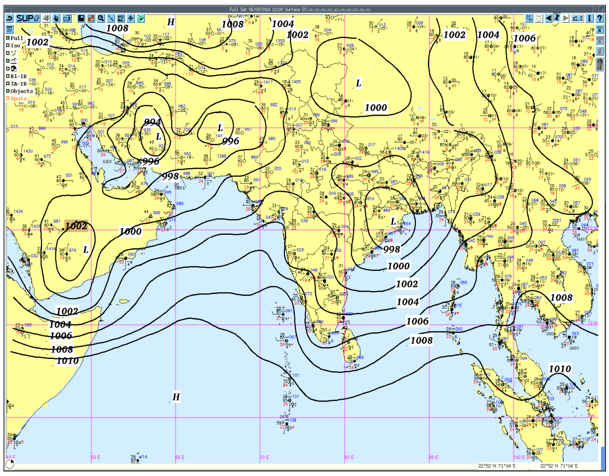
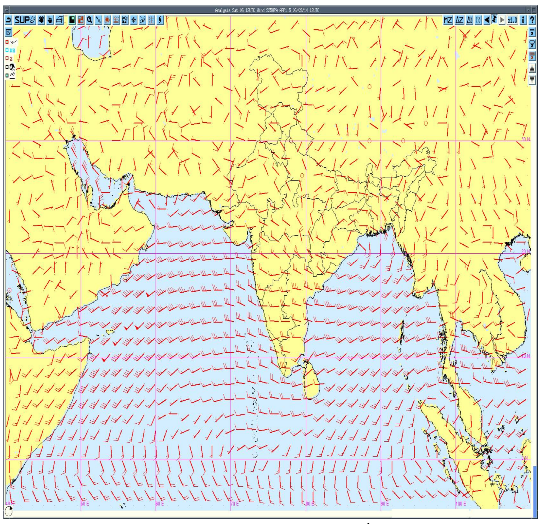


Fig. 5.3A: Sat. Image (12 UTC of 6th Sept 2014). **Fig 5.3B:** Surface Chart (12 UTC of 6th Sept. 2014).



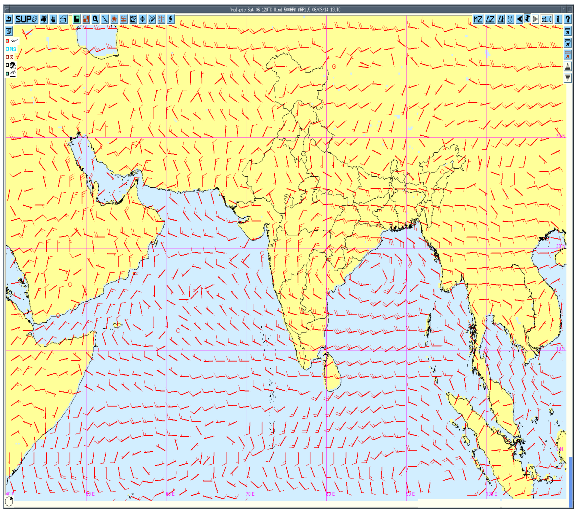


Fig.5.3C: 925 hPa Chart (6th Sept.2014). **Fig.5.3D:** 500 hPa Chart (6th Sept.2014).

5.3.3 Observational Data:

Rainfall data of some stations from Chandrapur and Gadchiroli on 7th July 2014 is given below.

DISTRICT: CHANDRAPUR	Rainfall in mm
BALLARPUR	18.0
BHADRAVATI	70.0
BRAMHAPURI	66.0
CHANDRAPUR	238.2
CHIMUR	36.0
GONDPIPRI	178.2
JOITI	63.0
KORPANA	141.4
MUL	141.8
NAGBHIR	35.2
POMBHURNA	185.0
RAJURA	207.0
SAOLI	127.2
SINDEWAHI	85.0
WARORA	35.0

DISTRICT: GADCHIROLI	Rainfall in mm
AHIRI	
ARMORI	107.0
BHAMRAGAD	
CHAMORSHI	332.0
DESAIGANJ	106.0
DHANORA	130.0
ETAPALLI	
GADCHIROLI	127.0
KORCHI	77.4
KURKHEDA	50.0
MULCHERA	**435.6**
SIRONCHA	175.6

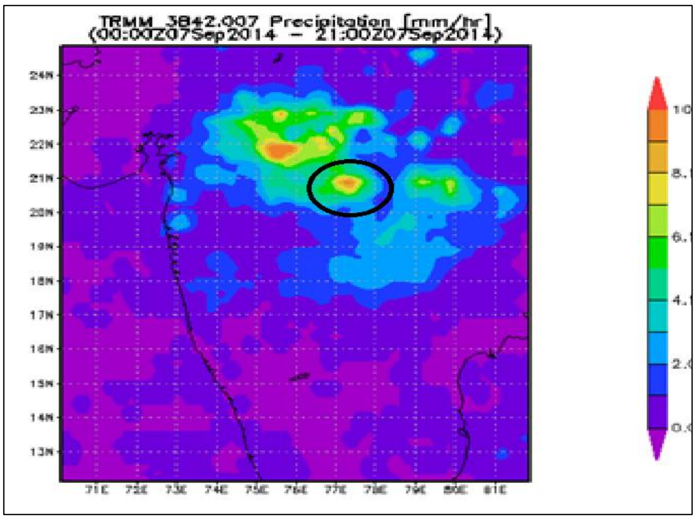


Fig.5.3E: TRMM 24 hrs precipitation accumulation forecast over Vidarbha region on 7th July 2014.

5.3.4 Media Coverage:

Marathi newspaper “Daily Loksatta” has reported in 7^{th} Sept. 2014 edition that Chandrapur – Gadhchiroli has lost the connectivity of almost 200 villages due to very heavy rainfall over the region .There is no electricity and telephone (Fig.5.3F).

चंद्रपूर-गडचिरोलीत २०० गावांचा संपर्क तुटला

प्रतिनिधी, चंद्रपूर

मुसळधार पावसाचे थैमान

चंद्रपूर तसेच गडचिरोली जिल्ह्यात आज मुसळधार पाऊस झाल्याने जनजीवन विस्कळीत झाले. गडचिरोलीत सिरोंचा, अहेरी व भामरागड तालुक्यातील २०० गावांचा संपर्क तुटला असून दूरध्वनी, वीज पुरवठा खंडीत, तर सिरोंचात अनेक घरांची पडझड झाली. विदर्भात नागपूरसह परिसरात वातावरणात पुन्हा एकदा गारवा निर्माण झाला. गोंदिया, भंडारासह पश्चिम विदर्भात मात्र पाऊस नव्हता.

गडचिरोली व चंद्रपूर या जुळ्या जिल्ह्यात आज सकाळपासूनच मुसळधार पाऊस सुरू आहे. सर्वत्र गणेश विसर्जनाची तयारी सुरू असतांना पावसाचे आगमन झाल्याने नागरिकांबरोबर बळीराजाही सुखावला आहे. या आठवड्याच्या पहिल्याच दिवसापासून पडल्याने वातावरणात गारवा निर्माण झाला होता व आठवडा संपायला येतांनाही पाऊस पडत असल्याने हा आठवडा मागील काही आठवड्याच्या तुलनेत थंड व गारवा निर्माण करून जात आहे. कारण, नागरिकांबरोबर बळीराजालाही आनंदात आहे.

आज सकाळपासूनच पाऊस पडत आहे. आठवड्यात चांगला पाऊस झाल्याने शेतकऱ्यांच्या कामालाही वेग आला आहे. शेतकरी आपल्या शेवटच्या टप्प्याची कामे करत असून जवळपास शेतकऱ्यांची पेरणीची कामे झाली आहेत. जिल्ह्यात या आठवड्यात चांगला पाऊस पडल्याने धरणातील पाणीसाठाही वाढला आहे. त्यामुळे काही प्रमाणात का होईना पाणी प्रश्नावर सध्या विराम लागला आहे. जिल्ह्यातील इतर तालुक्याच्या ठिकाणीही चांगला पाऊस पडत आहे.

आज या शहरात संध्याकाळपर्यंत सरी पडत असल्याने शाळकरी मुलांनाही सकाळची शाळा सुटल्यावर पावसाचा आंनद लुटला. वातावरणात गारवा निर्माण झाला आहे व नागरिक टपऱ्यावर गरम चहा व गरम नाश्त्याचा आनंद लुटतांना दिसून आले.

गडचिरोली जिल्ह्यात पावसामुळे मोठे नुकसान झाले आहे. सिरोंचा-भामरागड या दोन तालुक्यांना जोडणाऱ्या पर्लकोटा नदीवरून पाणी वाहत असल्याने भामरागड तालुक्यातील १५० गावांचा संपर्क तुटला आहे. तिकडे अहेरी, एटापल्ली, धानोरा तालुक्यातील अनेक गावे पाण्याखाली आली आहेत. सततच्या पावसामुळे वीज, दूरध्वनी पुरवठा खंडीत झाला आहे. व्यंकटपूर येथे काही घरांची पडझड सुध्दा झाली आहे. रस्ते बंद असल्याने बससेवा सुध्दा ठप्प झाली आहे.

Fig.5.3F: Marathi newspaper “Daily Loksatta”

5.4 An Exceptional Severe Thunderstorm in Mumbai city on 30^{th} Sept 2014

5.4.1 Incident:

A severe thunderstorm occurred on 30^{th} Sept, 2014 in Mumbai mainly affecting the city side of it in the evening. The maximum gusting of wind recorded Dynes Pressure Tube Anemograph (DPTA) was 113 kmph, uprooting the many trees in the Colaba area including few in the Colaba Meteorological office compound.

5.4.2 Synoptic Situations Supported by charts & images:

The Fig.5.4A shows that a low pressure area formed over peninsula on 30^{th} Sept. 2014. It may be seen from Fig.5.4B that a large cell of convective clouds was located over Konkan division on 30^{th} Sept. 2014. It has also been seen from Fig.5.4C & 5.4D that an upper air cyclonic circulation extending up to 5.8 Km was seen over Karnataka coast on 30^{th} Sept. 2014. It has been seen from Figures 5.4E & 5.4F of RADAR images during squally weather. A cell of convective cloud of height more than 12 km near Roha 50 Km Southeast of Colaba was seen at 12 UTC of 30^{th} Sept. 2014. The convective cell with developing stage was moving towards Mumbai with a speed of 60 kmph. The convective cloud crossing troposphere level (18 km) hit Colaba city at 13 UTC on 30th Sept. 2014. It may be seen from Fig.5.4G that the autographic chart of Colaba observatory has recorded South Easterly wind of speed 113 kmph during squally weather at 18:45 hrs. IST on 30th Sept. 2014. The big trees were found in broken / destructed condition near Colaba area, which has been reflected by news media in their news coverage on 30th Sept. & 1st Oct. 2014. It was due to micro burst during squally weather on 30th Sept. 2014. Colaba observatory reported 43 mm rain on 1st Oct. 2014.

5.4.3 Observational Data:

Colaba Observatory recorded 41 mm rainfall and Santacruz observatory recorded 17 mm of rainfall during the period of activity with maximum gusting of 113 kmph with average wind speed during the thunderstorm was 60 kmph. The surface temperatures showed an instantaneous deepening associated with increase in humidity levels.

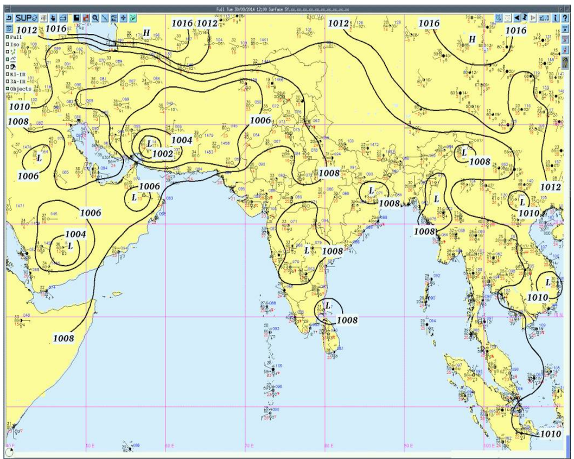


Fig.5.4A: Surface Chart of 12 UTC on 30th Sep**.**

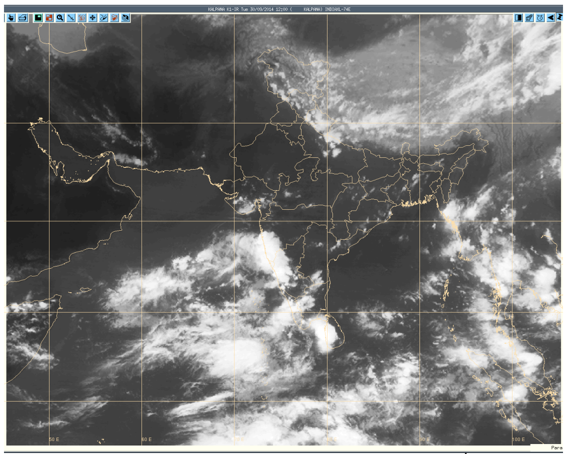


Fig.5. 4B: Sat Image of 12 UTC on 30th Sep

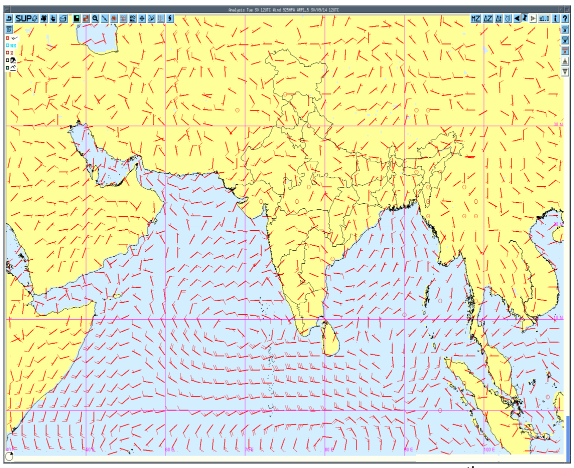


Fig.5.4C: 925 hPa of 12 UTC of 30th Sep.

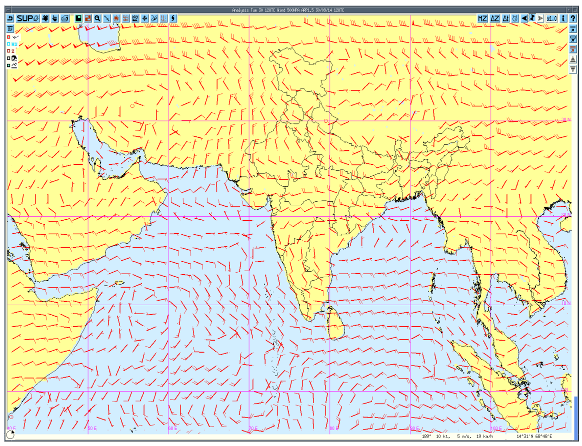
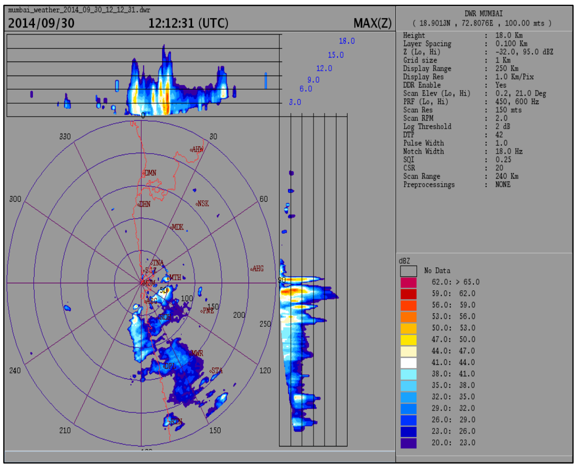


Fig.5.4D: 500 hPa of 12 UTC of 30th Sep



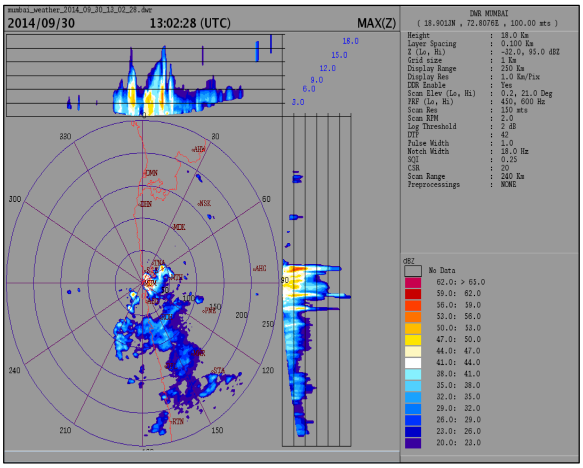
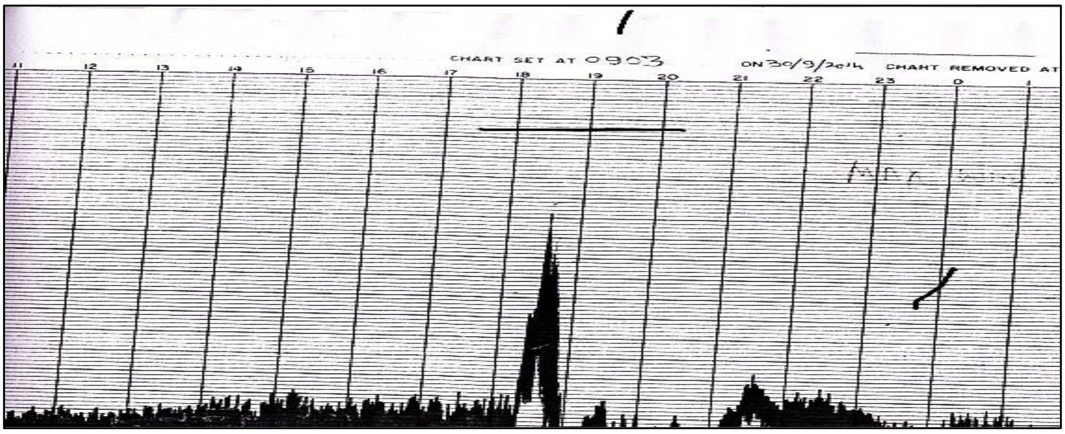


Fig.5.4E: Image of 12:12 UTC of 30th Sep.

Fig.5.4F: Image of 13:02 UTC of 30th Sep.



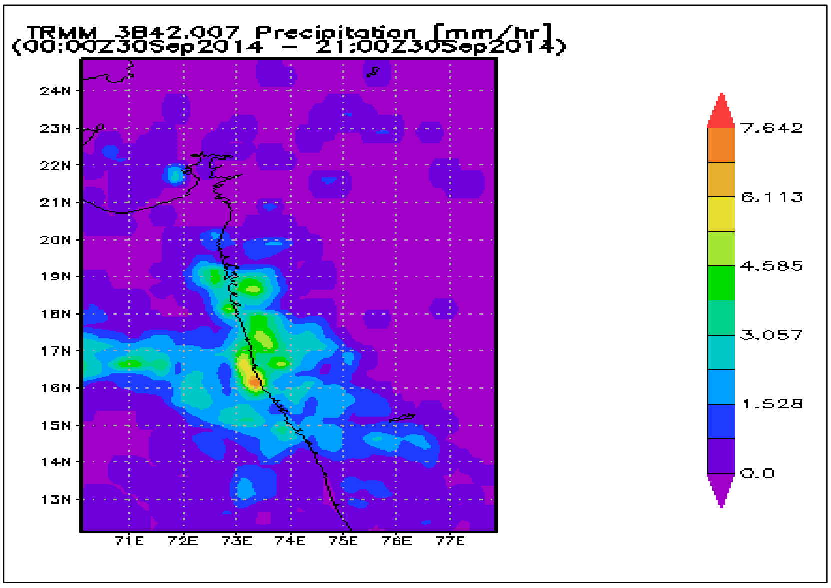


Fig.5.4H: TRMM rainfall map showing Heavy rainfall along the West Coast on 30th Sept. 2014.

5.4.4 Causes of Incidence:

A severe thunderstorm reported on 30th Sept. 2014 evening over Mumbai and adjoining areas with maximum gusting of 113 kmph lasting for few minutes. The prevailing high winds impact was mainly to city side then suburban, causing uprooting of more than 100 trees in Colaba area and around just in an hour plus as reported by civic authorities, causing damages to vehicles parked on the roadside. Train and road transport services also got affected due to trees falling and water logging over tracks and roads etc. The intense convective event produced 41 mm of rain over Mumbai.

5.4.5 Media Coverage:

The newspaper agencies and media reported destruction of large tree / falling of big trees in the Colaba region on 30th Sept. 2014. Report says that a late-evening thunderstorm on Tuesday offered some respite from the day's sweltering heat but threw road and train traffic out of gear, massively inconveniencing commuters on their way home. Major stations on Colaba Region were packed till late in the night; 80 train services were cancelled on the Main and Harbour lines. Weathermen called the storm a temporary phenomenon and said temperatures would remain high for the next two days. The storm dumped 41 mm of rain on Colaba, 17 mm over Santacruz. Winds gusting at 113 kmph accompanied with rains. The thunderstorm led to water-logging and knocked down more than 30 trees. The fallen trees in Colaba Mumbai due to squally weather on 30th Sept.2014 have been shown in Fig.5.4I and 5.4J.

Fig.5.4I: Fallen tree of IMD Colaba campus

Fig.5.4J: Fallen trees of Colaba area

5.5. Conclusions

The monsoon 2014 is reported a significant number of heavy rainfall events Maharashtra, but yet leaving behind deficient rainfall in many districts of Marathwada and Madhya Maharashtra subdivisions of the state. State has experienced the very to very heavy precipitation during its vigorous state as well as the withdrawing stage.

The heavy rains in July and September are due to heavy rainfall giving synoptic situation formed over Bay of Bengal and Arabian Sea.

i. Analysis of pressure chart has shown the gradual formation of Depression over Bay of Bengal and movement of the same over the land has given heavy to very heavy precipitation over Vidarbha region.
ii. On 30th July 2014, satellite pictures show the convergence zone over Pune District.
iii. Recently installed Doppler Weather Radar, Mumbai products, and TRMM forecast have helped to give heavy rainfall warning on 29 - 30th July 2014.
iv. The wind analysis at 700 hPa showed the east west shear zone on 6th September resulting in the heavy precipitation over eastern part of Maharashtra.
v. Similarly on 30th Sept. 2014, the convergence zone was very well captured by Radar imageries and TRMM forecast.
vi. In addition to heavy rainfall at “Malin” village, the triggered landslide disaster is likely pointing at the human interventions in the locality and this need to be taken as serious alarm for future too.
vii. Full efforts were made to keep all observational and other weather monitoring networks for consistent real time meteorological data. Liaisons with Mumbai Municipal Corporation for Mumbai city and State Government authorities like Irrigation Department, Hydrology Department and Disaster Management enhanced the rainfall data reception.

6

ANALYSIS OF UNPRECEDENTED HEAVY TO VERY HEAVY RAINFALL ACTIVITY OVER ASSAM AND MEGHALAYA DURING 21-23, SEPTEMBER 2014

M. K. Gupta, Sunit Das and Sanjay O'Neill Shaw

Due to its location in the eastern Himalayan in the eastern Himalayan periphery and fragile geo-environmental setting, NE India is vulnerable to water-induced disaster. During the southwest monsoon season the region receive very heavy rainfalls regularly leading to devastating floods. In this chapter, a meteorological analysis of a very heavy rainfall activity occurred in Assam and Meghalaya during late September resulting flash floods over the region has been presented.

6.1 Introduction

The monsoon over North East Region (NER) of India has its peculiarity of frequent heavy to very heavy rainfall and sometimes such events lead to floods. One of the primary causes of such type of rainfall activity is the interaction of basic monsoon flow with the orography and the synoptic disturbances formed/passing over the region and/or its neighbourhood. This region also receives ample amount of rainfall during all India break monsoon condition when monsoon trough shifts to the foothills of the Himalayas.

During 21st–23rd September 2014, there was unprecedented heavy to very heavy rainfall activity in Meghalaya which caused flash flood over East Garo Hills district of Meghalaya and districts of Goalpara, Kamrup (Rural) and Kamrup (Metro) of Assam. The roads were washed away and there was heavy destruction of railway track and other infrastructures. The flood caused hundreds of causalities and enormous loss of property affecting few lakhs of people in Meghalaya and Assam.

During that period, there was a low pressure area over Jharkhand and Odisha on 20th September 2014 and subsequently the system intensified and moved towards Bangladesh and adjoining Gangetic West Bengal on 22nd September 2014.

6.2 Climatological aspects of Heavy rainfall over NER

A heavy rainfall event over NE India gradually increases from the month of May and becomes maximum during the month of June (Das et. al., 2009). The areas of the region which are more prone to heavy rainfall are – (i) Plains of West Assam, (ii) North-East Assam and adjoining Arunachal Pradesh and (iii) Barak Valley and Southern parts of Meghalaya. The frequency of heavy rainfall over Central Assam, East Assam, and Nagaland is comparatively less as these zones are under rain shadow areas of Khasi & Jayantiya Hills and N.C. Hills.

6.3 Influence of the monsoon systems and orography on Heavy rainfall distribution in North East Region

The heavy rainfall over northeast India is primarily influenced by the monsoon trough, and tropical disturbances and the extra tropical systems in westerlies (Srinivasan et al., 1972). During the normal location of the monsoon trough, the rainfall over NER is significantly less. During all India break monsoon condition or weak monsoon condition, the monsoon trough shifts to the foothills of the Himalayas (Ramamurty, 1969). Accordingly, the maximum rainfall zone shifts to the northeast India.

Sinha Ray et al (1982) suggested that orography has major role in heavy rainfall over NER and concluded that heavy rainfall in the windward side seems to be mainly due to synoptic, sub-synoptic and convective scale system. Heavy rainfall on the lee side seems to be mainly due to synoptic and convective scale systems.

6.4 Analysis of District-wise Observed Rainfall over Meghalaya and Assam during 19th – 23rd September 2014

Table-6.1 suggests that observed rainfall over Meghalaya on 19th September 2014 was 42.7 mm with 250% excess of its normal. It was excess by 387%, 438%, 1428% and 1156% on 20th, 21st, 22nd and 23rd September respectively. Whereas the observed rainfall over Assam on 19th September 2014 was 26.4 mm with 203% excess of its normal. It was excess by 126%, 88%, 1664% and 385% on 20th, 21st, 22nd and 23rd September respectively (Table-6.2).

The observed rainfall over various districts of Meghalaya and Assam from 19th to 23rd Sept is given in Tables-6.3 and 6.4 respectively. Table-6.3 reveals that on 19th September, the highest rainfall was recorded in East Khasi Hills district as 85.5 mm which was 506% more than normal. On 20th the highest rainfall was recorded in South Garo Hills as 89 mm which was 773% more than normal. The highest rainfall on 21st was recorded in South Garo Hills as 101 mm with 1088% excess whereas on 22nd highest rainfall of 540 mm was recorded in West Garo Hills which was 4476% more than normal. On 23rd East Garo Hills recorded 345 mm which was 7741% more than normal.

Table-6.1: Rainfall over Meghalaya during 19th to 23rd September 2014

Date	OR	NR	Dep
19.09.2014	42.7	12.2	250
20.09.2015	43.5	8.9	387
21.09.2015	62.2	11.6	438
22.09.2016	227.1	14.9	1428
23.09.2016	174	13.9	1156

OR: Observed Rainfall (mm) ; NR: Normal Rainfall(mm) ; Dep: % Departure

Table-6.2: Rainfall over Assam during 19th to 23rd September 2014

Date	OR	NR	Dep
19.09.2014	24.6	8.1	203
20.09.2015	16.5	7.3	126
21.09.2015	14.3	7.6	88
22.09.2016	58.9	7.7	664
23.09.2016	49.5	10.2	385

OR: Observed Rainfall (mm) ; NR: Normal Rainfall(mm) ; Dep: % Departure

Table-6.4 reveals that on 19th and 20th September, the rainfall recorded in Goalpara district was 24.7 mm with 518% more than normal and 35.5 mm with 105% more than normal respectively which were highest amount in the three districts Goalpara, Kamrup (Metro) and Kamrup (Rural). On 22nd Goalpara received 314.9 mm rainfall with excess of 3113% where as Kamrup (Rural) and Kamrup (Metro) recorded as 149 mm (3365% excess) and 108.4 mm (2421% excess) respectively. Similar situation was also observed on 23rd when Goalpara, Kamrup (Rural) and Kamrup (Metro) received excess rainfall of 167%, 1085% and 2027% respectively.

During 19th to 23rd September, many stations of Meghalaya and Assam reported heavy to very heavy rainfall and extremely rainfall was observed at one or two stations. Stationwise distribution of heavy rainfall on 19th to 23rd September 2014 over Meghalaya and Goalpara, Kamrup (Rural) and Kamrup (Metro) districts of Assam are presented in Table-6.5.

6.5 Analysis of synoptic conditions during 19th – 23rd September 2014

The synoptic analysis reveals that on 20th September, a well-marked low pressure area lies over northwest Bay of Bengal and adjoining coastal areas of Gangetic West Bengal, Odisha, north coastal Andhra Pradesh and West central Bay of Bengal with an associated cyclonic circulation extending up to 5.8 kms a.s.l. The axis of monsoon trough at mean sea level passes through Amritsar, Karnal, Kanpur, Churk, Keonjhargarh, centre of well-marked low pressure area and thence south-eastwards to central Bay of Bengal. The low pressure system moved gradually towards north and on 21st September it was seen over Gangetic West Bengal and adjoining Jharkhand and Odisha with an associated cyclonic circulation extending up to 4.5 kms a.s.l. The western end of the axis of monsoon trough at mean sea level runs close to the foot hills of the Himalayas and the eastern part of it passes through Bareilly, Varanasi, Ranchi, centre of well-marked low pressure area and thence south-eastwards to central Bay of Bengal. Subsequently on 22nd September, the low pressure system was seen over northeast Jharkhand and adjoining Gangetic West Bengal and Bihar with associated cyclonic circulation extends up to 4.5 kms a.s.l. The axis of monsoon trough at mean sea level has become un-important. At mid-troposphere (200 hPa) an anticyclone was observed over the same location resulting in maintenance of the low pressure system in lower levels. Also due to the presence of this system, a southerly jet in lower levels with wind speed 40 knots was established over Bangladesh caused large scale moisture incursion to the NE region. The surface and upper air charts on 22nd and 23rd Sept are depicted in Figures.6.1 to 6.12.

6.6 Havoc caused by Heavy rainfall on 21st – 23rd Sept 2014

The heavy rainfall episode during 21st – 23rd Sept 2014 caused havoc in the state of Assam and Meghalaya. Newspapers reported horrifying details of the human tragedy and loss to property. The situation in Assam and Meghalaya were grim as many districts have being affected by floods and landslide with loss of hundreds of human lives. The worst hit areas were the districts of Garo hills in Meghalaya and the adjoining districts of Assam. Some of the villages in Garo Hills division were badly affected and became completely inaccessible due to road blockage by massive landslides in many areas. During this period over 100,000 people have been displaced and infrastructure worth several crores of rupees has been damaged. 80 per cent crop in North Garo Hills, 60 per cent in South West and West Garo Hills were assessed to have been destroyed.

In Assam many areas in three districts — Goalpara, Kamrup and Kamrup (metro) were severely affected. Many villages were submerged in the areas- Dudhnoi, Krishnai and Bolbala which led to massive loss of lives and properties. Approximately, 211,000 and 300,000 peoples were affected in Goalpara and Kamrup districts and whereas 82780 hectares of crop areas got affected in Goalpara districts alone. Flood water over ran NH-37 and 80 other roads, damaging bridges resulting disruption in communication (ASDMA daily flood report dated 24th Sept 2014).

Table-6.3: District-wise Rainfall over Meghalaya during 19th to 23rd September 2014

Date	EAST GARO HILLS			SOUTH GARO HILLS			WEST GARO HILLS			EAST KHASI HILLS			JAINTIA HILLS			RI-BHOI		
	OR	**NR**	**Dep**	**OR**	**NR**	**Dep**	**OR**	**NR**	**Dep**	**OR**	**NR**	**Dep**	**OR**	**NR**	**Dep**	**OR**	**NR**	**Dep**
19.09.2014	11.3	9	26	49	9.9	395	2.8	9.9	-72	85.5	14.1	506	89.8	24.8	262	9.2	1.6	475
20.09.2014	22.5	5.4	317	89	10.2	773	15.2	10.2	49	64.7	9.7	567	69.3	11	530	9.2	9	2
21.09.2014	105.5	13.4	687	101	8.5	1088	20.6	8.5	142	127.9	11.7	993	24.5	13.4	83	34.3	9.1	276
22.09.2014	380	12.4	2965	125	11.8	959	540	11.8	4476	121.1	10.4	1065	75.8	19.1	297	15.8	8.2	93
23.09.2014	345	4.4	7741	169	10.4	1525	62.2	10.4	498	343.8	13.2	2505	97.3	22.1	340	92.2	16	476

OR: Observed Rainfall (mm) ; NR: Normal Rainfall(mm) ; Dep: % Departure

Table-6.4: Rainfall over affected districts in Assam during 19th to 23rd September 2014

Date	GOALPARA			KAMRUP (RURAL)			KAMRUP (METRO)		
	OR	**NR**	**Dep**	**OR**	**NR**	**Dep**	**OR**	**NR**	**Dep**
19.09.2014	24.7	4	518	8.7	3.7	135	1	3.7	-73
20.09.2014	35.5	17.3	105	3.5	3.8	-8	6	3.8	58
21.09.2014	22.7	6.4	255	9.4	3.8	147	18.2	3.8	379
22.09.2014	314.9	9.8	3113	149	4.3	3365	108.4	4.3	2421
23.09.2014	28.6	10.7	167	86.5	7.3	1085	155.3	7.3	2027

OR: Observed Rainfall (mm) ; NR: Normal Rainfall(mm) ; Dep: % Departure

Table-6.5 : Stations with 24 hours rainfall 7 cm or more during 19th to 23rd September in Meghalaya and Goalpara, Kamrup and Kamrup (Metro) districts of Assam

Date	Stations with daily rainfall ≥ 7 cm
19th September	Cherrapunjee (RKM) =19, Cherrapunjee =15, Mawsynram =14, Jowai = 12
20th September	Rongara (ARG)= 15, Cherrapunji (RKM) = 13, Cherrapunji = 11, Baghmara (AWS) = 9, Mawsynram = 7, Jowai = 10
21st September	Mawsynram =19, Cherrapunjee =17, Williamnagar =13, Baghmara (AWS) =10, Rongara (ARG) =9, Shillong (CSO), Williamnagar (AWS) & Shillong (AWS) =8 each, Shella = 7
22nd September	Tikrikilla = 54, Williamnagar = 45, Goalpara (CWC) = 37, Goalpara = 34, Williamnagar (AWS) =31, Goalpara (AWS) = 32, Rangia (ARG) & Cherapunji (RKM) = 17 each, Rongara (ARG)= 16, Cherrapunji = 15, Baghmara (AWS) = 13, Puthimari (CWC) & Baihata Chariali (ARG) = 12 each, Guwahati A/P = 11, Nongstoin (AWS) = 10, Jowai = 9, Chandrapur = 8, Shella & Guwahati (ARG) = 7 each
23rd September	Cherrapunji (RKM) = 54, Cherrapunji =49, Williamnagar = 37, Williamnagar (AWS) =32, Nongstein (AWS) = 27, Shillong (CSO) = 21, Shillong (AWS) = 20, Jowai & Bhagmara (AWS) = 17 each, Guwahati A/P, Barapani, Umiam (ARG) & Khetri (ARG) = 15 each, Guwahati (ARG) = 12, Rongara (ARG) = 11, Puthimari (CWC) =10, Baihata Chariali (ARG) & Shella = 9, Rangia(ARG), Dhudhnoi (ARG) = 7 each

6.7 Probable Causes of the havoc

North East region receives heavy rainfall during the monsoon season with the average rainfall during the monsoon season being 133 cm to 279 cm with a minimum of 80 cm to 90 cm. Heavy rains during the monsoon season and the fragile nature of hilly tracks of the region causes frequent landslides. Also, recent developmental works like road construction and other human activities like deforestation have led to environmental degradation over the years. The heavy rainfall activity during 21st – 23rd Sept 2014 in Garo Hills area caused sudden flash flood in the rivers Dudhnoi, Krishnai, Singra and Jinjiram. The meteorological analysis suggests that the rain storm lasted for two days and it had moved from west to east and produced wide spread continuous heavy rain over Garo Hills and adjoining districts of Assam. It also reveals that the rain storm over the area was caused by the presence of a low pressure system over GWB adjoining Bangladesh together with the establishment of a southerly jet in lower levels over Bangladesh. Additionally, the local orography influenced in formation and maintenance of large scale convection causing the very heavy to extremely heavy rainfall activity over Garo Hills and its adjoining areas. On the other hand, ecologists blame it on encroachment of hill slopes and a degradation and even partial destruction of a network of wetlands that once were natural absorbers of excess rainwater.

6.8 Conclusion

Northeast region received fairly wide spread to wide spread rainfall activity with many stations reported heavy to very heavy rainfall during 21st - 23rd September 2014. During the same period, some stations of Meghalaya specially in Garo Hills experiences extremely heavy rainfall leading to flash flood over East Garo Hills district of Meghalaya and districts of Goalpara, Kamrup (Rural) and Kamrup (Metro) of Assam.

The synoptic situations responsible for such high impact rainfall activity was primarily due to a low pressure system over Jharkhand and Odisha on 20th September and subsequent movement of the system towards north and northeastwards over Bangladesh and adjoining Gangetic West Bengal on 22nd September. Secondly, the presence of a southerly jet in lower levels over Bangladesh caused large scale moisture incursion to the northeastern region of India which further enhanced the rainfall activity.

Acknowledgement:

The authors are thankful to Director General of Meteorology for his encouragement and support for this study.

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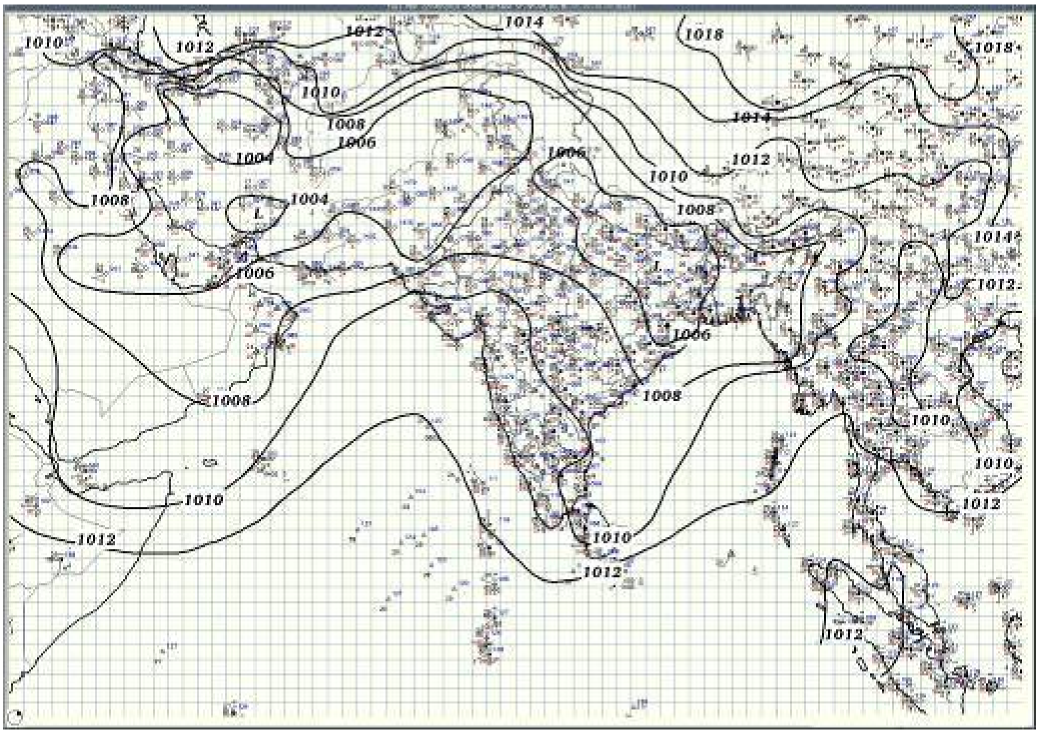


Fig.6.1: Surface Analysis 22.09.2014 03 U.T.C.

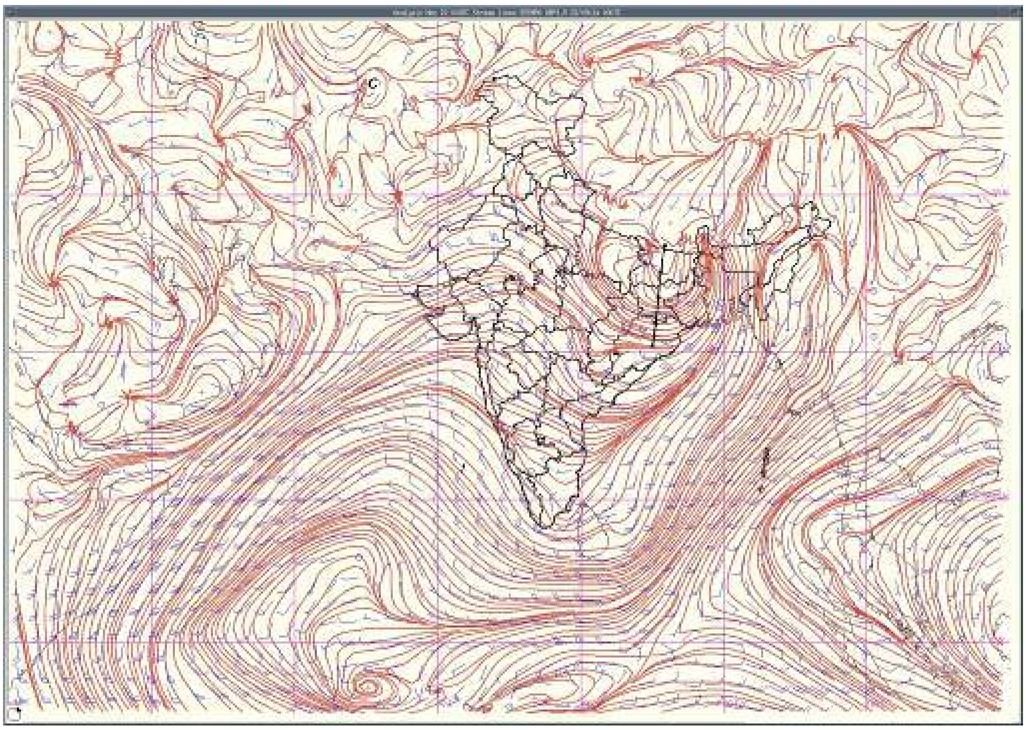


Fig.6.2: Upper air streamline analysis (925 hPa) 00 U.T.C. of 22.09.2014

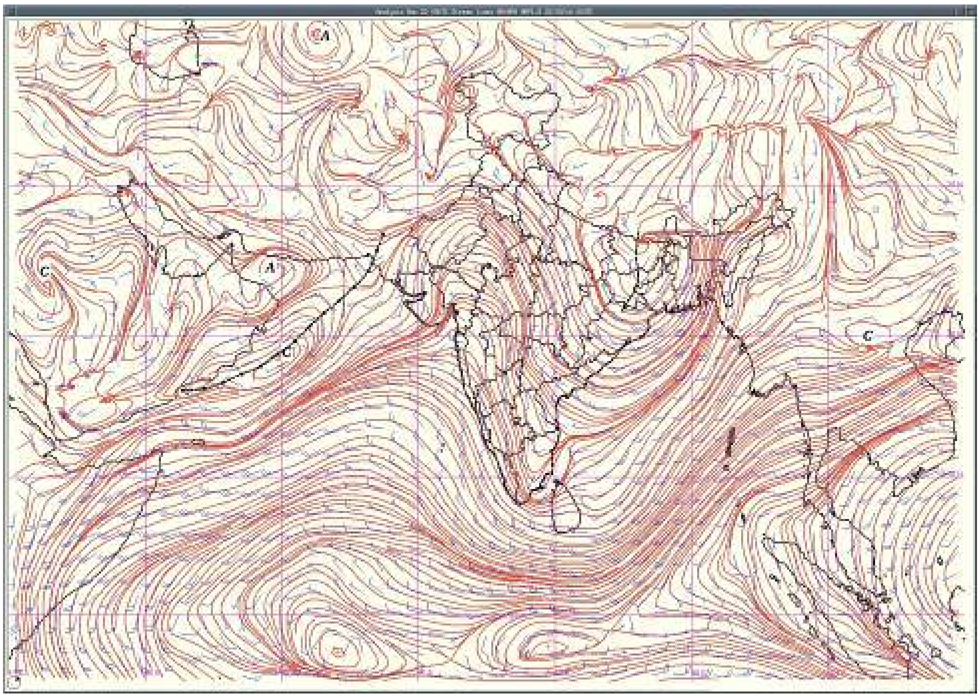


Fig.6.3: Upper air streamline analysis (850 hPa) 00 U.T.C. of 22.09.2014

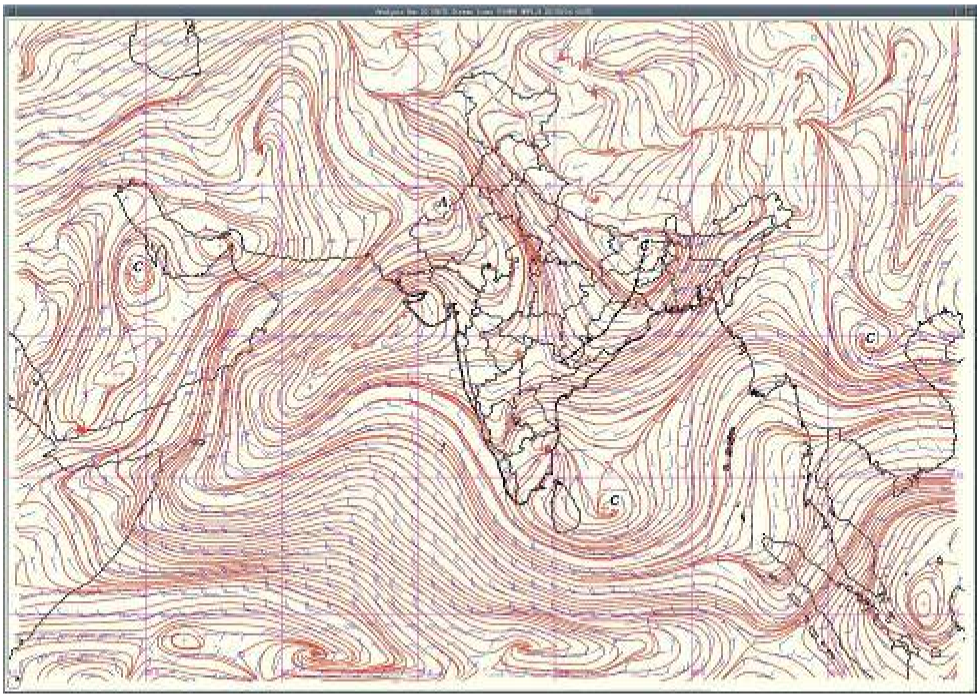


Fig.6.4: Upper air streamline analysis (700 hPa) 00 U.T.C. of 22.09.2014

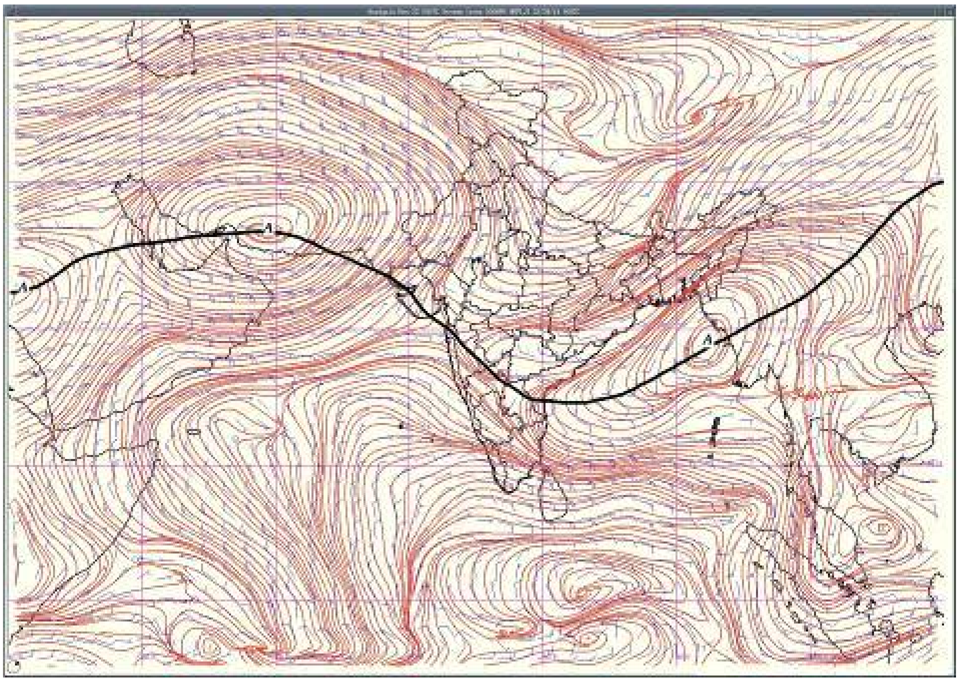


Fig.6.5: Upper air streamline analysis (500 hPa) 00 U.T.C. of 22.09.2014

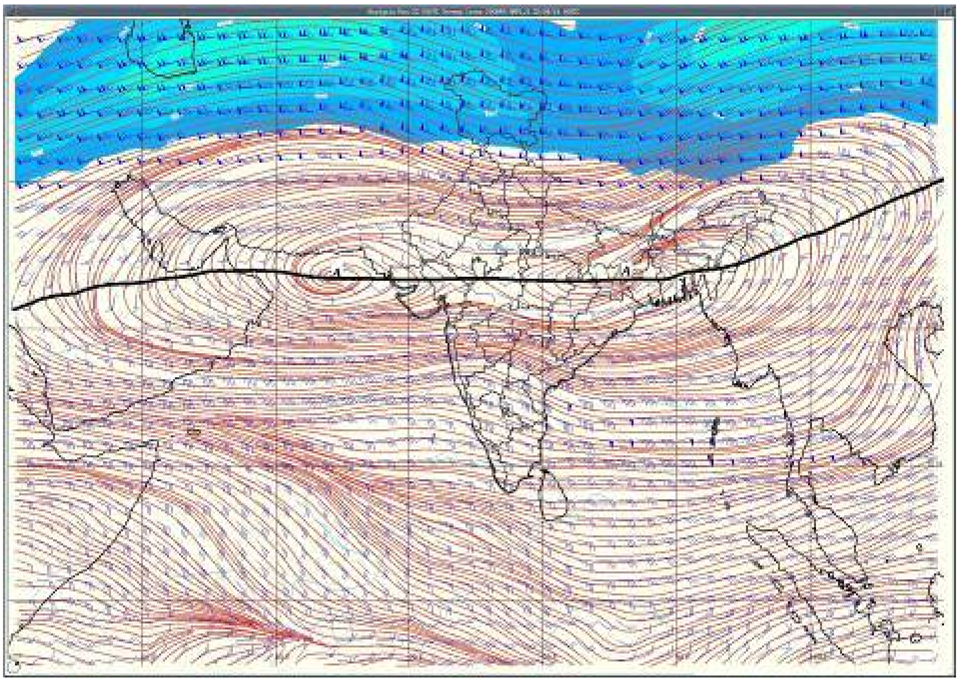


Fig.6.6: Upper air streamline analysis (200 hPa) 00 U.T.C. of 22.09.2014

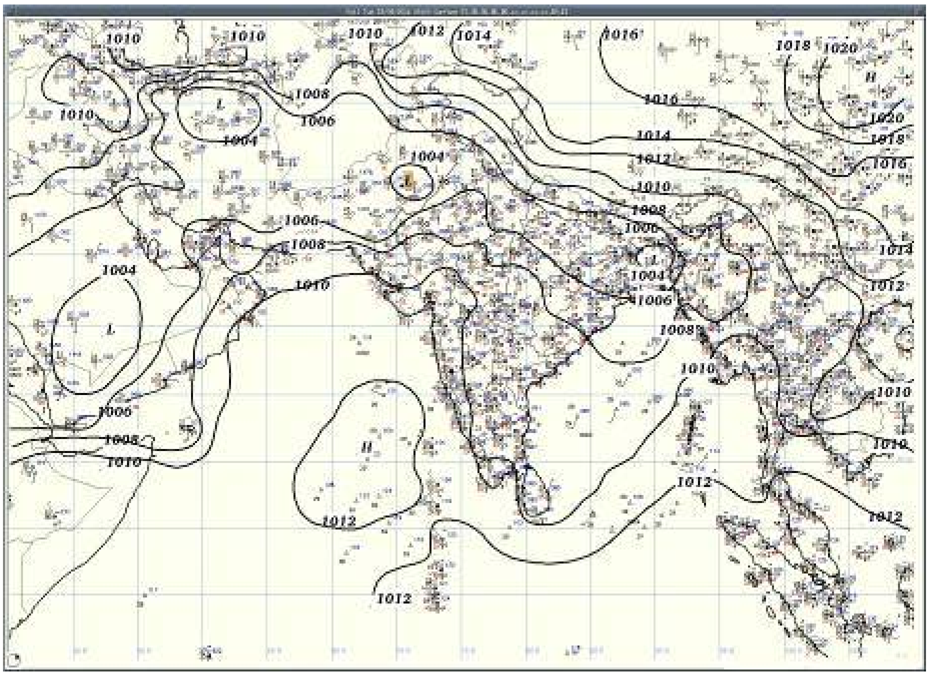


Fig.6.7: Surface analysis 23.09.2014 03 U.T.C.

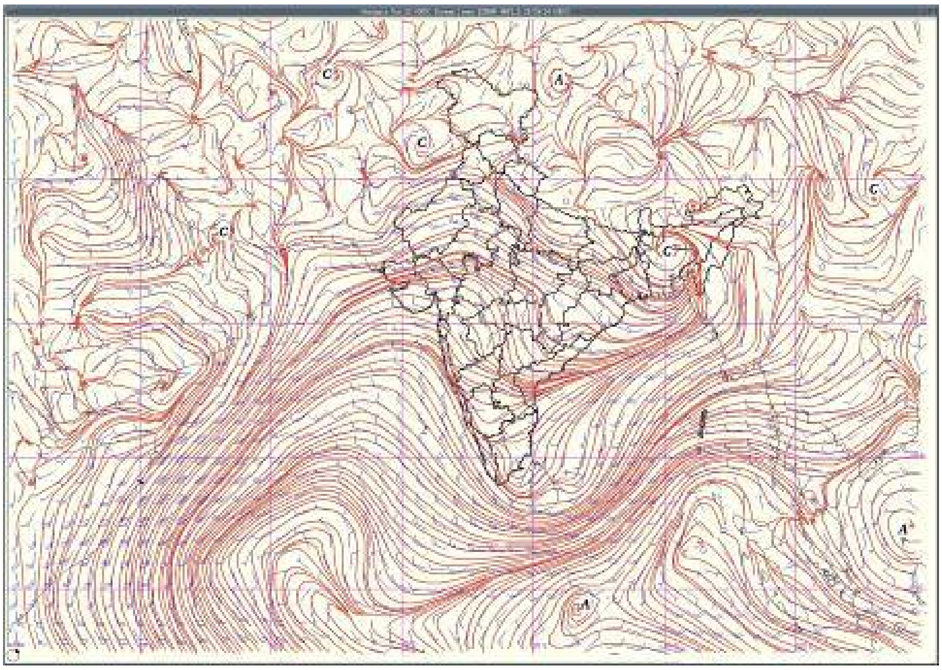


Fig.6.8: Upper air streamline analysis (925 hPa) 00 U.T.C. of 23.09.2014

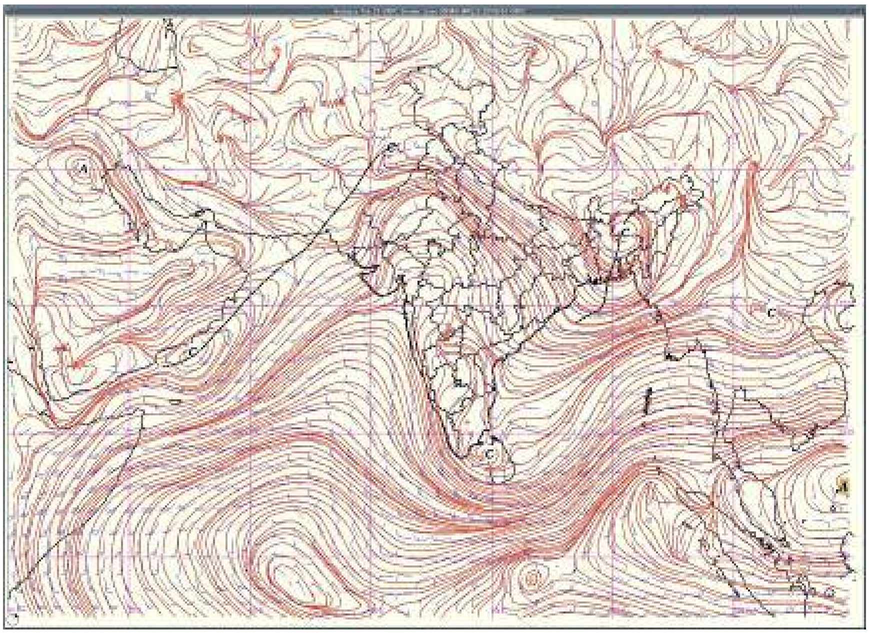


Fig.6.9: Upper air streamline analysis (850 hPa) 00 U.T.C. of 23.09.2014

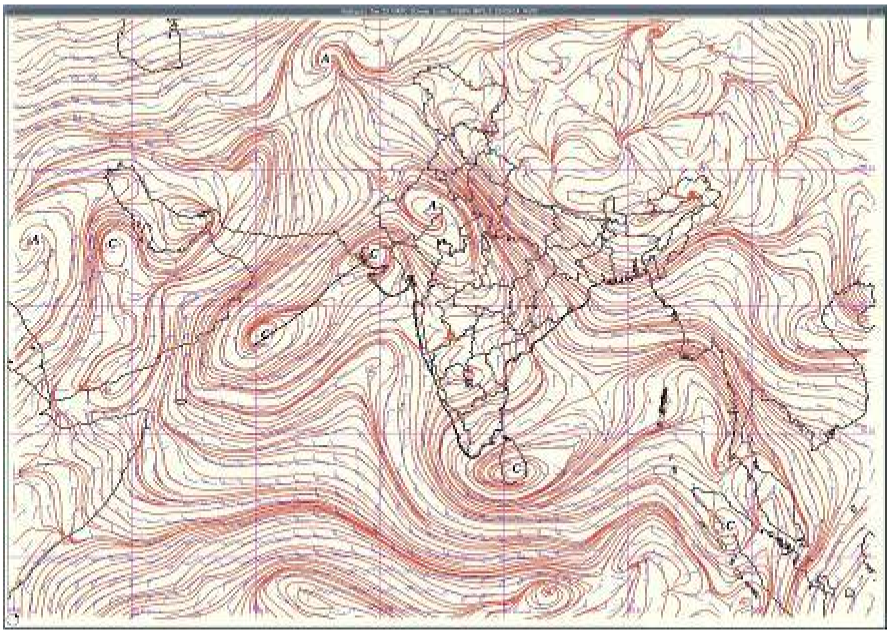


Fig.6.10: Upper air streamline analysis (700 hPa) 00 U.T.C. of 23.09.2014

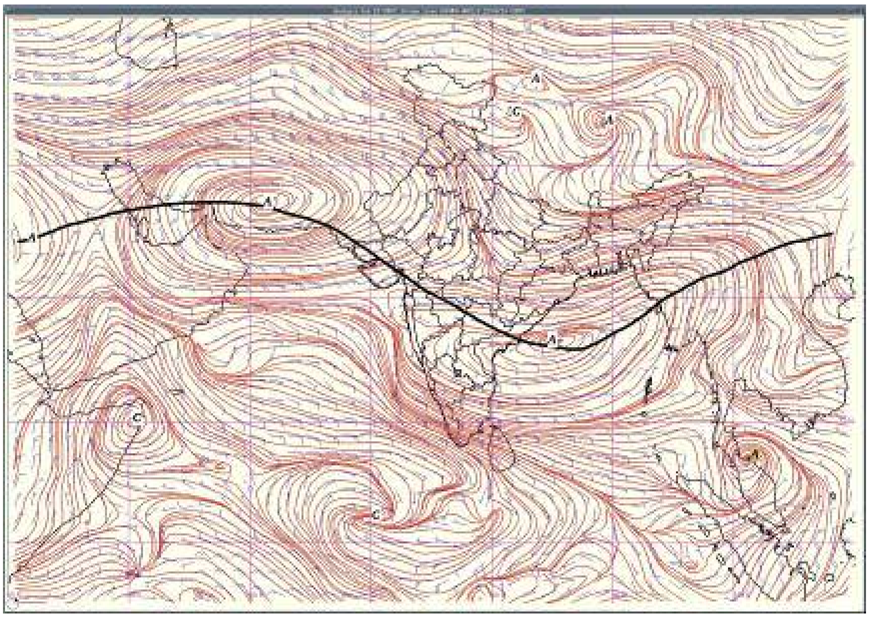


Fig.6.11: Upper air streamline analysis (500 hPa) 00 U.T.C. of 23.09.2014

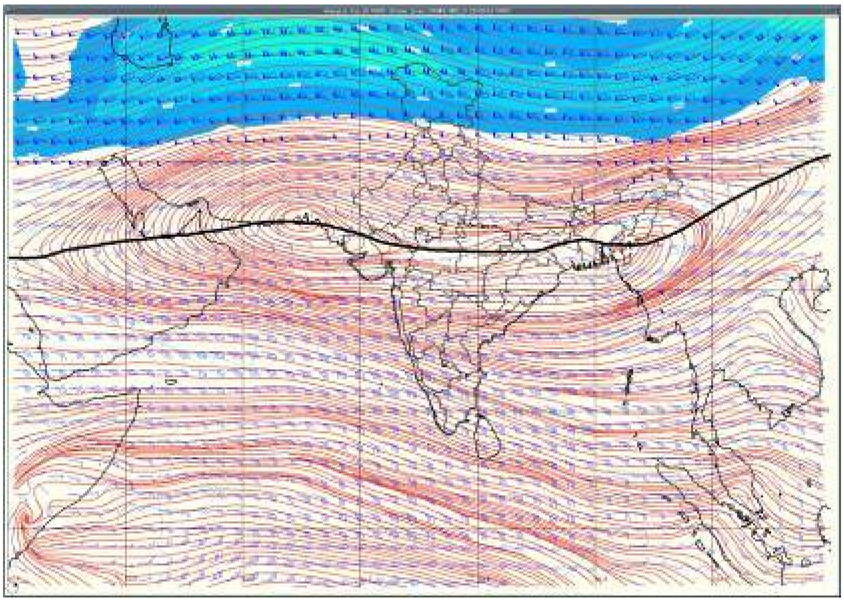


Fig.6.12: Upper air streamline analysis (200 hPa) 00 U.T.C. of 23.09.2014

7

ACTIVE MONSOON SPELLS OVER SOUTH INDIA DURINGSECOND HALF OF THE 2014 SW MONSOON SEASON

S. B. Thampi, S. R. Ramanan, S. Balachandran & S.Stella

In this chapter, an analysis of the active monsoon spells experienced overvarious meteorological subdivisions of south India during the second half of the 2014 southwest monsoon season has been discussed.

7.1 Introduction

Generally, the active/vigorous monsoon activity over South India occurs in associated with the various meteorological situations such as shifting of monsoon Trough south of its normal position, low level jet/ strong winds over Arabian Sea, active off-shore trough, formation and movement of low pressure systems such as troughs, cyclonic circulation, low, depression etc. During SW monsoon 2014, there was very good rainfall activity during the month of August over peninsular India, while the rainfall activity over the country as a whole was below normal. The rainfall activity over major parts of peninsular India enhanced during the last two weeks of August and the first week of September due to the two well-marked low pressure areas (WML), one over the Arabian Sea (23rd - 24th Aug.)

&one over the Bay of Bengal (27th Aug – 6th Sept.). Also the velocity convergence in the westerly flow combined with curvature effect over Lakshadweep arealed to moisture incursion and vertical motion over southern peninsular region during 27-29thAugust resulting in a very good rainfall over the region. A brief meteorological analysis of this active monsoon conditions experienced over south India during the above period have been described here.

7.2 Active/Vigorous monsoon

Active/ strong monsoon refers to rainfall of 1½ to 4 times the normal with rainfall of 5 cm in at least two stations, if that sub-division is along the west coast and 3 cm if it is elsewhere.Rainfall in that sub-division should be fairly widespread to widespread.Vigorous monsoon refers to rainfall more than 4 times the normal with rainfall of 8 cm in at least two stations if the sub-division is along the west coast and 5 cm if it is elsewhere.Rainfall in that sub-division should be fairly widespread or widespread. The day to day monsoon rainfall activity (vigorous (V)/ active (A)) over various subdivisions of south India for 2014 is given in Table-7.1.

7.3 General Features

Seasonal rainfall over south India during the SW monsoon 2014 was 665.4 mm, which is 93% of its LPA of 715.7 mm. South Interior Karnataka constituting 3% of the total area of the country received excess rainfall.

The southwest monsoon set in over Kerala on 6thJune, 5 days later than its normal date of 1st June. Same day, monsoon also advanced into most parts of south Arabian Sea, some parts of Tamil Nadu, most parts of southwest Bay of Bengal and some parts of west central Bay of Bengal.Subsequently it further advanced into most parts of south peninsula, east and adjoining parts of central India by 20th June. During the last week of June, the weakening of monsoon activity caused the re-appearance of the heat wave conditions over eastern parts of peninsular India. After a hiatus of 10 days, monsoon started reviving. During the first week of July, the presence of anticyclone over the peninsular region resulted in subdued rainfall activity over peninsular region.

Strong cross equatorial flow prevailed during July and August. The presence of ridge and formation of Cyclonic Storm over Arabian Sea prevented the cross equatorial flow to actually reach the west coast of peninsular India during first half of June. The cross equatorial flow was also weak during later part of the September as well. The axis of monsoon trough mostly remained normal/south of its normal position during July and first half of September.

7.4 Significant Synoptic Situations

While rainfall activity over the country as a whole during the month of August was below normal, there was very good rainfall activity over peninsular India.

Table-7.1: Daily monsoon activity for the period 20th August to 3rd September, 2014.

Dates→	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3
CAP								A	A	A	A	A	A		
TLGN			A					A	A	A	A	A	A		
RYSL						V								A	A
CK							A		A	V	A	A			
NIK	A		V	A	A	A	V	A	V	V	V	A			
SIK	A	A	A	A					A	A		A			
TN/PDC				V	A										
KRL			A	V	A				A	A	V	V	V	V	A
LKDP															

V - Vigorous A - Active.

The synoptic analysis for the period 19 August 2014 to 03 September 2014 reveals the synoptic systems like off shore trough along the west coast, Upper air tough/wind discontinuity with embedded upper air circulation in some of the sub division, existence of east-west shear line and formation of the Monsoon depression in the Bay of Bengal and WML over Arabian sea were responsible for the active monsoon spells over south India.

7.4.1 Coastal Andhra Pradesh(CAP)

This sub division experienced 6 days of continuous active monsoon spell from 27 August to 01 September. This could be attributed to the formation of the Monsoon low over west central and adjoining North West bay off North Andhra and south Orissa coast on 27/08/2014, its movement towards the coast and its location over Vidharbha on 01 September resulting in Six days of active monsoon.

7.4.2 Telangana (TLGN)

Under the influence of the same monsoon lowresulting in significant rainfall overCAP, Telangana also experienced active monsoonsituation during thesame period. In addition, the existence of an upper air cyclonic circulation on 21/08/2014 led to the active monsooncondition over Telangana on 22/08/2014.

An East west shear line was running across the peninsula and it moved from 10°north to 17° north from 19/08/2014 to 26/08/2014.

7.4.3 Rayalaseema (RYSL)

Rayalaseema experienced Vigorous monsoon activity due to the above mentioned eastwest shear line, on 25/08/2014.

7.4.4 Coastal Karnataka (CK)

The same east-west shear line led to active monsoon situation in CK on 26/08/2014.Strengthening of the westerly winds in the Arabian sea as well as existence of the offshore trough along the west coast were otherfactors leading to good monsoon activity from 28-31st August 2014.

7.4.5 North Interior Karnataka (NIK)

Existence of trough/wind discontinuity from Telengana to south TN resulted in active situation on 20/08/2014. An upper air circulation over Marathwada on 21st Aug led to vigorous activity on 22/08/2014. The east west shear line as stated above, Low pressure area over bay and off shores west coast trough resulted in good monsoon activity from 23 to 31 August.

7.4.6 South Interior Karnataka (SIK)

The East-west shear line with embedded circulation over SIK on 20th& 22ndhad resultedin active monsoon situation from 20thto 23rdAugust. The off-shore trough in west coast and existence of the low pressure in bay had strengthened the westerly flow accounting for the active situation on 28th, 29th& 31stAugust.

7.4.7 Kerala (KRL)

The shear line with embedded circulation over Lakshadweep had resulted in active/vigorous monsoon situation from 22ndto 24thof August over Kerala. The off shore west coast trough and the existence of the low pressure in bay had strengthened the westerly flow accounting for the active/vigorous situation from 28thAugust to 3rdSeptember.

7.4.8 Lakshadweep (LKD)

A well-marked low pressure areas (WML) over the Arabian Sea (23rd - 24th Aug.) and velocity convergence in the westerly flow combined with curvature effect over Lakshadweep area led to rainfall more than twice the normal.

7.4.9 TamilNadu (TN)

Existence of an upper air circulation over Comorin area and neighborhood on 22/08/2014resulted in vigorous monsoon activity over South TamilNadu on 23/08/2014. The northward march of the east-west shear line and its passage over North TamilNadu on 23rd Aug resulted in active monsoon situation on 24th Aug.

The rainfall figures overpeninsular India during the last two weeks of August and the first week of September are given in Table-7.2. Lakshadweep received more than twice the normal rainfalls whilethe met-subdivisions Kerala;North &South Interior Karnataka received more than one and a half times their respective normal rainfall. With the formation of twowell-marked low pressure areas (WML),one over the Arabian Sea (23rd - 24thAug.)&the other over Bay of Bengal (27th Aug – 6thSept.), the rainfall activity over major parts of peninsular India enhanced during the last two weeks of August. The MSLweather charts (Fig.7.1(a) & (b)) show the formation of WML over coastal Andhra- Pradesh and subsequent movement towards central and North-West India. Strong pressure gradient, of the order of 10 hPa, prevailed along the west coast. A feeble off-shore trough at MSL from south Maharashtra coast to north Kerala coast seen during 25 -26thAugust deepened and extended from North Maharashtra coast to south Kerala coast during 27-29thAugust.The satellite picture of 27th Aug (Fig.7.3) shows clouding associated with the off-shore trough over northeast and south east part of the Arabian sea and clouding over the southwest sector of the WML over west central Bay.Also the associated upper air cyclonic circulation between 1.5& 5.8 Km a.s.llies over west central Bay embedded in east – west trough as seen in Fig.7.2(a) & (b) on 29th Aug.On the Arabian Sea side, there was velocity convergence in the westerly flow combined with curvature effect over Lakshadweep area.

This led to moisture convergence and vertical motion over southern peninsular region during 27-29thAugust resulting ina very good rainfall over the region.

Table-7.2: The weekly rainfall departures of cumulative rainfall departures from 1st June for the study period.

	20/08/14 Week ending	20/08/14 seasonal	27/8/14 Week ending	27/8/14 seasonal	03/9/14 Week ending	03/9/14 seasonal
CAP	-27	-35	-5	-32	58	-25
TLGN	-85	-55	10	-50	124	-37
RYSL	-19	-27	116	-13	-27	-14
CK	-64	-7	16	-5	169	1
NIK	-4	-24	225	-5	178	8
SIK	3	14	112	20	81	23
TN/PDC	142	10	-11	7	-56	1
KRL	-65	-5	73	2	312	8
LKDP	48	-25	290	-4	171	3

The rainfall figures while the monsoon was vigorous over NIK and active over Telangana, SIK and Kerala on 22ndAug.,vigorous monsoon over CK and NIK on 29th Aug and over Kerala on 2nd September have been given in Fig.7.4 (a)(b)&(c) respectively.The week ending on 27th Aug. reported departures (Table-7.2) of 290% over LKDP, 225% over NIK, 116 % over RYSLM, 112% over SIK, 73 % over Kerala, 16 % and 10 % over CK and TLGN respectively. The monsoon activity (Table-7.1) was vigorous over NIK during 22, 26, 28-30thAug.and vigorous over TN/PDC and KRL on 23rdAug and again vigorous over KRL during 30th Aug.– 2ndSept.The week ending on 3rd Sept reported departures of 312 % over KRL, 178 % over NIK, 171 % over LKDP, 169 % over CK, 124 % over TLGN, 81 % over SIK and 58 % over CAP.The rainfall activity over Kerala and CK could be related with WML and active trough.So the Quantum jump in the rainfall could be attributed to the synoptic situations.Rainfall during these two weeks resulted in substantial increase of seasonal rainfall activity over the southern peninsular region.

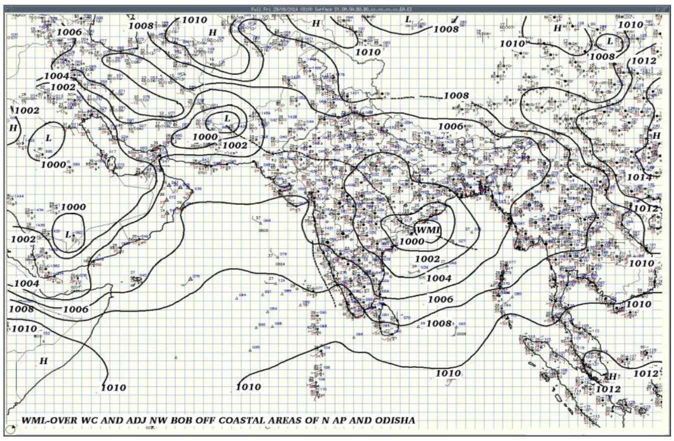


Fig.7.1(a):MSLP chart of 00UTC on 29th August 2014

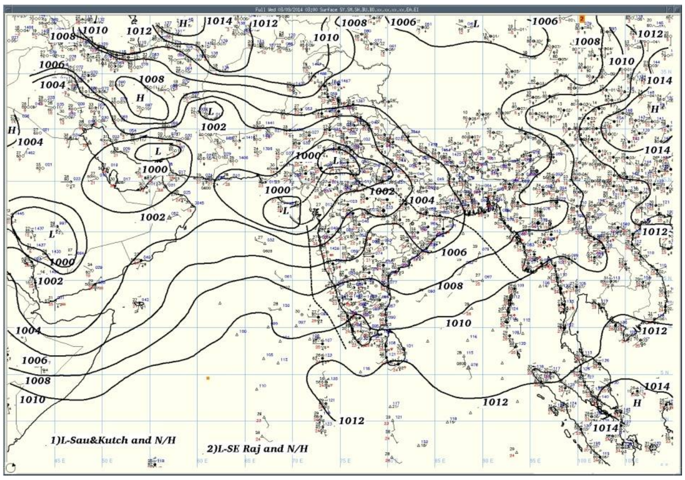


Fig.7.1(b):MSLP chart of 00UTC on 3rdSeptember 2014

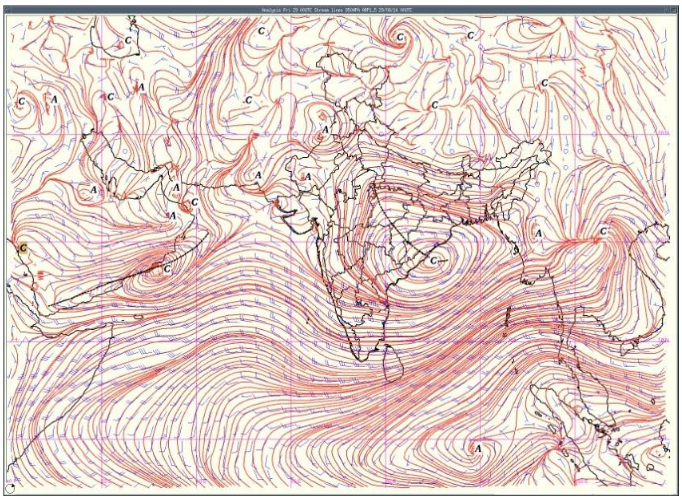


Fig.7.2 (a): Wind at 850 hPa at 00UTC on 29th August 2014

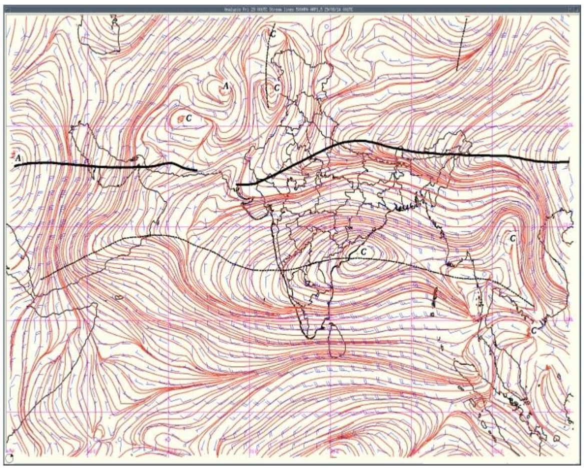


Fig.7.2(b): Wind at 500 hPa at 00UTC on 29th August 2014

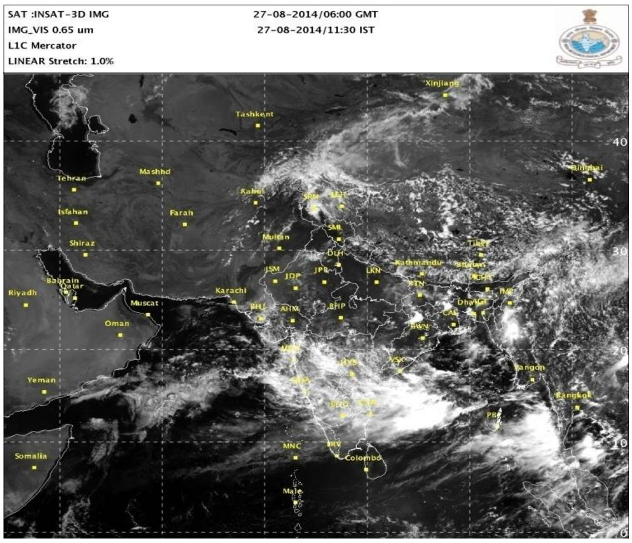


Fig.7.3: Visible satellite imagery of INSAT 3-D at 06 UTC on 27th August 2014

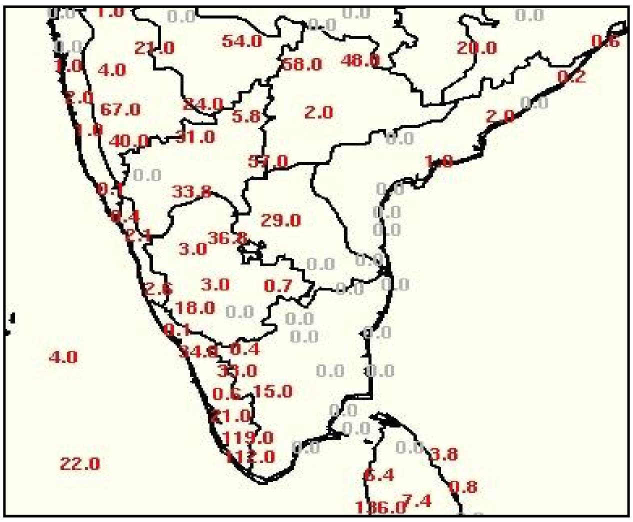


Fig.7. 4(a): Rainfall (24 hrs) of 22ndAugust 2014

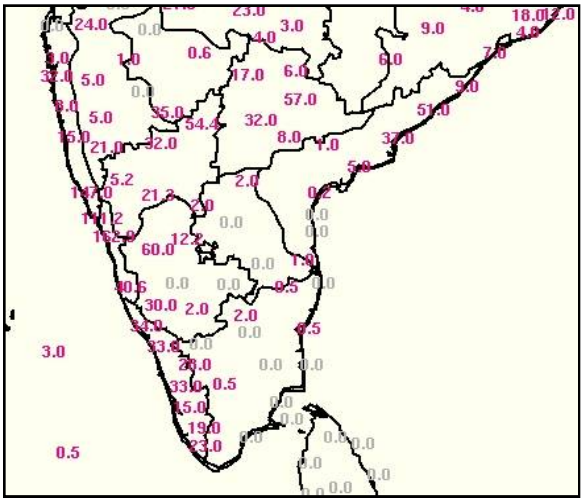


Fig.7.4(b): Rainfall (24 hrs) of 29th August 2014

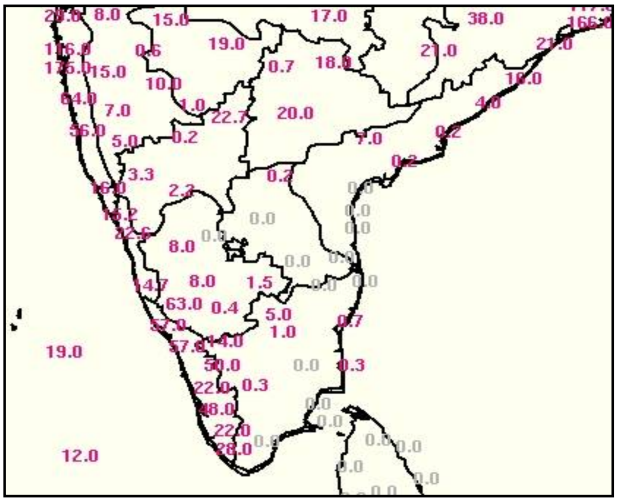


Fig. 7.4(c): Rainfall (24 hrs) of 2nd September 2014

8

RAINFALL STATISTICS

A. K. Srivastava, PulakGuhathakurta, and SurinderKaur

Rainfall over the country as a whole during the southwest monsoon season 2014 (778.0 mm) was the fourth lowest since 2001 after the years 2009(698.2), 2002(737.3) and 2004(774.2). The season also observed large intra seasonal variation with large rainfall deficiency in June and above normal rainfall during September. In this chapter, various spatial and temporal features of rainfall during the season and their statistics have been discussed.

8.1. General Features:

The southwest monsoon season rainfall over the country as a whole was below normal. Moreover, it was marked by significant spatial and temporal variability.While, central, peninsular and eastern/ northeastern parts of the country received normal rainfall, northwestern parts of the country received deficient rainfall. Rainfall deficiency over some subdivisions of Northwest India viz. West Uttar Pradesh, Haryana, Chandigarh & Delhi and Punjab exceeded 50%. Also, during the first half of the season (1 June to 31 July) country received only 78% of its Long Period

Average (LPA) value(rainfall realized during June month was only 58% of its LPA value),while, during the second half of season (1August to 30 September) it received 97% of its LPA value.On monthly scale, rainfall for the country as a whole was deficient during June, normal during July and August and nearly above normal during September.

For the country as a whole, seasonal rainfall at the end of the southwest monsoon season (June to September) was 87.7% of its Long Period Average (LPA) value. For the country as a whole, the LPA value of southwest monsoon season rainfall, based on data of 1951- 2000 is 89 cm.

During the season, out of 36 meteorological subdivisions, only 1 subdivision (South Interior Karnataka) received excess rainfall, 23 received normal rainfall and remaining 12 subdivisions received deficient rainfall (Fig.8.1).

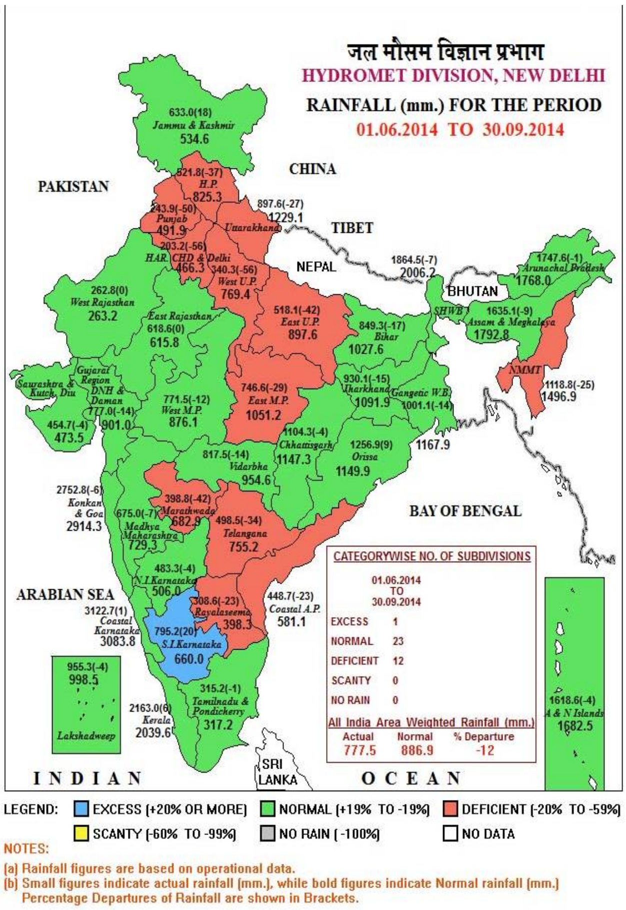


Fig.8.1: Sub-division wise monsoon rainfall distribution (% departure).

Fig.8.2 shows the number of sub-divisions receiving deficient rainfall during the monsoon season for the last ten years.

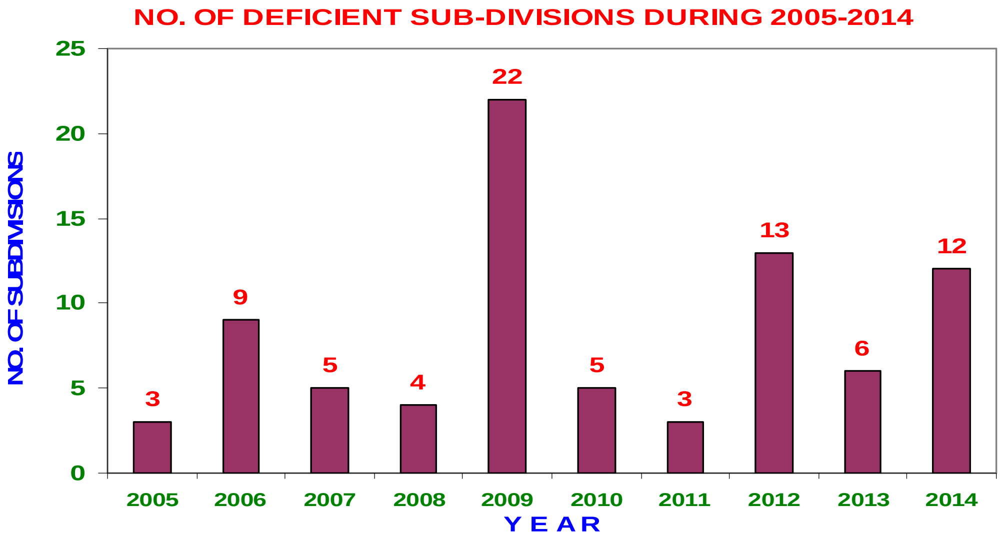


Fig.8.2: Number of sub-divisions receiving deficient rainfall during the last 10 years.

Fig.8.3 shows the district wise rainfall distribution during the southwest monsoon season over the country. During the season, out of 615 districts, 56 districts received excess rainfall, 279 received normal rainfall, 223received deficient rainfall, 56 districts received scanty rainfall and 1 district no rainfall. Percentage of districts with excess/normal and deficient/scanty rainfall for the years 2005-2014 is given in the table below:

Year	Excess/Normal	Deficient/Scanty
2005	72	28
2006	60	40
2007	73	27
2008	76	24
2009	41	59
2010	69	31
2011	76	24
2012	59	41
2013	72	28
2014	54	46

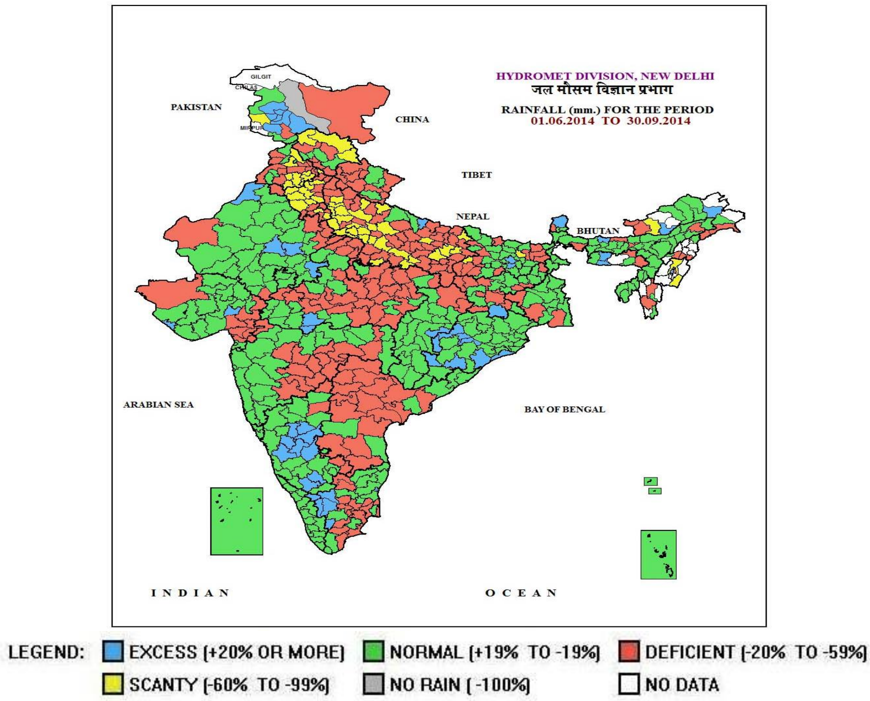


Fig.8.3: District wise monsoon rainfall distribution (% departure).

8.2 Monthly rainfall distribution:

8.2.1 Meteorological Sub-division wise monthly distribution of rainfall:

During June, rainfall activity over the country as a whole was very subdued. The rainfall for the month this year (95.3 mm) was the third lowest since 1901 after the years 2009 (85.7mm) and 1905 (87.4 mm). Most parts of the country received deficient/scanty rainfall. For June 2014, rainfall over the country as a whole was 58.3 % of its Long Period Average (LPA) value.Out of 36 meteorological subdivisions, 6 received normal rainfall, 19 received deficient rainfall and remaining 11 subdivisions received scanty rainfall(Fig.8.4a).During July, rainfall activity over the country as a whole was near normal. West peninsula and central parts of the country received excess/normal rainfall. However, many meteorologicalsubdivisions of north/northeast region and east peninsula received deficient rainfall. For July 2014, rainfall for the country as a whole was 90.4 % of its LPA value.Out of 36 meteorological subdivisions, 3 subdivisions (Orissa, Konkan & Goa and South Interior Karnataka) received excess rainfall, 17 received normal rainfall, 15 received deficient rainfall and remaining 1 subdivision (Lakshadweep Islands) received scanty rainfall(Fig.8.4b).

During August, rainfall activity over the country as a whole was near normal.Most parts of peninsula and eastern/northeastern region of the country received excess/ normal rainfall. Some 36 meteorological subdivisions of these regions viz. Arunachal Pradesh, North & South

Interior Karnataka, Kerala and Lakshadweep Islands received one and half to two times of its respective normal rainfall values. However, many meteorological subdivisions of north/northwest and central India received deficient / scanty rainfall. Rainfall deficiency over some meteorological subdivisions of northwest India viz. East & West Uttar Pradesh, Haryana, Chandigarh & Delhi and Punjab exceeded 50%. For August 2014, rainfall over the country as a whole was 89.9 % of its LPA value.Out of 36 meteorological subdivisions,8 received excess rainfall, 13 received normalrainfall, 12 received deficient rainfall and remaining 3 subdivisionsreceived scanty rainfall (Fig.8.4c).During September, rainfall activity over the country as a whole was generally good.It was above normal over the northwestIndia, near normal over central and east & northeast India and below normal over Peninsular India.Jammu & Kashmir received about four times of its LPA rainfall value, while West Rajasthan and Gujarat state received more than one and half times of its respective LPA values. Most of the rainfall occurred during the week ending on 10 September. However, rainfall deficiency over somemeteorological subdivisions viz. Uttar Pradesh, Uttarakhand, Rayalaseema and Marathwada was around 50 %. Out of 36 meteorological subdivisions, 9 received excess rainfall, 14 received normal rainfall and remaining 13 received deficient rainfall (Fig. 8.4d).

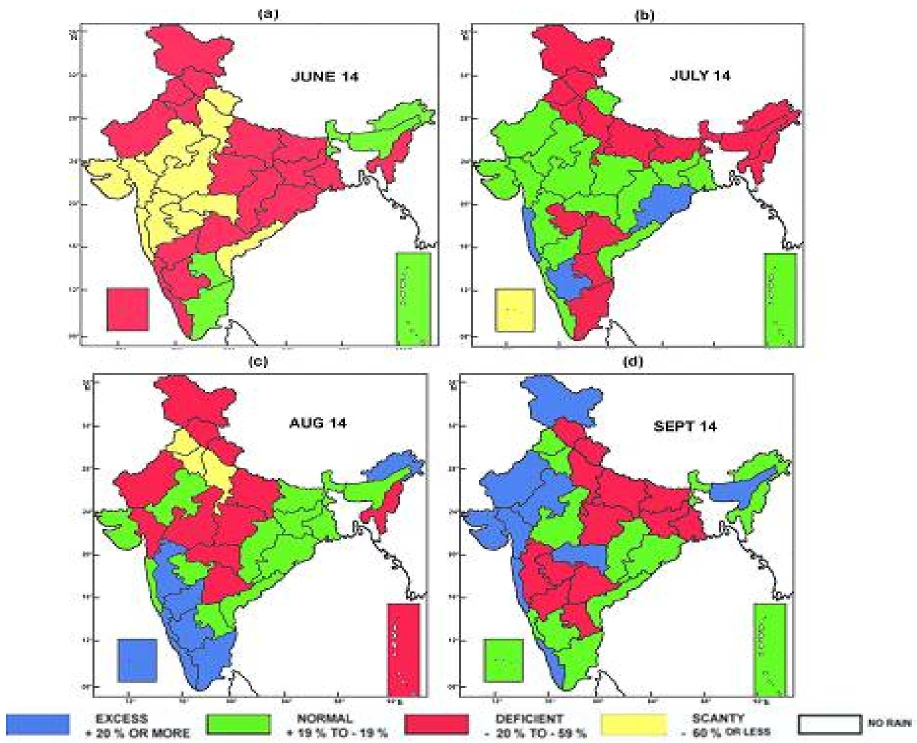


Fig.8.4 (a-d): Monthly sub-division wise rainfall percentage departure for June, July, August and September 2014.

Table-8.1: Monthly and seasonal sub-division wise rainfall statistics for the 2014 monsoon season

Sr. No.	SUB-DIVISION NAME	JUNE			JULY			AUGUST			SEPTEMBER			MONSOON		
		ACTUAL	NORMAL	% DEP	ACTUAL	NORMAL	% DEP	ACTUAL	NORMAL	% DEP	ACTUAL	NORMAL	% DEP	ACTUAL	NORMAL	% DEP
1	A & N ISLANDS	416.6	438.6	-5	467.6	407.7	15	321.6	403.8	-20	412.9	432.4	-5	1618.6	1682.5	-4
2	ARUNACHAL	415.8	500.4	-17	392.4	536.1	-27	612.6	359.9	70	337.5	371.6	-9	1747.6	1768.0	-1
3	ASSAM & MEGHALAYA	414.9	502.3	-17	370.3	553.9	-33	435.3	410.3	6	406.9	326.3	25	1635.1	1792.8	-9
4	NAG.,MANI.,MIZO.,TRIP	268.3	412.1	-35	295.7	415.0	-29	280.0	380.1	-26	306.1	289.7	6	1118.8	1496.9	-25
5	S.H.W.B.&SIKKIM	543.2	485.2	12	384.6	615.8	-38	564.1	495.2	14	373.4	410.0	-9	1864.5	2006.2	-7
6	GANGATIC W.B.	182.6	244.4	-25	300.6	331.7	-9	295.6	312.3	-5	222.2	279.5	-20	1001.1	1167.9	-14
7	ORISSA	92.2	214.1	-57	496.2	337.0	47	385.2	362.1	6	281.1	236.7	19	1256.9	1149.9	9
8	JHARKHAND	139.7	197.5	-29	321.3	334.6	-4	289.1	315.8	-8	178.2	244.0	-27	930.1	1091.9	-15
9	BIHAR	115.2	168.5	-32	265.4	343.5	-23	306.6	291.6	5	161.1	224.0	-28	849.3	1027.6	-17
10	EAST U.P.	47.8	107.8	-56	224.5	298.0	-25	138.1	294.5	-53	106.6	197.3	-46	518.1	897.6	-42
11	WEST U.P.	21.8	71.1	-69	153.1	258.2	-41	80.4	291.6	-72	84.4	148.5	-43	340.3	769.4	-56
12	UTTARAKHAND	62.9	167.8	-63	462.7	428.1	8	264.2	426.3	-38	107.9	206.9	-48	897.6	1229.1	-27
13	HAR., CHANDI., DELHI	25.9	45.9	-44	72.4	165.8	-56	35.2	173.6	-80	68.0	81.0	-16	203.2	466.3	-56
14	PUNJAB	20.6	44.4	-54	76.3	186.0	-59	41.9	170.4	-75	105.3	91.1	16	243.9	491.9	-50
15	HIMACHAL PRADESH	54.4	95.4	-43	214.4	306.9	-30	167.1	283.0	-41	86.5	140.0	-38	521.8	825.3	-37
16	JAMMU & KASHMIR	35.5	64.1	-45	100.5	192.4	-48	134.2	186.0	-28	362.8	92.1	294	633.0	534.6	18
17	WEST RAJASTHAN	13.8	29.9	-54	94.3	102.7	-8	69.6	89.3	-22	84.6	41.3	105	262.8	263.2	0

Table-8.1 continued….

18	EAST RAJASTHAN	23.6	62.5	-62	196.9	225.2	-13	261.0	228.4	14	136.7	99.7	37	618.6	615.8	0
19	WEST M.P.	30.6	105.4	-71	337.4	291.6	16	209.3	308.7	-32	192.5	170.4	13	771.5	876.1	-12
20	EAST M.P.	91.8	133.7	-31	283.4	347.8	-19	236.1	369.7	-36	139.6	200.0	-30	747.4	1051.2	-29
21	GUJARAT REGION	12.2	129.9	-91	341.8	336.7	2	154.5	277.7	-44	268.6	156.7	71	777.0	901.0	-14
22	SAURASHTRA &	22.6	85.9	-74	166.2	188.2	-12	147.7	124.6	19	118.2	74.8	58	454.7	473.5	-4
23	KONKAN & GOA	258.9	700.0	-63	1354.7	1110.0	22	703.8	759.6	-7	436.7	344.7	27	2752.8	2914.3	-6
24	MADHYA M'RASHTRA	44.0	145.6	-70	277.9	242.2	15	240.6	189.1	27	120.4	152.4	-21	675.0	729.3	-7
25	MARATHAWADA	30.4	143.3	-79	105.0	187.2	-44	178.9	188.2	-5	84.5	164.2	-49	398.8	682.9	-42
26	VIDARBHA	63.3	168.0	-62	337.6	311.9	8	191.7	305.7	-37	224.9	169.0	33	817.6	954.6	-14
27	CHATTISGARH	102.7	182.8	-44	422.4	376.2	12	327.9	373.3	-12	253.3	215.0	18	1104.8	1147.3	-4
28	COASTAL A.P.	35.0	103.9	-66	141.1	160.4	-12	144.8	157.7	-8	128.9	159.1	-19	448.7	581.1	-23
29	TELANGANA	55.4	135.9	-59	142.9	238.2	-40	172.0	218.8	-21	126.6	162.3	-22	498.5	755.2	-34
30	RAYALASEEMA	65.7	67.7	-3	64.4	94.2	-32	109.0	103.3	5	73.6	133.1	-45	308.6	398.3	-23
31	TAMIL NADU	47.8	46.0	4	50.6	68.0	-26	117.7	87.4	35	98.9	115.8	-15	315.2	317.2	-1
32	COASTAL KARNATAKA	492.7	867.7	-43	1168.1	1159.7	1	1099.0	755.5	45	349.6	300.9	16	3122.7	3083.8	1
33	N.I.KARNATAKA	50.4	104.6	-52	136.8	135.0	1	206.3	120.4	71	90.3	146.0	-38	483.3	506.0	-4
34	S.I.KARNATAKA	106.8	141.5	-25	271.6	216.1	26	256.6	161.4	59	162.3	141.0	15	795.2	660.0	20
35	KERALA	454.4	649.8	-30	677.8	726.1	-7	732.0	419.5	74	297.4	244.2	22	2163.0	2039.6	6
36	LAKSHADWEEP	244.1	330.2	-26	116.1	287.7	-60	469.1	217.5	116	134.8	163.1	-17	955.3	998.5	-4

Monthly and seasonal sub-division wiserainfall statistics for the 2014 monsoon season are given in the Table-8.1.

The following table gives the respective number of subdivisions receiving excess, normal, deficient and scanty rainfall during the four months of monsoon season 2014.

Month	Jun	Jul	Aug	Sept
Excess	0	3	8	9
Normal	6	17	13	14
Deficient	19	15	12	13
Scanty	11	1	3	0
Rainfall (% OF LPA)	58.3	90.4	89.9	108.1

8.2.2 District wise monthly distribution of rainfall:

Monthly district wise rainfall percentage departures for June, July, August and September 2014 are shown in Fig.8.5 (a-d). During June, rainfall was deficient over most of the districts of the country except for the sub divisions Assam & Meghalaya, Sub-Himalayan West Bengal & Sikkim, Tamil Nadu & Puducherry and south Interior Karnataka. Out of the total 617 districts for which data were available, only 38 districts received excess rainfall, 99received normal rainfall, 233 received deficient rainfall and 243 districts received scanty rainfall in June.

During July, over the country as a whole, rainfall was above normal over most of the districts. All districts of Odisha, Konkan & Goa and Coastal Karnataka received excess/normal rainfall. However, most of the districts of Nagaland, Mizoram Manipur & Tripura, West Uttar Pradesh, Haryana, Chandigarh & Delhi, Punjab, Jammu & Kashmir, Marathwada, Telangana, Rayalaseema and Tamil Nadu& Puducherry received deficient rainfall.Out of the total 615 districts for which data were available, 126received excess rainfall, 179 received normal rainfall, 222 received deficient rainfall and 88 districts received scanty rainfall.

During August, many districts of South Peninsula, east/northeast India, Rajasthan and Gujarat received excess/normal rainfall, while rest of the districts generally received deficient rainfall. Almost all districts of Gangetic West Bengal, Odisha, Rayalaseema, Coastal Karnataka, North Interior Karnataka, South Interior Karnataka and Kerala received excess/normal rainfall. However, for West Uttar Pradesh and Haryana, Chandigarh & Delhi, all the districts received deficient/scanty rainfall and most of the districts of East Uttar Pradesh, Uttarakhand, Punjab, Himachal Pradesh, West Rajasthan, West Madhya Pradesh, East Madhya Pradesh, Gujarat Region and Vidarbha received deficient rainfall.Out of the total 612 districts for which data were available, 142received excess rainfall, 172 received normal rainfall, 186 received deficient rainfall and 112 districts received scanty rainfall in August.

During September, many districts of South Peninsula, central and northern/ northeastern region received deficient/scanty rainfall,while rest of the country generally received excess/normal rainfall. Almost all districts of Odisha, Jammu & Kashmir, East Rajasthan, Saurashtra& Kutch, Konkan & Goa, Kerala received excess/normal rainfall.However, many districts of Jharkhand, Bihar, East Uttar Pradesh, West Uttar Pradesh, Himachal Pradesh, East Madhya Pradesh, Marathwada, Telangana and North Interior Karnataka received deficient rainfall and all districts of Uttarakhand and Rayalaseema received deficient rainfall. Out of the total 612 districts for which data were available, 172received excess rainfall, 173 received normal rainfall, 216 received deficient rainfall and 51 districts received scanty rainfall in September.

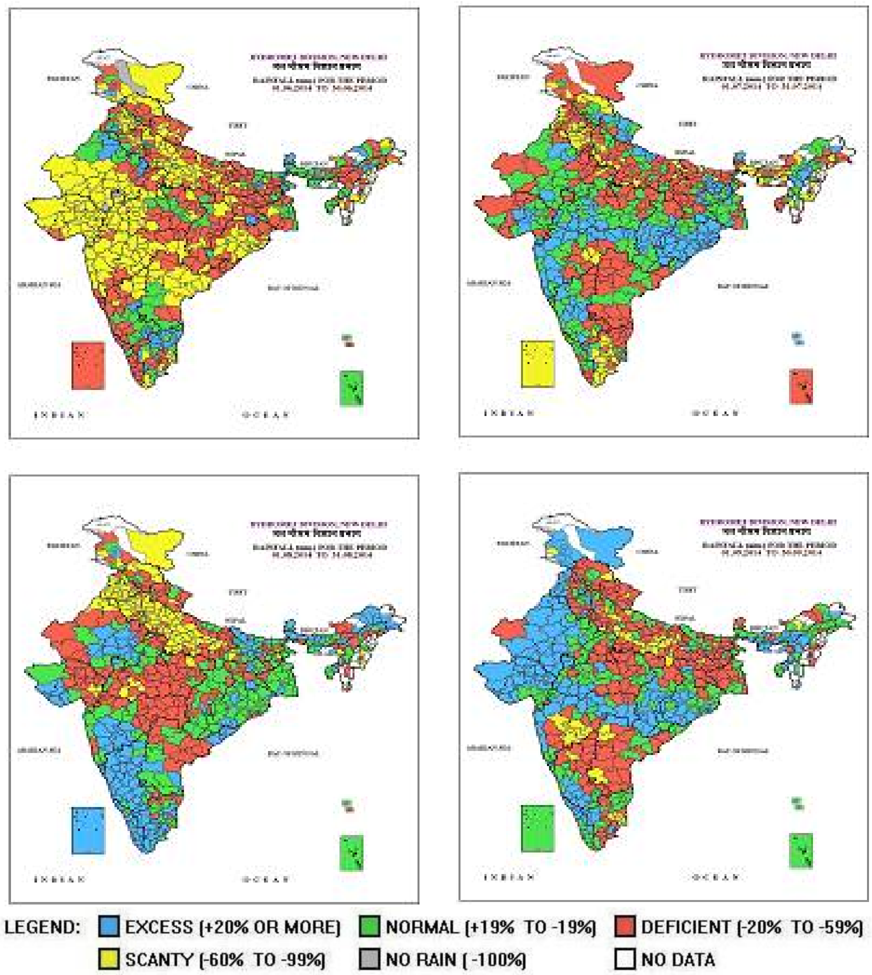


Fig.8.5 (a-d): Monthly district wise rainfall percentage departure for June, July, August and September 2014.

The following table gives number of districts receiving excess (E), normal (N), deficient (D), scanty (S) or no rain (NR) during the months of June, July, August and September in each of the met subdivisions.

S.NO.	SUBDIVISION NAME	JUNE					JULY					AUGUST					SEPTEMBER				
		E	N	D	S	NR	E	N	D	S	NR	E	N	D	S	NR	E	N	D	S	NR
1	A & N ISLAND	0	2	1	0	0	2	0	1	0	0	0	2	1	0	0	0	3	0	0	0
2	ARUNACHAL PRADESH	2	3	5	3	0	2	3	5	2	0	8	0	4	0	0	1	7	3	1	0
3	ASSAM & MEGHALAYA	4	15	13	0	0	4	9	10	9	0	12	13	7	1	0	19	9	4	1	0
4	Naga, Mani,Mizo& Trip.	1	5	6	6	0	2	3	6	7	0	2	6	4	2	0	5	5	4	0	0
5	SHWB & SIKKIM	3	6	1	0	0	1	3	4	2	0	4	5	1	0	0	1	5	3	1	0
6	GANGETIC WEST BENGAL	0	4	8	1	0	2	7	4	0	0	1	11	1	0	0	0	6	7	0	0
7	ODISHA	0	1	10	19	0	25	5	0	0	0	5	24	1	0	0	16	13	1	0	0
8	JHARKHAND	1	3	16	4	0	7	9	8	0	0	3	12	8	1	0	2	3	18	1	0
9	BIHAR	3	8	20	7	0	9	4	21	4	0	13	16	7	2	0	2	10	24	2	0
10	EAST UTTAR PRADESH	0	2	19	20	0	3	11	22	5	0	0	4	17	20	0	0	7	20	14	0
11	WEST UTTAR PRADESH	1	1	7	21	0	0	4	17	9	0	0	0	3	27	0	1	3	18	8	0
12	UTTARAKHAND	0	0	7	6	0	6	5	2	0	0	0	2	9	2	0	0	0	11	2	0
13	HAR. CHD & DELHI	2	3	13	13	0	0	2	13	16	0	0	0	6	25	0	4	10	13	4	0
14	PUNJAB	1	4	4	11	0	0	1	11	8	0	0	1	2	17	0	9	4	7	0	0
15	HIMACHAL PRADESH	0	2	7	3	0	1	6	2	3	0	0	3	6	3	0	0	4	7	1	0
16	JAMMU & KASHMIR	2	1	10	6	1	0	5	10	4	0	5	5	6	3	0	18	0	0	1	0
17	WEST RAJASTHAN	2	2	0	6	0	1	5	4	0	0	2	1	5	2	0	9	0	1	0	0
18	EAST RAJASTHAN	2	3	4	13	1	2	13	8	0	0	10	5	8	0	0	12	10	1	0	0
19	WEST MADHYA PRADESH	0	1	6	22	1	12	11	6	1	0	1	8	17	4	0	10	13	7	0	0
20	EAST MADHYA PRADESH	0	6	12	2	0	0	11	9	0	0	0	3	16	1	0	1	5	14	0	0
21	GUJARAT REGION	0	0	0	20	0	5	9	6	0	0	0	3	15	2	0	11	7	2	0	0
22	SAURASHTRA & KUTCH	1	0	1	7	0	2	4	3	0	0	6	2	1	0	0	8	1	0	0	0
23	KONKAN & GOA	0	0	3	5	0	5	3	0	0	0	2	5	1	0	0	4	4	0	0	0
24	MADHYA MAHARASHTRA	0	0	3	7	0	6	3	1	0	0	5	2	3	0	0	3	2	3	2	0
25	MARATHWADA	0	0	0	8	0	0	2	3	3	0	2	3	3	0	0	0	2	3	3	0
26	VIDARBHA	0	0	5	6	0	6	3	2	0	0	0	1	10	0	0	6	2	3	0	0
27	CHHATTISGARH	0	3	12	3	0	9	7	2	0	0	1	11	6	0	0	9	6	3	0	0
28	COASTAL A. P.	0	0	4	5	0	1	4	4	0	0	4	0	5	0	0	0	4	5	0	0
29	TELANGANA	0	1	3	6	0	0	1	9	0	0	0	4	6	0	0	1	1	6	2	0
30	RAYALASEEMA	0	3	1	0	0	0	1	3	0	0	1	3	0	0	0	0	0	3	1	0
31	TAMILNADU & P'CHERY	10	10	6	7	1	5	4	12	13	0	18	10	6	0	0	6	10	12	6	0
32	COASTAL KARNATAKA	0	0	3	0	0	0	3	0	0	0	3	0	0	0	0	1	2	0	0	0
33	N.I. KARNATAKA	0	0	5	6	0	3	4	4	0	0	9	2	0	0	0	0	2	8	1	0
34	S.I. KARNATAKA	3	9	4	0	0	5	6	4	1	0	11	4	1	0	0	6	5	5	0	0
35	KERALA	0	1	13	0	0	0	8	6	0	0	13	1	0	0	0	7	7	0	0	0
36	LAKSHADWEEP	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0

8.3 Daily rainfall distribution

Area weighted daily rainfall (in mm) and its long term (1951-2000) normal value for the country as a whole and for the four homogeneous regions during 1 June to 30 September are shown in Fig. 8.6.For the country as a whole, rainfall averaged was below normal on most of the days till second week of July. It was nearly half its normal value, at a stretch from 22 June to 11 July. Thereafter, it was generally either normal /above normalon many days till the end of August. During September, it was above normal for the first eight days of the month and was even more than twiceof its normal value on some occasions. Thereafter, it was generally below/near normal till the end of the season.

Over the homogeneous region of Northwest India, daily rainfall was generally below normal on many occasions during the season. During second fortnight of August and second fortnight of September, it was substantially below normal. However, during the first week of September, it was substantially above normal on some occasions.

Over the East & Northeast India, daily rainfall was substantially above normal during few days of August and September and was generally near normal during most of the season.

Over the Central India, daily rainfall was substantially above normal on many occasions from 15 July to 6 August and again from 30 August to 9 September. For most of the days it was generally below normal during rest of the season.

Over the South Peninsula, daily rainfall was generally near normal on most of the days during the season except for the period 23 June-4 July when it was substantially below normal and for the period 26-30 August when it was substantially above normal.

8.4 Weekly rainfall distribution

Area weighted cumulative weekly rainfall percentage departure for the country as a whole and the four homogeneous regions (NW India, NE India, Central India and South Peninsula) for the period 1 June to 30 September is shown in Fig.8.7. Cumulative rainfall departure was negative throughout the season. However, the large rainfall deficiency of about 45% till mid-June gradually reduced to about 10% by the second week of September.

Cumulative weekly rainfall departure for all the homogeneous regions was also below normal during the whole season. Cumulative rainfall at the end of season was 79% of LPA over Northwest India, 88% of LPA over East & Northeast India, 90% of LPA over Central India and 93% of LPA over South Peninsula.

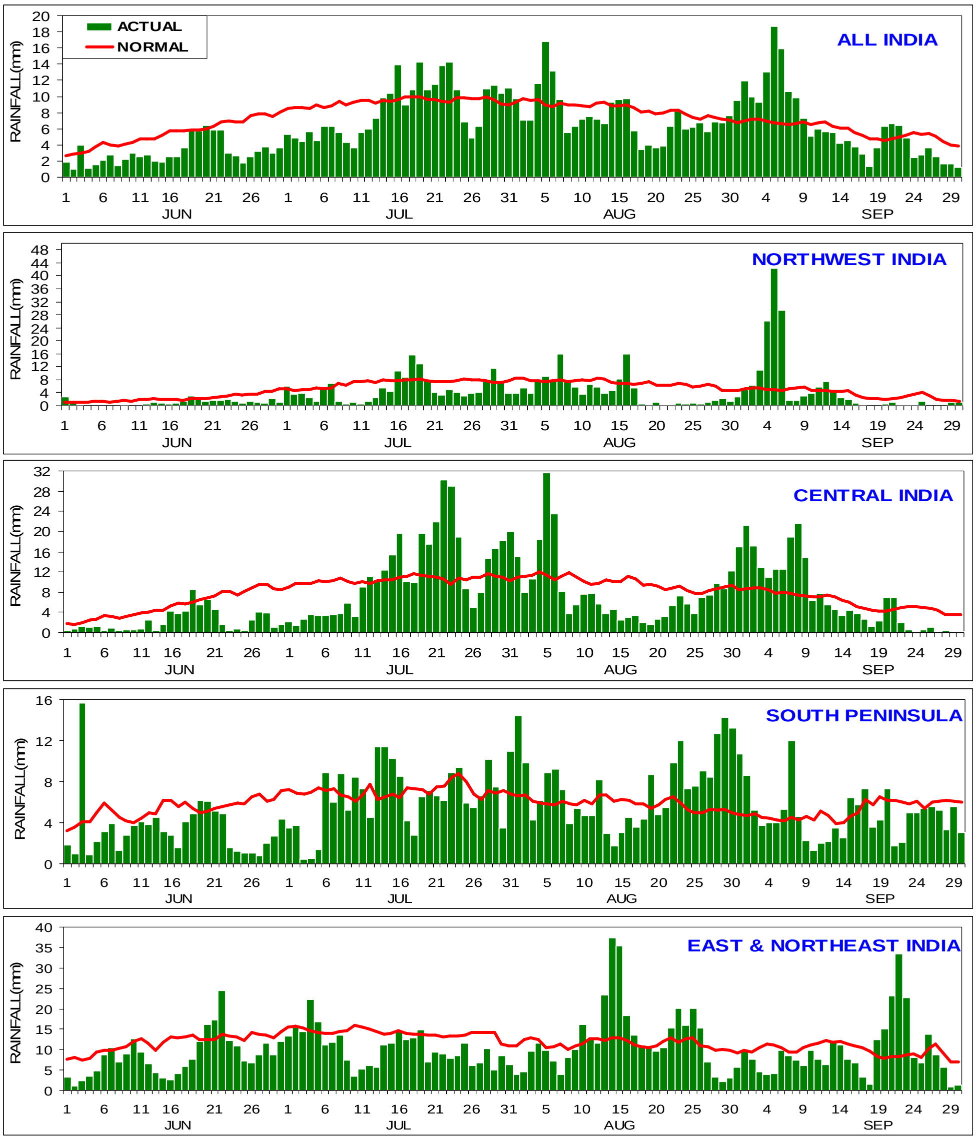


Fig.8.6: Daily area weighted rainfall (mm) (vertical bars) and its long term (1951-2000) average (solid line) over the country as whole and the four homogeneous regions during the season.

Week by week and cumulative weekly rainfall percentage departure for each of the 36 meteorological subdivisions from 1 June to 30 Sept. is shown in Fig. 8.8 and 8.9 respectively.Weekly rainfall was excess or normal during most of the weeks (more than 50% of the weeks) only for a some subdivisions of south peninsula and northeastern region viz. Coastal Karnataka, North & South Interior Karnataka, Kerala, Tamil Nadu, Arunachal Pradesh and Andaman & Nicobar Islands. Similarly, cumulative weekly rainfall was also excess or normal during most of the weeks (more than 50% of the weeks) for only some subdivisions of eastern / northeastern and peninsular India viz. Andaman & Nicobar Islands, Arunachal Pradesh, Sub-

Himalayan West Bengal & Sikkim, Gangetic West Bengal, Odisha, Jharkhand, East Rajasthan, West Madhya Pradesh, Konkan & Goa, Chattisgarh, Rayalaseema, Tamil Nadu, South Interior Karnataka and Kerala. For Nagaland, Manipur, Mizoram & Tripura, East & West Uttar Pradesh, Punjab and Marathwada, cumulative rainfall was deficient /scanty during all the weeks of the season.

8.4 Heavy Rainfall Events

During the 2014 southwest monsoon season, very heavy rainfall (≥ 12.5 cm in 24 hours)/ extremely heavy rainfall (≥ 25 cm in 24 hours) events were reported at many stations. At some stations, record rainfall (in 24 hrs.) for the month was also reported. The month wise and station wise distribution of extremely heavy rainfall events is given in Table 8.2. Record rainfall (in 24 hrs.) for the month reported during the season is given in Table 8.3.

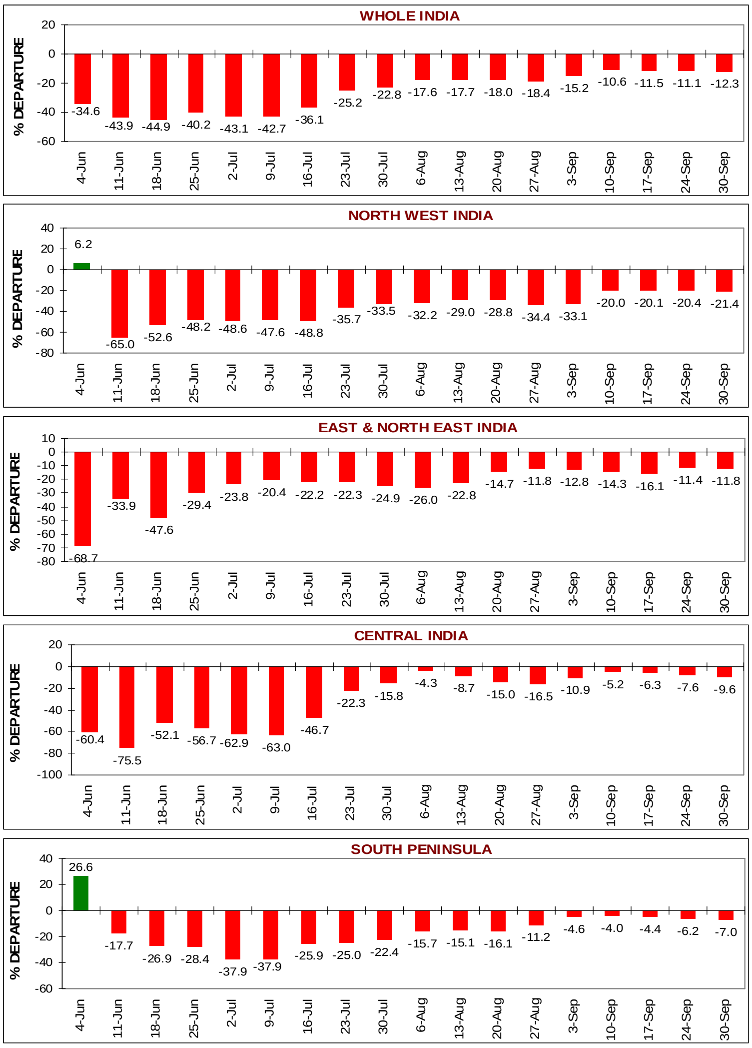


Fig.8.7: Area weighted cumulative weekly rainfall percentage departure for the country as a whole and the four homogeneous regions.

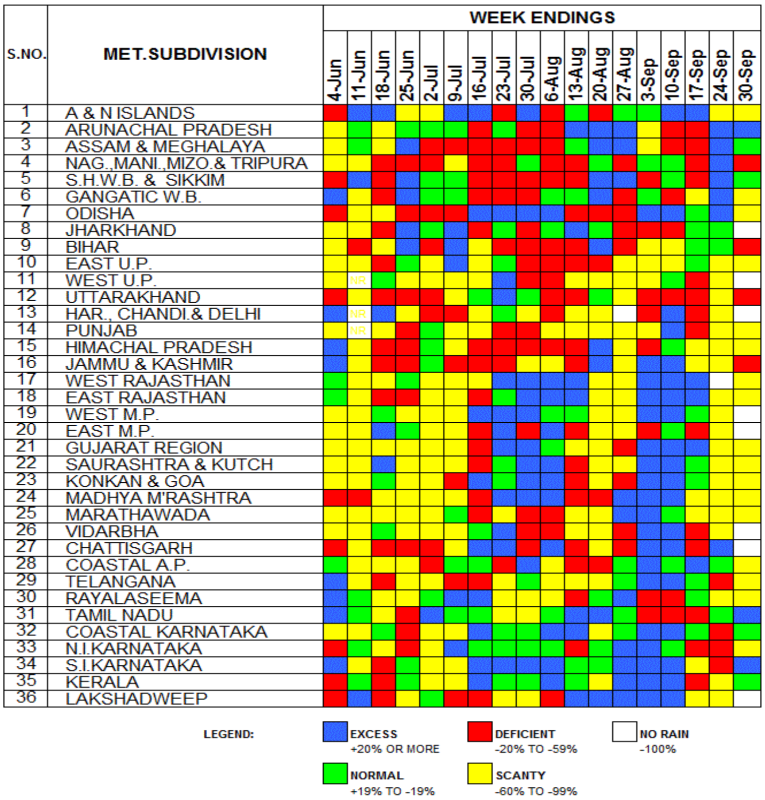


Fig.8.8: Sub-division wise weekly rainfall.

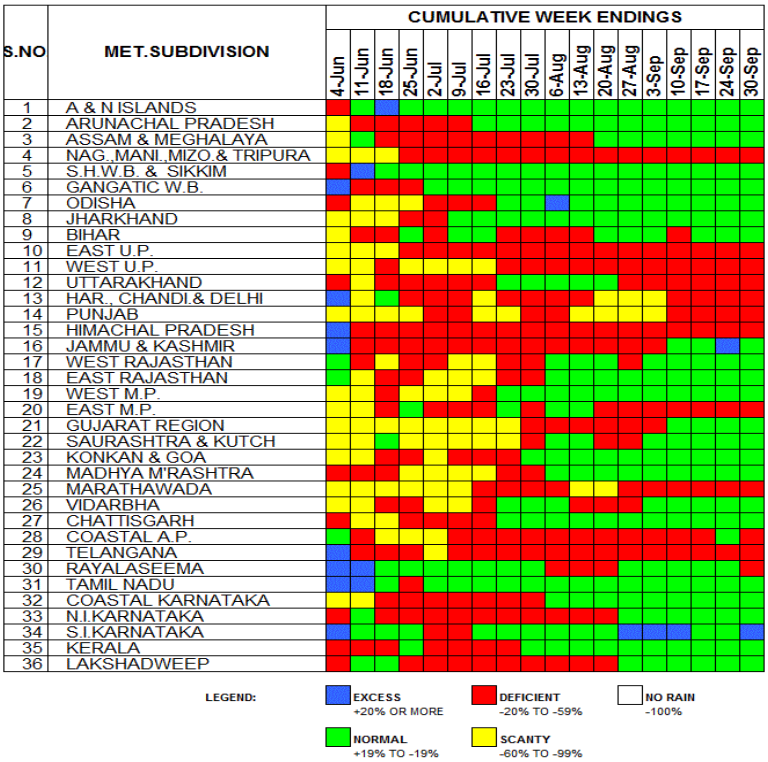


Fig.8.9: Sub-division wise cumulative weekly rainfall.

Table-8.2: Month wise list of stations, which reported extremely heavy rainfall (≥ 25 cm) in 24 hours during the monsoon season.

DATE (JUNE 14)	STATION	NAME OF SUBDIVISION	RAINFALL (cm)
7	GOSSAIGAON	ASSAM & MEGHALAYA	32
	BAROBHISHA	SUB-HIMALAYAN W.B. & SIKKIM	27
16	KODINAR	SAURASHTRA & KUTCH	38
21	MAWSYNRAM	ASSAM & MEGHALAYA	31
22	MAWSYNRAM	ASSAM & MEGHALAYA	54
23	MAWSYNRAM	ASSAM & MEGHALAYA	40
25	CHENGMARI / DIANA	SUB-HIMALAYAN W.B. & SIKKIM	30
30	BAGHDOGRA AP	SUB-HIMALAYAN W.B. & SIKKIM	25

DATE (JULY 14)	STATION	NAME OF SUBDIVISION	RAINFALL (cm)
7	KAISERGANJ	EAST UTTAR PRADESH	44
8	CHERRAPUNJI	ASSAM & MEGHALAYA	78
13	SALEBHATTA ARG	ODISHA	27
	SUBRAMANYA	COASTAL KARNATAKA	25
	AGUMBE	SOUTH INTERIOR KARNATAKA	25
16	RENUKA / DADHAU	HIMACHAL PRADESH	30
18	BHIRA	KONKAN & GOA	27
19	JODIA	SAURASHTRA & KUTCH	26
	AGUMBE	SOUTH INTERIOR KARNATAKA	25
21	ANANDPUR	ODISHA	27
	KANKER (ANANTAGARH)	CHHATTISGARH	27
22	SARAIPALI	CHHATTISGARH	34
	BIJEPUR	ODISHA	27
23	KHAKNAR	WEST MADHYA PRADESH	41
	CHIKHALDA	VIDARBHA	28
	MAHABALESHWAR	MADHYA MAHARASHTRA	25
29	VIKRAMGAD	KONKAN & GOA	28
	IGATPURI	MADHYA MAHARASHTRA	26
30	BHIRA	KONKAN & GOA	37
	KADI	GUJARAT REGION	32
31	MAHABALESHWAR	MADHYA MAHARASHTRA	43
	GOKARNA	COASTAL KARNATAKA	36
	SOHELA	ODISHA	30
	DAHANU	KONKAN & GOA	27
	HULIKAL ARG	SOUTH INTERIOR KARNATAKA	26
	SILVASSA	GUJARAT REGION	25

Table-8.2: Continued……

DATE (AUG 14)	STATION	NAME OF SUBDIVISION	RAINFALL (cm)
1	AGUMBE	SOUTH INTERIOR KARNATAKA	40
	DWARKA	SAURASHTRA & KUTCH	39
	SIDDAPURA	COASTAL KARNATAKA	29
2	AGUMBE	SOUTH INTERIOR KARNATAKA	25
4	SAMBALPUR	ODISHA	34
	DIGHA	GANGETIC WEST BENGAL	31
5	PALLAHARA	ODISHA	40
	MAHABALESHWAR	MADHYA MAHARASHTRA	31
	KARERA	WEST MADHYA PRADESH	25
7	BHINAY	EAST RAJASTHAN	27
8	CONTAI	GANGETIC WEST BENGAL	29
12	BIJOLIYA	EAST RAJASTHAN	29
14	MAWSYNRAM	ASSAM & MEGHALAYA	38
	EKANGERSARAI	BIHAR	25
15	MAWSYNRAM	ASSAM & MEGHALAYA	37
	GAJOLDOBA	SUB-HIMALAYAN W.B. & SIKKIM	30
	MOTIHARI	BIHAR	27
16	MAWSYNRAM	ASSAM & MEGHALAYA	38
24	MAWSYNRAM	ASSAM & MEGHALAYA	37
25	MAWSYNRAM	ASSAM & MEGHALAYA	37
26	HASIMARA	SUB-HIMALAYAN W.B. & SIKKIM	26

DATE (SEPT 14)	STATION	NAME OF SUBDIVISION	RAINFALL (cm)
3	IDAR AWS	GUJARAT REGION	30
5	KATRA	JAMMU & KASHMIR	28
6	KAWA AWS	JAMMU & KASHMIR	26
7	MULCHERA	VIDARBHA	44
	BHOPALPATNAM	CHHATTISGARH	27
	R. UDAIGIRI	ODISHA	26
8	KHANDWA	WEST MADHYA PRADESH	37
9	HALOL	GUJARAT REGION	27
22	TIKRIKILLA	ASSAM & MEGHALAYA	54
23	CHERRAPUNJI RKM	ASSAM & MEGHALAYA	54

Table-8.3: Record rainfall (in 24 hrs.) during the monsoon season

S. No.	STATION	RAINFALL DURING PAST 24 Hrs. (mm)	DATE	PREVIOUS RECORD (mm)	Date of record	Year of record
			(June 14)			
1	IMPHAL	120.4	15	106.6	2	1974
2	MALDA	188.6	28	182.2	23	2000
			(July 14)			
1	BAHRAICH	341.6	7	202.7	15	1989
2	TUNI	133.0	8	100.1	5	2003
3	TIRUPATHI AP	113.1	6	101.8	26	1985
4	KARAIKAL	94.8	7	81.2	21	1984
			(Aug 14)			
1	DIGHA	308.1	4	298.6	11	1993
2	PATNA AP	178.0	14	165.4	29	1914
	DWARKA	394.7	1	302.3	7	1933
3	RAICHUR	114.6	25	107.7	14	1914
			(Sept 14)			
1	GUWAHATI AP	155.3	23	133.9	17	1949
2	AMRITSAR IAF	146.0	6	100	26	1988
3	GULMARG	128.0	5	110.8	10	1992
4	BANIHAL	188.8	5	159.7	10	1992
5	KUKERNAG	119.4	4	57.8	10	1992
6	GANGANAGAR	196.4	5	86	4	1992
7	KHANDWA	368.0	8	278	22	1998
8	JAGDALPUR	164.0	7	163.8	24	1911
9	RAMAGUNDEM	152.6	7	145.3	20	1998

9

NWP PRODUCTS FOR MONSOON WEATHER MONITORING AND PREDICTION AT VARIOUS TEMPORAL / SPATIAL SCALES

Y.V. Rama Rao, V.R. Durai and Ananda Kumar Das

This chapter discusses the verification of operational forecasts in the short range (up to 3 days) and medium range (up to 7 days) weather forecasts based on Global Forecasting System (GFS) and Weather Research and Forecast (WRF) model operational at India Meteorological Department (IMD) for the 2014 southwest monsoon season.

9.1. Introduction

The Global Forecast System GFS (GSI 3.0.0 and GSM 9.1.0), adopted from National Centre for Environmental Prediction (NCEP), at T574L64 (~ 23 km in horizontal) resolution and Weather Research and Forecast (WRF) (27/9 km horizontal; 38 vertical) were implemented at India Meteorological Department (IMD), New Delhi on IBM based High Performance Computing Systems (HPCS) in June 2011 for day-to-day operational use. The real-time outputs are made available to IMD operational forecasters and various users through the national web site of IMD (www.imd.gov.in) and ftp server (IP 125.21.185.50).

The objective of this report is to document the performance skill of these models in spatial and temporal scale during summer monsoon 2014. Rainfall is one of the most difficult parameter to predict due to its large spatial and temporal variation. A detailed rainfall prediction skill of the model is described in this report. Daily rainfall analysis generated at the resolution of 0.5^0 resolution from the use of daily rain gauge observations (IMD) and satellite

(TRMM) derived quantitative precipitation estimates is used as the observed dataset for the validation purpose. GFS T574 performance statistics of upper level wind, temperature and relative humidity forecasts over Indian monsoon regions are also described.

9.2 The Global Forecast System (GFS)

The Global Forecasting System (GFS) run at IMD is a primitive equation spectral global model with state of art dynamics and physics (Kanamitsu 1989, Kalnay et al. 1990, Kanamitsu et al. 1991; Durai and Roy Bhowmik. 2013). The GFS *(GSI 3.0.0 and GSM 9.1.0*), adopted from National Centre for Environmental Prediction (NCEP), at T574L64 (~ 23 km) in horizontal resolution was implemented at India Meteorological Department (IMD) New Delhi on IBM based High Performance Computing Systems (HPCS) in June 2011. More details about the global model GFS are available at http: //www.emc.ncep.noaa.gov/ gmb/moorthi/gam.html.The main objective of this study is to investigate the precipitation forecast skill of the GFS T574 in the medium range time scale over Indian region during South West Monsoon 2014. Daily rainfall analysis from National Data Center (NDC), IMD Pune generated at the resolution of 0.5^0 from the use of daily rain gauge observations (IMD) and satellite (TRMM) derived quantitative precipitation estimates is used as the observed dataset for the validation purpose.

The list of type of data being used in Global Data Assimilation System at IMD is available at IMD web site. The Global Data Assimilation (GDAS) cycle runs 4 times a day (00, 06, 12 and 18 UTC). The assimilation system is a global 3-dimensional variational technique (3D- VAR), based on NCEP Grid Point Statistical Interpolation (*GSI 3.0.0*) scheme, which is the next generation of Spectral Statistical Interpolation (SSI). Forecast model integrated for 7 days based on 00 & 12 UTC initial conditions. The analysis and forecast for 7 days is performed using the HPCS installed in IMD Delhi. One GDAS cycle and seven day forecast (168 hour) with GFS model at T574L64 resolution takes about 1 hour 30 minutes on IBM Power 6 (P-6) machine using 20 nodes (640 processors).

9.3 Verification Procedures

In this study, rainfall verifications were carried out for GFS model run at 00 UTC and the accumulation period of the rainfall forecast has been matched with the verification analysis which is from 03 UTC of a day to 03 UTC of next day was verified against daily rainfall analysis at the resolution of 0.5^0 based on the merged rainfall data combining gridded rain gauge observations prepared by IMD Pune for the land areas and TRMM 3B42RT data for the Sea areas. In order to examine the performance of the model in different homogeneous part of the country, we selected six representative region (square/rectangular domain) for (a) All India (land areas: (Lon: 68^0 E – 98^0 E, Lat: 9^0 N – 37^0 N), (b) Central India (CE: Lon: 77^0 E – 82^0 E, Lat: 18^0 – 23^0 N), covering Vidarbha and neighbourhoods, (c) East India (EI: Lon: 83^0 E – 88^0 E, Lat: 22^0 – 27^0 N), covering Orissa and neighbourhoods, (d) North-east India (NE: Lon: 90^0 E – 95^0 E, Lat: 24^0 N -29^0 N), (e) North-west India (NW: Lon:

73^0 E – 75^0 E, Lat: 24^0 N –29^0 N), covering Rajasthan and Haryana, (f) South Peninsular India (SP: Lon: 76^0 E - 81^0 E, Lat: 12^0 N- 17^0 N), covering Kerala and neighbourhood and (g) West coast of India (WC: Lon: 70^0 E - 75^0 E, Lat: 13^0 N - 18^0 N), covering Konkan-Goa. Performance for each region is evaluated by computing grid point by point comparisons (Durai et al. 2010; Roy Bhowmik et al. 2008).

The temporal and spatial distribution of observed and model predicted rainfall has been studied. Direct comparison is made of accumulated values of seasonal mean error (bias) and root mean square Error (RMSE).

These are defined as follows:

Mean error (Bias):

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)$$

***Root mean square error (*RMSE):**

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$$

Anomaly Correlation coefficient:

$$ACC = \frac{\sum_{i=1}^{N}(X_i - \overline{C_i})(O_i - \overline{C}_i)}{\sqrt{\sum_{i=1}^{N}(X_i - \overline{X}_i)^2}\sqrt{\sum_{i=1}^{N}(O_i - \overline{O}_i)^2}}$$

Where, F_i and O_i are the i^th forecast and observation; N=122 days for summer monsoon season

RMSE indicates total amount of difference between forecast and observation map. The score is always greater than or equal to 0.0. If the forecast is perfect, the score of RMSE equals to 0.0.Where N is the total number of samples, i = 1, 2… N and X is the GFST574 rainfall estimation, C is the observed climatology and O is the gauge observation at the grids. In addition to these simple measures, a number of categorical statistics computed from the elements of rain/no-rain contingency table are applied. Then at each grid point each verification time is scored as falling under one of the four categories of correct no-rain, forecasts (Z), false alarms(F) , misses(M), or hits(H).

Probability of detection (POD) or hit rate:

$$POD = \frac{H}{H + M}$$

Threat score (critical success index):

$$TS = \frac{H}{H + M + F}$$

9.4 Verification Results

9.4.1 Rainfall Prediction Skill

9.4.1.1 Observed and forecast fields

Fig.9.1 illustrates the spatial distribution of mean rainfall (mm/day) of the season based on the observations and Day-1 to Day-7 forecast from *GFS T574* for the period from 1

June to 30 September 2014. The observed rainfall distribution shows a north south oriented belt of heavy rainfall along the west coast and Assam & Meghalaya with a peak of ~ 15 - 20 mm/day. It over predict rainfall over some parts of North East India in all day-1 to day-5 forecast. The sharp gradient of rainfall between the west coast heavy rainfall and the rain shadow region to the south east, which is normally expected, is noticed in the observed field. A rainfall belt of order 10 -15 mm is noticed over the eastern central parts of the country over the domain of monsoon low. In, general, the forecast fields of seasonal mean rainfall of GFS T574, could reproduce the heavy rainfall belts along the west coast, over the northeast Bay of Bengal and over the domain of monsoon low. However, some spatial variations in magnitude over northeast region with heavy rainfall belt extending westwards along the foothills of Himalayas in Day-5 and 7 forecasts are noticed during the summer monsoon season of 2014.

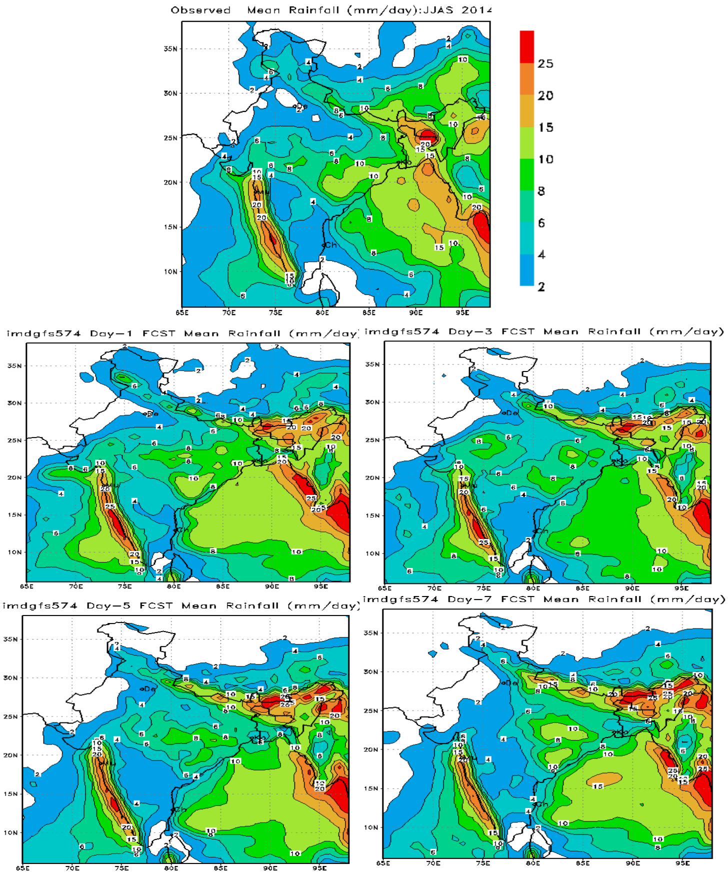


Fig.9.1: Spatial distribution of seasonal mean observed rainfall and Day-1, Day-3, Day-5 and Day-7 forecast rainfall (mm/day) from GFS T574 for the period from 1 June to 30 September 2014.

9.4.1.2 Spatial characteristics of seasonal (JJAS) rainfall Error

The spatial distribution of monthly mean error (forecast-observed) rainfall (mm/day) based on day-1 to day-5 forecast of *GFS* Day-1, Day-3 (top panel) and Day-5, Day-7 (bottom pane) forecast over Indian monsoon region for monsoon 2014 is depicted in Fig.9.2. Results show that the magnitude of mean errors is 5 mm/day for all day-1 to day-7 forecast

(~ of the order -5 to +5 mm/day) over most parts of the country except over Sub Himalayan West Bengal (SHWB) and Northeast region in day-1, 3 and extending westwards in day-5, 7 along foothills of Himalayas, where it is in the order of +10 to +15 mm/day. Also the rainfall was negative of the order -6 mm/day over west coast, West Bengal, Jammu & Kashmir with increasing magnitude up to -10 mm/day in day-5, 7 forecasts. The spatial pattern of the areas of positive (excess) and negative (deficient) errors are more or less uniform in all the month during the season.

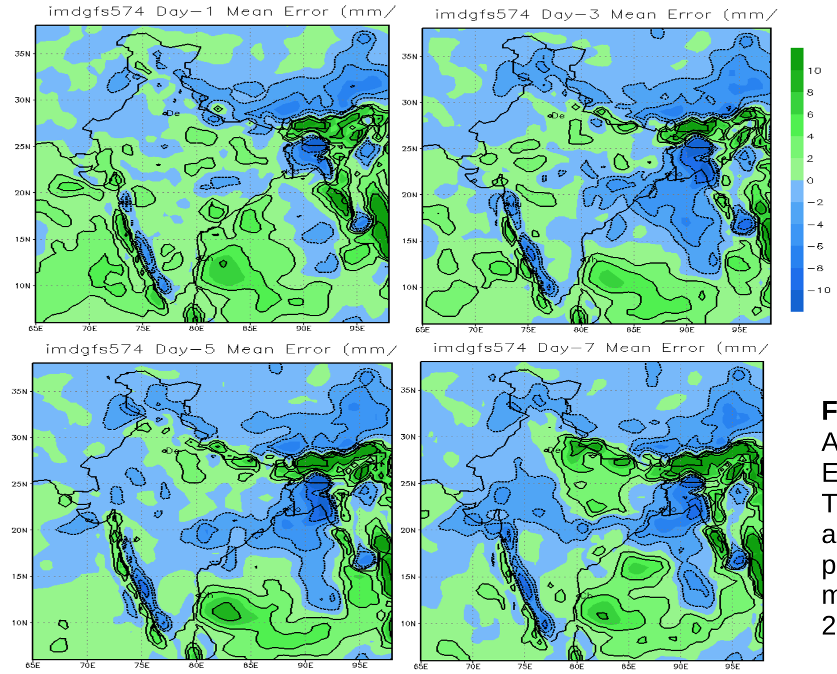


Fig.9.2: Monthly (June, July, August and September) Mean Error (ME) (mm/day) of GFS T574 Day-1, Day-3 (top pane) and Day-5, Day-7 (bottom panel) forecast over Indian monsoon region for monsoon 2014.

The spatial distribution of seasonal root mean square error (rmse) rainfall (mm/day) based on Day-1, Day-3, Day-5 and Day-7 forecast of GFS *T574* for the period from 1 June to 30 September 2014 is shown in Fig.9.3. RMSE is a measure of the random component of the forecast error. The values of rmse are higher over the regions where the daily rainfall variability is also high. The less rmse over southern peninsular India indicates that the day to day rainfall variability over this region is small as compared to other regions. The rmse of day-1 to day-7 forecasts of the model has a magnitude between 10 and 25 mm, except over the Sub Himalayan West Bengal (SHWB), west coast of India and central India where the magnitude of rmse exceeds 30 mm. The spatial distribution of rmse pattern of all day-1 to day-7 forecast is consistent with the area of maximum and minimum rmse values. The spatial pattern of rmse of the model day-1 to day-7 forecast shows that the errors are of a more systematic in forecasts lead time as observed in mean absolute error (MAE) pattern.

The anomaly correlation coefficient (ACC) between the observed and the model forecasts precipitation for Day-1, Day-3, Day-5 and Day-7 of GFS T574 is shown in Fig.9.4. Over most of the country, the magnitude of day-1 and day-3 anomaly CC lies between 0.3 and 0.5, while over the monsoon trough regions, the magnitude of anomaly CC exceeds 0.5. A small area over south west Rajasthan has a magnitude of anomaly CC exceeding 0.6 in GFS 574 in day-1 to day-3 forecast. The anomaly CC exceeding 0.3 is considered to be good for precipitation forecast. The spatial distribution of the values of anomaly CC decreases with longer forecast length. This indicates that the trend in precipitation in the day-1 to day-3 forecasts of the model is in good phase relationship with the observed trend over a large part of the country. The magnitude of anomaly CC decreases with the forecast lead time, and by day 5 anomaly CC values over most of India are between 0.1 and 0.4 with parts of Jammu & Kashmir with 0.5. The pockets near the east coast and south peninsular India where the anomaly CC values are below 0.1. The CC is further reduced by 0.1 to 0.2 over most parts of the region by Day-7.

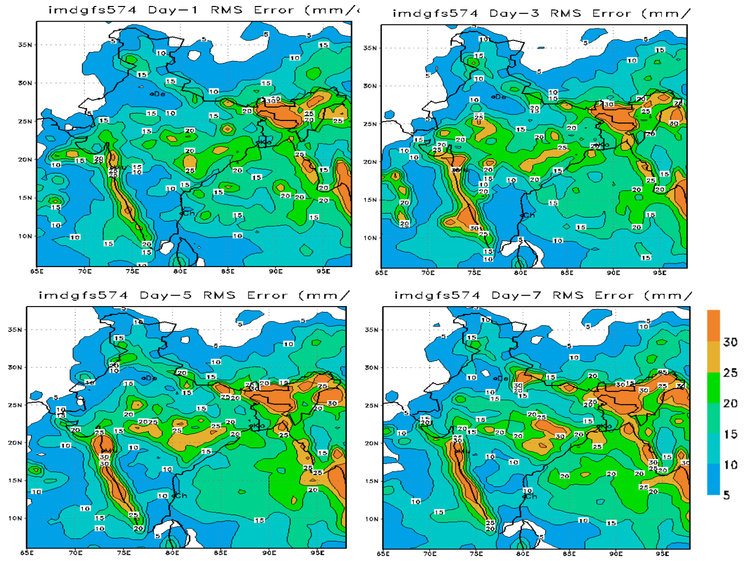


Fig.9.3: Seasonal Root Mean Square Error (RMSE in mm/day) of GFS T574 Day-1, Day-3, Day-5 and Day-7 Forecast over Indian monsoon region for the period from 1 June 30 September 2014.

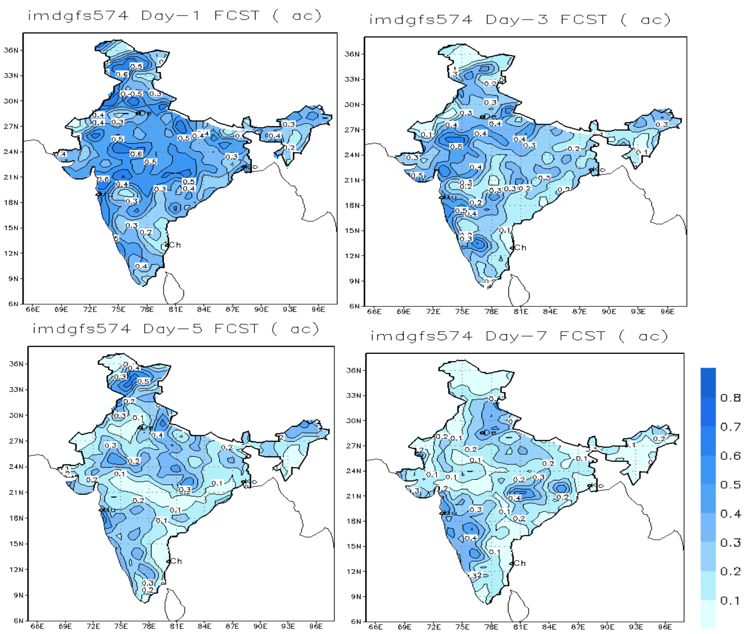


Fig.9.4: Spatial distribution of anomaly correlation coefficient (ACC) between the observed and the model predicted rainfall for Day-1, Day-3, Day-5 and Day-7 of GFS T574 for the period from 1 June to 30 September 2014.

9.4.1.3 Rainfall Forecast skill score

The standard WMO method of the verification of outputs (WMO 1992) is not adequate for precipitation due to its great temporal and spatial variability. The statistical parameters based on the frequency of occurrences in various classes are more suitable for determining the skill of a model in predicting precipitation. This aspect of model behaviour is further explored in Fig.9.5 probability of detection (POD) and Fig.9.6 thread score (TS) for rainfall threshold of 10 mm/day are presented.

The probability of detection (POD) is equal to the number of hits divided by the total number of rain observations; thus it gives a simple measure of the proportion of rain events successfully forecast by the model. From Fig.9.5, it is seen that the probability of detection is more than 50% for rainfall threshold value of 10 mm/day for day-1 and day-3 forecast, while it is further below for day-5 and day-7 forecast. It is also seen that skill is a strong function of forecast lead time (day-1 to day-7) , with the POD decreasing from more than about 50% in day-1 forecast over most parts of the country to less than 50% in day-7 forecast for rain amount of 10 mm/Day. Higher values of POD more than 50% are observed over climatologically heavy rainfall areas West Coast, northeast India and foothills of Himalaya in all day-1 to day-7 forecast.

Threat score (TS), also known as the critical success index (CSI, e.g., Schaefer, 1990); or equitable threat score (ETS) which is a modification of the threat score to account for the correct forecasts due to chance (Gilbert, 1884), is for verification of the skill in precipitation forecasting. The threat score (TS) is the ratio of the number of correct model prediction of an event to the number of all such events in both observed and predicted data. It can be thought of as the accuracy when correct negatives have been removed from consideration, that is, *TS* is only concerned with forecasts that count. It does not distinguish the source of forecast error and just depends on climatological frequency of events (poorer scores for rarer events) since some hits can occur purely due to random chance. The higher value of a threat score indicates better prediction, with a theoretical limit of 1.0 for a perfect model. The threat score (TS) of day-1, day-3, day-5 and day-7 forecasts for monsoon 2014 is shown Fig.9.6. The TS for rainfall amount of 10 mm/day are more than 0.4 over monsoon trough regions in day-1 forecast and decreasing to 0.3 by day-5 and day-7 forecast with higher values of more than 0.6 are observed over West Coast, northeast India in all day-1 to day-7 forecast.

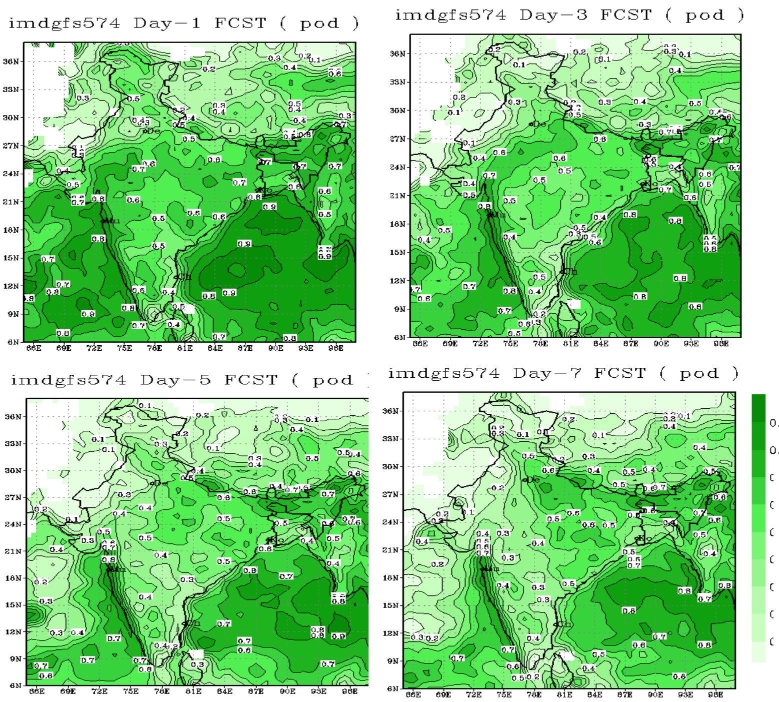


Fig.9.5: Spatial distribution of POD between the observed and the model predicted rainfall for 10 mm/day, Day-1, Day-3, Day-5 and Day-7 of GFS T574 for the period from 1 June to 30 September 2014.

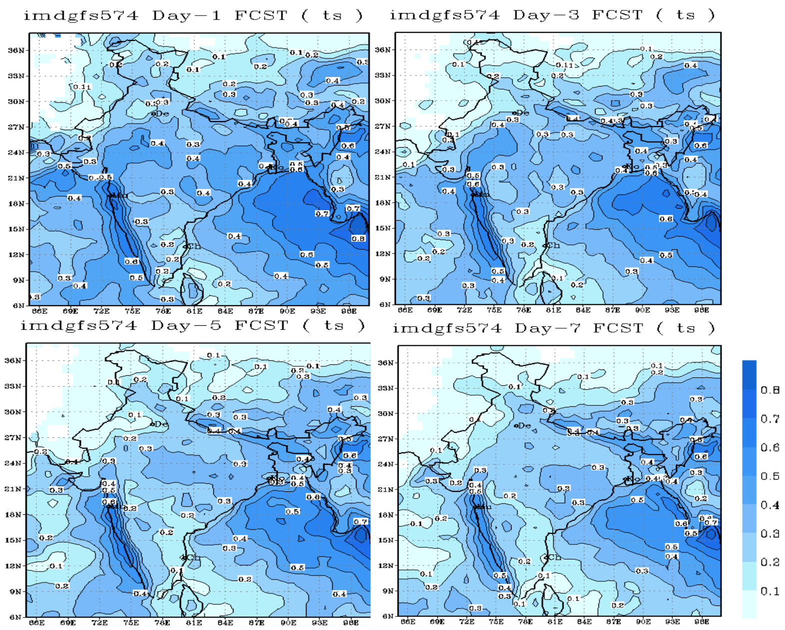


Fig.9.6: Spatial distribution of threat score (TS) for rainfall threshold of 10 (mm/day) for Day-1, Day-3, Day-5 and Day-7 forecast of GFS T574 for the period from 1 June to 30 September 2014.

9.4.2 Monsoon Circulation Features

9.4.2.1 Seasonal Mean wind pattern

In Fig.9.7, Seasonal mean 850 and 200 hPa wind Analysis (m/s) from GFS T574 over Indian monsoon region for the summer season 2014 is presented. The seasonal (JJAS) mean 850 hPa wind analysis could capture low level westerly jet with a peak strength over the south west Arabian sea and the monsoon trough extending from northwest Bay of Bengal to northwest wards across the country**.** During the early summer months, increased solar heating begins to heat the Indian subcontinent, which would tend to set up a monsoon circulation cell between southern Asia and the Indian Ocean. However, the subtropical jet stream occupies its winter position at about 30^0N latitude, south of the Himalayan Mountains in 200 hPa. As summer progress, the subtropical jet slides northward (Fig.9.7). The extremely high Himalayas present an obstacle for the jet; it must "jump over" the mountains and reform over central Asia. When it finally does so, a summer monsoon cell develops, supported by the tropical jet stream overhead.

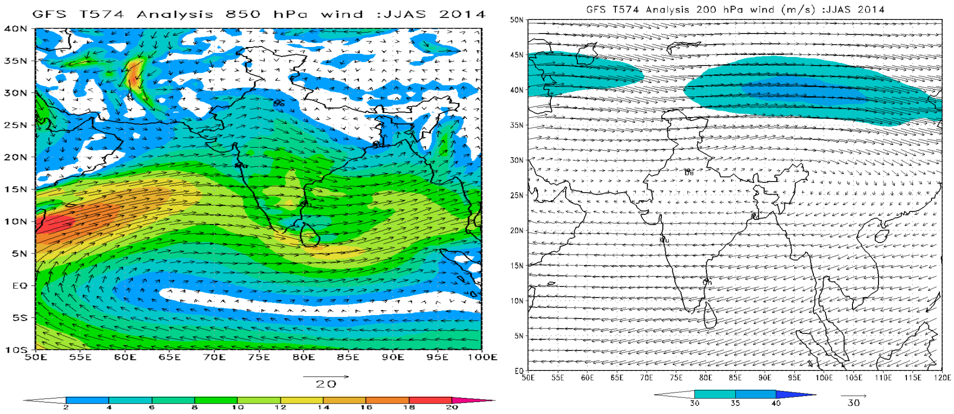


Fig.9.7: Seasonal mean 850 and 200 hPa wind Analysis (m/s) from GFS T574 over Indian monsoon region for the summer season 2014.

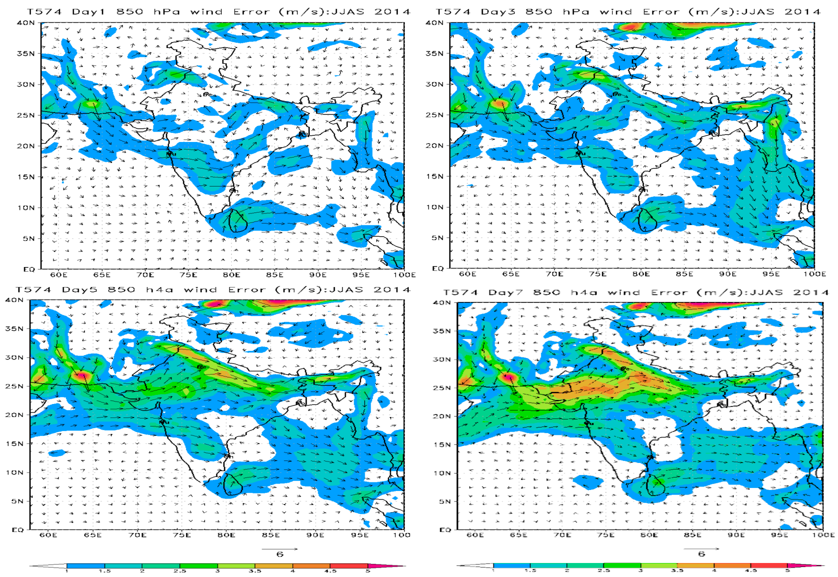


Fig.9.8: Seasonal 850 hPa wind Error (m/s) from GFS T574 day-1, day-3, day-5 and day-7 forecast over India during monsoon 2014.

In Fig.9.8, Seasonal mean wind error (m/s) (at 850 hPa) of GFS T574 day-1, day-3, day-5 and day-7 forecast over India during monsoon 2014 is presented. GFS T574 forecast shows bias of westerly wind over most parts of the parts of country extending up to the foot hills (indicating weak monsoon trough). Over the Myanmar it has been westerly bias. The magnitude of bias is found to grow with the forecast lead time. The westerly bias over NE Arabian Sea and adjoining Gujarat coast is found to be slightly stronger in the day-3 to day-7 forecast. The mean wind error (m/s) (200 hPa) from GFS T574 over Indian monsoon region for the Monsoon 2014 depicted in Fig .9.9. The subtropical jet stream occupies its position over India during June is around 35^0N latitude, north of the Himalayan Mountains. As summer progresses, the subtropical jet slides northward and located around 40^0 N in July and 45^0 N in August 2014. The day-3 to day-7 forecast have easterly bias north of 20^0 N over India, southerly bias over Pakistan and Afghanistan, south-easterly bias over SW Arabian Sea during July and August month.

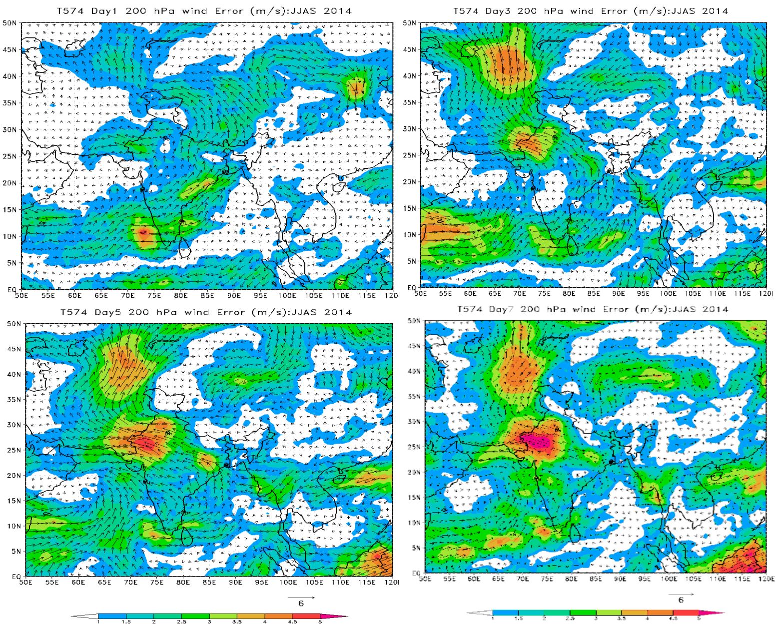


Fig.9.9: Seasonal 200 hPa wind Error (m/s) from GFS T574 day-1, day-3, day-5 and day- 7 forecast over India during monsoon 2014.

9.4.2.2 Forecast Error in Specific humidity

In Fig.9.10, Spatial distribution of mean error in specific humidity (g/kg) at 850 hPa of day-1, day-3, day-5 and day-7 forecast errors from GFS T574 for monsoon 2014 is presented. The mean error in the forecast is computed from the model analysis. In order to understand the characteristic features of monsoon captured by the model, the model performance is examined in terms of spatial seasonal mean specific humidity error (bias) during 1 June to 30 September 2014. The specific humidity spatial error analysis shows that a large positive bias over foothills of Himalaya extending westwards from day-3 to day-7 and this positive bias increases in magnitude over the length of forecast i.e. from day-1 to day-7. GFS T574 forecast errors shows negative bias over southwest Arabian Sea and adjoining Pakistan and over Bay of Bengal in day-1 and the magnitude of this negative bias is almost same from day-1 to day-7 forecast.

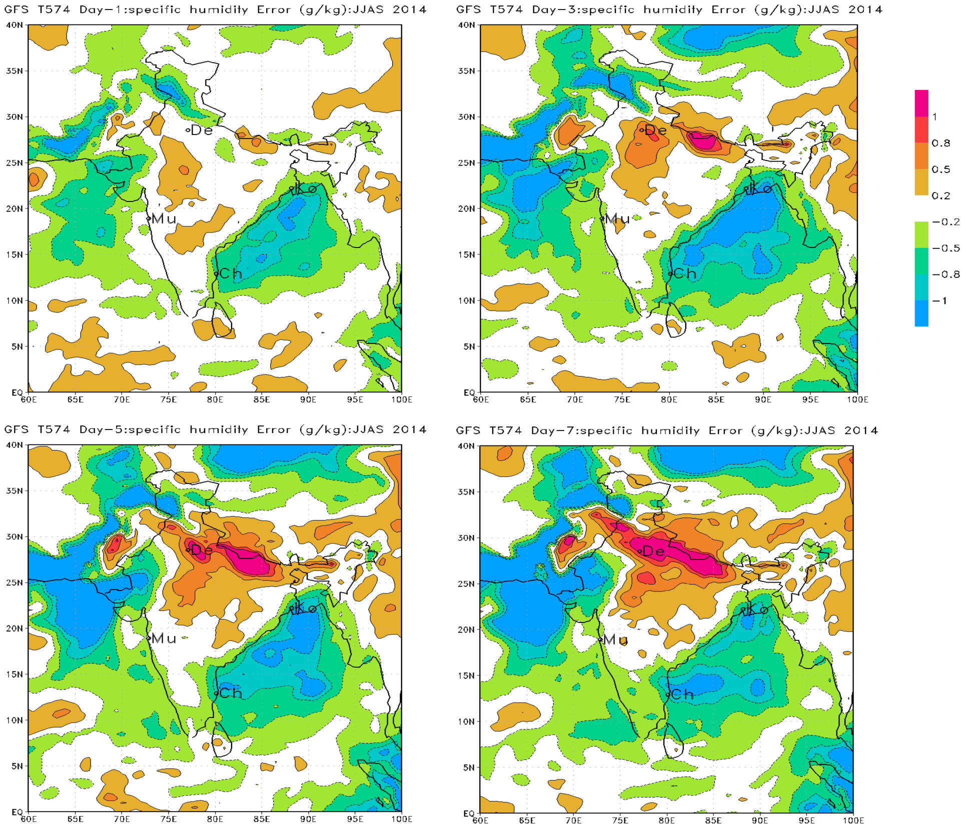
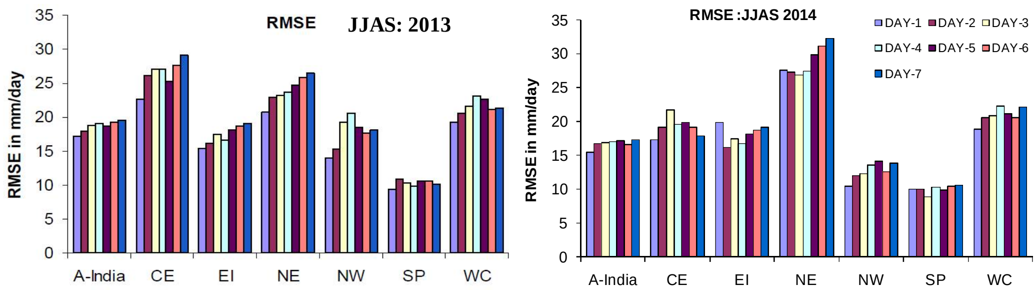


Fig.9.10: Spatial distribution of seasonal mean error in specific humidity (g/kg) at 850 hPa during monsoon 2014.

9.4.3 Prediction Skill Improvement

The skill improvement of GFS T574 during monsoon 2014 is accessed against the same during 2013. The seasonal mean RMSE of GFS T574 Day-1 to Day-7 forecast over Indian monsoon region for the period from 1 June 30 September 2013 (left panel) and 2014 (right panel) is shown in Fig.9.11. The model forecast shows a significant reduction of RMSE in rainfall during 2014 as compared to the same during 2013 over all the *sub-division* of India in all day-1 -to day-7 forecast. More improvement is noticed over Central India in all day-1 -to day-7 forecast during monsoon 2014. The daily domain average RMSE is high for west coast and NE India regions and relatively small for the southern peninsular region in all day-1 to day-7 forecasts during the monsoon 2014.

The seasonal mean all India mean spatial CC of day-1 to day-7 forecast of GFS T574 during monsoon 2013 and 2014 is shown in Fig.9.12. The domain average spatial CC is 0.34 for day-1 and became 0.2 in day-7 forecast during Monsoon-2014 compared to 0.32 for day-1 reducing to 0.15 in day-7 during Monsoon-2013. The spatial CC of GFS day-1 to day-7 forecast during monsoon 2014 is relatively high as compared to the same during monsoon 2013.



9.11: seasonal mean RMSE of GFS T574 Day-1 to Day-7 forecast over Indian monsoon region for the period from 1 June 30 September 2013 (left panel) and 2014 (right panel).

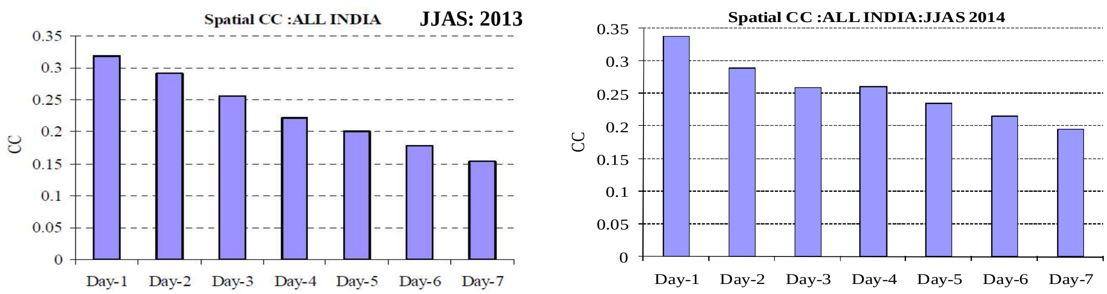


Fig.9.12: seasonal all India mean spatial CC of day-1 to day-7 forecast of GFS T574 during monsoon 2013 (left) 2014 (right).

In order to understand the characteristic features of monsoon captured by the model, the model performance is examined in terms of vertical structure of zonally averaged (long 60^0 E to 100^0 E) specific humidity error (bias) of day-1, day-3,day-5 and day-7 at 77^0 E during the monsoon 2014 (Fig.9.13). The specific humidity error analysis in monsoon 2014 shows under estimation of specific humidity below 600 hPa with a peak of negative bias between 850 hPa and 600 hPa, extending northward up to 30^0 N with two minima, one at the equator and another between 15^0 N - 20^0 N around 800 hPa. In the lower levels from surface between Lat 10^0 N and 15^0 N, there is a negative bias of specific humidity. Above 550 hPa, the error is positive with a maximum value between 550 hPa and 450 hPa and Lat 10^0N - 15^0N. The magnitude of bias increases with the forecast lead time.

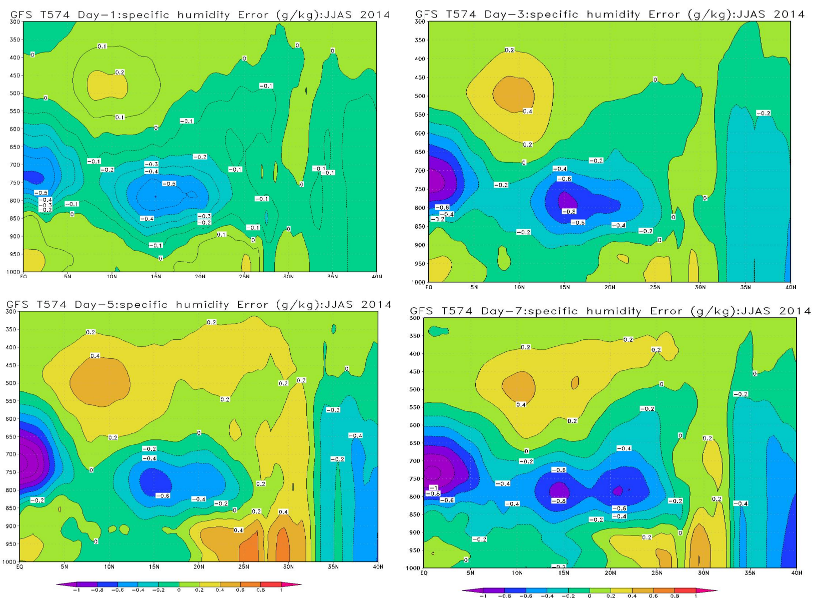


Fig.9.13 Vertical cross-section of Long (68 -98 E) averaged GFS T574 day-1, day3, day5 and day-7 forecast of *specific humidity Error (g/kg)* over Indian monsoon region for the period from 1 June 30 September 2014.

9.5 Performance of Operational WRF Model during Southwest Monsoon 2014

This chapter of the report discusses about the performance of Weather Research and Forecast (WRF) (Version 3.2) model operational at India Meteorological Department, New Delhi during monsoon 2014. The verification of the forecasts has been conducted as per the availability of verification analyses which are the rainfall analysis (0.5^{o}X0.5^{o}) of IMD and mesoscale analyses generated through WRF-DA (Version 3.4) assimilation system. The study covered continuous scores and a few categorical scores for rainfall forecast over whole India and over seven selected zones. The standard spatial error maps for a few meteorological variables have been produced relevant to performance verification.

9.5.1 Introduction

Along with its assimilation component WRF Data Assimilation (WRFDA), the mesoscale modelling system is in operation in IMD for short-range forecasting of weather events up to three days. The performance verification of the WRF forecasts has been carried out in the annual reports of monsoon published in IMD from the year 2010 to 2013 (Das, et al., 2011). The standard well known scores have usually been computed especially for quantitative precipitation forecast (QPF). Other parameters have also been evaluated through diagnostic methods for better understanding of the errors. The verification practice in IMD using continuous and categorical scores within a framework of neighbourhood technique has limitation in evaluating model performance at higher resolution (Hogan et al., 2010). But, the use of advanced diagnostic methods of verification is restricted due to the unavailability of reference data set (observations or verification analyses) with a reasonable resolution (temporal and spatial) to match the resolution of model forecasts. The NWP division in IMD, New Delhi every year carries out standard verification exercises for different model forecasts (generated or utilized) during southwest monsoon season. This present report only focuses on evaluation of real-time forecasts of WRF model during southwest monsoon 2014.

9.5.2 Methodology

9.5.2.1 Modelling system

During southwest monsoon season 2014, the WRF model (ARW) with its assimilation component has been operational to deliver three days forecasts twice daily at 00 UTC and 12 UTC. The data assimilation component, WRF Data Assimilation (WRFDA) takes global GFS analysis and all other quality controlled observations as its input and generates mesoscale analysis. The analyses with modified boundary condition (available from GFS) are then provided to WRF model for operational forecasting. The model domains (mother - 27 km and a nested domain - 9 km) covered the area of responsibility for Regional Specialized Meteorological Center (RSMC), New Delhi and Indian region respectively(20^{o} S to 45^{O} N; 40^{O} E to 120^{O} E/0^{O} to 38^{O} N; 64^{O} E to 100^{O} E). The observational data from GTS and other sources after decoding and quality control has been pre-processed to create

PREPBUFR files (in NCEP-BUFR format) which is used as an input to WRFDA system. Observations are accumulated within ±3 hour time-window from a specific hour to generate corresponding PREPBUFR file. In the assimilation system, all conventional observations over a domain (20^{O} S to 45^{O} N; 40^{O} E to 120^{O} E) have been ingested to create improved mesoscale analysis.

WRF model is a non-hydrostatic high-resolution mesoscale model. The model has been configured with full physics for during day to day operational run. The summary of the model configuration used for operational purpose in IMD is given in Table-9.1. The detail description can be found out in the relevant model documentation (WRF, 2011) maintained by National Center for Atmospheric Research (NCAR), USA.

The post-processing programs WPP (WRF Post Processor) and NCL (NCAR Command Language) package have been utilized for the processing of model forecasts so that it can utilized by the MET (Model Evaluation Tools). WPP program converted WRF forecasts to grib2 format and NCL prepared “netcdf” files for observed and forecast rainfall.

9.5.2.2 Data

The performance evaluation has been carried out with verification analyses available during the period. Rainfall analyses were used at 0.5^{o} resolution available from National Data Center, IMD, Pune (Mitra et al., 2009). A sub-domain over Indian region (specified by latitude range 6.5^{o}N to 38.5^{o}N and longitude range 66.5^{o}E to 100.5^{o}E) has been considered for verification over the Indian region. The accumulation period of the rainfall forecast has been matched with the verification analysis which is from 03 UTC of a day to 03 UTC of next day. The scope of verification of WRF-ARW model has been restricted only to mother domain with horizontal resolution of 27 km at 00 UTC and 12 UTC.

Table-9.1. WRF model configuration summary.

Characteristic feature	Selected configuration
Double nested domains Horizontal resolution	27 Km outer domain and 9 km inner domain
Horizontal grid	Arakawa C grid (staggered)
Vertical coordinate	Terrain following 38 σ levels (staggered)
Time integration	Third order Runge-Kutta Scheme
Cloud Microphysics	WRF single moment 5-class cloud microphysics
Cumulus convection	Grell 3 dimensional ensemble cumulus physics scheme
Planetary boundary layer	Mellor-Yamada-Janjic planetary boundary layer scheme
Short-wave radiation Long-wave radiation	Goddard short-wave radiations physics Radiation Rapid radiative transfer model (RRTM) long-wave
Land-surface model	Eta and Noah Land Surface Model for surface physics

Table-9.2: Seven geographical regions considered for rainfall verification

Zone Name	Geographical Region of India	Abbreviated name
Zone 1	Kerala	KRL
Zone 2	West Coast	WC
Zone 3	Southern Peninsula	SP
Zone 4	Central India	CTR or CI
Zone 5	East India	EI
Zone 6	North-East India	NE
Zone 7	North-West India	NW

Table-9.3. Classification of Rainfall based on intensity

Descriptive Term	**Rainfall amount in mm**
No Rain	0.0
Very light Rain	0.1- 2.4
Light Rain	2.5 – 10.5
Moderate Rain	10.6 – 35.5
Rather Heavy	35.6 – 64.4
Heavy Rain	64.5 – 124.4
Very Heavy Rain	124.5 – 244.4
Extremely Heavy Rain	≥ 244.5
Exceptionally Heavy Rain	When the observation is near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall exceeds 120 mm.

9.5.2.3 Verification strategy

The categorical verification scores along with standard continuous scores for rainfall have been computed to evaluate model performance. The different rainfall categories are defined on the basis of the classification used in India Meteorological Department (described in Table-9.3). In this study, last two categories above heavy rain class are not considered for the verification purpose. In this document, categorical skill scores, Critical Success Index (CSI or threat score), BIAS score (FBIAS) and Gilbert Skill Score (GSS or equitable threat score) have been computed over seven specified zones and over India as a whole. The standard scores e.g. mean error (ME) and root mean square error (RMSE) have also been calculated for verification. The locations and extents of seven selected zones are shown in Fig. 9.14 and their description has been given in Table-9.2.

The relevant description on the spatial error patterns for mean sea level pressure, and wind at 850 and 200 hPa has been added along with rainfall forecast verification. The error in model forecast during whole monsoon season 2014 which was computed averaging all over Idia has been analyzed to bring out inadequacies of the model to portray monsoon circulation in a realistic manner. Spatial distribution of mean error and RMSE for monsoon season - 2014 have been described. The elaboration for very much relevant parameters e.g. temperature, relative humidity and geopotential height have been skipped to shorten the length of the report. Many figures in results and discussion section have been dropped due to obvious supposition projected from the existing figures.

9.6. Results and Discussion

The discussion of the report is collectively partitioned in three parts described below. Although, three partitions are separated by notion for better readability but time to time the obvious linkages are put forth within the write up of each portion.

a) Verification of rainfall

i. The evaluation of daily rainfall forecasts series averaged over country as a whole during southwest monsoon season 2014 against observation and climate normal.

ii. Continuous scores and categorical skill scores for different rainfall threshold are calculated over India and over other seven specified zones.

b) Verification of wind components and mean sea level pressure (MSLP), relative humidity at 700 hPa.

Verification of Rainfall

(i) Times series of daily rainfall has been derived for observation and WRF forecasts for three days. The average over Indian domain mentioned in earlier section has been done to calculate the daily rain rate over the country as a whole. The Fig.9.15, representing daily time series of all India rainfall rates. Vertical bars in green gives observed rainfall time series along with daily normal value plotted in red curve. Other lines of the figure shows the daily rainfall rates in 24 hour, 48 hour and 72 hour forecasts which are plotted along with observed and normal values. It was evident that the forecast series could not capture reasonably the lull periods of the season in which observed rainfall was below normal. The active i.e. the peaks in the observed field has never been missed in the model forecasts. The 24 hour forecast has larger tendencies to overestimate all India rainfall merely throughout the season compared to other forecast hours. Model produced daily rainfall rate gradually decreases along with forecast hours. The days with peaks rain spells are fairly detected but sharp drops for certain days have been missed out by the model.

(ii) Fig.9.6 gives skill scores for two different rain categories above 10.5 mm and 35.5 mm averaged over whole India and over seven specific zones as well. The scores over individual zones show variation but deteriorate with an increase in rain amount. The model shows consistent degradation of forecast accuracy for a few zones (e.g. SP, EI, and NE zones) for all rainfall categories and all forecast hours. Whereas, the established forecast accuracy has been maintained over west coast and Kerala where the rainfall amount is considerably higher compared to other regions due to topography.

Verification of Other Variables

Forecast errors of wind components, mean sea level pressure and relative humidity at 700 hPa have been included in the report to get an understanding of the facts found in rainfall verification. Seasonal error features of wind have been discussed sequentially only for 24 hour forecast during the whole monsoon season-2014. In the description, 48 hour has been skipped as drastic difference has not been seen in 48 hour from the features of 24 hour.

Errors in wind components for 24 hour have been plotted in Fig.9.17. Top four panels in two rows show the mean errors of zonal and meridional wind components at 850 hPa and last two rows for 200 hPa. The hatched areas and dotted areas in the plots represent positive bias and negative bias respectively. Therefore, the hatched portion depict westerly bias for zonal wind and southerly bias for meridional wind contrary to that dotted areas means easterly bias in zonal wind and northerly bias in meridional wind.

The mean errors in zonal wind illustrate that the westerly bias (hatched area) prevalent at lower level (850 hPa) and strengthening of lower level wind flow is maximum over southern part of Arabian sea where low level jet (LLJ) have been established. A compensating easterly bias has been noticed north of the zone mentioned above for lower level westerly. The monsoon flow crossing over peninsular Indian and reaching to BOB usually takes turn toward foothills becomes easterly following monsoon trough up to northwest (NW) India. But, in the model forecast, enhancement in westerly over Bay of Bengal (BOB) took place towards NE India extending up to South China Sea (hatched area in Fig. 9.17a). Model could not simulate properly the easterly flow over the area of Gangetic plain running parallel to foothills. This implicates that in the model forecasts the monsoon trough have not been well established rather the lower level flow gather northerly bias over North BOB and Eastern India (Fig. 9.17c). The meridional wind at 850 hPa exhibits northerly bias over whole Arabian Sea and over southern peninsula. The upper-air easterly zonal flow over BOB and Arabian Sea has been strengthened (dotted area with -ve bias in Fig. 9.17e). The meridional flow at 200 hPa has been characterized mostly by southerly bias all over the region. The RMSE in zonal wind (Fig. 9.17 b and 17f) have spatial distribution coherent with ME. Areas with large ME also match with large RMSE. But, the RMSE in meridional wind does not follow mean error rather shows random distribution patterns both at lower and upper levels.

Fig.9.18 is attributed to error features of MSLP and relative humidity at 700 hPa. The top four panels show ME (left panels) and RMSE (right panels) of MSLP for 24 hour and 48 hour averaged over whole season. The pressure depression bias is widespread over whole monsoon region which intensifies towards northern latitudes which increases in 48 hour. The bias did not show uniform nature but with comparative lower values over central India and Sri Lanka. In turn a comparative high formation is noticed in mean error over CI. This probably nudges the rainfall pattern towards overestimation. The spatial distributions of RMSE in MSLP display that the errors are less over oceanic area compared to the errors over land mass. The RMSE values are higher over higher topography and over the region of heat low. The error increases all over India with an increase in forecast duration.

Although, monsoon flow along with pressure depression bias in MSLP stimulate strong monsoon but the negative bias in relative humidity at 700 hPa shows that the model has a dry bias in lower tropospheric levels. The lower four panels show the forecast errors in relative humidity for 24 hour and 48 hours. On contrary, the moistening bias over Somali jet region over Arabian Sea suggests the model has to be tuned for proper distribution of moisture in lower levels. The RMSE of relative humidity at 700 hPa is ~ 15 % in 24 hour forecasts which increases to ~ 25 % in 48 hours. The spatial maps of RMSE show an error maximum over peninsular India and adjoining region.

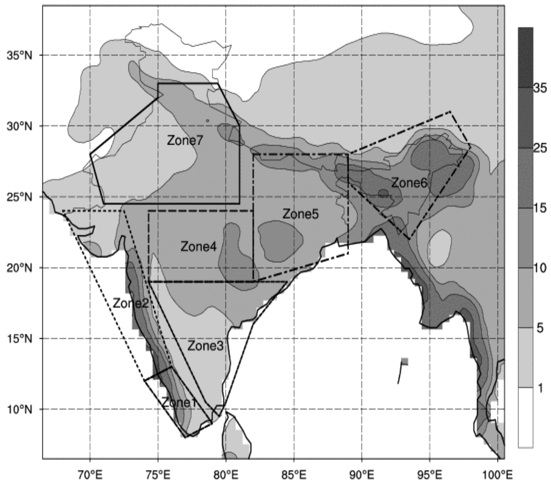


Fig. 9.14: Locations of seven geographical regions for rainfall verification along with GPCC climate normal rainfall in mm/day.

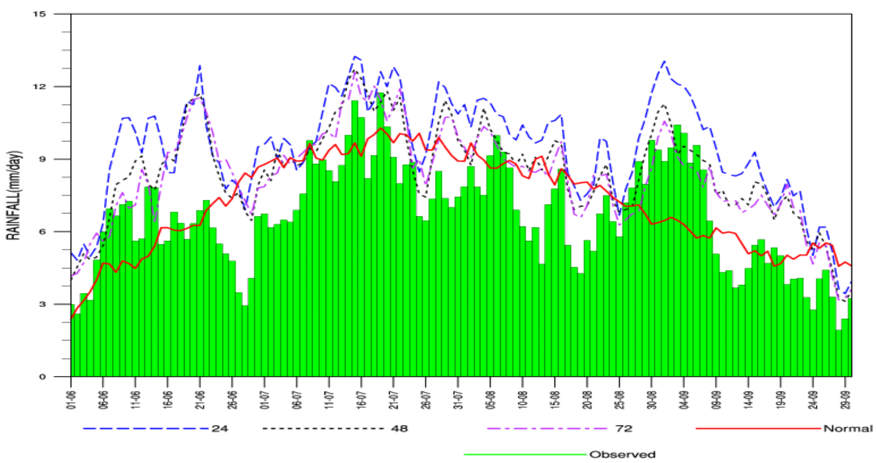


Fig. 9.15: All India daily rainfall time series during southwest monsoon season 2014.

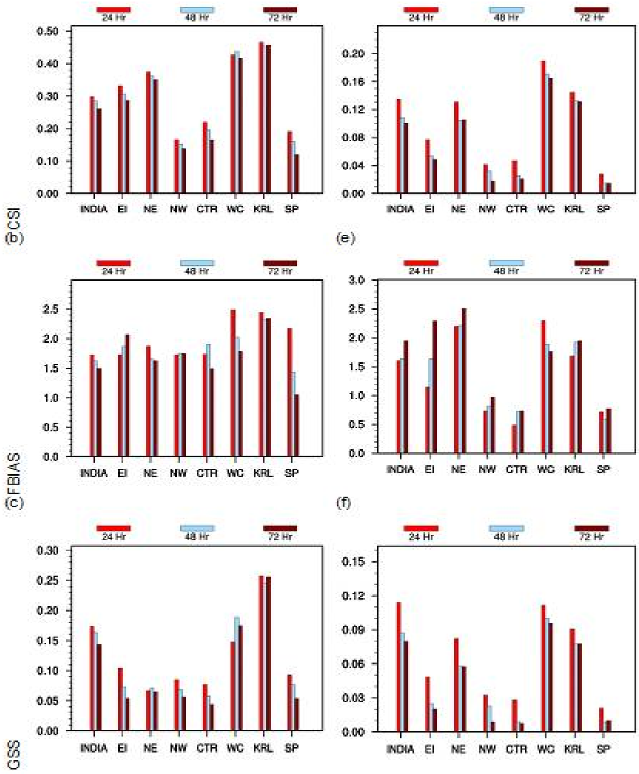


Fig. 9.16: Mean values of CSI, FBIAS and GSS during whole monsoon season 2014 which are computed averaging over all India and other seven selected zones. (a) CSI, (b) FBIAS and (c) GSS for rainfall category greater than 10.5 mm (left panel); (d), (e) and (f) represent the same for the category > 35.5 mm (right panel) averaged over whole India.

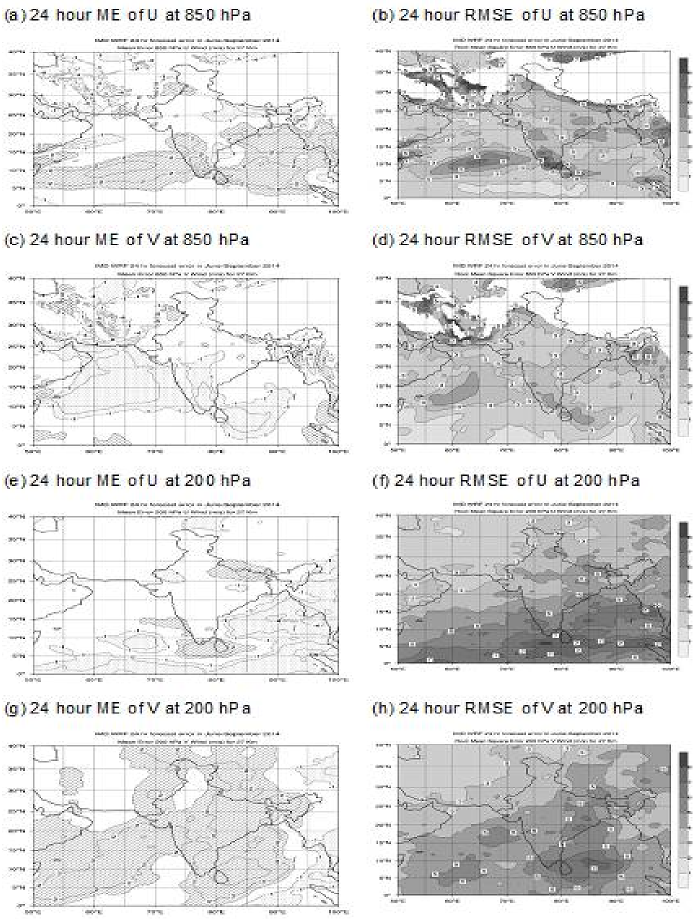


Fig. 9.17: 24 hour forecast errors in wind components (a), (b) and (c), (d) at 850 hPa; (e), (f) and (g), (h) at 200 hPa for u wind and v wind respectively during whole monsoon season 2014.

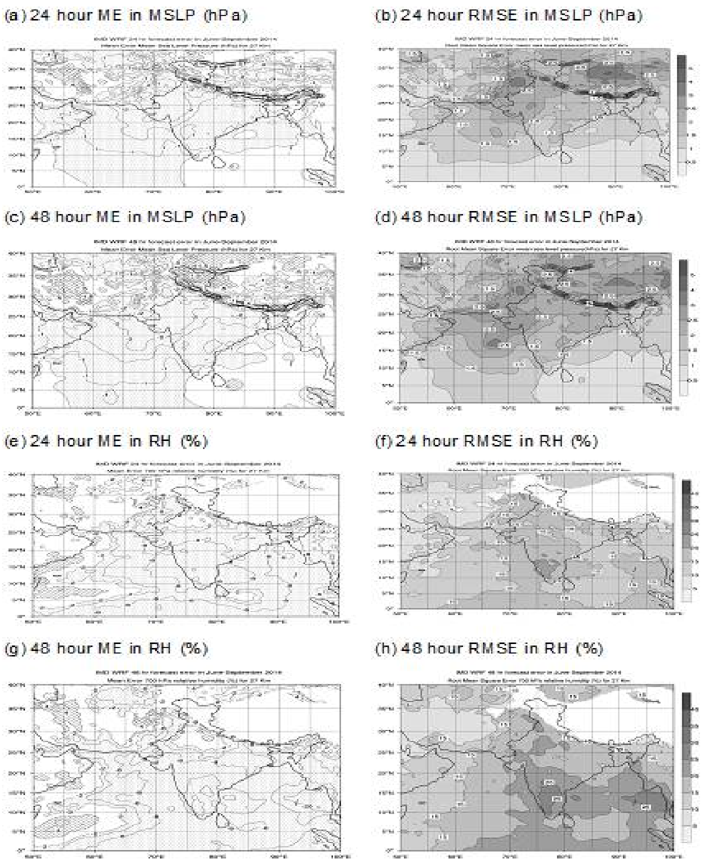


Fig. 9.18: Spatial distribution of seasonal mean errors during whole monsoon season 2014 in MSLP and relative humidity at 700 hPa. The errors in MSLP are in (a), (b) for 24 hour and (c), (d) for 48 hour respectively. The errors in RH are in (e), (f) for 24 hour and (g), (h) for 48 hour respectively.

9.7 Summary and Concluding remarks

This report assesses the performance of GFS T574L64 model over Indian region in spatial and temporal scale during summer monsoon season of 2014. The verification of rainfall is done in the spatial scale of 50 km, in a spatial scale and also country as a whole in terms of skill scores, such as mean error, root mean square error, correlation efficient, time series and categorical statistics such as, POD and TS. The study demonstrates that the performance of GFS T574 in predicting rainfall varies with geographical location and synoptic regime. Magnitude of RMSE is found to be slightly higher for GFS T574, indicating higher variability in the performance of the model. Validation results show that the T574 forecasts, in general, is skilful over the regions of climatologically heavy rainfall domains. Performance of the model is also examined in terms of tropospheric wind circulation and vertical cross section of specific humidity bias to understand the monsoon rainfall features captured by the model. The skill of wind forecast of the model during monsoon season is also examined. From the result presented above, the following Conclusions may be drawn. The observed variability of daily mean precipitation over India is reproduced remarkably well by the day-1 to day-7 forecasts of GFS model. It also have reasonably good capability to capture large scale rainfall features of summer monsoon, such as heavy rainfall belt along the west coast, over the domain of monsoon trough and along the foot hills of the Himalayas. In general, GFS showed considerable skill in predicting the daily rainfall over India during monsoon periods. The comparison of GFS forecast during monsoon-2014 with monsoon-2013 shown, there is a significant improvement in monsoon rainfall special correlation coefficient (CC) around 17% to 28% in day-4 to day-7. Similar improvement also noted in TS for moderate to heavy rainfall prediction (more than 3 cm) around 10% to 40% in day-4 to day-7. This improvement is mainly the availability more observations from various new satellites.

The performance verification of WRF model shows that the model has a consistent tendency of over prediction in rainfall. The positive bias in the rainfall distribution shows systematic nature for each specific zone in every months of monsoon. Therefore, bias correction is a viable option to improve forecast quality. The shift due to irregular movement of low pressure systems from Bay of Bengal towards land has been depicted to be a consistent limitation of the model forecasts. The wind biases found in the forecasts indicated the fact the evolution of large scale monsoon systems within monsoon environment have also not been captured well by the model. Various physical parameterisation schemes has to be tested to identify the more better physical and boundary layer process suitable for Indian monsoon region in WRF model to improved for better prediction of weather systems in terms of monsoon lows and associated rainfall.

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10

PERFORMANCE OF REAL TIME EXTENDED RANGE FORECAST DURING SOUTHWEST MONSOON 2014

D. R. Pattanaik, O. P. Sreejith and D. S. Pai

This chapter discusses the performance of Multi-model Ensemble (MME) extended range forecasts based on two coupled models (NCEP-CFS version 2; CFSv2 and JMA) for the 2014 southwest monsoon.

10.1 Introduction

The forecasting of southwest monsoon rainfall on extended range time scale is vital for the vast agro-economic country like India. In last few decades, many statistical and dynamical models have been developed for predicting the summer monsoon rainfall both in the extended range and the seasonal scale. Atmospheric General Circulation Models (AGCM) and Coupled GCMs (CGCMs) are the main tools for dynamical seasonal scale prediction. Some of the recent studies have highlighted that the coupled models with one-tier approach can enhance the predictability of the summer monsoon precipitation (Pattanaik & Kumar 2010; Pattanaik et al., 2013; Pattanaik 2014). One of the dominants factors, which, influences the Intra-seasonal oscillation of monsoon is the Madden Julian Oscillation (MJO), which is the leading mode of tropical intra-seasonal climate variability and is characterized by organization on a global spatial scale with a period typically ranging from 30-60 days. The capability of numerical models in capturing MJO signal is very crucial in capturing the active/break cycle of monsoon. Now the growing demand for the country like India is to have a better forecast of monsoon on extended range time scale. The India Meteorological Department (IMD) has been issuing the operational extended range forecast since 2009 to various users. In the present article the real time forecasting of monsoon activity over India during June to September on extended range time scale is (2 to 3 weeks and up to a month) analyzed for recent monsoon season of 2014, which is one of the deficient years of recent time.

10.2 A brief discussion on dynamical models outputs used

For the real-time monitoring of intra-seasonal monsoon rainfall IMD utilizes the products from two well known coupled models viz., the National Centre for Environmental Prediction's (NCEP's) Climate Forecast System version 2 (CFSv2) and the JMA's ensemble prediction model (EPS). The CFSv2 was made operational at NCEP in March 2011, which is upgraded version of nearly all aspects of the data assimilation and forecast model components of the previous version (CFSv1). The atmospheric model has a spectral triangular truncation of 126 waves (T126) in the horizontal (equivalent to nearly a 100 Km grid resolution) and a finite differencing in the vertical with 64 sigma-pressure hybrid layers. The oceanic component is the GFDL Modular Ocean Model V.4 (MOM4). The CFSv2 runs with 16 members per day in operations and it has the capability of simulating MJO in a better way compared to that of CFsv1 (Saha et. al., 2014). A recent study by Pattanaik and Kumar (2014) have demonstrated better extended range forecast skill in CFSv2 model compared to that of CFSv1 model.

The other numerical prediction model used is the Ensemble Prediction System (EPS) of Japan Meteorological Agency (JMA). The JMA EPS is an atmospheric general circulation model (AGCM) that is a low-resolution version (TL159) of the Global Spectral Model (GSM) used for short- and medium-range forecasting with 50 ensemble members and is integrated on every Wednesday with forecasts for subsequent 32 days.

Based on the respective hindcasts climatology of each of the two models the weekly anomaly field is calculated from CFSV2 and JMA model with forecast period valid from every Thursday to Wednesday during the monsoon season of 2014 coinciding with days 2-8, days 9-15, days 16-22 and days 23-29 (called week-1, week-2, week-3 and week-4 respectively). The anomalies fields are converted into uniform latitude-longitude grid (0.50 x 0.50) and the MME is prepared with giving equal weights to all the three models and the forecast for 4 weeks are prepared on every Thursday.

10.3 Observed intra-seasonal activity of southwest monsoon 2014

The seasonal rainfall over India during 2014 indicated deficient monsoon year with all India departure of -12% from the long period average (LPA) during JJAS. Associated with moderate warming over the Central Pacific Ocean the onset of monsoon over Kerala was delayed by 5 days and it arrived on 6th June over Kerala. As seen in the all India daily rainfall variation (Fig. 8.6), after delayed start the monsoon conditions during entire June and extending up to middle of July was very weak. Followed by this long weak monsoon conditions there was some revival of monsoon during second half of July. Another weak spell of monsoon is also noticed during 2nd week to 4th week of August. The monsoon again revived during end of August and first week of September. The withdrawal of monsoon commenced on 23rd September and followed by this weak monsoon conditions prevailed towards the remaining parts of September. In order to see the qualitative performance of intra-seasonal monsoon forecast for 2014 monsoon season, following episodes are considered.

i) Delayed onset of monsoon over Kerala and dry spell of June
ii) Revival of monsoon during 2nd half of July and first week of August
iii) Transition of monsoon from active to weaker phase during middle of August
iv) Transition of monsoon from weak to active phase during first week of September

10.3.1 Delayed onset of monsoon over Kerala and dry spell of June

As indicated earlier the monsoon onset over Kerala in 2014 was delayed by 5 days. The MME forecast for 3 weeks based on the initial condition of 14th May, 2014 clearly captured the delayed onset of monsoon over Kerala with negative anomalies indicated over entire southern Peninsular till 4th of June, 2014 (Figs. 10.1a-c). Following the late onset of monsoon the entire June, 2014 witnessed weak monsoon conditions (Fig.8.6) with a monthly departure of about -42%. The MME forecast rainfall anomalies based on the initial condition of 4th June and valid for 4 weeks till 02 July 2014 indicated negative anomalies over most parts of India (Figs.10.2a-d). Although the onset of monsoon over Kerala was indicated in week-1 forecast valid for 05-11 June in terms of positive anomalies over southern tip of India (Fig. 10.2a), the subsequent progress and activity of monsoon was also very weak in the MME forecast (Figs. 10.2b-d). Thus, the MME forecast clearly captured the delayed onset of monsoon and also the subdued activity of monsoon in June, 2014. .

(a) Week 1 (15-21 May) | (b) Week 2 (22-28 May) | (c) Week 3 (29 May-04 June)

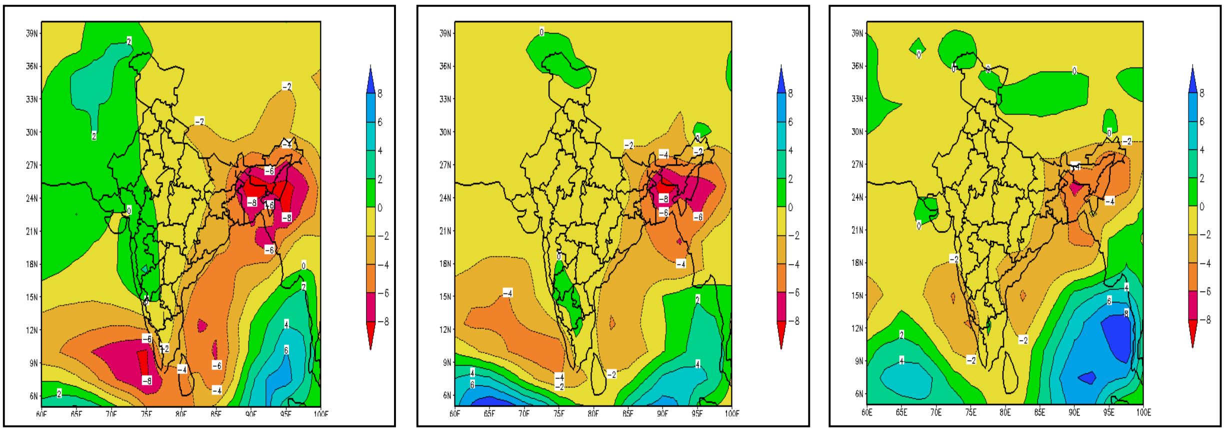
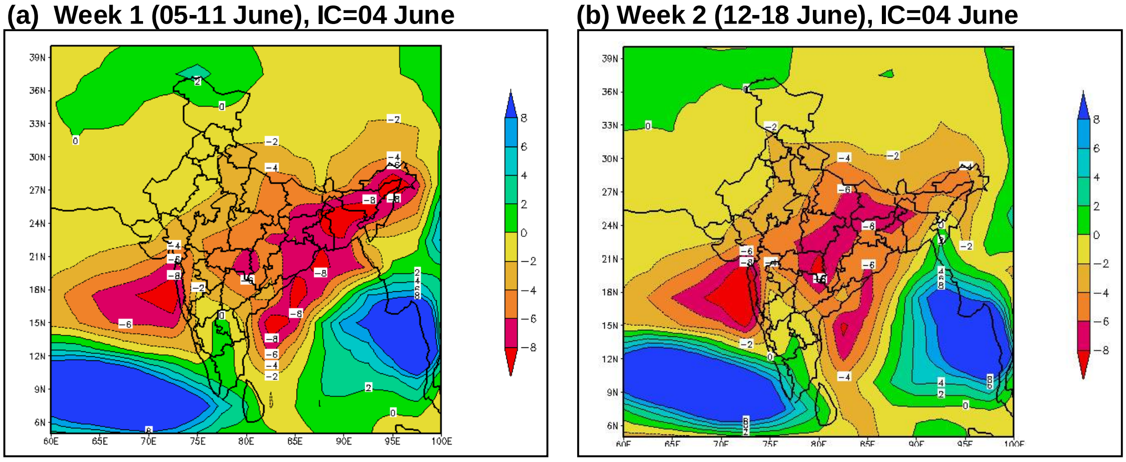


Fig. 10.1: MME forecast rainfall anomalies for 3 weeks based on 14 May & valid for 15 May-04 Jun 2014.

(a) Week 1 (05-11 June), IC=04 June | (b) Week 2 (12-18 June), IC=04 June



(c) Week 3 (19-25 June), IC=04 June | (d) Week 4 (26 June-02 July), IC=04 June

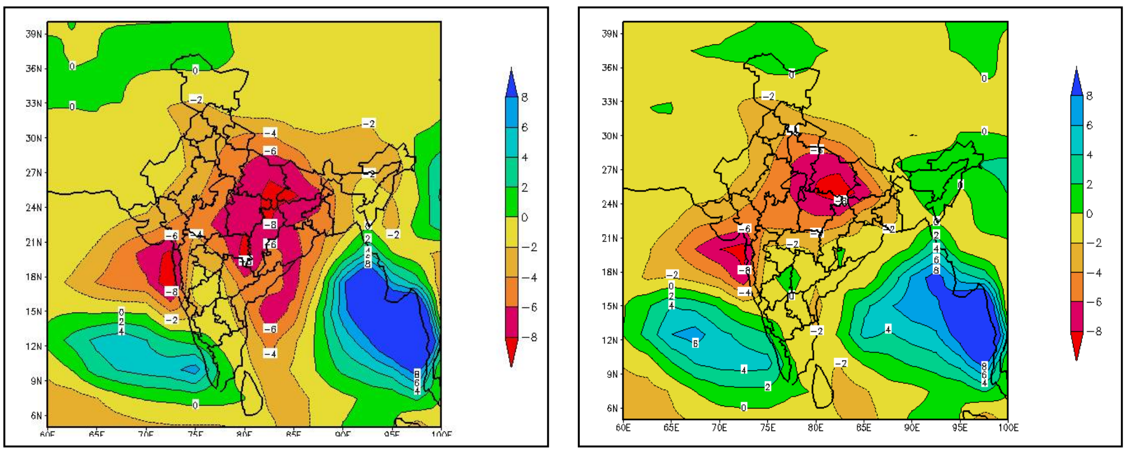


Fig. 10.2: MME forecast rainfall anomalies for 4 weeks based on 04 June, 2014 and valid for 4 weeks from (a) 05-11 June, (b) 12-18 June, (c) 19-25 June and (d) 26 June to 02 July, 2014.

10.3.2 Revival of monsoon during second half of July and first week of August

As seen in the all India daily rainfall variation (Fig.8.6), the weak monsoon conditions of June continued till middle of the July. With the formation of the land depression (21st – 23rdJuly) over northeastern parts of Odisha and adjoining areas of Gangetic West Bengal along with the other two low pressure areas (11th-18th July & 27th-31stJuly) over Northwest Bay of Bengal, the monsoon activity over central and peninsular India was revived during the period. The MME forecast for 3 weeks based on the initial condition of 16th July and valid for the period from 17th July to 06 August, 2014 clearly demonstrated the revival of monsoon with most parts of central, northwest and west-coast of India indicated positive anomalies (Figs.10.3a-c).

10.3.3 Transition of monsoon from active to weaker phase during middle of August

The marginal weak spell of monsoon persisted during the three weeks period from 7 August to 27 August as indicated by negative departure of all India weekly rainfall departure variation (Fig.8.7). The MME forecast for three weeks based on the initial condition of 6th August mostly indicated weak spell of monsoon during the period from 7 to 27 August (Fig.10.5a-c).

10.3.4 Transition of monsoon from weak to active phase during early September

After the weak spell of monsoon in second half of August, the monsoon revived towards the beginning of September. The formation of the well marked low pressure area over the Bay of Bengal and its west-northwestwards movement across the central parts of India, which took a more northward course from 4th Sept and thereafter interacting with the trough in the mid-latitude westerlies in the lower tropospheric levels, caused heavy to very heavy rainfall resulting severe floods in Jammu & Kashmir during first week of September. Another low pressure area over Saurashtra & Kutch and adjoining northeast Arabian Sea during 2-4 September revived the rainfall activity over central and northwest India. The formation and movement of the another well marked low pressure area during 5-9 September over north Bay of Bengal off west Bengal–Bangladesh coasts helped the monsoon trough to shift southwards of its normal position and thus led to vigorous monsoon activity over north, east central and adjoining peninsular India as indicated by large positive departure of rainfall during the week from 4-10 September, 2014 (Fig.8.7). The MME forecast of rainfall for three weeks based on 27th August and valid from 28 August to 17 September indicated revival of monsoon over most parts of India (Fig.10.5a-c), although the magnitude of heavy rainfall over J & K region is underestimated.

(a) Week 1 (17-23 July) *(b) Week 2 (24-30 July)* *(c) Week 3 (31July -06 Aug)*

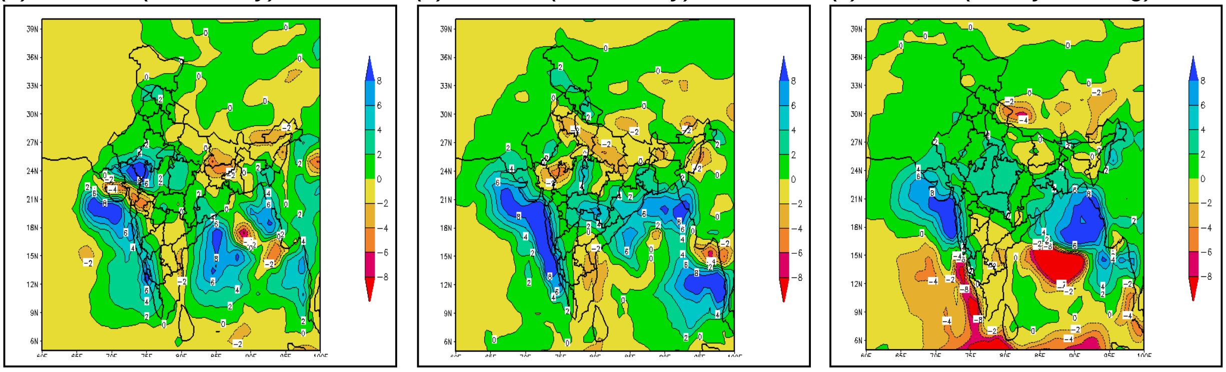


Fig. 10.3: MME forecast rainfall anomalies for 3 weeks based on 16 July & valid for 17 Jul-06 Aug 2014

(a) Week 1 (07-13 Aug) *(b) Week 2 (14-20 Aug)* *(c) Week 3 (21-27 Aug)*

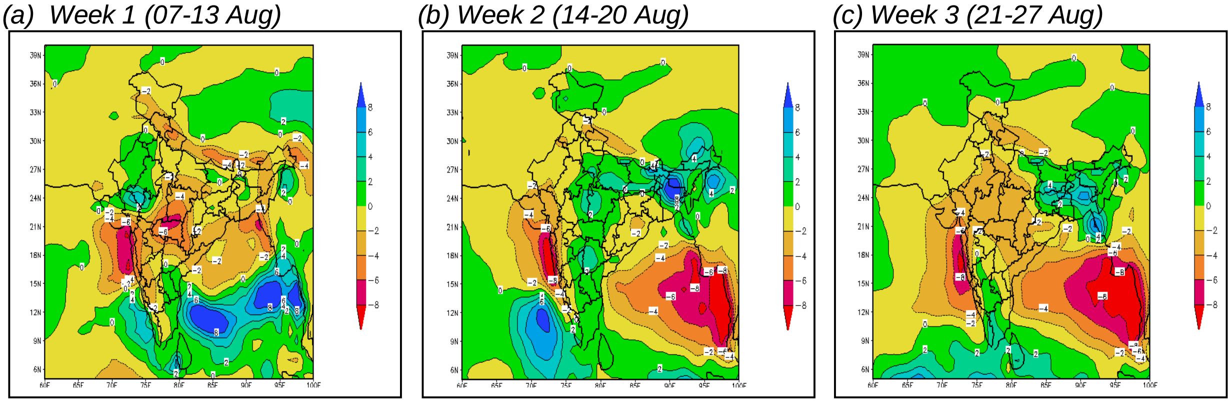


Fig. 10.4: MME forecast rainfall anomalies for 3 weeks based on 06 Aug & valid for 07-27 Aug, 2014

(a) Week 1 (28 Aug-03Sep) *(b) Week 2 (04-10 Sep)* *(c) Week 3 (11-17 Sep)*

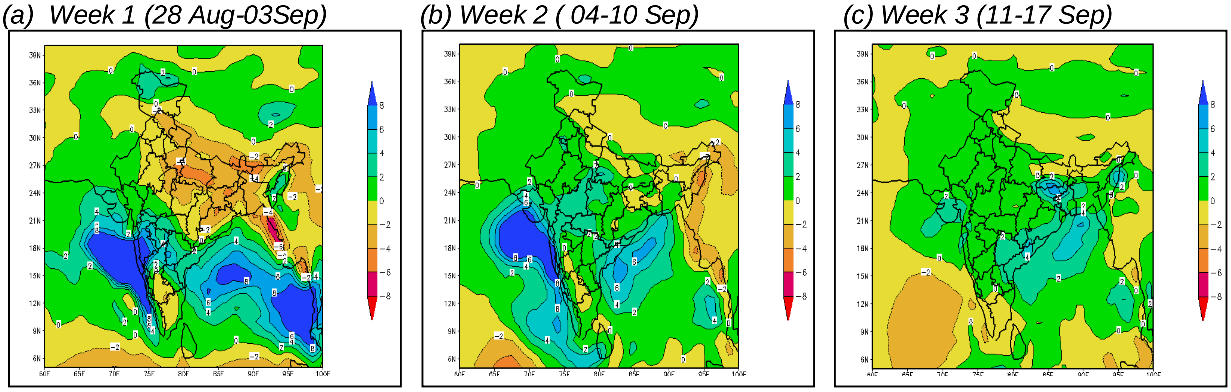


Fig.10.5: MME forecast rainfall anomalies for 3 weeks based on 27 Aug & valid for 28 Aug-17 Sep,2014

10.4 Quantitative Verification of Extended Range Forecast

In order to see the quantitative verification of extended range forecast the observed weekly rainfall departure for three weeks period during 2014 monsoon season is correlated with the corresponding MME forecasts rainfall for three weeks averaged over India as a whole of India and 4 homogeneous regions of India and the correlation coefficient (CC) is shown in -

Fig. 10.7. As seen from Fig. 10.7, over the country as a whole and 4 homogeneous regions of India the MME forecast shows significant CCs till 2 weeks except in case of northeast India, which shows significant CC for week 1 (days 2-8) only. The skill of MME forecast over Northwest India is found to be the best among other regions up to week-2 forecasts followed by that of central India and south Peninsula.

The actual rainfall departures during three weeks with observed rainfall departure for the country as a whole along with MME forecast rainfall departure valid for 3 weeks is shown in Fig.10.7. Similarly the MME forecast rainfall departure and corresponding observed rainfall departure over the 4 homogeneous regions of India during the entire monsoon season of 2014 is also shown in Fig.10.8.

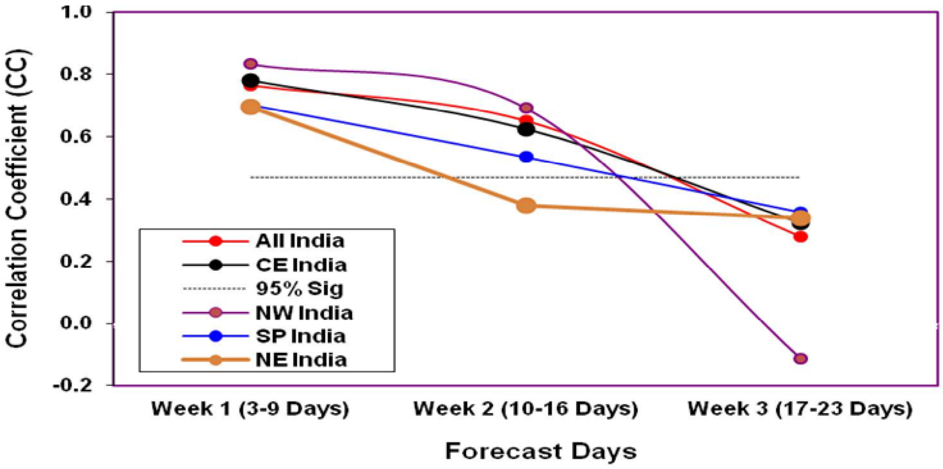


Fig.10.6: Correlation coefficient between observed rainfall departure and MME forecast rainfall departure during 2014 monsoon season for all India and 4 homogeneous regions.

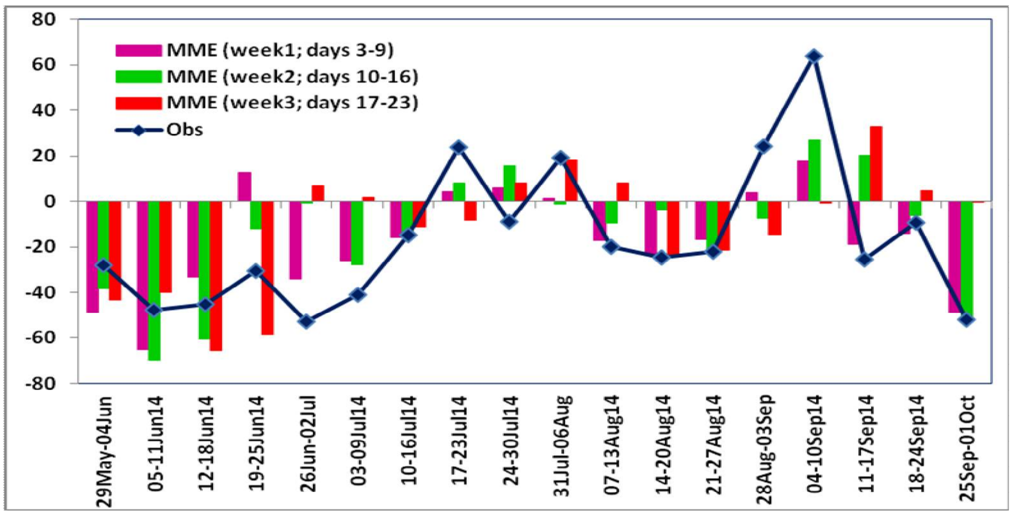


Fig.10.7: Observed and MME forecasts rainfall departure for the country as a whole in 2014.

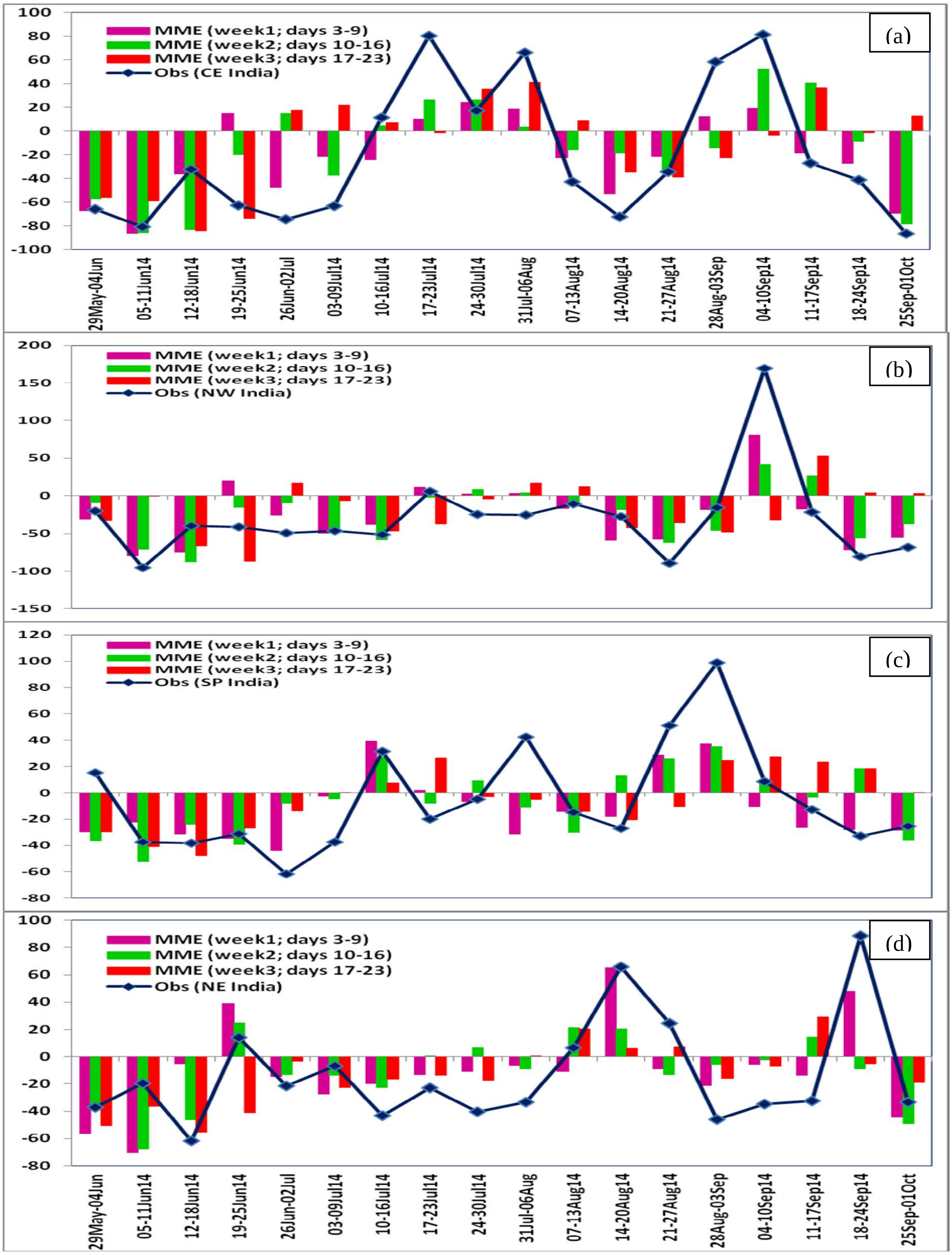


Fig. 10.8: Observed and MME forecasts rainfall departure for 3 weeks over (a) Central (CE); (b) Northwest (NW); (c) South Peninsula (SP); and (d) Northeast (NE) India.

As seen from Fig.10.7, with respect to all India rainfall, the MME forecast has captured reasonably well the different phases of monsoon like weak spells during June and first half of July, revival during 2nd half of July, weak phase of August, active phase during 04-10 September and withdrawal phase towards end of September. Similarly over the 4 homogeneous regions the MME forecast also perform very well the rainfall departure during different phases of monsoon (Fig. 10.9).

10.5 Summaries and Conclusions

- The monitoring and forecasting of monsoon activity on extended range time scale is evaluated for 2014 monsoon season during June to September. The Multi-model ensemble (MME) based on NCEP CFSv2 and JMA coupled model is used for this purpose.
- The MME forecasts captured the (i) Delayed onset of monsoon over Kerala and dry spell of June, (ii) Revival of monsoon during 2nd half of July, (iii) transition of monsoon from active to weaker phase during middle of August and (iv) transition of monsoon from weak to active phase during early part of September.
- Quantitative verification indicates that the MME forecast of all India rainfall shows significant CC between observed and forecast rainfall departure at east for 2 weeks. The MME forecast also captured the rainfall departure during different phases of monsoon such as the onset phase, active phase and withdrawal phase.
- Over the homogeneous regions of India the MME forecast shows significant CCs till two weeks except in case of northeast India, which shows significant CC till week-1 (days 2-8).
- The real time extended range forecast capability of IMD is being strengthened through the collaborative work with IITM, NCMRWF and NCEP. IMD has started using the coupled models outputs available from IITM, Pune and the same will be used operationally for inclusion in the MME forecast from the next monsoon season.

Acknowledgement

The authors are also thankful to Deputy Director General of Meteorology (NWP) for providing valuable supports. The author is also thankful to DDGM (Hydrology) for providing daily observed rainfall data on met subdivision level used in the present study. Thanks are also due to IITM, Pune, NCEP and JMA for providing the forecast products used in the present analysis.

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11

Operational and Experimental Long and extended Range Forecasts

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This chapter discusses the various operational forecasts issued by India Meteorological Department (IMD) for the monthly and seasonal rainfall over India and date of monsoon onset over Kerala for the 2014 southwest monsoon season and its verification. The chapter also discusses the experimental forecasts generated using IMD's dynamical global forecasting system based on the based on an atmospheric general circulation model and that obtained from various climate research centers within the country and abroad.

11.1. Introduction

Every year, India Meteorological Department (IMD) issues various operational forecasts for the southwest monsoon rainfall and date of monsoon onset over Kerala. These forecasts are prepared using models based on the latest statistical techniques with useful skill (Pai et al. 2011). This year, the long range forecast for the 2014 southwest monsoon rainfall was issued in 3 stages. The first stage long range forecast issued on 24th April consisted of only forecast for season (June-September) rainfall over the country as a whole. In the second stage (9th June), along with the first update for the April forecast, forecast for season rainfall over the four broad geographical regions (northwest India, central India, south Peninsula and northeast India) and that for monthly rainfall over the country as a whole for the months of July and August were issued. In the 3rd stage (12th August), along with the forecast for the rainfall during the second half of the monsoon season over the country as a whole, second update for the season rainfall over the country as a whole and first update for the season rainfall over the four broad geographical regions were issued.

IMD also prepares experimental forecast for monthly, second half of the monsoon season (August-September) and season (June to September) for the country as whole with different lag periods using a dynamical global forecasting system based on an atmospheric general circulation model (AGCM). The global monthly and season forecasts for rainfall and temperature prepared using IMD's seasonal forecast model (SFM) updated 20th of every month is now available through IMD, New Delhi website (www.imd.gov.in).

A brief description of IMD's operational statistical and experimental dynamical forecasting systems is discussed here along with the verification of the forecasts generated by these forecasting systems. In addition, the experimental forecasts for the southwest monsoon season rainfall over the country from various national and international research institutes obtained by IMD as guidance before issuing operational forecasts have also been discussed.

11.2 Operational Long Range Forecast System for SW Monsoon Rainfall over India

11.2.1 The 3-Stage Statistical Ensemble Forecasting System for the Forecasting of Season Rainfall over the Country as a Whole

For the first stage forecast of season (June to September) rainfall over the country as a whole issues in April and for its first update, a set of 8 predictors that having stable and strong physical linkage with the season rainfall. Details of these 8 predictors are given in the Table-11.1 along with their signs of impact (Favorable/ Unfavorable for normal/excess monsoon) on 2014 SW Monsoon. It may be noted that, 2 of the old parameters (Northcentral Pacific 850hPa zonal wind (May) & North Atlantic sea surface temperature (SST) (Dec+Jan)) were replaced by 2 new parameters (Northcentral Pacific 850 zonal wind gradient (May) & Northeast Pacific to Northwest Atlantic SST anomaly gradient (Dec+ Jan)). The old predictors were replaced as their relationship with the all India summer monsoon season rainfall (ISMR) showed significantly weak in the recent years. For the April forecast, first 5 predictors listed in the Table-11.1 were used. For the update forecast issued in June, the last 6 predictors were used that include 3 predictors used for April forecast. Out of the 5 predictors used for April forecast, one predictor (East Asia Pressure (Feb+Mar)) was favorable. On other hand, one predictor (Warm water volume anomaly (Feb+Mar)) was unfavorable and the remaining 3 predictors were neutral. In case of June forecast, out of 6 predictors, 2 predictors (NINO3.4 SST Anom. Tendency (MAM(O)-DJF(-1)) and North Central Pacific Zonal Wind Gradient 850 hPa (MAY)) were unfavourable, and 1 predictors (East Asia Pressure (Feb+Mar)) were favourable for normal/ above normal monsoon rainfall. The remaining 3 predictors were neutral.

Table-11.1: Details of the 8 predictors used for the ensemble forecast system for the forecasting of 2014 southwest monsoon rainfall over the country as a whole.

No.	***Predictor***	***Used for forecasts in***	***Correlation Coefficient (1981-2010)***	***Favorable/ Unfavourable/ Neutral***
1.	Europe Land Surface Air Temperature Anomaly (January)	April	0.42	N
2.	Equatorial Pacific Warm Water Volume Anomaly (February + March)	April	-0.35	U
3.	SST Gradient Between Northwest Pacific and Northwest Atlantic (December +January)	April and June	-0.48	N
4.	Equatorial SE India Ocean SST (FEB)	April and June	0.51	N
5.	East Asia MSLP (FEB + MAR)	April and June	0.51	F
6.	NINO 3.4 SST Anomaly Tendency MAM(O)-DJF(-1)	June	-0.45	U
7.	North Atlantic MSLP (MAY)	June	-0.48	N
8.	North Central Pacific Zonal Wind Gradient 850 hPa (MAY)	June	-0.57	U

In the ensemble forecasting system, the forecast for the seasonal rainfall over the country as a whole was computed as the ensemble average of the forecasts prepared from a set of selected models. Using multiple linear regression (MR) and projection pursuit regression (PPR) techniques, two separate sets of all possible models (based on all possible combinations of models) were constructed first. Based on the performance of these models during some fixed independent test period, a set of few best models from all possible MR and PPR models were selected for ensemble average. The independent forecasts were used based on moving training method with a fixed window period of 23 years. The standard error of the 5–parameter and 6- parameter ensemble forecasting systems were taken as ±5% and ±4% respectively.

To prepare the April ensemble average forecast, out of all the total 62 models (32 MR and 32 PPR models), best 5 (all MR) models were used. During the independent forecast period of 1981-2013, the standard error of the 5-parameter ensemble forecast system is 6.47% of LPA. The performance of the April forecasting system for the independent test period (1981-2013) is shown in Fig.11.1a. To prepare the June ensemble average forecast, out of all the total 126 models (63 MR and 63 PPR models), best 20 (16 MR and 4 PPR) models were used. The performance of the June forecasting system for the independent test period (1981-2013) is shown in Fig.11.1b. During the independent forecast period of 1981-2013, the standard error of the 6-parameter ensemble forecast system is 6.13% of LPA.

A five category probability forecast was also prepared based on the statistical ensemble forecasting system. The probability forecast was prepared using normal probability distribution with the forecast from the ensemble forecasting system as the mean and the standard error of the respective ensemble forecasting system for the period 1981-2013 as the standard deviation. The probabilistic forecasts for the 2014 southwest monsoon season issued in April, June and August are given in the Table-11.2. The most probable category is one that having value higher than corresponding climatological value and that is the highest among all categories.

The second update for the forecast of season rainfall over the country as a whole was prepared based on the forecast for the second half of the monsoon season prepared in July and the realized rainfall during the first half of the monsoon season. The probabilistic forecast is prepared using the normal probability distribution with the second updated forecast as the mean and the standard error of the June ensemble forecasting system for the period 1981-2013 as the standard deviation.

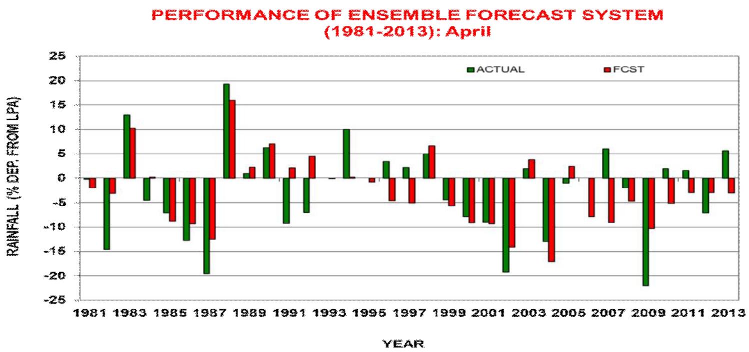

Fig.11.1a: Performance of the April ensemble forecasting system for the seasonal rainfall over the country as whole for the period 1981-2013.

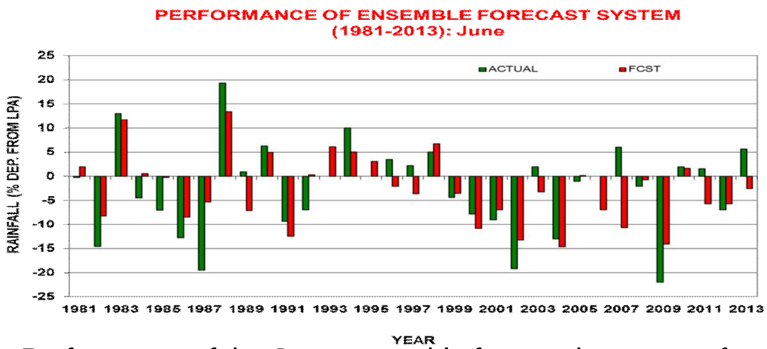

Fig.11.1b: Performance of the June ensemble forecasting system for the seasonal rainfall over the country as whole for the period 1981-2013.

Table-11.2: The 5 category probability forecasts for the 2014 monsoon season rainfall over the country as whole based on April and June ensemble forecasting systems.

Category	Rainfall Range (% of LPA)	Forecast Probability (%)			Climatological Probability (%)
		April	June	August	
Deficient	Less than 90	**18**	**33**	**68**	16
Below Normal	90 - 96	**33**	**38**	**24**	17
Normal	96 -104	**38**	**26**	**8**	33
Above Normal	104 -110	**9**	**3**	**0**	16
Excess	more than 110	**2**	**0**	**0**	17

11.2.2 PCR Model for the Rainfall during the Second Half of the Monsoon Season (August- September) Over the Country as a Whole

A separate set of 5 predictors were used for the development of the PCR model based on data for the period 1958-2013. The model uses moving training period method for the prediction with a constant window period of 23 years. In this method, for the prediction of rainfall for a reference year, data of 23 years just prior to the reference year was first used for PC analysis of the 5 predictor data set. First few PCs that explain 80% of the total variability of the predictors set during these 23 years (training period) were then related against the predictor series for the same period using the multiple linear regression method. Scores of the selected PCs for the reference year were then calculated using the PC loading matrix and predictor values for the reference year. These score values along with the coefficients of the trained regression equation were used for calculating the predictor value for the reference year. In this way, rainfall during the second half of the southwest monsoon season over the country as a whole was predicted for the period 1981-2013.

The model RMSE for the independent forecast period (1981-2013) is 11% of LPA and multiple correlation coefficients (C.C) is 0.69. For training the model for 2014, data for the period 1991-2013 was used. The standard error of the model for the training period (1991-2013) is 9.02% of LPA. However, average of model standard errors during the last 10 years (2003-2013) was taken as the model error for issuing the forecast. This is 8% of LPA. The performance of the model for the period 1981-2013 is given in the Fig.11.2.

Tercile (3 category) probability forecasts for the rainfall during the second half of the monsoon season were prepared based on the respective model forecast error distributions. For this purpose, the tercile rainfall categories with equal climatological probabilities (33.33% each) were defined based on the data for the period 1951-2010. The tercile probability forecast was prepared using normal probability distribution with the forecast from the PCR model as the mean and the model standard error during the training period as the standard deviation. The tercile probability forecasts for the rainfall during the second half of the 2014 monsoon season are given in the Table-11.3.

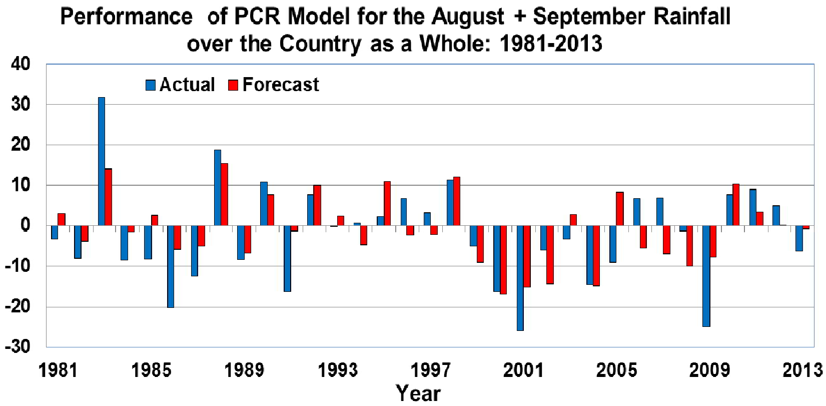

Fig.11.2: Performance of PCR model for the rainfall during the 2013 second half of monsoon season over the country as whole for the period 1981-2013.

Table-11.3: The tercile probability forecasts for the rainfall during the second half of the 2014 monsoon season over the country as a whole.

Category	Rainfall Range (% of LPA)	Forecast Probability (%)
Below Normal	<94	**46**
Normal	94 -106	**43**
Above Normal	>106	**11**

11.2.3 Principal Component Regression Models for the Monthly (July & August) rainfall

Quantitative and probability forecasts for monthly rainfall over the country as a whole for the July and August were issued using PCR models based on separate predictor data sets. The methodology used was same as that used for the PCR model for second half of the monsoon season (section 11.2.2). Forecasts for July and August were issued in June along with the update forecast. The model error of the July & August was taken as ± 9% of LPA each.

For the forecast of July rainfall over the country as a whole, a PCR model with 6 predictors was developed using data for the period 1958-2013. For the forecast of August rainfall, a PCR model with 5 predictors using data for the period 1976-2013.

For the 2014 forecast, the monthly forecasts were generated using 1991-2013 as the training period. The performance the PCR models for the monthly rainfall forecast for the period 2001-2013 is given in the Table-11.4. The tercile probability forecasts for the 2014 monthly rainfall are given in the Table-11.5.

Table-11.4. Performance of PCR models for the monthly (July, August and September) rainfall over the country as a whole for the period (2001-2013).

YEAR	JULY RAINFALL		AUGUST RAINFALL	
	ACTUAL	ACTUAL	FORECAST	FORECAST
2001	95	81	88	100
2002	49	98	84	82
2003	107	96	109	98
2004	81	96	87	80
2005	115	72	96	125
2006	98	107	95	95
2007	98	98	95	89
2008	83	101	102	95
2009	96	74	86	82
2010	103	105	97	106
2011	85	109	89	90
2012	87	101	100	94
2013	107	98	98	100
RMSE (% OF LPA) (2001-2013):	**± 12%**		**± 12%**	

Table-11.5: The tercile probability forecasts for the 2014 monthly (July and August) rainfall over the country as a whole.

Category	July Model		August Model	
	Rainfall Range (% of LPA)	Forecast Probability (%)	Rainfall Range (% of LPA)	Forecast Probability (%)
Below Normal	<94	**53**	<94	**43**
Normal	94 -106	**35**	94 -106	**35**
Above Normal	>106	**12**	>106	**22**

11.2.4 Forecast of the Seasonal Rainfall over the Four Geographical Regions

For the forecast of season rainfall over each of the four geographical regions (northwest India, central India, south Peninsula, and northeast India) issued in June, separate PCR models were developed. The method was similar to the PCR models for the monthly forecast. However, in the PCR models for the geographical regions, fixed window period of 30 years was used to train the models. Thus the forecast for the 2014 was generated using 1984-2013 as the training period. The model error for each of the geographical regions was taken as 8% of LPA. The performance of the PCR models for the four geographical regions for the period 2001-2013 is given in the Table-11.6. The tercile probability forecasts for the 2014 are given in the Table-11.7.

The first update for the season rainfall over each of the four geographical regions issued in August was estimated as the product of the difference in the first and second update forecasts for the season rainfall over the country as a whole and the fraction of the rainfall departure during the first half of the monsoon season over the respective region to that over the country as a whole.

11.3. Operational Forecast Model for the Date of Monsoon Onset over Kerala

An indigenously developed statistical model (Pai and Rajeevan, 2009) was used for preparing the operational forecast of the onset of monsoon over Kerala. The model based on 6 predictors used the principal component regression (PCR) method for its construction. Independent forecasts were derived using the sliding fixed window period of length 22 years. The model for 2014 was trained using data for the period 1992-2013. Fig.11.3 shows the performance of the forecast for the period 1997-2013. The RMSE of the model is about 4 days.

11.4 Verification of Operational Forecasts

11.4.1 Forecasts for the Southwest Monsoon Rainfall

This year, the long range forecast for the 2014 southwest monsoon rainfall was issued in 3 stages. The first stage long range forecast issued on 24th April consisted of only forecast for season (June-September) rainfall over the country as a whole. In the second stage (9th June), along with the first update for the April forecast, forecast for season rainfall over the four broad geographical regions (northwest India, central India, south Peninsula and northeast India) and that for monthly rainfall over the country as a whole for the months of July and August were issued. In the 3rd stage (12th August), along with the forecast for the rainfall during the second half of the monsoon season over the country as a whole, second update for the season rainfall over the country as a whole and first update for the season rainfall over the four broad geographical regions were issued.

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 95% of LPA (below normal) with a model error of ± 5% of LPA). This forecast was downgraded to 93% ± 4% of LPA (below normal) in the first update in June, and further downgraded to 87% ± 4% of LPA (deficient) in August. The actual season rainfall for the country as a whole is 88% of LPA, which is less than the first stage forecast issued in April by 7% of LPA. On the other hand, it is less than the first update by 5% of LPA and more than the second update by just 1% of LPA. Thus the actual season rainfall over the country as whole is within the limits of second forecast update.

Considering the four broad geographical regions of India, the forecast issued in June (August) for the season rainfall over northwest India was 85% (76%) of LPA, that over Central India was 94% (89%) of LPA, that over northeast India was 99% (93%) of LPA, and that over South Peninsula was 93% (87%) of LPA all with a model error of ± 8%. The actual rainfalls over northwest India, central India, northeast India and south Peninsula were 79%, 90%, 88% and 93% of the LPA respectively. The actual season rainfall over northwest India is 6% less than the forecast issued in June and 3% more than that its August update. Similarly, the actual season rainfall over Central India is 4% less than the forecast issued in June and 1% more than that its August update. In case of south Peninsula, the actual season rainfall is exactly equal to the forecast issued in June and 6% more than that its August update. On the other hand, the season rainfall over northeast India is less than forecasts issued in both June and August by 11% and 5% of LPA respectively. Thus the actual season rainfalls over northwest India, central India and south Peninusla are within the limits of the forecasts issued in both June and August. In case of northeast India, though the actual season rainfall (88% of LPA) is within the limits of forecast (93% ± 8%) issued in August, it is less than its lower limit of forecast (91 (99-8) % of LPA) issued in June.

The forecast for the second half of the monsoon season (August –September) for the country as a whole was 95% with a model error of 8% of LPA against the actual rainfall of 97% of LPA. Thus the forecast for the rainfall during the second half of the monsoon season over the country as a whole is also within the forecast limits.

The forecasts for the monthly rainfall over the country as a whole for the months of July & August issued in June were 93% & 96% respectively with a model error of ± 9%. The actual monthly rainfall during July and August is 90% of LPA each. Thus the forecasts for the July and August rainfalls are underestimate to the realized rainfall by 3% of LPA and 6% of LPA respectively and are within the forecast limits. The Table-11.8 gives the summary of the verification of the long range forecasts issued for the 2014 Southwest monsoon.

11.4.2 Forecast for the Monsoon Onset over Kerala

Based on an indigenously developed statistical model, it was predicted on 15th May 2014 that monsoon will set in over Kerala on 5th June with a model error of ±4 days. The forecast came correct as the actual monsoon onset over Kerala took place on 6th June, 1 day later than the forecasted date. Thus this is the tenth consecutive correct operational forecast for the date of monsoon onset over Kerala since issuing of operational forecast for the event was started in 2005.

Table–11.6: A comparison of the performance of forecasts for the seasonal rainfall by PCR models for NW India, NE India, Central India South Peninsula and.

YEAR	NWI		NEI		CI		SPNI	
	Actual	Forecast	Actual	Forecast	Actual	Forecast	Actual	Forecast
2001	91	87	89	97	95	91	90	98
2002	74	84	93	89	83	90	68	93
2003	108	106	96	101	108	107	89	108
2004	79	71	89	97	89	89	85	97
2005	90	108	77	95	110	97	112	109
2006	94	88	85	99	116	94	95	88
2007	85	86	110	108	108	99	125	106
2008	105	93	98	97	96	87	96	88
2009	65	72	76	97	80	92	94	88
2010	112	95	82	98	104	103	118	113
2011	107	95	87	94	110	109	100	90
2012	92	96	91	101	96	96	90	97
2013	109	94	73	93	95	95	115	109
RMSE (% OF LPA) (2001-13)	**± 10%**		**±12 %**		**± 12%**		**± 12%**	

Table-11.7: The tercile probability forecasts for the 2014 seasonal rainfall over the four broad geographical regions.

Rainfall Category	NW India		Central India		South Peninsula		Northeast India	
	Range (% of LPA)	Forecast Probability (%)	Range (% of LPA)	Forecast Probability (%)	Range (% of LPA)	Forecast Probability (%)	Range (% of LPA)	Forecast Probability (%)
Below Normal	<92	**71**	<94	**51**	<93	**50**	<95	**33**
Normal	92-108	**26**	94-106	**34**	93-107	**35**	95-105	**37**
Above Normal	>108	**3**	>106	**15**	>107	**15**	>105	**30**

Table-11.8: Verification of operational forecast issued for 2014 southwest monsoon rainfall.

Region	Period	Forecast (% of LPA)			Actual Rainfall (% of LPA)
		24th April	9th June (1st Update)	12th August (2nd Update)	
All India	June to September	95 ± 5	93 ± 4	87 ± 4	88
Northwest India	June to September		85 ± 8	76 ± 8	79
Central India	June to September		94 ± 8	89 ± 8	90
Northeast India	June to September		99 ± 8	93 ± 8	88
South Peninsula	June to September		93 ± 8	87 ± 8	93
All India	July		93 ± 9		90
All India	August		96 ± 9	96 ± 9	90
All India	August to September			95 ± 8	98

11.5. Experimental Forecasts

11.5.1 IMD Seasonal Forecast Model (SFM)

Since 2004, IMD has been generating experimental dynamical forecast for the southwest monsoon rainfall using the seasonal forecast model (SFM) of the Experimental Climate Prediction Center (ECPC), USA. Till 2010, the model forecasts were prepared using persistence SST anomaly method. From 2011 onwards, the model forecasts were prepared using both persistence SST anomaly method and forecasted SST method. In the later method, global SST forecasts from NCEP coupled forecasting system (CFS) version 2 model was used as boundary forcing for the SFM model. It was observed the forecast SST method has better skill than persisted SST anomaly method. Therefore, as of now the experimental forecast from SFM is prepared based on the forecasted SST method only.

The skill scores (correlation coefficient (C.C) and root mean square error (RMSE)) of the SFM model for the monthly, second half of the season and seasonal rainfall over the country as a whole at different lag periods are given in the Table-11.9. For generating the forecasts, ten ensemble member forecasts were obtained using the initial conditions corresponding to 00Z from 21st to 30th of each month on which the forecast was prepared. Fig.11.4 shows the spatial distribution of rainfall anomaly forecast for the 2014 monsoon season based on 5 different lag periods (‘0’ to ‘5’ months). The verification of the monthly, second half and seasonal rainfall during 2014 southwest monsoon season is given in the

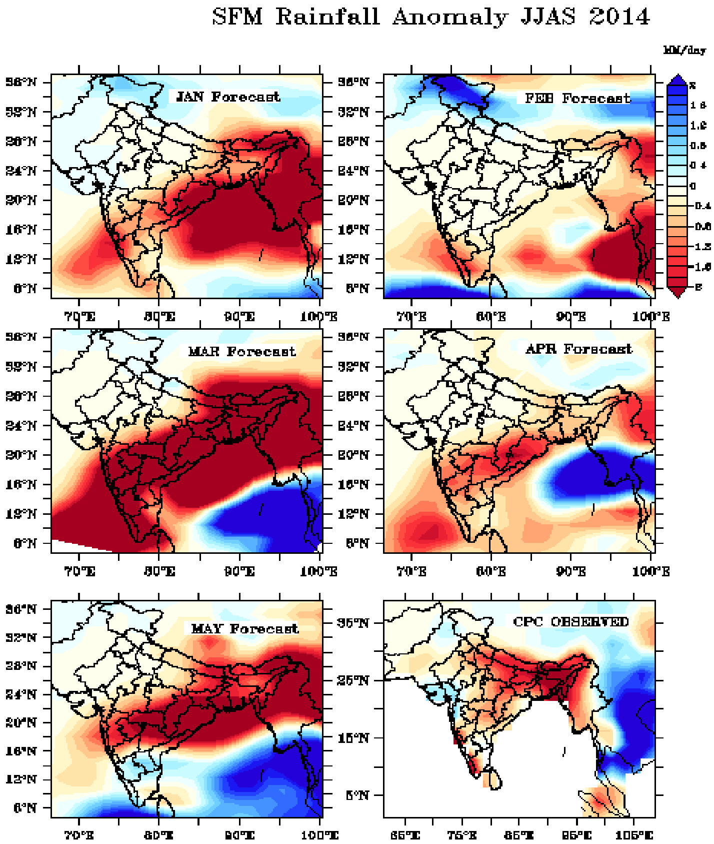

Fig.11.4: Spatial distribution of rainfall anomaly forecast from IMD SFM based on different initial conditions. The observed rainfall anomaly obtained from NCEP CPC is also shown.

Table-11.9: Skill scores (C.C & RMSE) of IMD SFM model for the monthly, second half and seasonal rainfall over the country as whole at different lags. The scores were calculated for the hindcast period of 1982-2011.

Forecast issued	JUN		JUL		AUG		SEP		JJAS		AUG-SEP	
	C.C	**RMSE**	**C.C**	**RMSE**	**C.C**	**RMSE**	**C.C**	**RMSE**	**C.C**	**RMSE**	**C.C**	**RMSE**
Jan	-.07	21	-0.01	16	0.43	12	0.20	22	0.33	9	0.35	13
Feb	0.06	19	-0.01	16	0.31	11	0.41	18	0.34	9	0.49	9
Mar	0.04	20	0.31	15	0.27	14	0.39	16	0.50	8	0.52	10
April	0	19	0.15	15	0.36	12	0.41	18	0.46	9	0.51	11
May	-0.2	21	0.27	16	0.09	14	0.16	22	0.33	9	0.29	12
Jun	-	-	0.37	13	0.05	14	0.22	21	-	-	0.28	12
Jul	-	-	-	-	0.28	13	0.44	18	-	-	0.45	11

Table-11.10: Forecast from IMD SFM for the monthly, second half and season rainfall during the 2014 southwest monsoon season over the country as a whole at different lags.

Forecast issued in	Rainfall (% of LPA)					
	Jun	Jul	Aug	Sep	June to Sep	Aug-Sep
January	108	83	77	54	81	71
February	93	89	92	68	89	85
March	105	75	71	55	78	70
April	110	103	83	73	88	83
May	99	83	79	84	85	84
June	-	90	106	150	-	124
July	-	-	97	97	-	97

Table-11.11: Forecasts for 2014 southwest monsoon season rainfall over the country as a whole received from various climate research centers/ research groups/ individuals.

Sr. No.	Institute	Model	Forecast for 2014 (% of LPA)	
			Issued in April	Issued in June
1.	Indian Institute of Tropical Meteorology (IITM), Pune	IITM CFS2 T382 (Monsoon Mission Model)	96 (Feb ICs)	96 (Apr ICs)
2.	Space Applications Centre, Ahmedabad.	Empirical model based on Genetic Algorithm	94 ± 4	No update
3.	Indian Institute of Technology, Bhubaneswar	Multi Model Ensemble	95	93
4.	C-MMACS, Banglore	The Variable-Resolution GCM	ST scenario: Normal El Nino: Deficit	No update
5.	CDAC, Pune	NCEP GFS T170L42	82 (March IC)	79 (April IC)
6.	IISc, Banglore (Prof: Iyengar)	Intrinsic Mode Function (IMF) method	94 ± 6	NA
7.	Onkari Prasad (Retired IMD)	South Indian Ocean convergence zone based relation	Normal	No Update

11.5.2 Forecasts for Seasonal Rainfall from Indian Institutes

Apart from IMD, many other research institutions in India are also involved in the long range forecasting research. Each year, these institutes provide experimental forecasts to IMD prior to issuing of operational forecast. The forecasts received from different Indian institutes are given in the Table-11.11. These forecasts include the forecasts generated by IITM, Pune under monsoon mission project launched by Ministry of Earth Sciences (MoES) for developing state-of-the-art dynamical prediction system for monsoon rainfall on different time scales. Under monsoon mission, IITM is coordinating and working along with different climate research centers from India and abroad on the development of a coupled model for the forecasting Indian summer monsoon rainfall. Climate Forecast System (CFS) of NCEP, USA has been identified as the basic modeling framework for this purpose. The model has a very high horizontal resolution of approximately 38km (T382).

As seen in the Table-11.11, the experimental forecasts from most of the models indicated below normal to deficient (≤ 96% of LPA) monsoon season rainfall over the country as whole.

11.5.3 Forecasts from Major International Climate Prediction Centers

Several international climate prediction centers regularly generate and provide global seasonal forecasts based on dynamical models (Atmospheric/ coupled GCMs) through web. Some of these centers also prepare Multi-Model Ensemble (MME) forecasts using combinations of forecasts prepared by different centers. It may be mentioned that none of these centers prepare forecasts specifically for the Indian region. The skill of the multi model ensemble forecasts has been found to be better than that of the individual models. Inferences derived from the MME forecasts from 3 centers and individual coupled model forecasts from 3 centers issued in March/April are summarized in the Table-11.12a. Similarly, inferences derived from the MME forecasts from 4 centers and individual coupled model forecasts from 6 centers issued in May/June are summarized in the Table-11.12b. It is seen from the Tables-11.12a & 11.12b that the forecasts from most of the models were indicating below normal to normal rainfall over most parts of the country.

11.6 Conclusions

The forecast for the monsoon onset date over the Kerala was correct once again as in the previous 9 years. The season rainfall over the country as a whole and that over four broad geographical regions (northwest India, central India, northeast India and south

Peninsula) were within the limits of the forecasts updated in August and accurate. Similarly, the forecasts for the monthly rainfall (for July and August) as well as that for the rainfall during the second half of the monsoon season over the country as a whole were also accurate.

The observed rainfall deficiency of about 7-12% of LPA in all the four broad geographical regions was mainly caused by the large rainfall deficiencies over most parts of the country during June resulted from the delayed progress of the monsoon over these areas. The delayed monsoon progress in turn was caused by the below normal heating of the Indian subcontinent during the pre-monsoon season resulting in weaker than normal monsoon flow into the region. However, the monsoon gained its normal strength around the middle of July. It may be noted that this year, the observed conditions over the equatorial Pacific during prior and early part of the monsoon season were close to be classified as the border line El Nino. Forecasts from several global models were also indicating formation of weak El Nino during the middle of the monsoon season. However, subsequent weak air-sea coupling over the region led to the weakening of El Nino conditions from early July resulting in ENSO neutral conditions during remaining part of the monsoon season. This helped monsoon to remain more or less normal thereafter. However, the season also witnessed strong intra seasonal variation in the rainfall activity with long break monsoon spell in the middle of August caused by unfavourable phase of Madden Julian Oscillation (MJO) and short active monsoon spells during middle of July and early part of August caused by passage of low pressure systems along the monsoon trough region. In the early part of September, the interaction between the western disturbances moving across north India and monsoon low pressure systems caused increased rainfall activity over north, northwest India and central India. The country received near normal rainfall (94% of LPA) during the period July to September period. But due to the large rainfall deficiency in June, the 2014 season rainfall over the country as a whole (88% of LPA) ended as deficient (<90% of LPA).

The experimental forecasts from IMD SFM for the season rainfall over the country as whole at all lag periods could correctly indicate realized deficient rainfall. The experimental forecasts from most of the other Indian institutes and international climate centers also indicated below normal to deficient rainfall.

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Pai, D. S. and M. Rajeevan, 2009, Summer monsoon onset over Kerala: New Definition and Prediction, J. Earth Syst. Sci. 118, No. 2, pp123–135.

Table-11.12a: Inferences derived from seasonal forecasts from various climate centers for the 2013 southwest monsoon season issued during March/ April 2013.

S. No	Centre issuing the Forecast	Model used for preparing the MME forecast	Inference for 2014 (issued in March/April2014)
1.	ECMWF, UK	ECMWF	JJA & JAS (March 2014): Normal rainfall is most likely over most parts of the country except some areas of north and northwest India.
		EUROSIP MME of 4 Coupled Models:	JJA (March 2014): Normal rainfall over most parts of the country.
2.	International research Institute for Climate and Society, USA	7 Models (AGCM & CGCM)	JJA & JAS (March 2014): Climatological probabilities for most parts of the country except Gujarat.
3.	WMO LC-LRFMME, South Korea	5 Models	JJA (March 2014): Below Normal rainfall is most likely over some areas of northwest and northeast India. Above normal rainfall is most likely over some areas of Peninsula, central India and north India. Country as a whole: Normal
4.	Japan Agency for Marine-Earth Science and Technology	Coupled Model	JJA (March 2014): Negative rainfall anomalies over most parts of the country except over some areas over east coast of the country where positive rainfall anomalies are predicted
5.	NCEP, USA	CFS (Version 2)	JJAS (March 2014): All India: 98% of LPA

Table-11.12b: Inferences derived from seasonal forecasts from various climate centers for the 2014 southwest monsoon season issued during May/ June 2013.

S. No	Centre issuing the Forecast	Model used	Inference for 2014 (issued in May/June 2014)
1.	Met Office, UK	Glo Sea 5	JJA & JAS (May 2014): Normal to above normal rainfall over most Northeast India. Below normal rainfall over remaining areas.
2.	Meteo France	Meteo France Coupled Model	JJA & JAS (May 2014): Below normal rainfall over most parts of the country.
3.	NCEP, USA	CFS (Version 2)	JJAS (May 2014): Normal rainfall over most areas of the country. Below normal rainfall over areas south of Himalayas. All India: 99 %of LPA
4.	ECMWF, UK	ECMWF	JJA (May 2014): Below normal rainfall over Northwest India and neighboring central India and some areas of North Peninsula. Climatological probabilities for remaining areas. JJA (May 2014): Below normal rainfall is over Northwest India. Remaining areas have climatological probabilities.
		EUROSIP MME of 4 Coupled Models:	JJA (May 2014): Below normal rainfall over most parts of the country. Northeast India, have climatological probabilities. JJA (May 2014): Below normal rainfall over Northwest India and neighboring central India and some areas of North Peninsula. Remaining areas have climatological probabilities.
5.	WMO LC-LRF MME, South Korea	AGCM and CGCM Forecasts from 7 GPCs	JJA (May 2014): Below normal rainfall over most areas. Climatological probabilities over Northeast India. JAS (May 2014): Below Normal rainfall over some areas over central Peninsula. Other areas have climatological probability
6.	IRI, USA	7 Models (AGCM & CGCM)	JJA & JAS (May 2014): Climatological probabilities for entire region.
7.	APEC Climate Centre, South Korea	15 Models from the APEC region	JJA (March 2014): Above Normal rainfall is most likely over some southern and eastern parts. Below normal rainfall over some northern areas of NE India. Climatological probabilities over remaining parts of the country
8.	Japan Agency for Marine-Earth Science and Technology	Coupled Model	JJA (May 2014): Below normal rainfall over most parts of the country. Normal rainfall over Northeast India:
9.	Japan Meteorological Agency (JMA)	Coupled Model	JJA (May 2014): Below normal rainfall over parts of Northwest and central India. Climatological probabilities over remaining parts of the country

12

NEW SATELLITE PRODUCTS FOR THE MONSOON MONITORING

A. K. Mitra, Virender Singh and A. K. Sharma

This Chapter discusses application of newly launched INSAT-3D satellite imageries & products in monitoring of onset and advance of monsoon, enhanced imageries of cyclonic circulations pattern, active and break spells of monsoon, the withdrawal of monsoon and a new online tool for monitoring the INSAT-3D data for weather and climate studies.

12.1 Introduction

The south west monsoon over India is characterized with rainfall regimes, active-break periods and synoptic scale monsoon disturbances. The seasonal monsoon rainfall during June to September is more than 70% of annual rainfall for almost all meteorological sub-divisions of India except a few in southeastern part of the peninsula (Krishnamurthy 2000). Hence any deviation from the mean monsoon characteristics can upset various agricultural and hydrological practices and hence influence the economy in different parts of the country. Therefore, the better understanding of the mean monsoon rainfall distribution in different spatial and temporal scales through the diagnostic studies with observational data sets is essential for prediction of monsoon rainfall in different space and time scales.

In the Northern Hemisphere summer, hot air rising from the Indian sub-continent pulls in moist air from the Indian Ocean, deluging the Indian sub-continent with its annual monsoon. The location and extent of the rainfall during monsoon determines which areas experience drought or flooding. Prior to satellite era, understanding of monsoon was based on the meteorological data collected by land-based observatories and ships. The launch of first satellite TIROS-I dedicated to the study of weather and climate was started on 1st April, 1960 marked the beginning of satellite era in the meteorology. Since then more than 350 satellites have been launched to monitor the weather and climate of the earth.

Satellite remote sensing has brought a new dimension of understanding of the processes that govern our earth-atmosphere system which affects almost every known activity of human beings either directly or indirectly. The weather agencies are constantly striving to find out the weather elements as a parameter, either in the form of actual data concerning current weather or in the form of a forecast of future conditions. Satellites basically measure the radiance coming from the earth's surface and cloud tops. By making such measurements at appropriate wavelengths and applying physical and statistical techniques, it is possible to compute a wide range of products for weather purposes. Further, the satellite meteorological data on a global scale are vital inputs for initialization purposes in Numerical Weather Prediction models, particularly over data-sparse areas like the Indian Ocean.

The initial period of satellite era, polar orbiting satellites were the main satellite inputs to monsoon forecasting and are used in monsoon predictions on different time-scales. But data from geostationary satellites are significant sources of information for the diagnosis and prediction of large scale weather phenomena. The successful launch of indigenous geostationary satellite INSAT-3D on 26th July 2013 has provided a new opportunity to the Indian meteorologists. The mission objectives of INSAT-3D satellite are mainly focused on the monitoring the earth's surface, carryout oceanic observations in various spectral channels from its 6-channel Imager payload and to provide the vertical profile of temperature and humidity parameters of the atmosphere.

Considering all the above, a study has been undertaken to analyze the characteristics of monsoon circulation features over India region during southwest monsoon, 2014 with the help of INSAT-3D satellite imageries and its derived products. The study can be taken as a better utilization of satellite observations for monitoring and prediction of monsoon circulation and precipitation over India.

12.2 Circulation features during onset and advance phase of southwest Monsoon, 2014

12.2.1 Advance of monsoon over Andaman Sea

Advance of southwest monsoon over Andaman Sea normally takes place around last week of May with a standard deviation of about one week. Low level cross equatorial monsoon flow has started appearing over south of Arabian Sea and adjoining south Bay of Bengal. During the last few days, considerable increase in the rainfall activity over the Bay of Bengal has also been observed. The cross equatorial flow is likely to strengthen and deepen, which in turn would lead to further increase in the rainfall activity over the area. As a result, monsoon is likely to advance over Andaman Sea during next three days. Similar pattern observer during 17th - 18th May2014, an easterly wave trough embedded in the northern hemispheric equatorial convergence zone developed into a cyclonic circulation over south Andaman Sea and neighborhoods. Associated with this, low level cross equatorial monsoon flow strengthened over the region resulting in the advance of southwest monsoon over most parts of Andaman Sea and some parts of southeast Bay of Bengal on 18th May and remaining parts of Andaman Sea, some more parts of southeast Bay of Bengal and some parts of southwest and east central Bay of Bengal on 19th. Thus the southwest monsoon current reached over south Andaman Sea 2 days before normal date of 20th May and can be seen from INSAT-3D visible channel (0.5µm) images of 1-Km resolution in the Fig -1 from 17th to 20th May 2014.

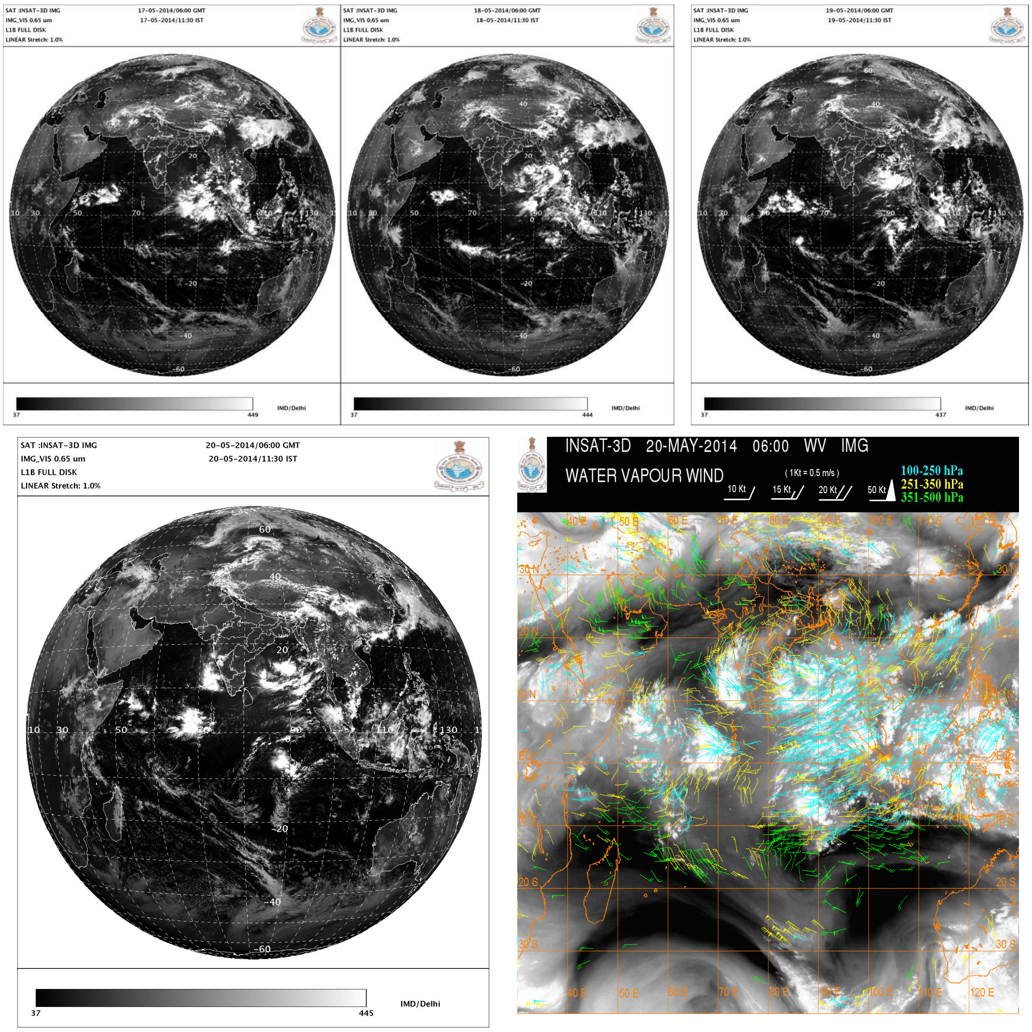


Fig. 12.1: INSAT-3D visible channel images from 17-20 May 2014 and WVW on 20th May 2014.

It can be seen from the figure that over the Bay of Bengal and Andaman Sea, broken low/medium clouds with embedded moderate to intense convection observed over south Bay between lat.7.0°N to 11.0°N and long. 84.0°E to 93.0°E. The INSAT-3D Water Vapor Winds (WVW) on 20th May 2014, 0600 UTC, as shown in the Fig.11.1 indicated the strong mid and upper level winds over the Andaman Sea.

12.2.2 Onset of monsoon over Kerala

India Meteorological Department has declared onset of monsoon over Kerala on 6th June 2014, 5 days later than its normal date of 1st June. It can be seen from the INSAT-3D Infra-red (IR) imageries that just before the onset of monsoon over Kerala, deep convective cloud area starts increasing over southeast Arabian Sea and neighboring areas. Sequence of imageries of IR shows the rapid northward movement of the clouds from 5th to 6th June 2014 i.e., the time of monsoon onset Fig.12.2 (a, b, c). The moisture influx can also be seen from the water vapor imagery on the same day Fig.12.2 (d). At this phase, monsoon also advanced into most parts of south Arabian Sea, some parts of Tamil Nadu, most parts of southwest Bay of Bengal and some parts of west central Bay of Bengal.

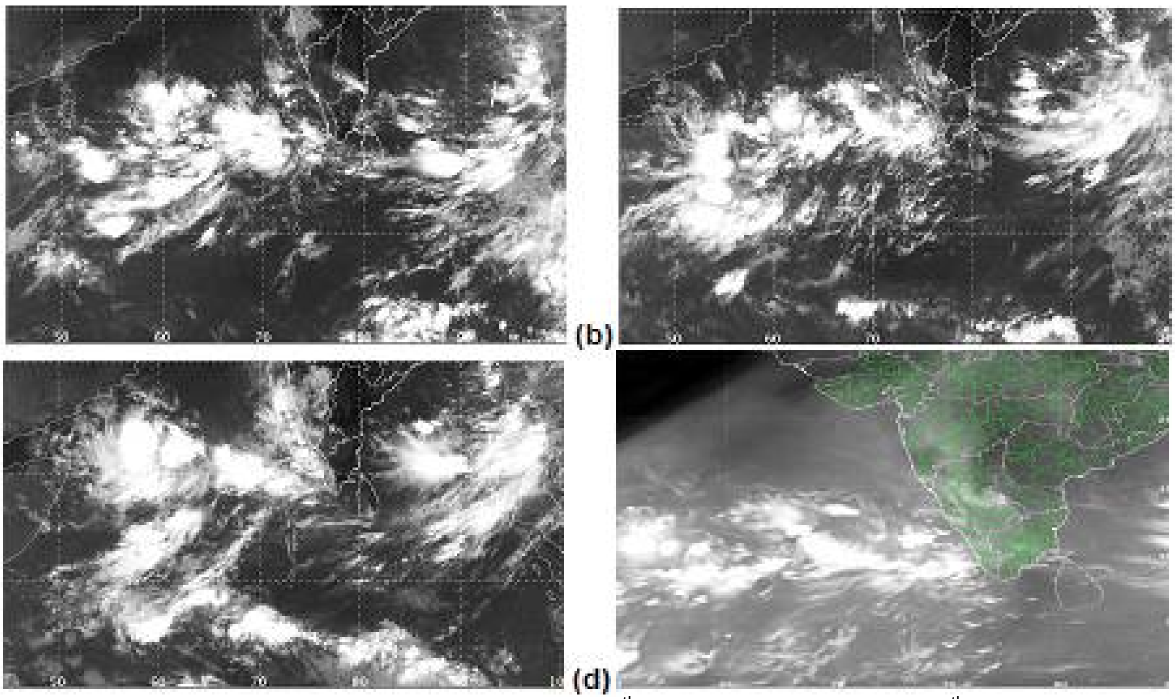
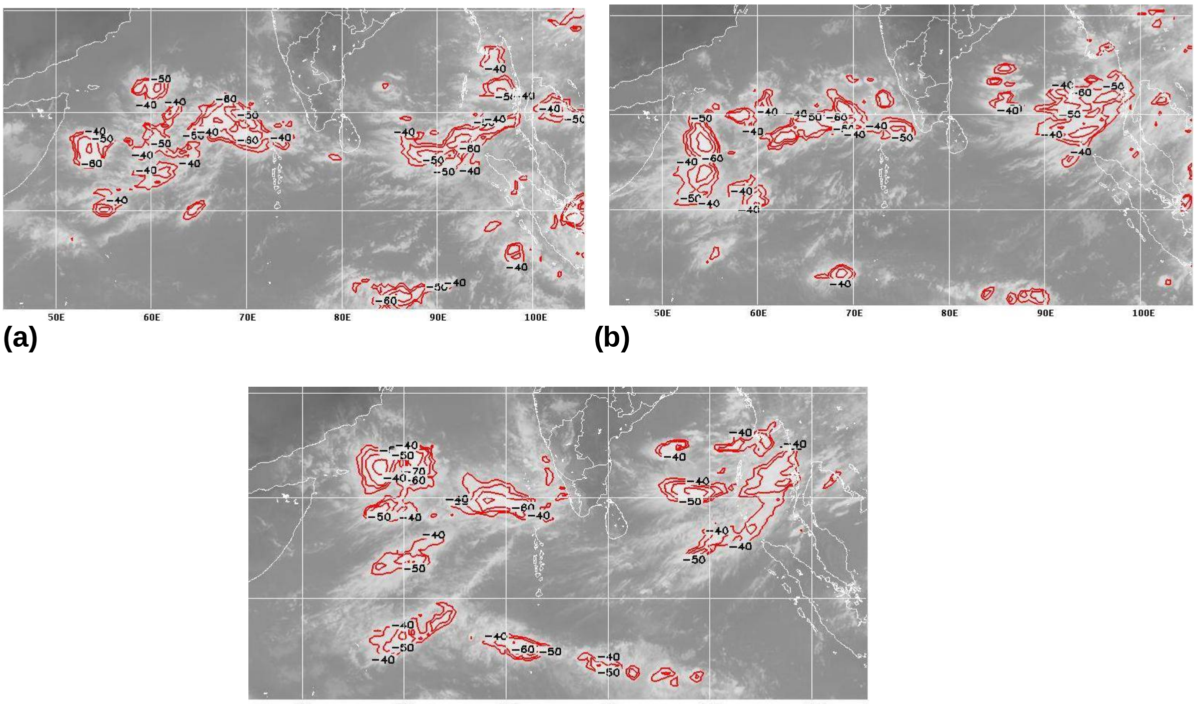


Fig.12.2(i) : INSAT-3D- IR imageries for (a) 5th June (0300UTC) (b) 6th (0300UTC) (c) 7th (0300UTC) indicating flow of onset of SW-Monsoon over Kerala and (d) 6th June'2014 (0300UTC) water vapour image showing moisture inflow on the day of onset of monsoon over Kerala.



(a) (b) (c)

Fig. 12.2(ii): Kalpana-1 IR Cloud top temperatures during the onset phase of 2014 Monsoon (a)5th, b)6th and c) 7th June 2014, 0600 UTC).

The depth of convection can be very well monitored with the help of cloud top temperature (CTT) from Kalpana-1 satellite in the Fig.(12.2(ii) a, b, c). In the figure the value of CTT contours increases at the time of monsoon onset from 5th June to 6th June near neighboring areas of Kerala. Singh (2004) has also found from the satellite imageries that the increase in depth of convection implies decrease in CTT and *vice-versa*.

12.3 Application of satellite-derived Outgoing Longwave Radiation (OLR) For Monitoring of Monsoon Features

12.3.1 Monsoon Onset

The outgoing long wave radiation has been used traditionally for radiation budget studies of the Earth atmospheric system. This is mainly due to the fact that in the tropics, the OLR is largely modulated by cloudiness. In particular it varies with the cloud top temperature, and consequently, low values of OLR indicate major convective system. In general at IMDPS, total outgoing long wave radiation (OLR) flux, thermally emitted from earth atmosphere system, is estimated by applying regression equation relating OLR flux with geostationary Indian National Satellite (INSAT-3D) VHRR observed WV (5.7to 7.1μm) and infrared window radiances (10.5 to 12.5 μm).

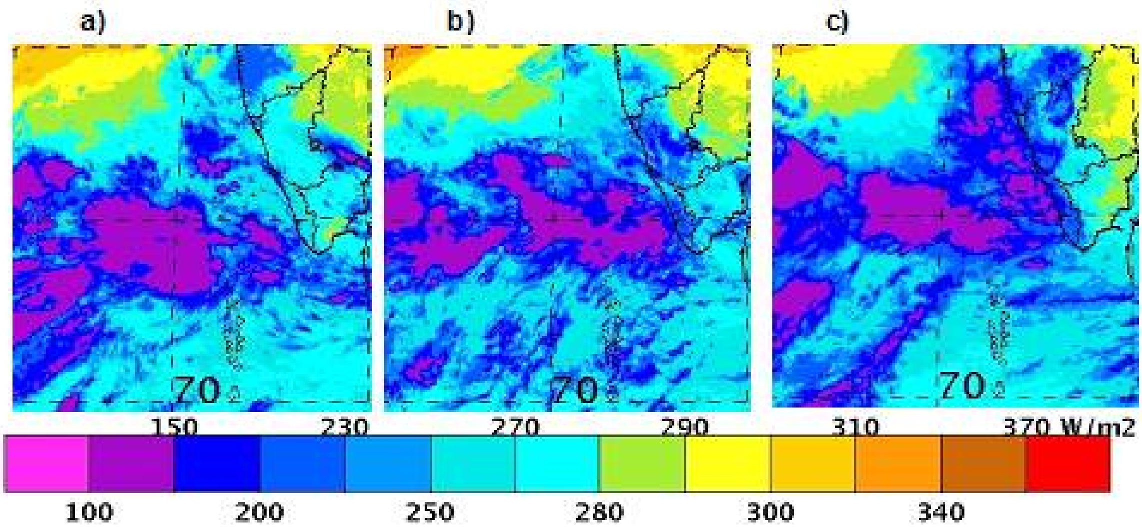


Fig.12.3: Daily Average OLR values on a)5th June, b) 6th June and c) 7th June 2014.

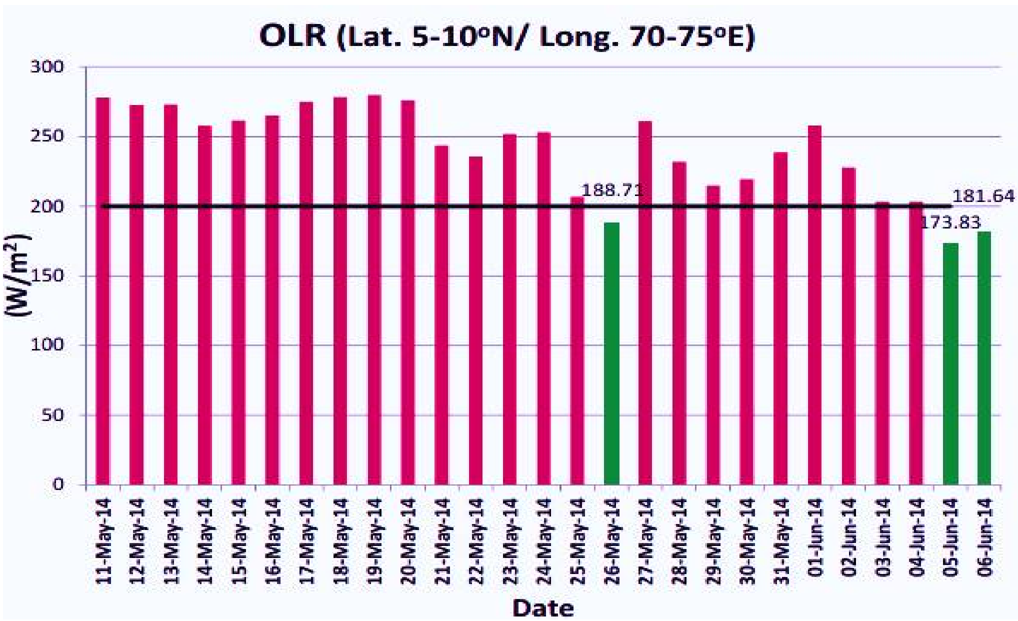


Fig.12.4. INSAT-3D OLR values during onset of monsoon 2014.

A low value of OLR (below 200 W/m2) indicates the presence of deep clouds. Before the onset of monsoon over Kerala, the daily mean distribution of OLR shows gradual decrease of OLR value over these areas. One of the criteria, adopted by IMD in 2006, for declaring the date of monsoon onset over Kerala is based on OLR. The INSAT derived OLR value must be below 200 Wm-2 in the box, Lat 5-10^{0}N and Long 70-75^{0} E. On 6th of June 2014, Fig.12.3 (b) shows the OLR values were less than 190 W/m2 over the south Arabian Sea. These values are confined to the box for consecutive last 2 days and can be seen on Fig.12.4.

12.3.2 Monsoon Withdrawal

The monsoon withdrawal normally starts from the country around 1st September and continues till about 15 October, when it completely withdraws from the country. As per IMD, withdrawal over the country may be declared keeping the spatial continuity, reduction in moisture as usually depicted in the water vapor imageries and prevalence of dry weather for 5 days. From satellite imageries this can be observed by the water vapor imageries as it provides a measure of moisture content of the atmosphere at middle levels and helps in deciding the withdrawal of monsoon. It is mainly used to assess the monsoon withdrawal pattern along with the visible and IR imageries and derived products such OLR values.

Fig.12.4 shows the INSAT-3D water vapor imageries during the withdrawals phase of monsoon. In 2014, a change in the lower tropospheric circulation pattern over the region from cyclonic to anti cyclonic during 16th - 17th Sept has made conditions favorable for the withdrawal of southwest monsoon from the western parts of Rajasthan and mainly dry from 17th Sept (Fig.12.4(a)).

The southwest monsoon withdrew from western parts of Rajasthan and some parts of Punjab and Haryana on 23rd September 2014 shown in (Fig.12.4 (b)). Subsequently, some more parts of Kutch area and remaining parts of west Rajasthan on 26th as displayed in (Fig.12.4(c)). On 28th September, it further withdrew from remaining parts of Punjab, Haryana, Chandigarh & Delhi and east Rajasthan; some parts of Jammu & Kashmir, Himachal Pradesh, east Uttar Pradesh, Madhya Pradesh and Saurashtra; most parts of west Uttar Pradesh and some more parts of Gujarat Region, Kutch and north Arabian Sea (Fig.12.4(d)). As on 30th September, the withdrawal line passed through Jammu, Una, Bareilly, Kanpur, Nowgong, Ujjain, Vadodara, Porbandar (Fig.12.4 (e)).

Similar kinds of pattern have also been observed from daily OLR product from INSAT-3D (Fig.12.4). It can be clearly seen from the figure that the values are above 270-280 W/m^2

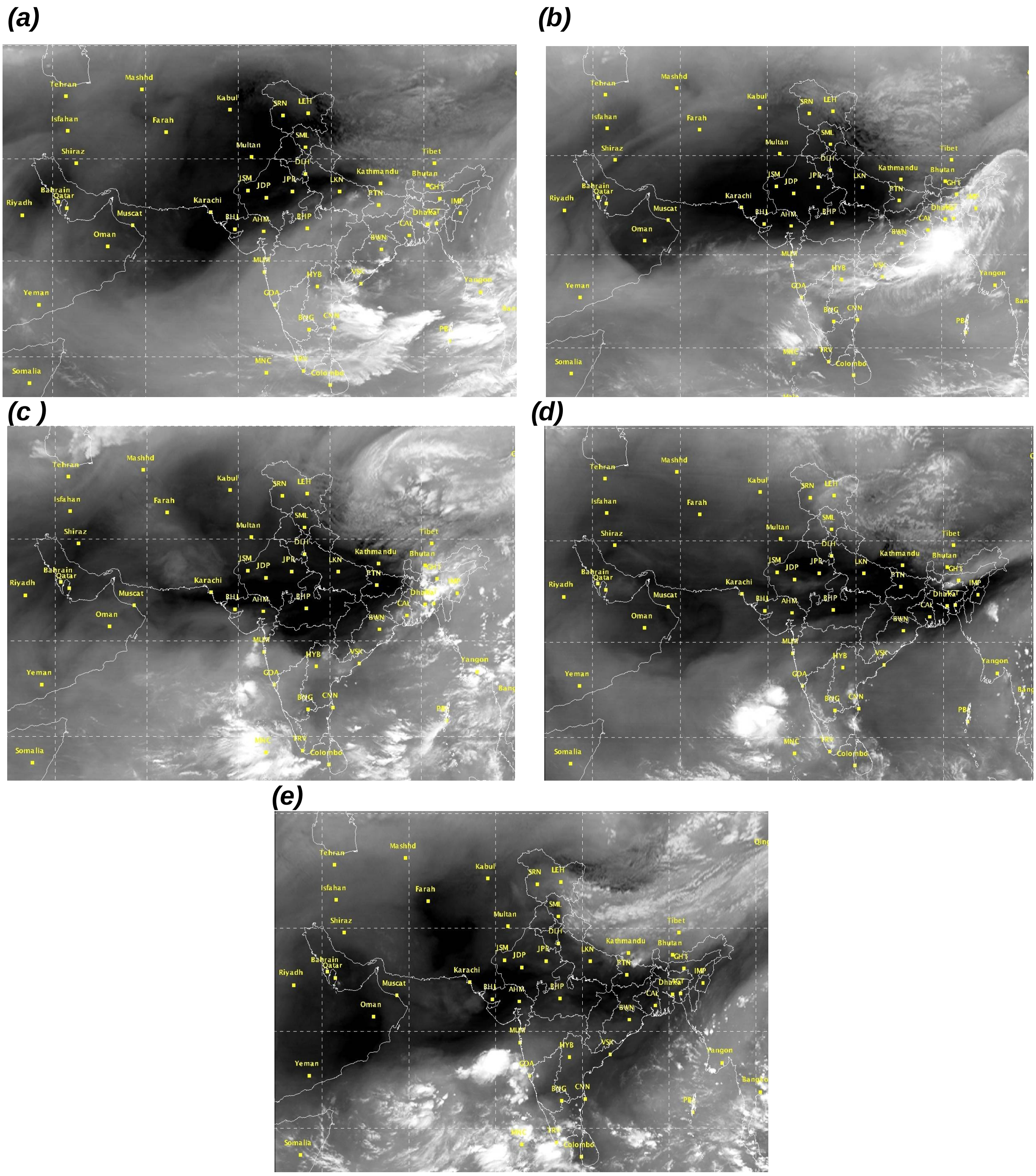


Fig.12.4: INSAT-3D Water vapor imagery of 0600 UTC on a) 17/09/2014, b)23/09/2014, c)26/09/2014, d)28/092014 and e) 30/09/2014

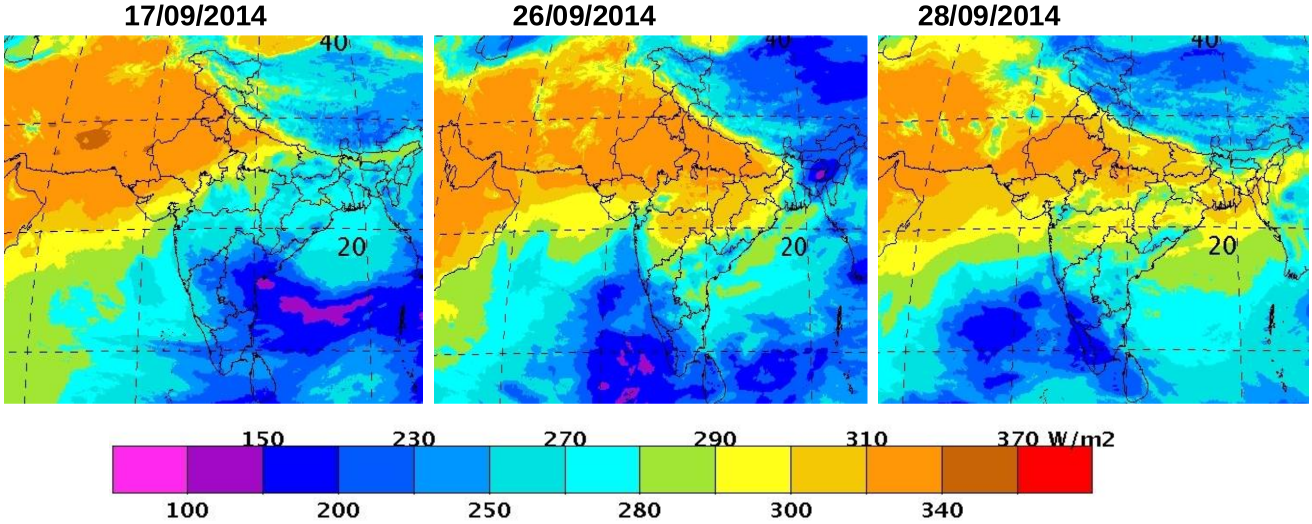


Fig. 12.5: INSAT-3D OLR values during withdrawal of monsoon 2014.

12.4 Chief Synoptic Features during Monsoon Season as Observed Through Satellite Imageries

12.4.1 Cyclonic Storm (CS) 'NANAUK' over the Arabian Sea *(10-14 June 2014)*

In the month of June, one CS and one low pressure area formed. The CS 'Nanauk' (10^{th}–14^{th}June) which formed over east Arabian Sea at the leading edge of the monsoon current aided the further advance of Arabian branch up to south Gujarat coast. It developed in association with the southwest monsoon surge over Arabian Sea during the onset phase. This also caused temporary hiatus in progress of monsoon over south India. The system was well monitored mainly with satellite observations, supported by meteorological buoys and coastal and Island observations. The half hourly INSAT/ Kalpana imageries, available microwave imageries from NOAA/METOP/MODIS system installed at New Delhi and scatteometry products were used for monitoring of the system.

To meet the international standard for tracking the cyclones through satellite imageries, two new products have been introduced in line of Cooperative Institute for Meteorological Satellite Studies / University of Wisconsin-Madison, (CIMSS, USA) at IMDPS, New Delhi. In this methodology, INSAT-3D IR (4Km) resolution images are enhanced using two primary enhancement curves. These enhancements are used to highlight various different features within the imagery, with each enhancement used for different purposes. These two enhancements are named as *i) BD Curve Enhancement* and *ii) NHC Curve Enhancement*. The methodology of these curves is detailed in http://tropic.ssec.wisc.edu/misc/other/faq/faq_enhance.html.

According to satellite imageries, the initial curves band pattern changed to central dense overcast (CDO) pattern as the system intensified into a cyclonic storm. A low level cyclonic circulation formed on 9th June morning. It became a well marked low pressure area over east Arabian Sea region in the morning of 10th June. It concentrated into a depression over the same region in the afternoon of 10th June, 2014. The lowest cloud top temperature was about -75^{O}C. As the favorable environmental parameters like vorticity and divergence/convergence continued to prevail on 10th and 11th, even though the vertical wind shear were not favorable, the depression moved west-northwestwards and intensified into a deep depression around midnight of 10th June, 2014 and further into a cyclonic storm (CS), 'NANAUK' in the early morning of 11th June 2014. It continued to move west–northwestward for some more time till early morning of 13th June.

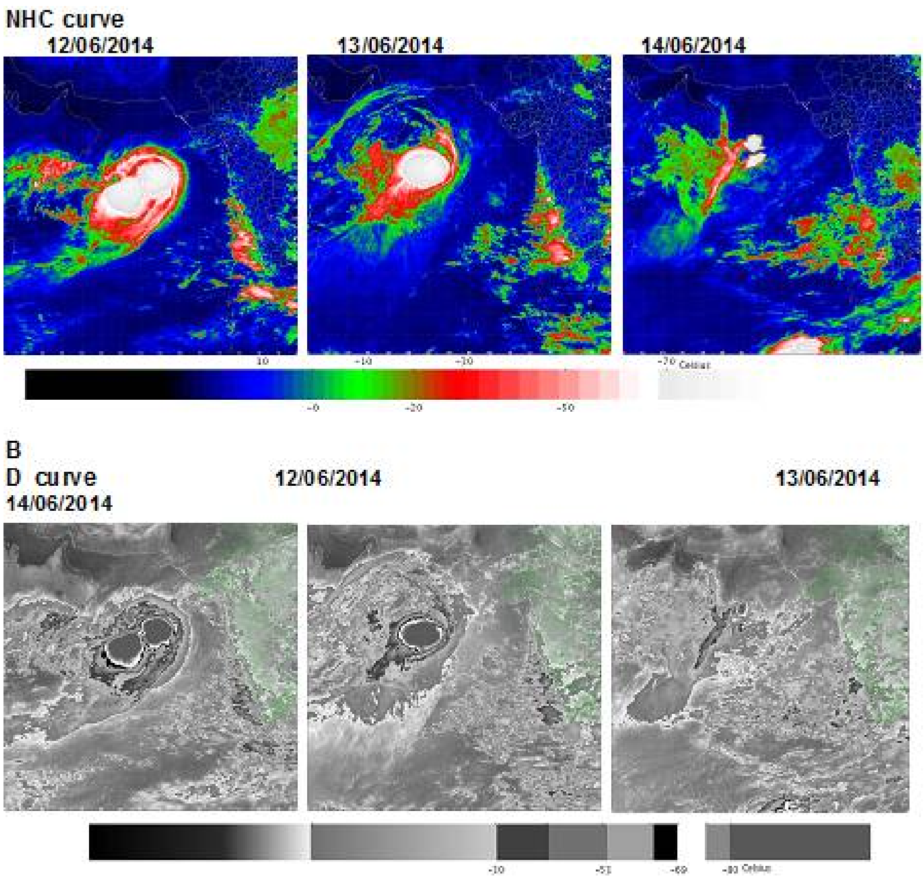


Fig. 12.6: INSAT-3D Enhancement curves at 0300 UTC of 12th, 13th and 14th June 2014.

In the Fig. 12.6, the intensification and weakening of the cyclone can be very well monitored by the NHC and BD curve by its temperature values from 12/06/2014 to 14/06/2014 of 0300 UTC. The maximum intensity was T 3.0 corresponding to 45 knots. The CDO pattern changed to the shear pattern due to increase in vertical wind shear during the weakening of the system on 13/06/2014. There was rapid weakening as the cyclonic storm changed to depression from 0600 UTC to 1200 UTC of 13/06/2014. Further, it then moved northwards to northwest and adjoining west-central Arabian Sea and weakened into a well marked low pressure area over the same region in the morning of 14/06/2014.

12.4.2 Monitoring Active and Break Spells of Monsoon

The location of monsoon trough (MT) has biggest influence on the rainfall over Indian sub-continent, particularly over the central parts of the country during the monsoon season. The monsoon trough shows periodical movements to the north and south of its normal position (Singh, 2006). In the normal position, it extends from northwest India to the north Bay of Bengal region. The monsoon lows/depressions periodically forming over the North Bay of Bengal moving northwestward across the country maintain the normal position and activity of the trough. Sometimes, the low-pressure systems do not form over the Bay and in this situation a westerly trough affecting northwest India results in the shift of the whole trough to the foothills of the Himalayas. This situation of the monsoon trough over the foothills of the Himalayas is referred to as a *'break'* in the monsoon, since except for the sub-Himalayan area and Tamilnadu, the whole country gets very little rain. The sub-Himalayan area receives heavy rainfall during the break period. The strengthening/weakening and fluctuations of MT can be effectively monitored with the help of satellite imageries and products like OLR and QPE. For detailed climatology of 'breaks', one may refer to Ramamurthy (1969) and De, et. al (2002).

According to south west monsoon 2014, the axis of monsoon trough mostly remained normal/south of its normal position during July and first half of September. It extended up to mid tropospheric levels without its characteristic tilt. From INSAT-3D, monthly average OLR and a new rainfall product Hydro-Estimator (HE) have been used to monitor the fluctuations of MT from July to September 2014. The details of HE method is given in the http://www.imd.gov.in/section/satmet/dynamic/INSAT3D_Catalog.pdf

It can be seen from the Fig. 12.7(a), that during the normal position of MT the average OLR values in the month of July were around 200 W/m2 and the corresponding monthly rainfall from HE method was 300 mm. During August, MT mostly remained north of its normal position/close to foot hills of Himalayas, and can be seen by the higher values of OLR and deficient rainfall from HE method in Fig. 7(b). The OLR and HE rainfall feature pattern

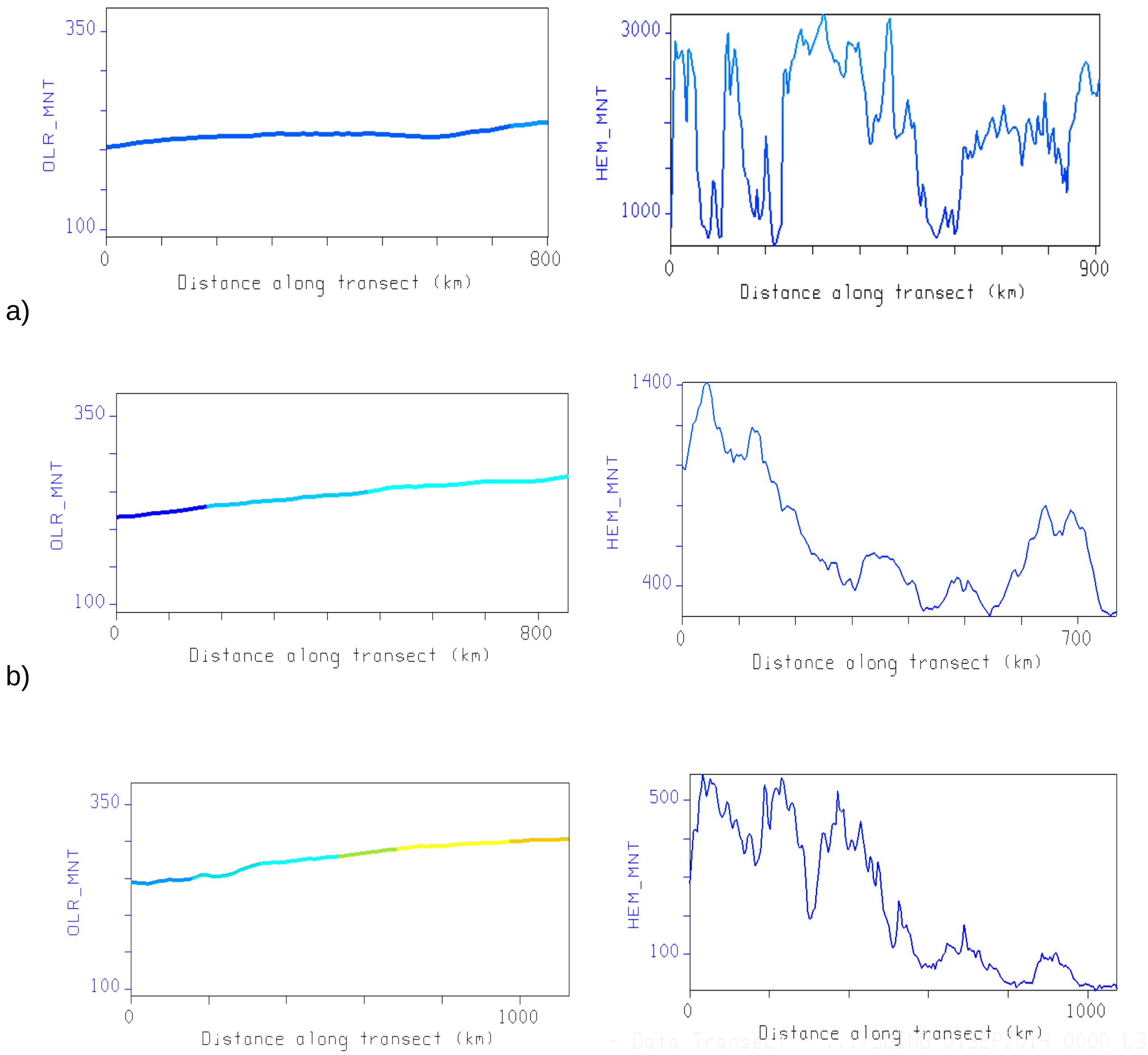


Fig.12.7: Monthly averaged INSAT-3D OLR (in W/m2) and corresponding HE rainfall (mm) over the location of MT for the month of a) July b) August and c) September 2014.

resembled typical break like situation. Thereafter, MT became less apparent and subsequently, the axis of MT also weakened thereby becoming less delineated since 22nd September and can be represented by higher values of OLR i.e., 300 W/m2 and lesser HE rainfall around 100mm in Fig.12.7(c). It can be stated that the variation in OLR in this case appears to represent the variation in the HE rainfall product in the MT region during the monsoon. During the entire monsoon season, there are 13 low pressure systems formed. These included 10 low pressure areas, one cyclonic storm (CS), a land depression and a deep depression. All are very well monitored by the INSAT-3D/Kalpana satellite imageries.

12.5 On-line INSAT Data Visualization Tool - *RAPID*

In SATMET Division, an on-line INSAT data visualization tool called '*RAPID'* have been introduced to analyses live INSAT-3D/3A and Kalpana-1 satellite data for weather forecast and climate studies (Fig.12.8). The software is opened on the following URL: ***http://125.21.185.39***, and has the GIS capability to map the digital satellite data onto the user specific tasks. The software has been exclusively prepared by the SAC/ISRO team in consultation with SATMET Division. The user can see the data on half hourly, daily, weekly and monthly time period.

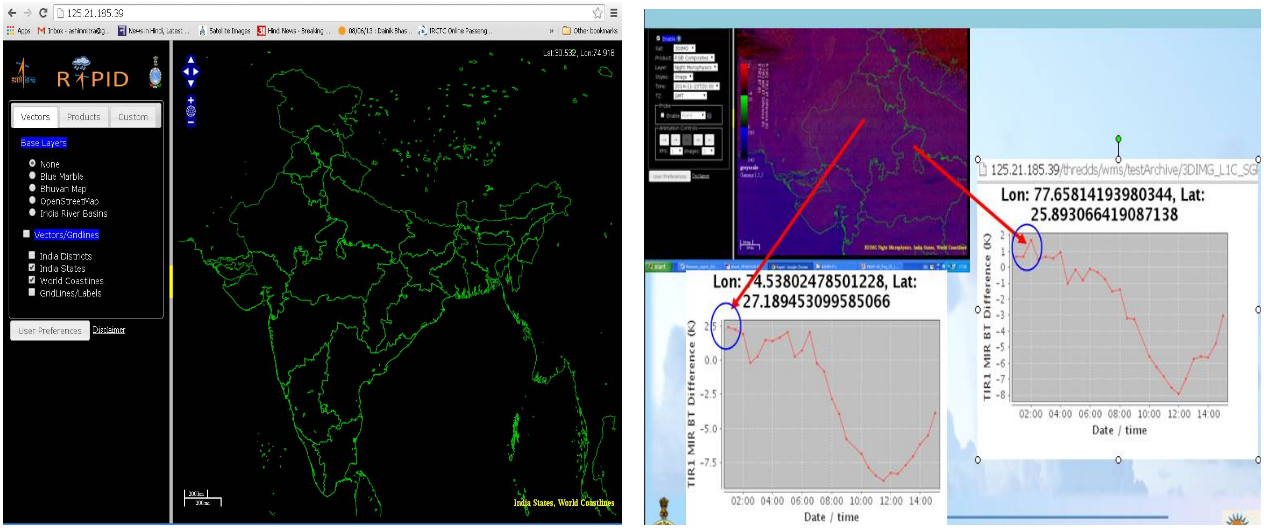


Fig.12.8: Demonstration of INSAT data visualization tool 'RAPID'**.**

Various operation such as contouring of the image, transect of the two points, area calculation, distance between two points can be applied on the brightness temperature of the INSAT-3D/INSAT-3A/CCD and Kalpana-1 satellite. Weather fluctuations as shown in this report can be generated by this tool very efficiently.

The vertical profiles of the temperature and moisture profiles from INSAT-3D sounder can also be seen on line for *now-casting* purposes. INSAT-3D sounder derived products such as Total Precipitable Water (TPW) and Lifting Index (LI) etc, for the climate studies can be easily done with this tool.

12.6 Conclusions

INSAT-3D imageries and its derived products played a dominant role in monitoring onset and advance of monsoon, withdrawal of monsoon circulations,etc,. Following broad conclusions can be made from the above results and discussion.

- Monsoon adavancement over Andaman and onset over Kerala has been very well captured by the high resolution of INSAT-3D visible images. The circulation pattern over Andaman has also been dipicted by water vapor winds.
- During onset, the depth of convection can be very well monitored with the help of cloud top temperature (CTT).
- The minimum OLR during onset was below 190 W/m2 during monsoon season, 2014.
- The intensification and weakening of the cyclones can be very well monitored by the NHC and BD curve.
- The strengthening/weakening and fluctuations of monsoon trough have been effectively monitored with the help of satellite imageries and products like monthly average OLR and HE rainfall product.
- The withdrawal of monsoon from the country can be very well monitored with the water vapor imageries and derived OLR product. These two features are important criteria for declaring withdrawal of monsoon from northwest India apart from the rainfall.
- From user point of view , an on-line INSAT data visualization tool called '*RAPID'* have been introduced to analyses live INSAT-3D/3A and Kalpana-1 satellite data for weather and climate studies.

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13

VALIDATION OF AUTOMATIC WEATHER STATION (AWS) DATA FOR MONITORING AND PREDICTION OF THE LOW PRESSURE SYSTEMS DURING THE MONSOON SEASON

M. Mohapatra, M.R. Ranalkar and S. Sunitha Devi

India Meteorological Department has established a network of 675 AWS across the country during the period 2006-2012. This chapter discusses validation of AWS data for monitoring and prediction of the low pressure systems during the 2014 southwest monsoon season. Performance of AWS during each system is analysed and presented.

13.1 Introduction

Surface observations are of paramount importance in monitoring weather and climate. India Meteorological Department maintains a network of 559 conventional observatories across the country which also includes part time observatories. The network stations are randomly distributed and distance between two observatories is not less than 100 km. The requirement of surface observational network was thoroughly reviewed by the steering committee constituted by Ministry of Earth Sciences. The committee recommended establishing a network of Automatic Weather Stations (AWS) to augment conventional surface observatory network. Until year 2006, there were 253 meteorologically unrepresented districts in the country especially in North and Northeast India. The committee recommended installing AWS on priority in data sparse region so as to bridge surface observational gaps as per guidelines provided by World Meteorological Organisation (WMO, 2010).

In accordance with the recommendations of the committee, under Modernization Project Phase-I, a network of 550 AWS have been installed across the country. In order to have a uniform distribution of network stations, efforts have been taken to install one AWS in each district of India. In the year 2006-2007, a network of 125 AWS was established by IMD across the country. These AWS were primarily installed along the coastline to strengthen the surface observational network for monitoring low pressure systems including cyclonic disturbances. A fairly dense network of AWS as shown in Fig.13.1 is now available for operational utilization.In addition to AWS, a network of 1350 Automatic Rain Gauge (ARG) Stations is also being established across the country under the Modernization Program Phase-I with about 1240 stations already installed in different states.The performance of AWSs has been validated by Bhatia et al (2008) and Mohapatra et al (2009, 2010, 2011, and 2012) and they have found that AWS has provided useful observations of pressure, 24-hr pressure change, wind and rainfall in their study of low pressure systems.The objective of this study is to evaluate the performance of AWS/ARG in monitoring low pressure systems with respect to pressure, wind speed and rainfall including cyclonic disturbances affecting India during 2014.

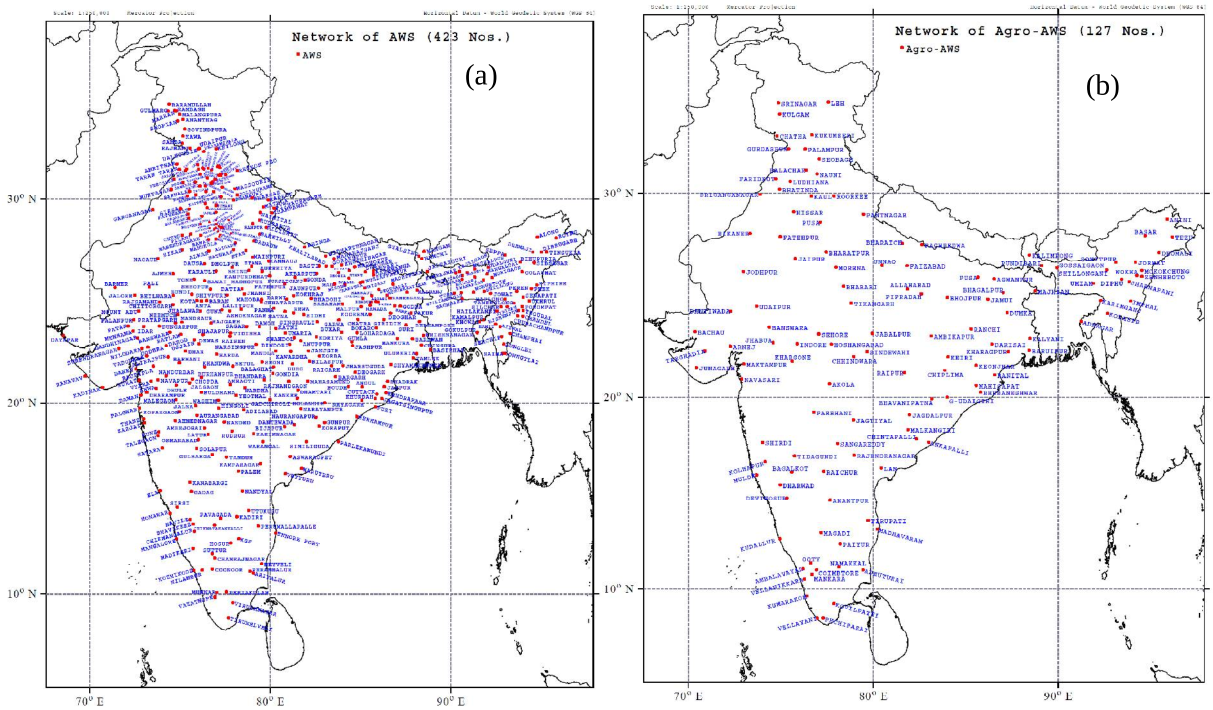

Fig. 13.1: (a) Network of 423 AWS and **(b)** 127 Agro-AWS established during 2008-2012.

13.2 Data and Methodology

The hourly AWS and ARG data have been analyzed for monitoring and prediction of low pressure systems during the SW Monsoon season 2014. The systems developed during pre-onset phase are also considered for analysis.

In all 13 monsoon lows (1 Cyclonic Storm, 2 Depressions and 10 low / well marked low pressure areas) formed during the season. These systems were continuously monitored by AWS and ARG Stations in addition to the conventional network of surface and upper air observatories, Satellite and RADAR derived products etc for the issuance of necessary weather bulletins and advisories. A summary of these systems is given in Table-13.1.

The network of AWS and ARG is sufficiently dense and adequate for monitoring the systems. The results are presented, analyzed and discussed in section 13.4. The broad conclusions are also presented in section 13.5.

13.3 Results and Discussions

The performance of AWS and ARGs during the low pressure systems have been analysed and some representativelow pressure systems are presented and discussed in the following sub-sections.

13.3.1 Cyclonic Storm 'Nanauk' over the Arabian Sea during 10th– 14th June 2014

A Cyclonic Storm (CS) 'NANAUK' developed from a low pressure area over east central Arabian Sea on 9th June, 2014. Moving north-north-westwards, it intensified into a Cyclonic Storm (CS), 'NANAUK' in the early morning of 11th June 2014. Continuing its north-north-westwards, it weakened into a low pressure area over northwest Arabian Sea in the morning of 14th June, 2014. However, its remnant re-curved and moved north-eastwards leading to revival and progress of monsoon along the west coast of India. The wind speed and the daily rainfall recorded by AWS in the state of Maharashtra is analysed in Fig.13.2 and Fig.13.3 respectively. The rise of wind speed is seen during 10-11 June 2014. There was no appreciable fall in Station level Pressure (SLP) as the system was far from the coast (figure not shown).

13.3.2 Low pressure area over coastal Bangladesh and neighbourhood during 19th – 22nd June 2014

Under the influence of a cyclonic circulation over northwest Bay of Bengal and neighbourhood, a low pressure area formed over coastal areas of Bangladesh and neighbourhood on 19th. It lay over Gangetic West Bengal and neighbourhood on 20th and over Bangladesh and adjoining West Bengal on 21st & 22nd. It became less marked on 23rd. However, the associated cyclonic circulation persisted over the region with a trough aloft, up to 26th and became less marked on 27th.

Table-13.1:A summary of LPS formed during the season

Sr. No.	Category	Period	Place of formation	Direction of movement	Place of Dissipation
(1)	**Cyclonic Storm (Nanauk)**	10th14th June	15.5°N/68.5°E over east central Arabian Sea	Northwest	Northwest and adjoining west central Arabian Sea.
(2)	**Low pressure area**	19th–2nd June	Coastal areas of Bangladesh and neighbourhood	Quasi-stationary	Bangladesh and adjoining west Bengal
(3)	**Low pressure area**	1st–7th July	North Bay of Bengal and adjoining coastal areas of Bangla Desh and Gangetic West Bengal	Northwest	east Uttar Pradesh and neighbourhood
(4)	**Low pressure area**	11th–18th July	Northwest Bay of Bengal off west Bengal and Odisha coasts.	West-northwest	southwest Uttar Pradesh and neighbourhood
(5)	**Depression (Land)**	21st–23rd July	Northeastern parts of Odisha and adjoining areas of Gangetic West Bengal.	West-northwest	west Madhya Pradesh and neighbourhood.
(6)	**Well marked low pressure area**	27th–31st July	Northwest Bay of Bengal and neighbourhood	West	interior parts of Odisha and neighbourhood
(7)	**Deep Depression**	3rd (12Z)–7thAug.	Coastal areas of west Bengal and neighbourhood	West-northwest	central parts of north Madhya Pradesh and neighbourhood
(8)	**Low pressure area**	9th–11th Aug.	North Bay of Bengal and neighbourhood	Northwest	southern parts of Bihar and neighbourhood
(9)	**Well marked low pressure area**	23rd(00Z) –24thAug.	East-central Arabian Sea and adjoining coastal areas of Karnataka and Maharashtra	Stationary	In-situ
(10)	**Well marked low pressure area**	27thAug–6th Sept.	West-central and adjoining northwest Bay of Bengal off north Andhra Pradesh-south Odisha coasts.	West-northwest	Punjab and adjoining Rajasthan & Haryana
(11)	**Low pressure area**	2nd–4th Sept.	Saurashtra & Kutch and adjoining northeast Arabian Sea	North	Kutch & neighbourhood
(12)	**Well marked low pressure area**	5th–9th Sept.	North Bay of Bengal off west Bengal-Bangladesh coasts	West-northwest	WestMadhya Pradesh and adjoining east Rajasthan
(13)	**Well marked low pressure area**	16th–24th Sept.	Northwest Bay of Bengal and adjoining coastal areas of Odisha and west central Bay of Bengal	Northwest, north & then northeast	North Bangladesh and neighbourhood

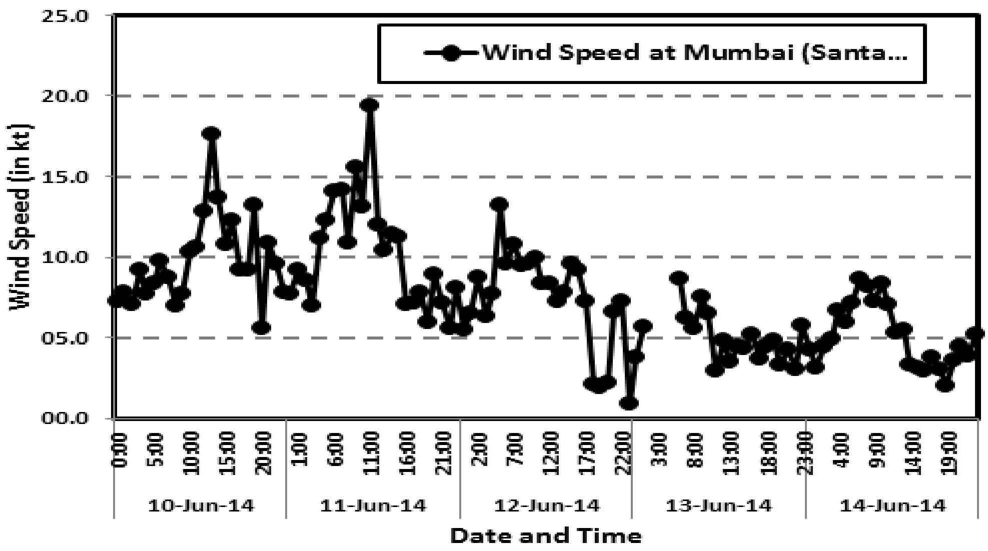

Fig.13.2: Variation of Wind Speed at MumbaiSantaCruz station during 10-14,Jun 2014.

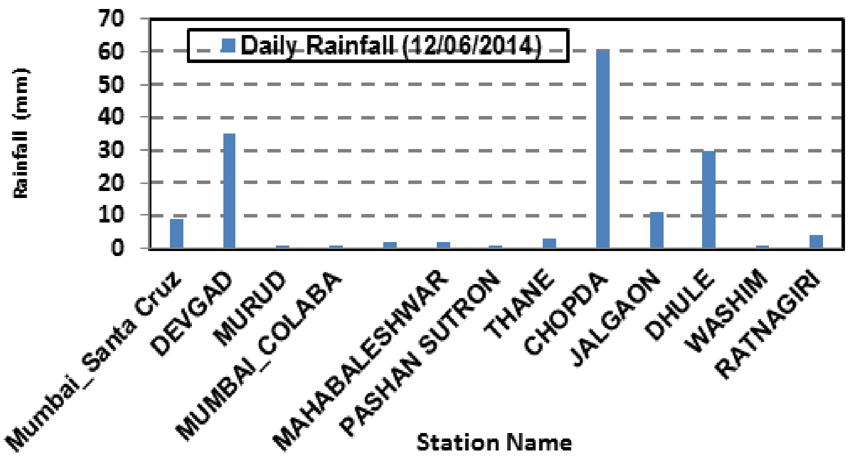

Fig. 13.3: Daily Rainfall recorded on 12th June 2014 at AWSs in Maharashtra under influence of Nanauk Cyclone.

The variation of wind speed, station level pressure and rainfall at two representative coastal AWS in West Bengal is presented in Fig.13.4, Fig.13.5and Fig.13.6respectively. It can be seen that variation in these parameters was captured very well by these AWS.It indicates that though there was diurnal variation in wind speed being maximum around 0000 UTC, there was substantial increase in wind speed from 20th night to 21st forenoon over both the station under the influence of the low pressure system (Fig.13.4).The pressure as expected also demonstrated the diurnal variation. However, the pressure fell from 19th, became minimum between 0800 and 1200 UTC of 20th and then increased gradually as the low pressure system moved to Bangladesh on 21st and 22nd June (Fig.13. 5).Under these synoptic features, the rainfall increased over Sagar Island from 19th to 20th June and then decreased on 21st and 22nd June. However, the AWS at Kolkata could not exhibit such behavior and reported light rainfall during entire period (Fig.13.6).

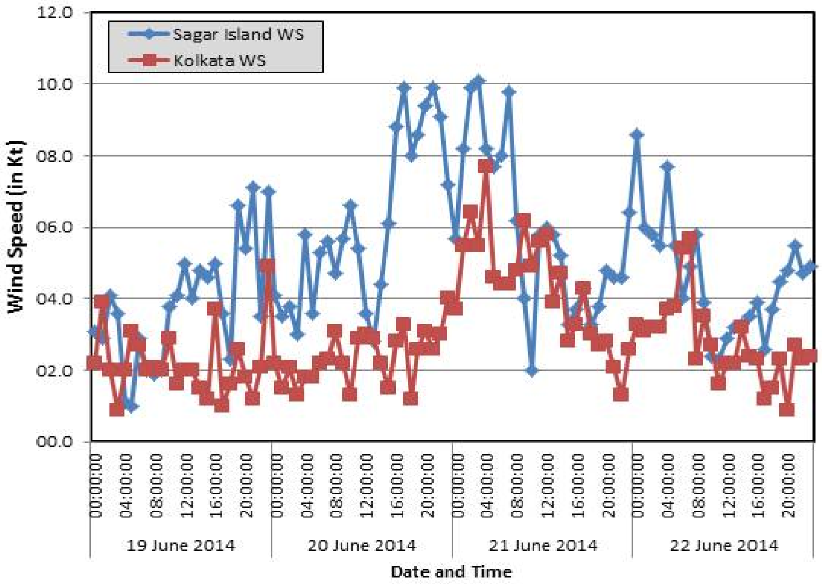

Fig.13.4: Variation of wind speed (WS) recorded at Sagar Island and Kolkata during low pressure over coastal Bangladesh during 19-22 June 2014.

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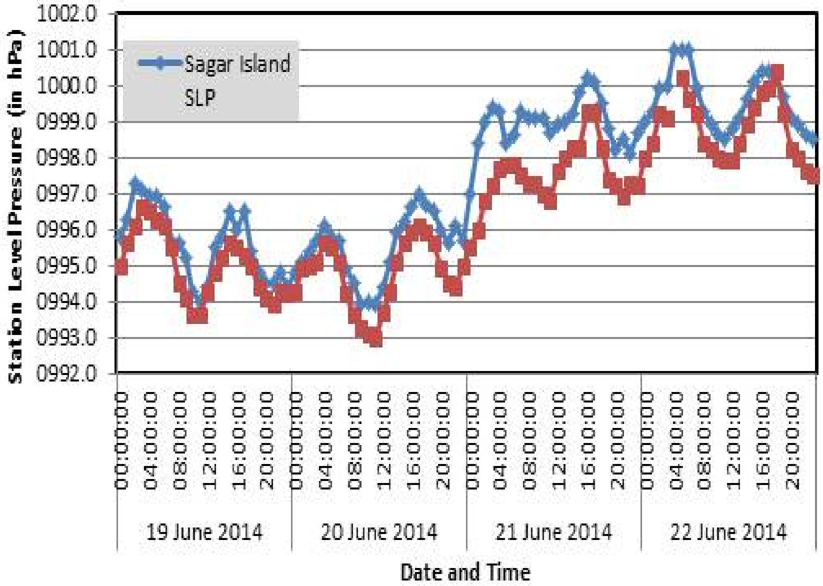

Fig.13.5: Variation of SLP at Sagar Island and Kolkata under influence of low pressure area over coastal Bangladesh during 19-22 June 2014.

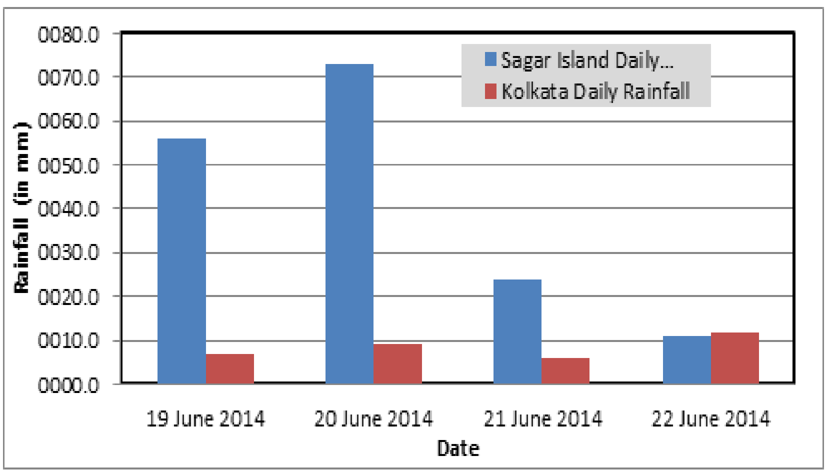

Fig.13.6: Daily rainfall recorded at Sagar Island and Kolkata AWS during low pressure area over Bangladesh during 19-22 June 2014.

13.3.3 Low pressure area over North Bay of Bengal and adjoining coastal areas of Bangladesh and West Bengal during 1st - 7th July 2014

Under the influence of a cyclonic circulation over coastal areas of Bangladesh and neighbourhood, a low pressure area formed over North Bay of Bengal and adjoining coastal areas of Bangladesh and Gangetic West Bengal on 1st July. Associated cyclonic circulation extended up to 7.6 kms a.s.l. tilting southwestwards with height on 1st July. It lay over Gangetic West Bengal and adjoining Bangladesh on 2nd with associated cyclonic circulation up to 9.5 kms a.s.l. tilting southwards with height. It lay over Gangetic West Bengal and neighbourhood on 3rd, over Gangetic West Bengal and adjoining Jharkhand on 4th, over northern parts of Jharkhand and adjoining Bihar on 5th and over east Uttar Pradesh and neighbourhood on 6th & 7th. It became less marked on 7th evening. However, associated cyclonic circulation extending up to upper tropospheric levels persisted there up to 8th and merged with the seasonal trough at mean sea level on 9th.

The variation of wind speed, station level pressure and rainfall at two representative coastal AWS in West Bengal is presented in Fig.13.7, Fig.13.8 and Fig.13.9 respectively. It can be seen that variation in these parameters was captured very well by these AWS.As the low pressure area lay over Gangetic West Bengal and neighbourhood on 3rd July, and moved northwestwards on 4th July onwards and became less marked on 7th July. The wind speed over Sagar Island gradually increased from 1st July onwards and became maximum around 1200 UTC of 3rd July and decreased gradually thereafter. Kolkata being the inland station exhibited similar variation, but with lower wind speed. Both the station reported diurnal variation in wind speed (Fig.13.7).

The station level pressure also responded to the passage of the low pressure system. It decreased from 1st July and became minimum around 1200 UTC of 3rd July and then increased gradually with northwestward movement of the system. Of course, the response to the low pressure system was embedded with prominent diurnal variation of pressure.

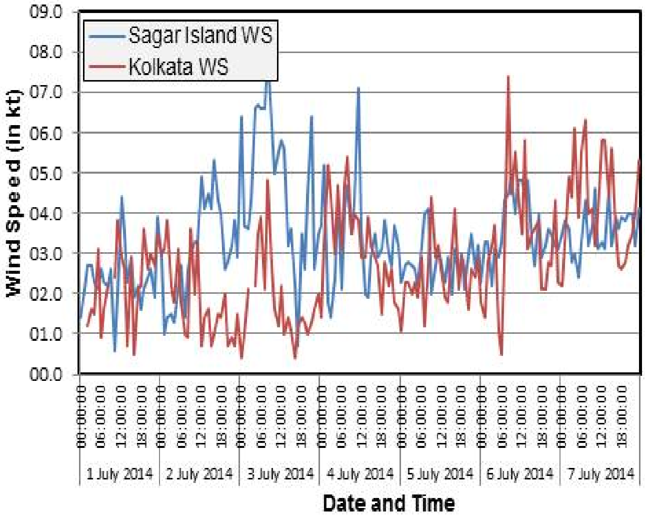

Fig.13.7: Variation of wind speed at Sagar Island and Kolkata under the influence of low pressure area over North Bay of Bengal during 1 -7 July 2014.

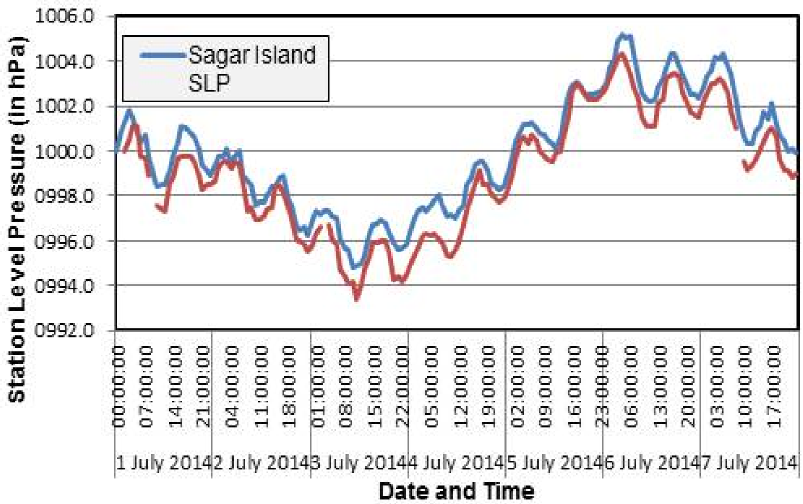

Fig.13.8: Variation of SLP at Sagar Island and Kolkata AWS under influence of low pressure area over North Bay of Bengal during 1 -7 July 2014

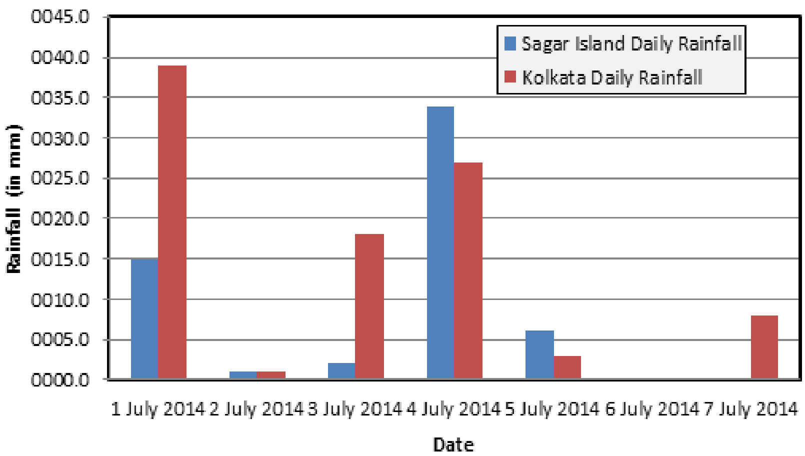

Fig.13.9: Variation of daily rainfall during over Sagar Island and Kolkata AWS during 1-7 July 2014.

13.3.4 Low pressure area over northwest Bay of Bengal during 11th– 18th July 2014

A cyclonic circulation between 1.5 & 7.6 kms a.s.l. lay over northwest Bay of Bengal and adjoining west central Bay of Bengal tilting southwestwards with height on 10th. Under its influence, a low pressure area formed over northwest Bay of Bengal off West Bengal and Odisha coasts on 11th. It lay over northwest Bay of Bengal and adjoining areas of Gangetic West Bengal and Odisha on 12th, over northwest Bay of Bengal and adjoining areas of Odisha and Gangetic west Bengal on 13th, over coastal areas of Odisha and neighbourhood on 14th, northern parts of Odisha and adjoining Chhattisgarh on 15th, over central parts of north Madhya Pradesh and neighbourhood on 16th, over northwest Madhya Pradesh and neighbourhood on 17th and over southwest Uttar Pradesh and neighbourhood on 18th. It became less marked on 19th. However, the associated cyclonic circulation extending up to mid tropospheric levels lay over central parts of Uttar Pradesh on 19th; over east Uttar Pradesh and adjoining Bihar on 20th and merged with the monsoon trough on 21st.

The variation of SLP at Bapatla AWS in Andhra Pradesh is depicted in Fig.13.10 and that at Angul AWS in Odisha is shown in Fig.13.11. The rainfall recorded at representative stations in Odisha on 15th July 2014 is shown in Fig.13.12. The AWS have responded well to the passage of system. The analysis endorsed the findings in section 13.3 and 13.4 with response to pressure, wind and rainfall to the passage of the low pressure system.

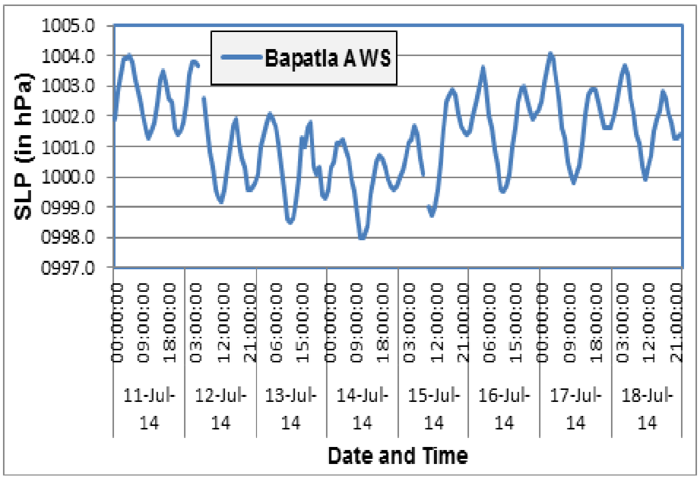

Fig.13.10: Variation in SLP at Bapatla AWS during 11-18 July 2014

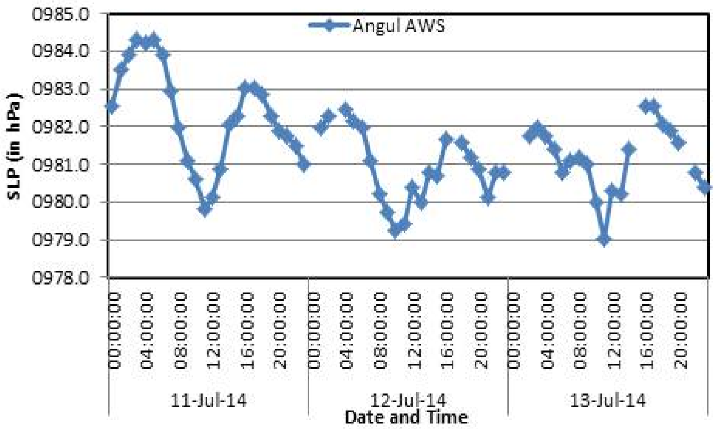

Fig.13.11: Variation of SLP at Angul AWS in Odisha during 11-13 July 2014.

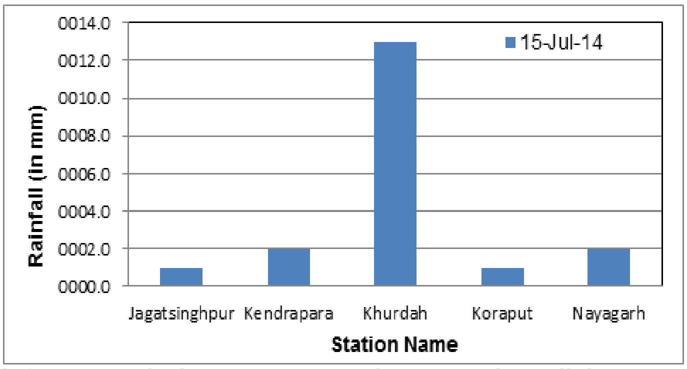

Fig.13.12: Rainfall recorded at representative AWS in Odisha on 15th July 2014.

13.3.5 Land Depression over northeastern parts of Odisha and adjoining areas of Gangetic West Bengal during 21st - 23rd July 2014

An upper air cyclonic circulation between 1.5 & 5.8 kms a.s.l. lay over northeast Bay of Bengal and neighbourhood on 19th. Under its influence, a low pressure area formed over north Bay of Bengal and adjoining areas of Gangetic West Bengal and Odisha and associated cyclonic circulation extended upto 7.6 kms a.s.l. on 20th. It rapidly concentrated into a Depression and lay centered over northeastern parts of Odisha and adjoining areas of Gangetic West Bengal, near Lat. 22^{O}N / Long. 87^{O}E about 50 kms east of Baripada at 0830 hours IST of 21st. It moved west-northwestwards and lay centered over south Jharkhand and neighbourhood near Lat. 22.5^{O}N / Long. 85.0^{O}Eabout 100 kms west southwest of Jamshedpur at 1730 hours IST 21st. It further moved westwards and lay centered over north Chhattisgarh and neighbourhood near Lat. 22.5^{O}N / Long. 82.5^{O}E about 50 kms southeast of Pendra at 0830 hours IST of 22nd and moved westwards and lay centered over east Madhya Pradesh and neighbourhood near Lat. 22.5^{O}N / Long. 81.0^{O}E, about 100 kms southeast of Jabalpur at 1730 hrs IST of 22nd. It further moved westwards and lay centered over west Madhya Pradesh and neighbourhood near Lat. 22.5^{O}N / Long. 77.5^{O}E about 50 kms southeast of Bhopal at 0830 hrs IST of 23rd and weakened into a well marked low pressure area over the same region by the afternoon of 23rd and persisted there in the same evening. It lay as a low pressure area over northwest Madhya Pradesh and neighbourhood on 24th, lay over southwest Rajasthan and neighbourhood in the evening and merged with the monsoon trough on 25th. However, the associated cyclonic circulation extending up to lower tropospheric levels persisted over southwest Rajasthan and neighbourhood on 25th, over northeast Rajasthan and neighbourhood on 26th & 27th; over Punjab and adjoining north Rajasthan on 28th and over Punjab and neighbourhood on 29th & 30th and became less marked on 31st July.

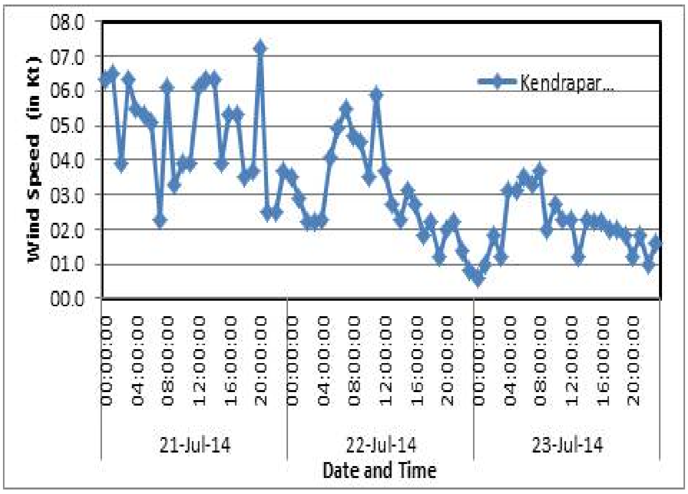

Fig13.13: Variation of wind speed at Kendrapara AWS in Odisha during 21-23 July 2014

The variation of wind speed at representative station Kendrapara in Odisha and of variation of rainfall at different AWSs in the states of Odisha, West Bengal and Madhya Pradesh are shown in Fig.13.13 and Fig.13.14 respectively. As the depression moved from Odisha to Chhattisgarh from 21st to 22nd July, high wind speed was recorded on 21st over Kendrapara (Odisha) on 21st and then decreased gradually.

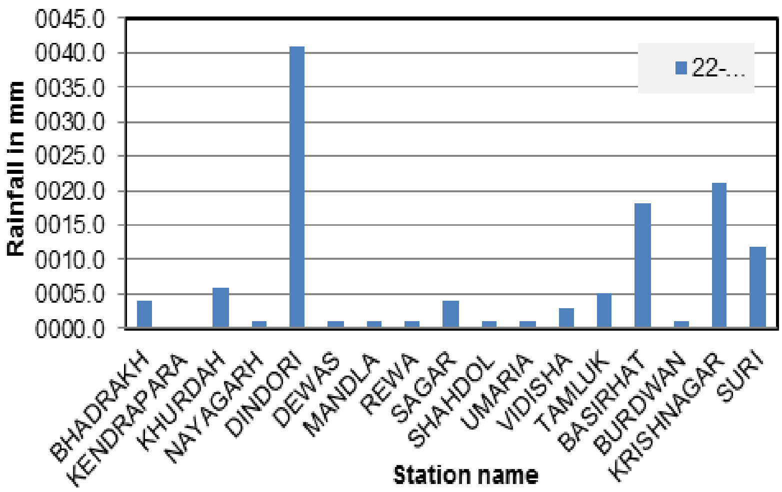

Fig.13.14: Rainfall recorded at AWS in the state of Odisha, West Bengal and Madhya Pradesh on 22nd July 2014.

13.3.6 Well marked Low pressure area over northwest Bay of Bengal and neighbourhood during 27th – 31st July 2014

A cyclonic circulation extending up to mid tropospheric levels lay over northwest Bay of Bengal and neighbourhood on 24th; over North Bay of Bengal and neighbourhood on 25th and again over northwest Bay of Bengal and neighbourhood on 26th. Under its influence, a low pressure area formed over northwest Bay of Bengal and neighbourhood on 27th and persisted there on 28th. It lay as a well marked low pressure area over the same region on 29th & 30th. Associated cyclonic circulation extended up to 7.6 km. a.s.l. tilting southwestwards with height. It lay as a low pressure area over interior parts of Odisha and neighbourhood on 31st July and became less marked on 1st Aug. However, the associated cyclonic circulation extending up to mid tropospheric levels laid over east Madhya Pradesh and neighbourhood on 1st Aug and over northeast Madhya Pradesh and adjoining southeast Uttar Pradesh on 2nd and merged with the monsoon trough on 3rd.

The variation of SLP at Kendrapara AWS in Odisha during 27-31 July 2014 is shown in Fig.13.15. The AWS captured the variation in SLP very well during passage of system. The daily rainfall recorded at AWS in Odisha is given in Table-13.2.

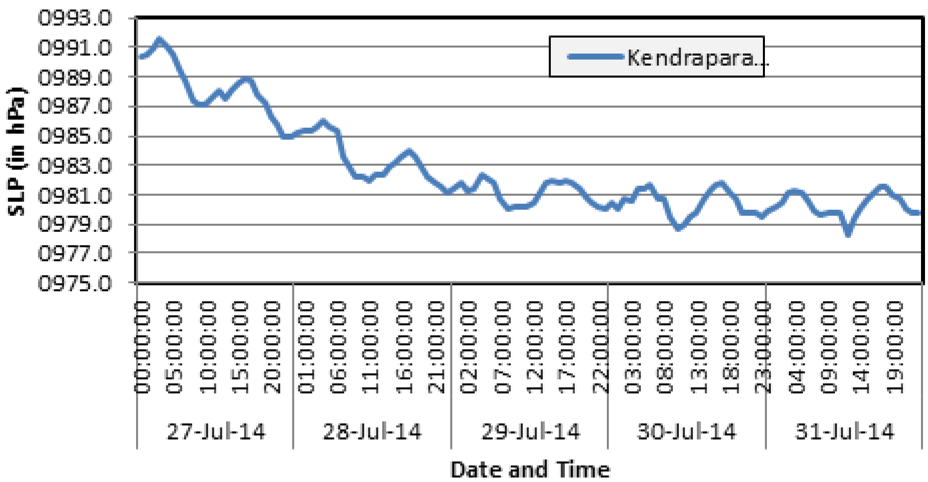

Fig.13.15: Variation of SLP at Kendrapara AWS under the influence of well marked low pressure area over Bay of Bengal.

Table-13.2: Daily rainfall recorded at AWS in the state of Odisha.

Station name	27 July 2014	28 July 2014	29 July 2014	30July 2014	31July 2014
Angul	4	-	6	1	3
Jagatsingpur	6	-	-	26	10
Kendrapara	-	67	-	-	-
Khurdah	8	-	11	3	61
Koraput	1	-	-	-	-
Nayagarh	4	2	3	-	68

13.3.7 Deep Depression over coastal areas of West Bengal and neighbourhood during 3rd - 7th Aug 2014

A cyclonic circulation between 5.8 & 9.5 kms a.s.l. lay over northwest Bay of Bengal and neighbourhood on 1st Aug. Under its influence, a low pressure area formed over north Bay of Bengal and neighbourhood on 2nd morning. It lay as a well marked low pressure area over the same region on 3rd morning. It concentrated into a Depression and lay centered over northwest Bay of Bengal and adjoining coastal areas of West Bengal near Lat. 21.5^{O}N and Long. 88.5^{O}E about 80 km southeast of Diamond Harbour at 1730 hours IST of 3rd.Moving slightly noth-northwestwards it intensified into a Deep Depression and lay centred over coastal areas of Gangetic West Bengal near Lat. 21.9^{O}N and Long. 88.3^{O}E, about 80 kms southeast of Kolkata at 2330 hrs IST of 3rd. It moved west and lay centred over Gangetic West Bengal and neighbourhood at 0830 hrs. I. S. T of 4th, near Lat. 22.5^{O}N and Long. 87.2^{O}E close to Midnapur. Further moving west northwestwards it lay centered over Jharkhand and adjoining Gangetic West Bengal near Lat. 22.2°N and Long. 86.1°E about 50 kms south of Jamshedpur at 1730 hours IST of 4th and over north Chhattisgarh, adjoining Jharkhand and east Madhya Pradesh near Lat. 22.2^{O}N and Long. 83.5^{O}E about 100 kms eastsoutheast of Ambikapur at 0830 hours IST of 5th. Further moving west northwestwards, it weakened into a Depression and lay centered over north Chhattisgarh and adjoining east Madhya Pradesh near Lat. 23.5^{O}N and Long. 82.5^{O}E about 150 kms, east of Umaria at 1430 hours IST of 5th and over northeast Madhya Pradesh and neighbourhood close to Sidhi near Lat. 24.0^{O}N and Long. 82.0^{O}E at 1730 hours IST of 5th. It further moved west northwestwards and lay centered over central parts of north Madhya Pradesh and neighbourhood about 50 kms southeast of Khajuraho, near Lat. 24.5^{O}N and Long. 80.2^{O}E at 0830 hours IST of 6th. It remained practically stationary and lay centered over the same region close to Nowgong near Lat. 25.0^{O}N and Long. 79.5^{O}E at 1730 hours IST of 6th. Moving slightly west-northwestwards it lay centered over northwest Madhya Pradesh and neighbourhood, near lat. 25.5^{O}N and Long. 78.5^{O}E, about 50 km. southeast of Gwalior at 0530 hrs.IST of 7th. Continuing the west northwestward movement, it weakened into a well marked low pressure area over northwest Madhya Pradesh and neighbourhood on 7th morning. It lay as a low pressure area over northwest Madhya Pradesh and adjoining east Rajasthan in the same evening. It merged with the monsoon trough on 8th. However, the associated cyclonic circulation extending upto mid tropospheric levels lay over northeast Rajasthan and neighbourhood on 8th & 9th, northwest Madhya Pradesh and adjoining southwest Uttar Pradesh on 10th, southwest Uttar Pradesh and neighbourhood on 11th and became less marked on 12th.

The variation in wind speed at Sagar Island and rainfall recorded at Sagar Island and Kolkata are shown in Fig.13.16 and Fig.13.17 respectively.The rainfall rrecorded at different

AWSs in West Bengal are also presented in Table-13.3. It indicates that AWS responded to the passage of the system. However, there were breaks in observation.

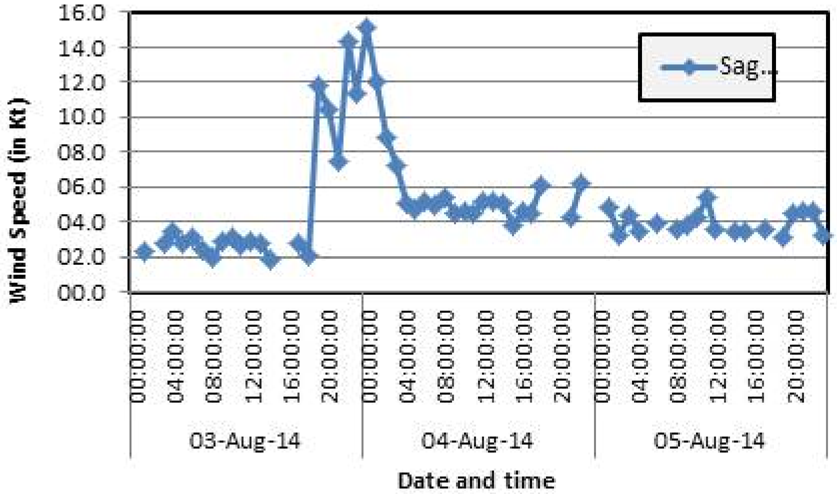

Fig.13.16: Variation in wind speed recorded at Sagar Island AWS.

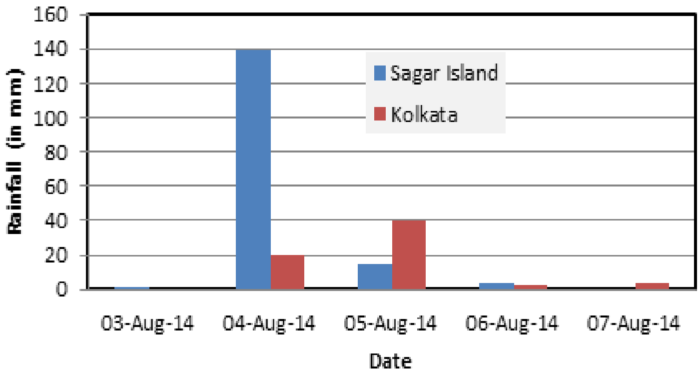

Fig.13.17: Daily rainfall recorded at Sagar Island and Kolkata

13.3.8 Low pressure area over north Bay of Bengal and neighbourhood during 9th – 11th Aug 2014

A cyclonic circulation between 5.8 & 7.6 kms a.s.l. lay over northwest Bay of Bengal andneighbourhood on 7th and over North Bay of Bengal and neighbourhood tilting southwestwards with height on 8th. Under its influence, a low pressure area formed over North Bay of Bengal and neighbourhood on 9th which lay over Gangetic West Bengal and neighbourhood in the same evening. It lay over northeastern parts of Jharkhand and neighbourhood on 10th, southern parts of Bihar and neighbourhood on 11th and merged with the monsoon trough on 12th. However, the associated cyclonic circulation extending up to 5.8 kms a.s.l. lay over east Uttar Pradesh and neighbourhood on 12th and over Bihar and adjoining Sub-Himalayan West Bengal & Sikkim on 13th. It lay embedded in a north-south trough over the region during 14th – 16th, lay over northern parts of Gangetic West Bengal and neighbourhood on 17th and over west Bengal & Sikkim and neighbourhood on 18th. It became less marked on 19th.

Table-13.3: Daily rainfall recorded at AWS in the state of West Bengal.

Station name	9th Aug. 2014	10th Aug. 2014	11th Aug. 2014
Tamluk	76	0	0
Bashirhat	0	0	0
Behrampur	0	0	27
Burdwan	0	0	0
Purulia	0	0	0
Suri	0	12	0
Garwa, Jharkhand		27	

13.3.9 Well marked low pressure area over west central & adjoining northwest Bay of Bengal during 27th Aug – 6th Sept 2014

An east-west shear zone at 5.8 kms a.s.l. extended along Lat. 14^{O}N across south Peninsula on 24th. It extended between 3.1 & 4.5 kms a.s.l. and ran roughly along: Lat. 15^{O}N across south Peninsula on 25th and along Lat.17^{O}N with an embedded cyclonic circulation over west central Bay of Bengal and neighbourhood on 26th. The east-west shear zone became less marked on 27th and under the influence of embedded cyclonic circulation over west central Bay of Bengal and neighbourhood, a low pressure area formed over west central and adjoining northwest Bay of Bengal off north Andhra Pradesh - south Odisha coasts on 27th. It persisted there on 28th. It lay as a well marked low pressure area over the same region on 29th and lay over south Chhattisgarh and neighbourhood on 30th. It lay over Vidarbha and adjoining areas of south Chhattisgarh and Telangana on 30th evening & persisted over the same region in the morning of 31st Aug. It lay over Vidarbha and adjoining east Madhya Pradesh on 31st evening. It lay as a low pressure area over central parts of south Madhya Pradesh and adjoining Vidarbha on 1st Sept.; over northwest Madhya Pradesh and neighbourhood on 2nd and over southeast Rajasthan and neighbourhood on 3rd and over central parts of Rajasthan on 3rd evening and over west Rajasthan and neighbourhood on 4th. It lay as a well marked low pressure area over northwest Rajasthan and adjoining areas of Haryana and Punjab on 5th and over Punjab and neighbourhood in the same evening. It lay as a low pressure area over Punjab and adjoining Rajasthan and Haryana on 6th and became less marked on 7th. However, the associated cyclonic circulation extending between lower & mid tropospheric levels lay over Haryana and adjoining Uttar Pradesh on 7th and became less marked on 8th.

The variation in SLP at Amdalavalsa AWS under influence of well marked low over northwest Bay of Bengal is shown in Fig.13.18 and daily rainfall recorded at AWS in Andhra Pradesh is shown in Fig.13.19.

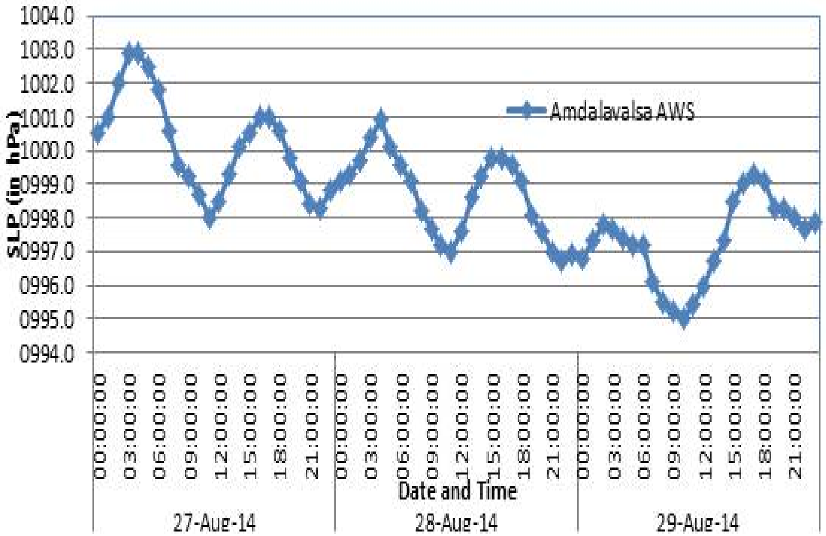

Fig.13.18: Variation of SLP at Amdalavalsa AWS in Andhra Pradesh under influence of well marked low during 27-29 August 2014.

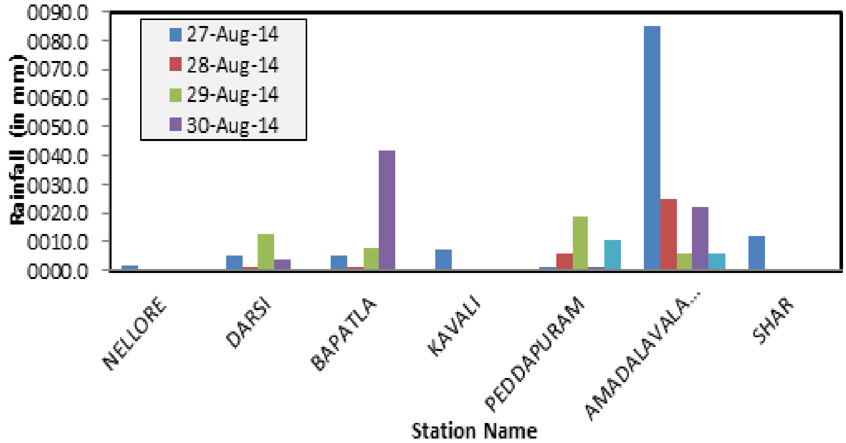

Fig.13.19: Variation in rainfall recorded at AWS in Andhra Pradesh.

13.3.10 Well marked low pressure area over North Bay of Bengal during 5th – 9th Sept 2014.

Under the influence of cyclonic circulation over northwest Bay of Bengal and neighbourhood, a low pressure area formed over North Bay of Bengal off west Bengal - Bangladesh coasts on 5th. It lay as a well marked low pressure area over northwest Bay of Bengal and adjoining Odisha - West Bengal coasts on 6th; over Odisha and adjoining Chhattisgarh on 7th and over Chhattisgarh and adjoining areas of Odisha and Vidarbha, on 7th evening. It lay over southwest Madhya Pradesh and adjoining north Madhya Maharashtra on 8th and lay as a low pressure area over west Madhya Pradesh and adjoining east Rajasthan on 9th. It became less marked on 10th. However, associated cyclonic circulation extending up to mid tropospheric levels persisted over the same region on 10th. It lay over north Rajasthan and adjoining areas of Haryana and Punjab on 11th and over Haryana and neighbourhood on 12th. It merged with the monsoon trough on 13th.

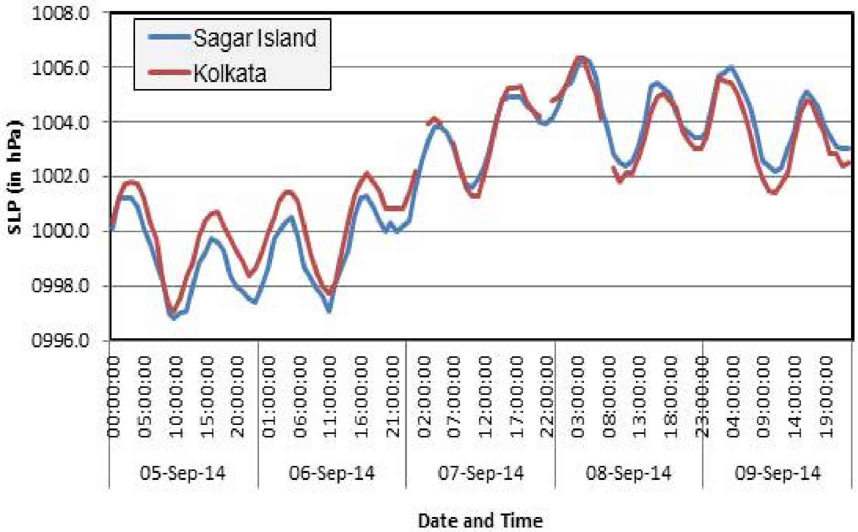

Fig.13.20: Variation of SLP at Sagar Island and Kolkata AWS

Variation of SLP under the influence of well marked low pressure area over North Bay of Bengal is shown in Fig.13.20.Janjgir AWS in Chhattisgarh recorded a rainfall of 8 mm on 7th Sept. 2014, 7 mm on 8th Sept. 2014 and 3 mm on 9th Sept. 2014 under the influence of this system.

13.4 Conclusions

With the availability of fairly dense network of AWS,data utility of AWS has further improved for monitoring and prediction of synoptic scale weather systems, especially the cyclonic disturbances. The analysis showed that the data could capture the major synoptic features associated with systems developed during monsoon season, 2014. Especially data of pressure, rainfall and wind are found to be helpful in monitoring the genesis, intensity, structure and movement of low pressure systems during 2014. The AWS data along with other observational systems could be used for better monitoring of systems especially beside synoptic hours. There are some sporadic instances of erroneous data which need to be filtered out or corrected through quality control procedures. The issue concerning errors in data and broken time series at a few stations can be addressed through regular maintenance and calibration of sensors to furtherimprove the efficiency of the AWS.

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14

AGROMETEOROLOGICAL FEATURES OF THE MONSOON AND SERVICES PROVIDED TO INDIAN AGRICULTURE

Nabansu Chattopadhyay, K. K. Singh, Kripan Ghosh,
R. Balasubramanian and Madhuri Kamble

The southwest monsoon 2014 was delayed from its normal date of onset. The spatial and temporal variability of the monsoon impacted the productivity and production of major crops in the country. Some of the crops could be sown within the sowing window in many regions, whereas, in other regions, like Marathwada, West Uttar Pradesh, Punjab, Interior Karnataka, Gujarat, Rayalaseema, Telengana alternate contingent crops were grown due to delayed or deficient rain. This Chapter discusses the distribution of rainfall over various parts of the country, its impact on the performance of the major crops and special agrometeorological services provided to cope with the agricultural risks during the season.

14.1 Introduction

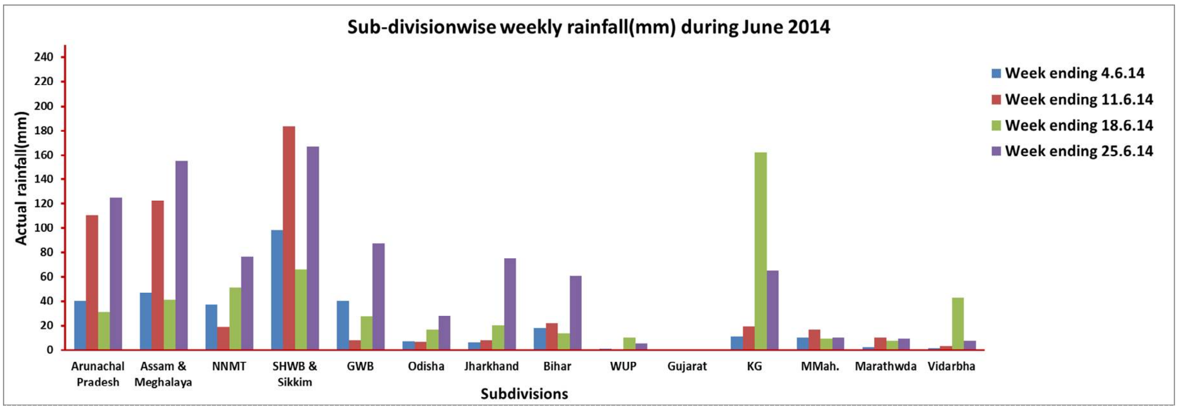
Indian agriculture is dependent heavily on the spatial and temporal distribution of monsoon rainfall. In recent past, uncertainty in both frequency and amount of rains in the monsoon season has affected the overall food grain production in the country and increased the risk to food security.

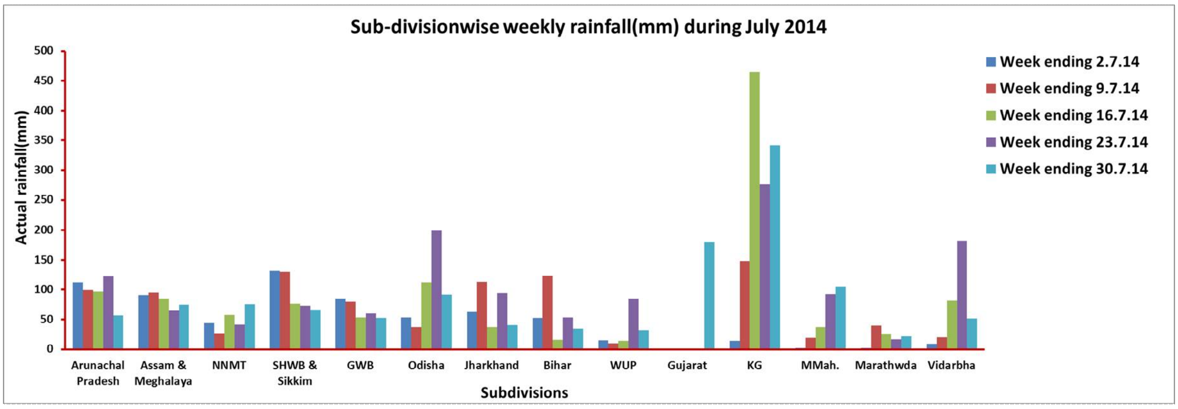
Both the years, i.e. 2009 and 2012, put a benchmark in the variable behaviour of the Indian summer monsoon. In the year 2009, the rainfall for the season (June-September) was 77% of its long period average (LPA). It was the third worst rainfall year since 1901, behind 1918 when there was a 25 per cent deficiency and 1972 when the deficiency was 24 per cent of the LPA. Poor rainfall distribution, mostly across the rice belt of northern and eastern India and some parts of south India, significantly impacted India's rice production for 2009. The effects of the poor rainfall were pronounced in Bihar, East Uttar Pradesh, West Bengal and Assam, where the crop is almost entirely dependent on monsoon rains. During 2012 also there was large variability in the advancement of monsoon as well as quantum and distribution of rainfall over different regions which had a direct bearing on the sowing operations of *kharif* and subsequently production of crops over many regions of the country. The monsoon of 2012 showed same pattern of monsoon as that of 2009 and was deficient by 19% till 18th July. The comparative analysis of the sowing pattern for 2012 to different monsoon years since 2009 shows that there has been a significant decline in the area of different crops.

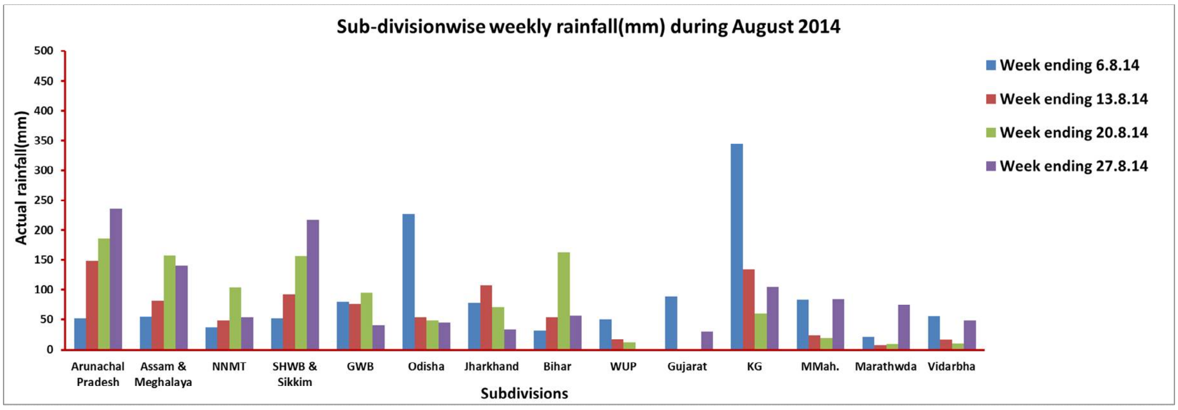
14.2 Monsoon 2014 and Indian Agriculture

Onset of monsoon has strong bearing on the sowing of *kharif* crops. In 2014, the monsoon was set in over Kerala on 6th June, 5 days later than its normal date of 1st June and covered the entire country by 17th July and withdrew late leaving 30% area of the country with deficient rainfall. During the course of this progression there was significant spatial and temporal variability which ultimately cause in the difference of productivity and production of major crops in the country. Some of the crops could be sown within the sowing window in many regions, whereas, in other regions, like Marathwada, West Uttar Pradesh, Punjab, Interior Karnataka, Gujarat, Rayalaseema, Telengana alternate contingent crops were grown due to delayed or deficient rain. Most affected subdivisions in terms of agricultural productivity and production are Marathwada, Haryana, West Uttar Pradesh, East Uttar Pradesh and Telangana, where rainfall deficiency was –42%, -56%, -56%, -42% and -34% respectively. Performance of different crops during monsoon 2014 is discussed below.

Rice: Kerala, Coastal Karnataka North eastern States like Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Sub-Himalayan West Bengal, Konkan and Goa, Gangetic West Bengal, Bihar, Jharkhand, Vidarbha, In Punjab, Odisha, West Uttar Pradesh. Weekly rainfall in the rice growing subdivisions during June to September 2014 is given in Fig. 14.1a to Fig. 14.1d. The impact of the rainfall on the agricultural operations of rice is depicted in Fig. 14.1e.







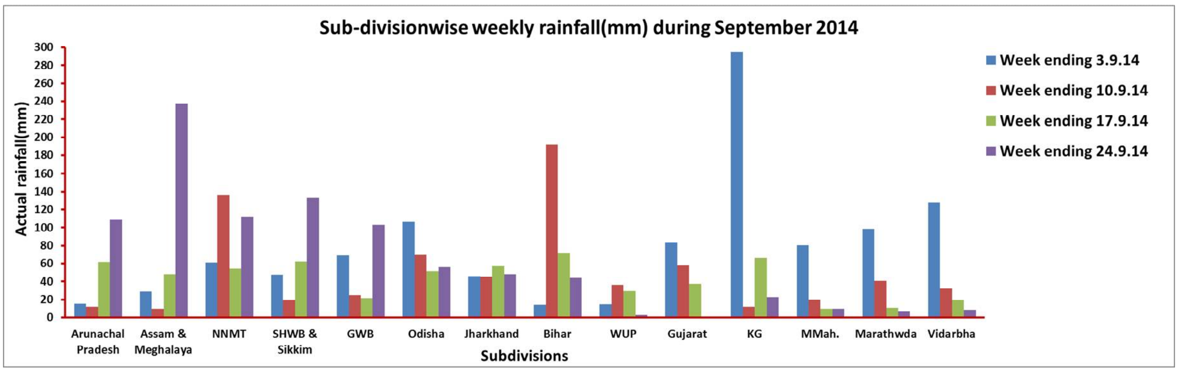
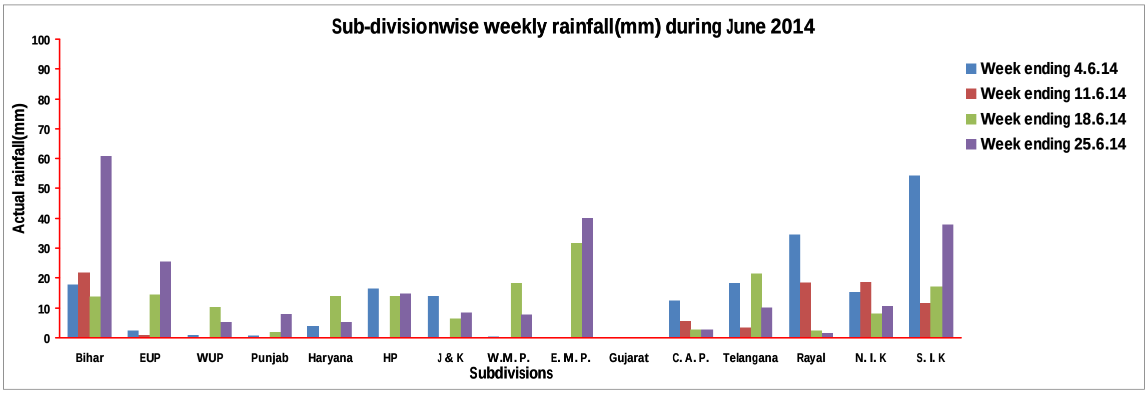
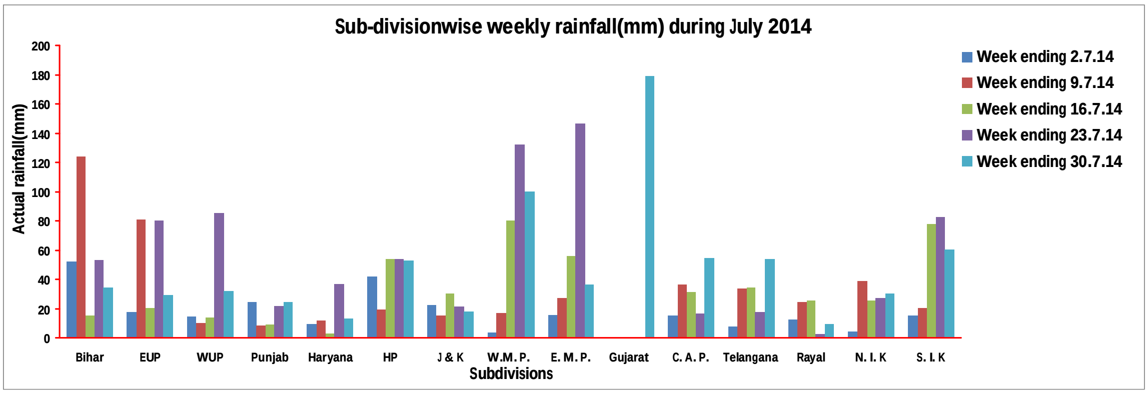
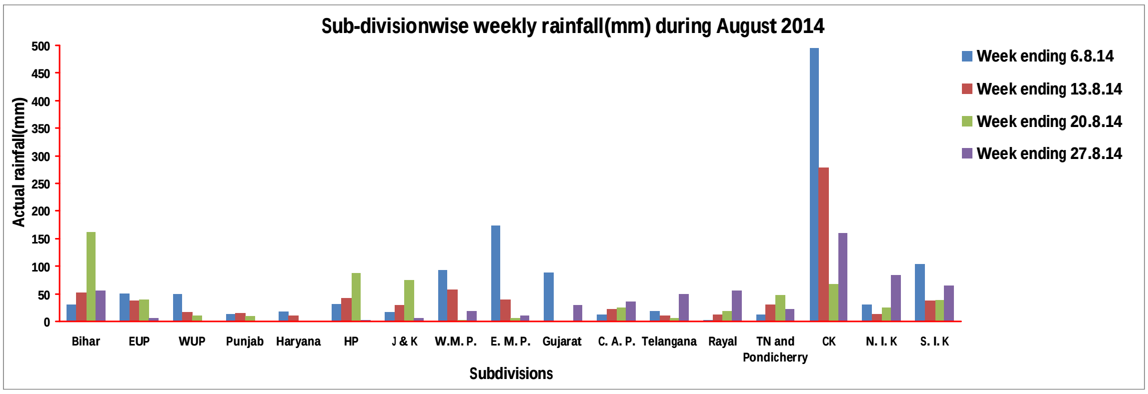


Fig.14.1: Sub-divisionwise weekly rainfall during (a) June, (b) July, (c) August and (d) September 2014







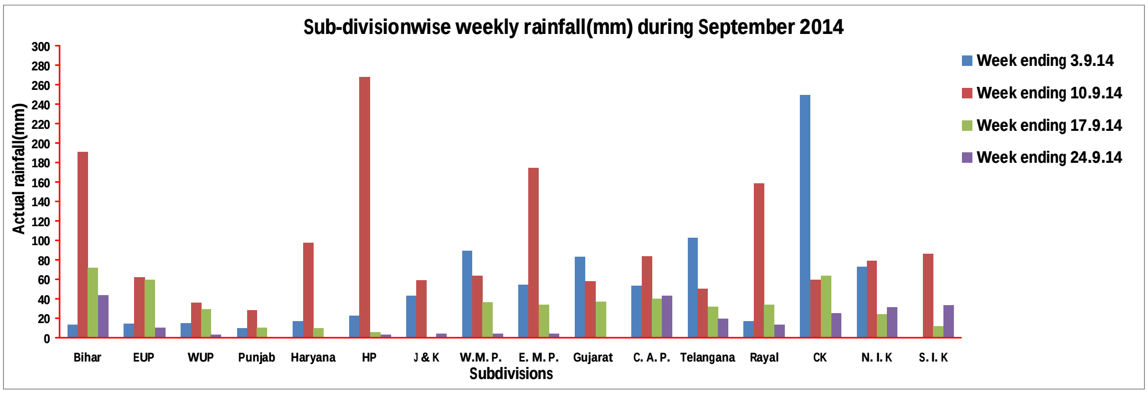


Fig. 14.2: Sub-divisionwise weekly rainfall during (a) June, (b) July, (c) August and (d) September 2014

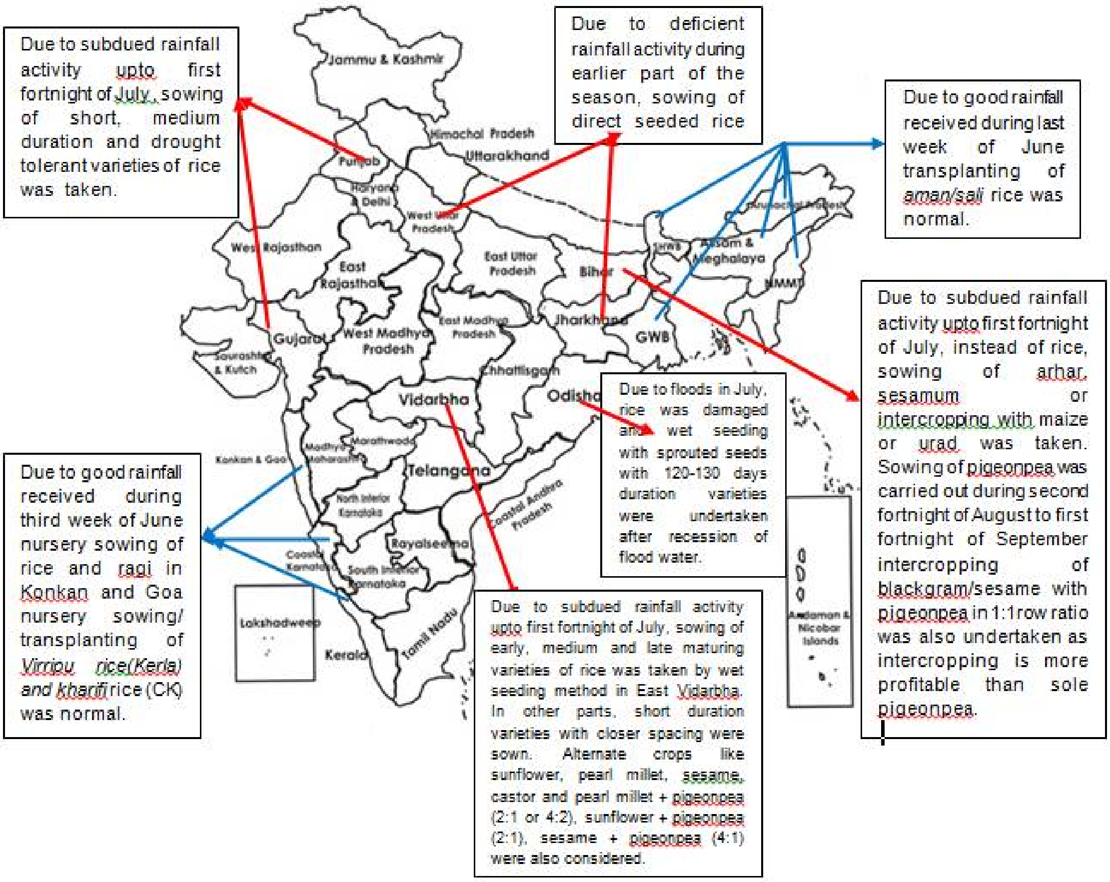


Fig. 14.1e: Agriculture situation of rice over the country.

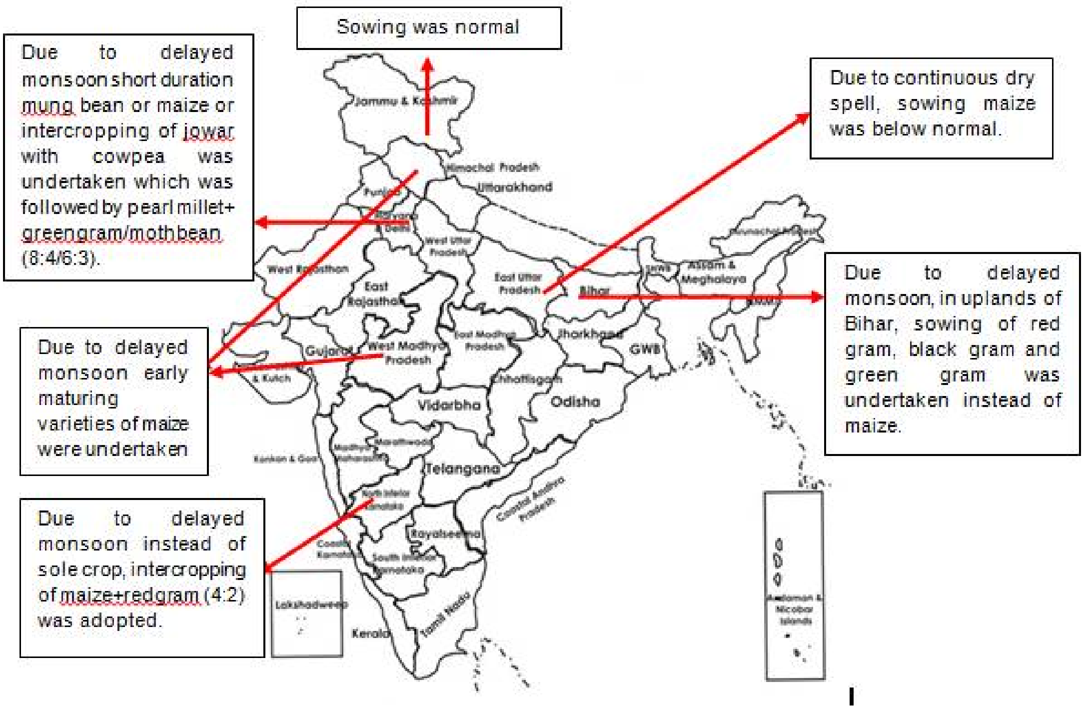


Fig. 14.2e: Agriculture situation of maize over the country.

Maize: The major maize growing States in India are Uttar Pradesh, Madhya Pradesh, Bihar, East Rajasthan, Himachal Pradesh, Jammu & Kashmir, Punjab, Gujarat, Andhra Pradesh and Interior Karnataka. Weekly rainfall in the maize growing subdivisions during June to September 2014 is given in Fig. 14.2a to Fig. 14.2d. The impact of the rainfall on the agricultural operations of maize is depicted in Fig. 14.2e.

Groundnut: The major subdivisions growing groundnut are Madhya Maharashtra, Chhattisgarh, Marathwada, Karnataka, Telangana and Rayalaseema. During 2014, sowing of groundnut was less in these subdivisions due to deficient rainfall. Weekly rainfall in the groundnut growing subdivisions during June to September 2014 is given in Fig. 14.3a to Fig. 14.3d. The impact of the rainfall on the agricultural operations of groundnut is depicted in Fig. 14.3e.

Cotton: Maharashtra, Andhra Pradesh, Madhya Pradesh, Gujarat and Karnataka are the states in which cotton is taken as the major crop. Bt cotton which is grown in about 4.2 million hectares of land in Maharashtra requires a lot of rain. Hence, in view of scarcity of rainfall farmers have selected medium duration cotton varieties for sowing. Weekly rainfall in the cotton growing subdivisions during June to September 2014 is given in Fig. 14.4a to Fig. 14.4d. The impact of the rainfall on the agricultural operations of cotton is depicted in Fig. 14.4e.

Sugarcane: Sugarcane is the most important cash crop in India, which is widely cultivated in subtropical and tropical region. Tropical regions in Maharashtra, Tamil Nadu, Gujarat, Karnataka, Andhra Pradesh, Orissa and part of Madhya Pradesh account for about 45% of the total area and about 55% of the total sugarcane production in the country, with average productivity of about 83 tonnes per hectare . Sub-tropical region comprising of Uttar Pradesh, Uttarakhand, Haryana, Punjab, Bihar, West Bengal and North Eastern States account for about 55% of area and about 45% of the total sugarcane production with an average productivity of about 56 tonnes per hectare. Planting of sugarcane in Madhya Maharashtra and Marathwada has been delayed and planting of new *adsali* sugarcane was below normal. In East Uttar Pradesh planting of sugarcane was below normal. The sugarcane acreage reported from Uttar Pradesh is around 23.07 lakh hectare, which is about eight per cent less than last year.

Pulses: India grows the large number of varieties of pulses in the world accounting for about 32% of the area and 23% of the world production. The important pulse crops are chickpea (48%), pigeon pea (16%), urdbean (9%), mungbean (7%), lentil (6%) and field pea (4%). The major pulse producing states are Madhya Pradesh (24%), Maharashtra (15%), Uttar Pradesh (12%), Rajasthan (12%) and Andhra Pradesh (9%), which together account for 72% of the total production. During 2014, on all India level, the production of pulses seems to decrease by 0.82 million tonnes.

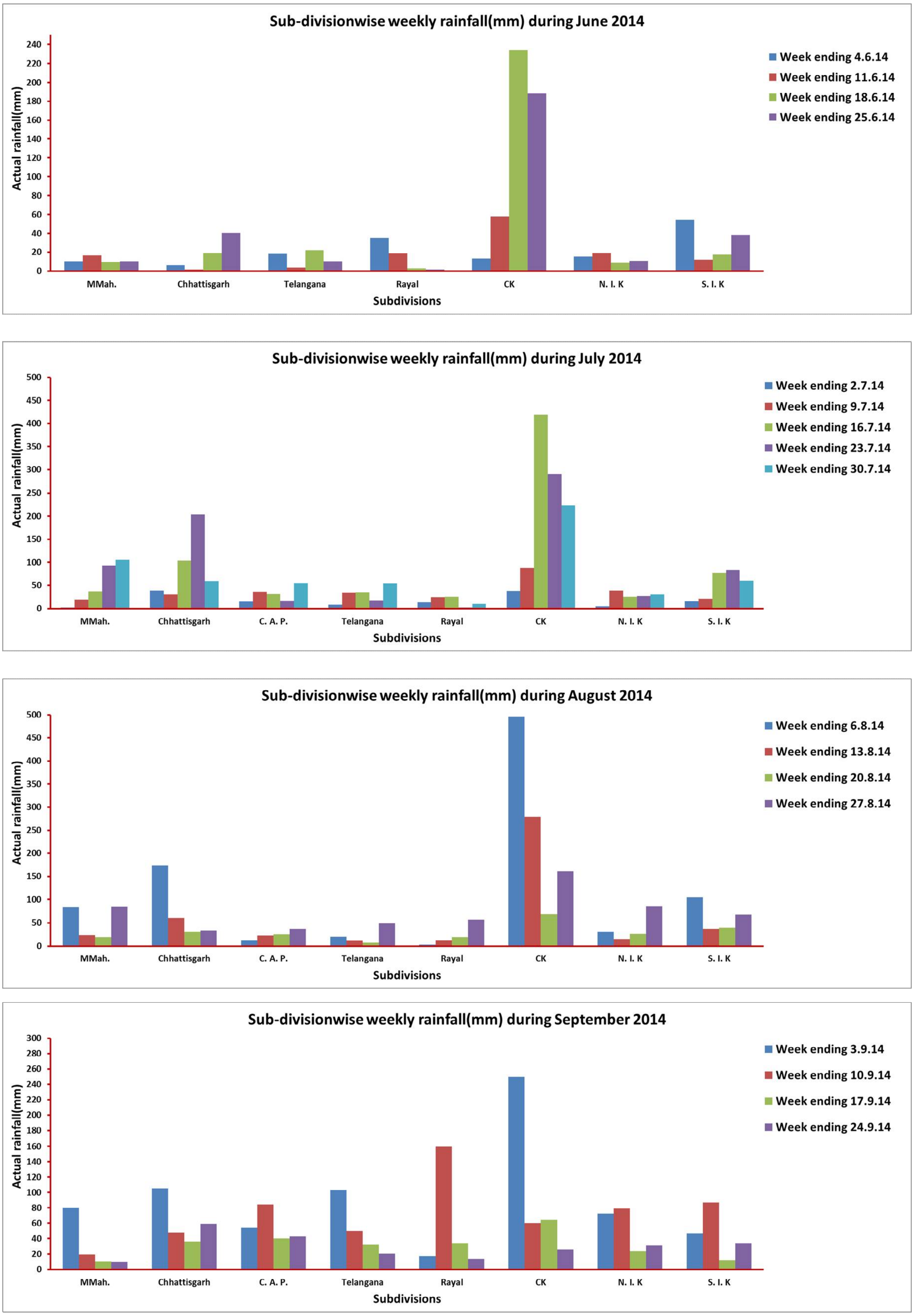


Fig. 14.3: Sub-divisionwise weekly rainfall during (a) June, (b) July, (c) August and (d) September 2014

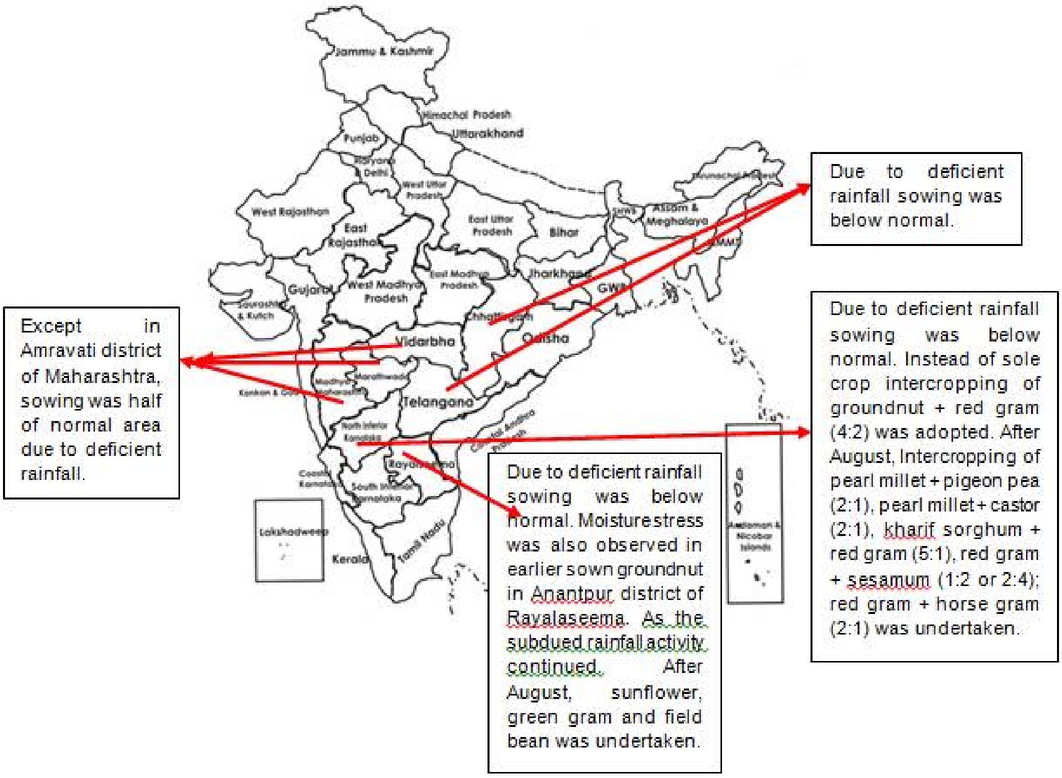


Fig. 14.3e: Agriculture situation of groundnut over the country

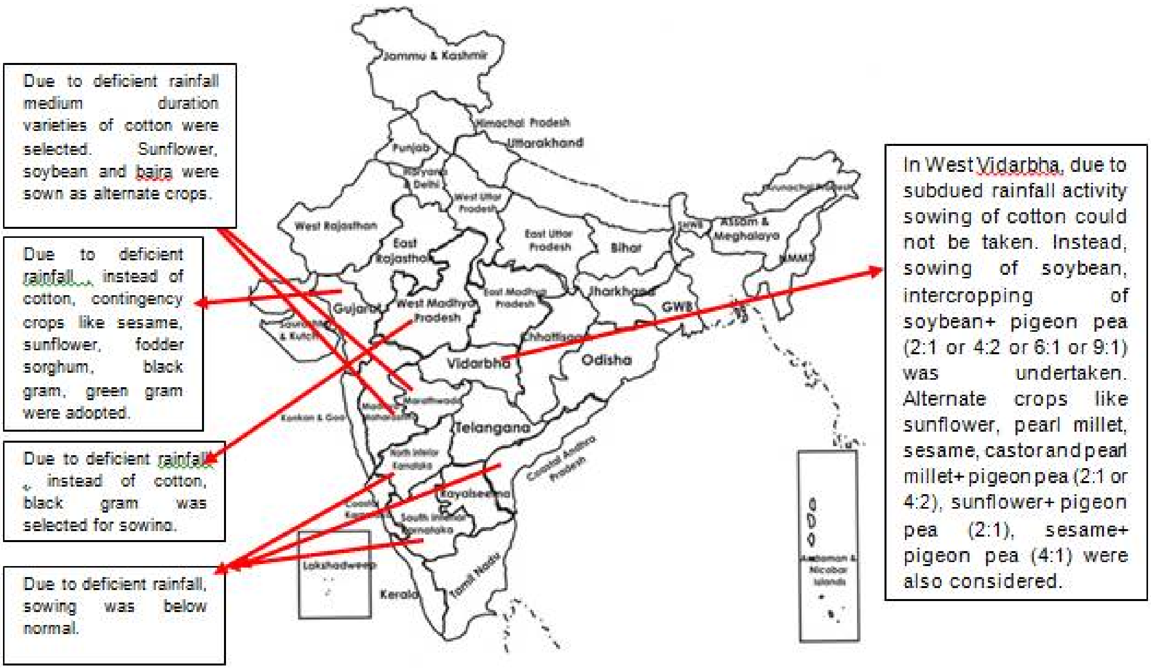


Fig. 14.4e: Agriculture situation of cotton over the country

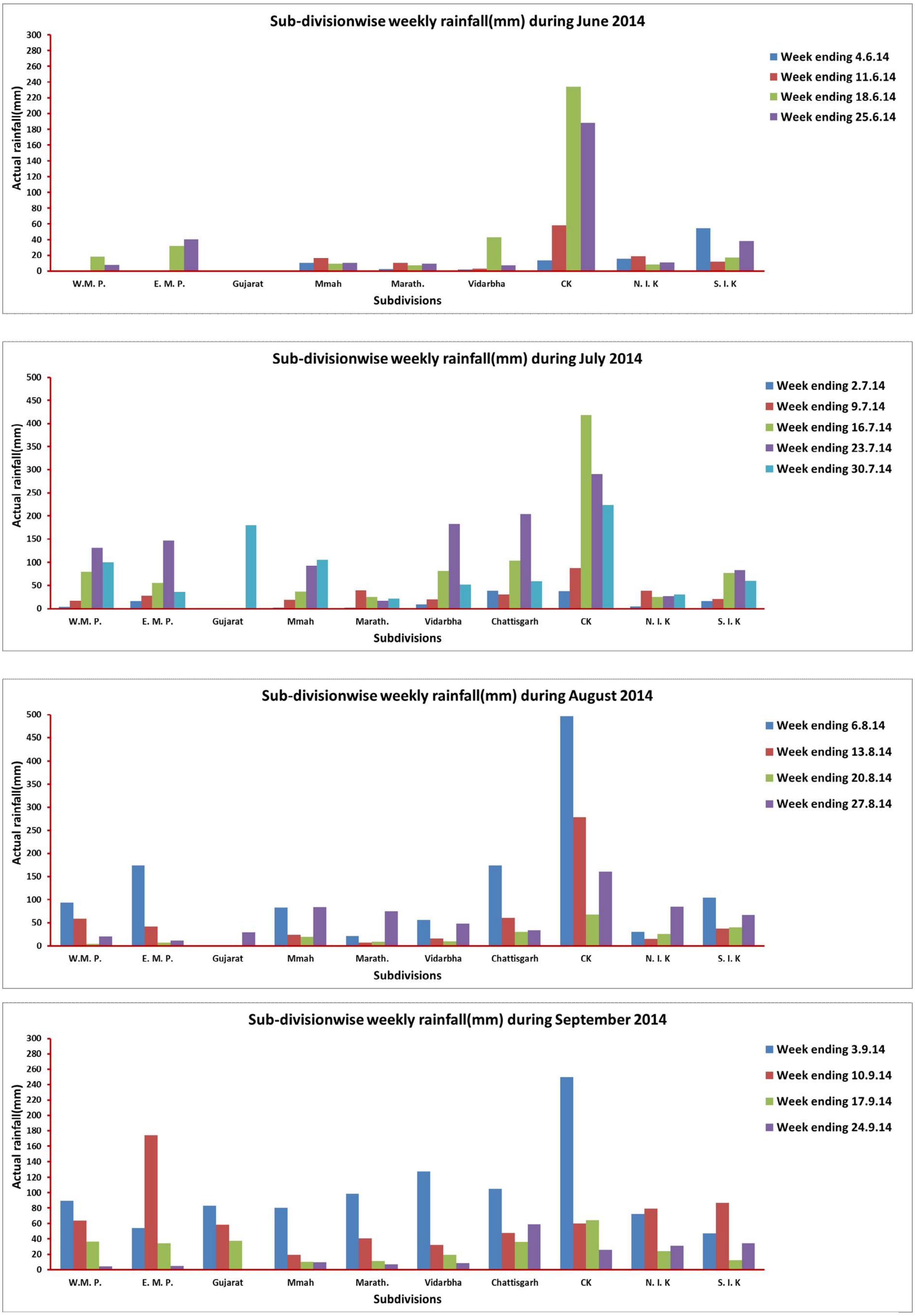


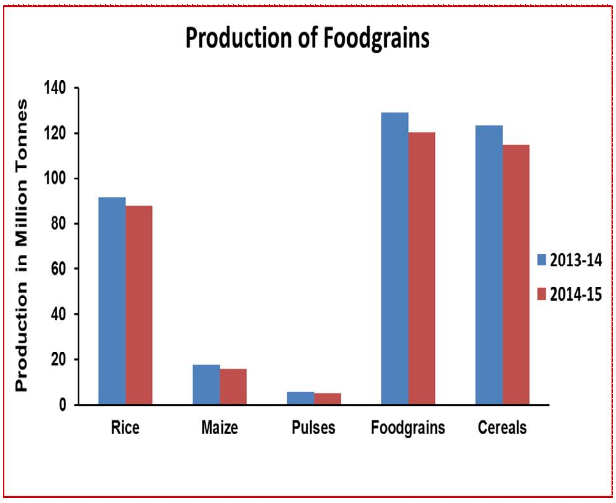
Fig. 14.4: Sub-divisionwise weekly rainfall during (a) June, (b) July, (c) August and (d) September 2014

14.3 Crop Production and Unusual weather

Southwest monsoon 2014 has shown wide swings of dry spells for districts in Haryana, Punjab, Uttar Pradesh to floods in Odisha, Chhattisgarh, Madhya Pradesh, Uttar Pradesh, Assam and Meghalaya during first half and Srinagar and Jammu during second half of the season. Absence of rain for the first six monsoon weeks in Gujarat and Maharashtra was also noticeable during SW monsoon 2014.

On All India level, according to the first estimation there may be decrease in the production of rice by 3.67 million tonnes as compared to previous year. The production of maize is supposed to decrease by 1.67 million tonnes. Below average production is seen in groundnut, soybean, black gram and maize due to scanty rains and / or dry spells experienced in these crop growing regions, especially south Gujarat, west Madhya Pradesh, pockets of Karnataka and Marathwada region. With monsoon reviving during the first week of July, the rice sowing pattern in central, east and northeast and larger part of peninsula improved remarkably. However, dry spells in Marathwada, south Gujarat and western Madhya Pradesh ended up with a mixed basket of normal output in rice and pulses in contrast to below average production in soybean, black gram, groundnut and maize.

As per reports there is no noticeable reduction in rice area compared to last year in Uttar Pradesh. State Government suggested to focus during *Rabi* on the 3.37 million hectares left unsown due to delayed monsoon. Much of the concentration will be on improving the output of pulses and oilseeds. Both were affected during *Kharif* Season due to delayed rains. All India production of major *kharif* crops is given in Fig. 14.5a and Fig. 14.5b.



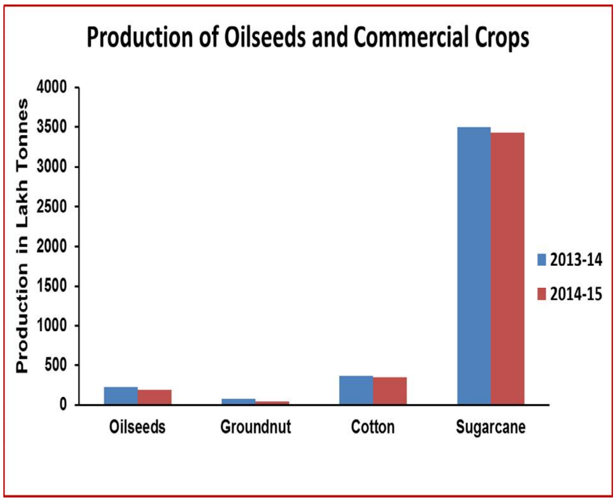


Fig. 14.5: Production of **(a)** Food grains & **(b)** Oilseeds and Commercial crops during monsoon 2013 and 2014.

14.4 Pest and Diseases Management during Southwest Monsoon2014

Due to the unusual weather some pest and disease incidences were also observed during southwest monsoon season without any major impact on crop production as compared to other years. Some of them are depicted in Fig. 14.6.

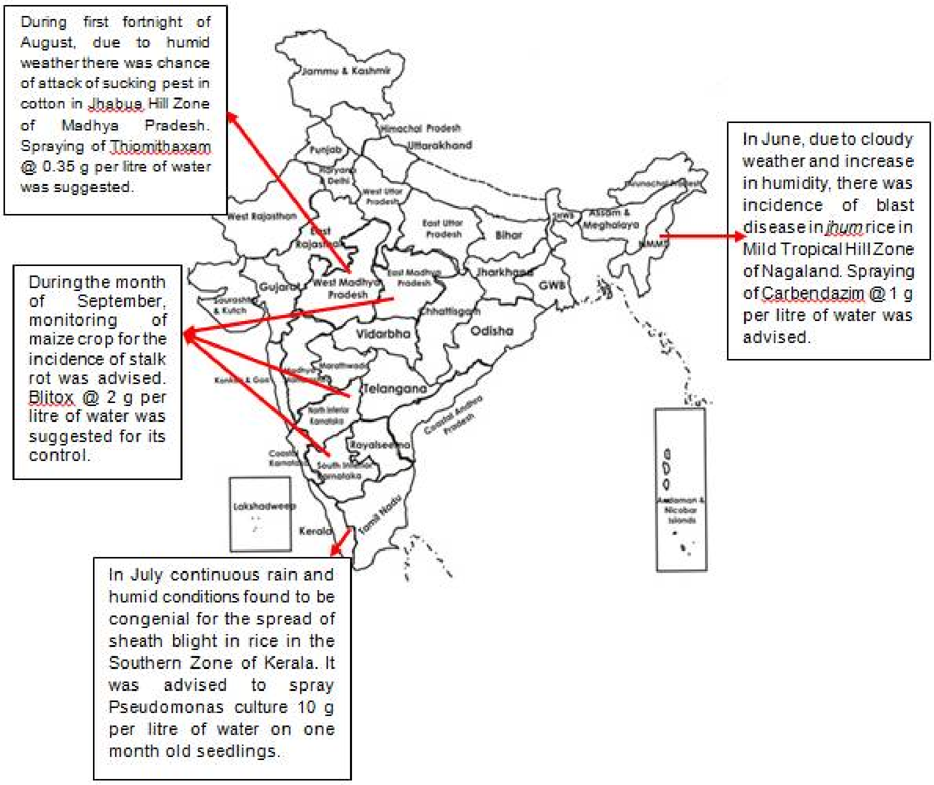


Fig.14.6: Pest and Disease incidences and Control Measures during SW monsoon 2014.

14.5 IMD Services to Agriculture during Monsoon 2014

In order to decrease the vulnerability of agriculture to increasing climatic variability and ultimately to increase the crop production, without putting additional stress on natural environment, through weather forecast and agromet advisories, IMD is operating a scheme, *viz.,* “Gramin Krishi Mausam Seva” (GKMS). IMD issues Agromet Advisories at district, state and National levels under this scheme. The district level agromet advisories are issued to the farming community of various districts of each State of the country by Agromet Field Units (AMFUs) located at State Agricultural Universities, ICAR institutes and IITs for taking decision on day-to-day farm operations. A joint initiative between Space Application Centre (SAC) and IMD was taken up to explore use of satmet products like NDVI for agro-advisory. Agrimet division, IMD, Pune in collaboration with International Centre for Radio Science (ICRS), Jodhpur has started preparation of soil moisture maps for the States of Gujarat, Madhya Pradesh and Uttar Pradesh. As a step forward, India Meteorological Department

(IMD) in collaboration with the Central Research Institute for Dryland Agricultural Research (CRIDA), ICAR, Hyderabad has started issuing agromet advisories operationally from monsoon 2014 for the farmers for next fortnight based on Extended Range Weather Forecast received from Indian Institute of Tropical Meteorology (IITM) with weekly updates. It has helped the farmers to plan agricultural operations well in advance.

14.6 Dissemination

Timely advisories on drought / cyclone / excessive rainfall and pest and crop diseases is disseminated through a multi-channel systems (radio, TV, print media, internet etc.) and SMS and IVRS through stakeholders like Reuter Market Lite, IFFCO Kisan Sanchar Limited (IKSL), NOKIA, Handygo, NABARD and Kisan Web Portal of Ministry of Agriculture, Govt. of India. At present, Agromet Advisory Bulletins are prepared for 608 Districts twice a week and also disseminated to the farmers through SMS and IVRS technology to 7.07 million farmers under Public Private Partnership. IMD in collaboration with Reliance Foundation disseminates the agromet advisories to the farmers in the form of IVR system. Also in collaboration with Central Silk Board, IMD will disseminate advisory for the sericulture farmers in 108 districts in the country. Along with Commonwealth Agricultural Bureaux International (CABI), IMD is planning to disseminate agromet advisories to the coffee grower farmers of districts Chickmagalur, Kodagu (Coorg) & Hassan in Karnataka.

14.7 Conclusions

From the qualitative and quantitative analysis it is seen that during southwest monsoon there were incidences of dry spell as well as wet spells which has considerably affected the production of various crops across the country. Rainfall was deficient during monsoon season in Punjab (-50%), Haryana (-56%), Maharashtra (Marathwada -42%), East Uttar Pradesh (-42%) and West Uttar Pradesh (-56%). In Uttar Pradesh 44 districts were declared by State Government as drought affected. On the other hand, subdivisions like Jammu & Kashmir, Assam and Odisha faced flood situations.

The delayed onset of rainfall forced the farmers to shift to short duration varieties; from cash crops to food crops or even fodder. Due to deficient rainfall the sown area under major crops like rice, maize, pigeon pea, sorghum and pearl millet was declined in Haryana. As per the first estimate, all India level production of all the major kharif crops seems to decrease as compared to previous year.

In order to manage the impact of adverse weather situation, IMD issued appropriate measures to farming community through the agromet advisories based on the medium range weather forecast as well as the extended range weather forecast. From the feedback of farmers it is revealed that these advisories have helped the farmers to take the appropriate farm decisions in time and has resulted in improvement in agricultural situations under aberrant weather condition in one hand and decline in the cost of cultivation in other hand.

15

SUMMARY AND CONCLUSIONS

D. S. Pai and S. C. Bhan

The first 13 chapters of the this report has discussed various operational aspects of monitoring and forecasting of the 2014 southwest monsoon season and verification of the forecasts. In the last chapter, impact of the realised monsoon rainfall on the various major crops in the country was discussed. In this final chapter of this report, summary of each of the previous chapters and conclusions of the report have been presented.

15.1. Introduction

In the first two of the 14 chapters of this report, various regional and global features associated with the 2014 southwest monsoon were discussed. In the next five chapters (chapters 3 to 7) described various extreme weather events such as very heavy rainfalls, floods, landslides etc. occurred over different regions of the country and their meteorological analysis. The chapter 8 discussed various rainfall features of the monsoon season, and the next 3 chapters discussed verification of operational forecasts issued by IMD for the monsoon rainfall at various time and spatial scales. Chapters 12 & 13 discussed the utility of the satellite and automatic weather station data in monitoring and prediction of the monsoon. The last chapter discussed the impact of monsoon performance on the major kharif crops in the country. In this final chapter of this report, summary of each of the previous chapters and some of the highlights of the report have been presented.

15.2 Summary of Previous Chapters

Brief summary of each of the previous 14 chapters is given below.

Chapter 1 discussed various regional features of the 2014 southwest monsoon like progress of the monsoon, transient and semi-permanent systems etc. The monsoon advanced over Andaman Sea 2 days prior to its normal date of 20thMay and set in over Kerala on 6th June, 5 days later than its normal onset date. Further advance was quite sluggish owing to the presence of a ridge along the western part of the sub-continent. A Cyclonic Storm 'Nanauk' formed over the east central Arabian Sea in the second week of June though aided the early advance of monsoon had adverse impact on the further advance of monsoon due to movement away from the west coast. In spite several brief hiatuses the monsoon covered the entire country on 17th July close to the normal date (15thJuly). However, monsoon withdrawal from northwest India was delayed due to rainfall activity over north India associated with the passage of mid-latitude westerly systems. The monsoon started withdrawing from west Rajasthan on 23rdSeptember (a delay of more than 3 weeks) against the normal date of 1stSeptember. Subsequently, it withdrew from the entire country, Bay of Bengal and Arabian Sea around18th October.In June, the semi-permanentheat low &heat trough was observed only in the first week due to the incursion of mid-latitude circulation regime into monsoon region thereafter. In July and first half of September, the axis of monsoon trough mostly remained normal/south of its normal position. Though it extended up to mid tropospheric levels, the characteristic tilt was missing. On the other hand in August, the monsoon trough was mostly north of its normal position/close to foot hills of Himalayas. The seasonal 'heat low' was less demarcated since second half of August except for the first half of September, when it became noticeable. Thereafter, it became less apparent and subsequently, the axis of monsoon trough also weakened resulting less delineated since 22nd September. The other semi-permanent systems like Tropical easterly Jet, Tibetan anticycloneetc. were also weaker than normal during most part of June and later part of August. In addition to the Cyclonic Storm 'Nanauk', 2 monsoon depressions and 10 low pressure / well marked low pressure areas formed during the season. Considering an average number of 2 monsoon depressions per month forming over the region, the number of monsoon depressions formed during this season was comparatively less. However, these low pressure systems caused well distributed rainfall over central India and adjoining northern plains.

Chapter 2 discussed the large scale global and regional scale monthly and seasonal climate anomaly patterns observed during the season and the possible factors responsible for observed spatial and temporal distribution of rainfall over the country. Warming sea surface temperatures (SSTs) over throughout the equatorial Pacific though reached to borderline El Niño levels, their subsequent cooling in the middle of the monsoon season obstructed further maturing of the event. Even though, the SSTs started to warm again in the since late part of the monsoon season, the ENSO conditions remaining within warm Neutral conditions till the end of 2014. In the Indian Ocean, negative Indian Ocean dipole (IOD) conditions prevailed in the early part of the monsoon season. Both these large scale conditions unfavourable for the normal monsoon resulted in large scale descending motion over the region, causinghuge rainfall deficiency (about 42% of long period average (LPA)) over country in the early part of the monsoon season (till around second week of July). The rainfall deficiency during the early part of July may have also been caused by the above normal typhoon activity over northwest Pacific. However, favourable MJO phases and formation and movement of 3 low pressure systems along the monsoon trough region helped monsoon activity to pick up over central India during the second part of July. However, unfavourable phases of MJO during the middle of August resulted in prolonged break monsoon conditions. This resulted monthly rainfall during August to remain less than normal in spite of cooling of SSTs over Pacific and formation of short lived low pressure systems. Once the MJO became weak in the late August monsoon again picked up and this resulted above normal rainfall during September. Thus the monsoon season featured strong intraseasonal variation in the rainfall.

Chapters 3 to 7 discussed occurrences of extreme weather events over different regions of the country and their meteorological analysis.

In Chapter 3, extreme rainfall events occurred over Jammu and Kashmir during the first week of September has been discussed. Though the region received deficient rainfall during July and August, Continuous wide spread heavy rainfall occurred during the first week of September. This was caused by a well-marked low pressure area that formed over Saurashtra and Kutch and neighbouring northeast Arabian Seas around 4th September. This systemmoved northward and thereafter interacted with the trough in the mid-latitude westerlies in the lower troposphere levels, caused heavy to very rainfall rainfall resulting in severe floods in hilly areas of Jammu and many districts of south & Central Kashmir. This also resulted in the complete submergence of Srinagar city where flood water touched above 20 feet at some places as per as per official sources. This unprecedented flood also caused death of about 283 persons in the region and large damage to the properties.

Chapter 4 discussed three flood events occurred over east India; in Odisha during 20-22 July & 1st week of August, 2014 and in Bihar during 14-16 August 2014. The first flood over Odisha was associated with the formation of a low pressure area over northwest Bay of Bengal and adjoining area of Gangetic West Bengal (GWB) and Odisha on 20th July, which intensified into a land depression on 21st July over north-eastern parts of Odisha and adjoining GWB. The second flood in Odisha occurred in Baitarani, Brahmani and tributaries of Mahanadi due to formation of a low pressure area over North West Bay of Bengal and its intensification into a deep Depression during 3-6 August, which spurred vigorous monsoon conditions over the Indo -Gangetic plains. The floodin Bihar was moderate and was associated with the break monsoon synoptic situation. The break monsoon situation was caused by the shifting of the monsoon trough towards the foot hills of Himalayas in the middle of August associated with the formation of a low pressure area over North Bay of Bengal on 9th August and its north-westwards movement and dissipation.

Chapter 5 discussed three incidences of extreme weather events occurred in Maharashtra. These are; very heavy rainfall in Malin Village, Pune in July leading to landslide, extremely heavy rainfall events in Gadhchiroli of Vidarbha in early September, and severe thunderstorm in Mumbai city in late September. The meteorological reason for the heavy rainfall in Malin Village was the active off shore trough along the west coast and a low pressure area over north Bay of Bengal during the last part of July. However, the land slide may also been caused by changes in the land use such as deforestation, levelling of steep hill areas for agriculture activities, construction nearby Dimbhe Dam 10 years ago, other construction activities etc. The exceptional heavy rainfall of 435.6 mm on 7th Sept, 2014, occurred in Gadhchiroli was part of fairly wide spread heavy rainfall over Vidarbha region in associated with the active monsoon conditions supported by the formation of a low pressure area over north Bay of Bengal. As a result the Chandrapur – Gadhchiroliarea had lost the connectivity of almost 200 villages of the region.The severe thunderstorm occurred on 30th Sept, 2014 in Mumbai that affected the city side of it in the evening was associated with the withdrawal phase of the monsoon.

In Chapter 6, an analysis of a destructive flash flood occurred In Assam and Meghalaya in late September has been presented. Unprecedented heavy to extremely heavy rainfall activity occurred over Garo Hills districts of Meghalaya during 21st – 23rd September 2014 causing enormous loss of life and property in Meghalaya and Assam. Meghalaya state recorded an excess rainfall of 438%, 1428% and 1156% on 21st, 22nd, and 23rd September respectively. In the same days, Assam recorded an excess rainfall of 88%, 664% and 385% respectively on the respective dates. The synoptic situations leading to such high impact rainfall activity was due to a low pressure system over Bangladesh and adjoining Gangetic West Bengal. Due to the presence of this system, a southerly jet in lower levels was established over Bangladesh causing large scale moisture incursion to the NE region. The above systems together with local orography resulted in formation and maintenance of large scale convection causing the very heavy to extremely heavy rainfall activity over Garo Hills and its adjoining areas.

Chapter 7 discussed an analysis of the active monsoon rainfall events experienced byvarious meteorological subdivisions of south India during the second half of the monsoon season. During August, peninsular India experienced very good rainfall activity while the rainfall activity over the country as a whole was below normal. The enhancement of rainfall activity over most parts of peninsular India during the last two weeks of August and the first week of September was associated with the two well-marked low pressure areas (WML), one over the Arabian Sea (23rd - 24th Aug.) &oneover the Bay of Bengal (27th Aug – 6th Sept.).

In Chapter 8, various features of rainfall during the southwest monsoon season have been discussed. The season (June- September) rainfall over the country as a whole was deficient (87.7 % of its Long Period Average (LPA)). The rainfall during the season was also characterized by noticeable spatial and temporal variability. Regions wise, the season rainfalls over 3 broad geographical regions (Central India, Northwest India and Northeast India) were below normal that over peninsular India was in the negative side of the normal. Rainfall deficiency over some subdivisions of Northwest India viz. West Uttar Pradesh, Haryana, Chandigarh & Delhi and Punjab exceeded 50%. Similarly, rainfall realized for the country as a whole during the first half of the season (June and July) was 78 % of its LPA value, while, same for the country as a whole during the second half of season (August and September) was 97 % of its LPA value. Month wise, the rainfall over the country as a whole was deficient during June, normal during July and August and in the positive side of the normal during September.Subdivision wise, the season rainfall was excess in 1 subdivision (South Interior Karnataka), normal in 23 subdivisions and deficient in the remaining 12 subdivisions. The season also experienced significant intraseasonal variation due to the formation of above normal number of low pressure systems with extremely heavy rainfalls experienced by many areas.

The performance of operational forecasts from GFS and WRF models in the short and medium range scales were discussed in the Chapter 9. The performance of GFS T574 in predicting rainfall varied with geographical location and synoptic regime. The root mean square error (RMSE) was found to be slightly higher for GFS T574, indicating higher variability in the model performance. The T574 forecasts, in general, were skillful over the regions of climatologically heavy rainfall domains. The observed variability of daily mean precipitation over India was reproduced remarkably well by the day-1 to day-7 forecasts of GFS T574. It also showed reasonably good skill to capture large scale features of the rainfall such as heavy rainfall belt along the west coast, monsoon trough region and along the foot hills of the Himalayas. In general, GFS T574 showed considerable skill in predicting the all India daily rainfall. The GFS forecastsfor day-4 to day-7 during the monsoon-2014 showed significant improvement (around 17% to 28%) in the special correlation coefficient (CC) of the monsoon rainfall compared to that during 2013. Similar improvement (around 10% to 40% for day-4 to day-7 forecasts) was also noted in Threat Score (TS) for the moderate to heavy rainfall prediction (more than 3 cm). This improvement is mainly due to the availability more observations from various new satellites. The verification of WRF model showed a consistent tendency for over prediction of rainfall. The positive bias in the rainfall distribution showed systematic nature for each specific zone in every months of monsoon. Therefore, bias correction is a viable option to improve forecast quality. The shift due to irregular movement of low pressure systems from Bay of Bengal towards land was found to be a consistent limitation of the model forecasts. The wind biases found in the forecasts indicated that the evolution of large scale monsoon systems within monsoon environment have not been captured well by the model. Various physical parameterisation schemes has to be tested to identify the more better physical and boundary layer process suitable for Indian monsoon region in WRF model to improve the prediction of monsoon lows and associated rainfall.

Chapter 10 discussed the performance of the Multi-model Ensemble (MME) extended range forecasts based on two coupled models (NCEP-CFS version 2 (CFSv2) and JMA) for the 2014 southwest monsoon. The MME forecasts captured the delayed onset of monsoon over Kerala and dry spell of June, revival of monsoon during 2nd half of July, transition of monsoon from active to weaker phase during middle of August and transition of monsoon from weak to active phase during early part of September. Quantitative verification indicates that the MME forecast of all India rainfall shows significant CC between observed and forecast rainfall departure at east for 2 weeks. Over the homogeneous regions of India the MME forecast shows significant CCs till two weeks, except in case of Northeast India, which shows significant CC till week-1.

Chapter 11 discussed methodology used for preparing various operational long range forecasts issued by IMD for the rainfall and operational forecast for the date of monsoon onset over Kerala and their verification for the 2014 southwest monsoon season. In addition, experimental forecasts for the monsoon rainfall prepared using IMD's seasonal forecast model (SFM) and that obtained from various national and international climate research centres were also discussed. This year, the long range forecast for the 2014 southwest monsoon rainfall was issued in 3 stages. IMD's operational forecasts wereprepared usingindigenously developed forecasting system based on statistical approach.The forecast for the monsoon onset date over the Kerala was correct once again as in the previous 9 years. The season rainfall over the country as a whole and that over four broad geographical regions (northwest India, central India, northeast India and south Peninsula) were within the limits of the forecasts updated in August and accurate. Similarly, the forecasts for the monthly rainfall (for July and August) as well as that for the rainfall during the second half of the monsoon season over the country as a whole were also accurate. The experimental forecasts from IMD SFM for the season rainfall over the country as whole at all lag periods could correctly indicate realized deficient rainfall. The experimental forecasts from most of the other Indian institutes and international climate centers also indicated below normal to deficient rainfall.

In Chapter 12, some applications of the newly imageries & products from newly launched INSAT-3D satellite for monitoring various aspects of monsoon such as onset, progress, and withdrawal of the monsoon, life cycle of low pressure systems, active and break spells of monsoon, etc. have been discussed. A new online tool for the visualisation of INSAT-3D data for weather and climate studies has also been discussed.Since early 2014, INSAT-3D data and its products are operationally available to the users and forecasters community. It is an exclusive meteorological satellite with the following mission objectives:a)To monitor earth's surface, carryout oceanic observations and its environment in various spectral channels of meteorological importance and b) provides the vertical profile of temperature and humidity parameters of the atmosphere.The Meteorological payloads are state-of-art and have significant technological improvement in sensor capabilities and higher resolution compared to earlier INSAT missions.

In Chapter 13, use of the AWS data in the monitoring and prediction of the low pressure systems formed during the 2014 southwest monsoon seasonhas been discussed. India Meteorological Department has established a network of 675 AWS across the country during the period 2006-2012. This fairly dense network of AWS has helped in further improvement of monitoring and prediction of synoptic scale weather systems, especially the cyclonic disturbances. Especially AWS data for pressure, rainfall and wind were found to be helpful in monitoring the genesis, intensity, structure and movement of low pressure systems. The AWS data along with other observational systems could be used for better monitoring of systems especially beside synoptic hours. There are some sporadic instances of erroneous data which need to be filtered out or corrected through quality control procedures. The issue concerning errors in data and broken time series at a few stations can be addressed through regular maintenance and calibration of sensors to further improve the efficiency of the AWS.

Chapter 14 discussed the spatial and temporal distribution of the 2014 southwest rainfall in the agriculture point of view and its impact on the performance of the major crops during the kharif season. The 2014 monsoonwas characterised by significant day to day as well as regional distribution in the rainfall. This has affected the productivity and production of major *kharif* crops over the country. In most parts of the country, normal sowing of major *kharif* crops could not be done due to the inadequate rainfall. Normal sowing window of many crops was closed and farmers carried out sowing of medium/short duration varieties of crops or go for sowing of alternate crops. Contingent crop planning was taken up in Gujarat, Maharashtra, Interior Karnataka, Rayalaseema, Telangana Haryana and West Rajasthan. However, the production of rice was quite stable in most of the rice growing subdivisions of the country. Flood situations affected rice and sugarcane in Uttar Pradesh and rice in Odisha and Jammu & Kashmir.There were no major incidences of pest and disease during the monsoon period. The impact of rainfall on the major *kharif* crops has been elaborately discussed in this report. For the season, IMD had issued Agromet Advisories for carrying out various agricultural operations like timely sowing, irrigation scheduling, fertilizer and pesticide application at district level. These advisories were based on the medium range weather forecasts and in collaboration with Agromet Field Units (AMFUs) located at State Agricultural Universities, ICAR institutes and IITs. Contingent crop planning was given based on the extended range weather forecast in collaboration with Indian Institute of Tropical Meteorology (IITM) Central Research Institute for Dryland Agriculture (CRIDA) and Indian Council of Agricultural Research, Hyderabad. Dissemination of the Agromet Advisories was done through various multi-channel systems including SMS and IVRS through private agencies.

15.3 Conclusions

The highlights of the 2014 southwest monsoon and conclusions are given below.

- The monsoon advanced over Andaman Sea 2 days prior to its normal date of 20th May and set in over Kerala on 6th June, 5 days later than its normal onset date. However, further advance was relatively slow.
- In spite of the regular but brief hiatuses during the advance phase, the monsoon covered the entire country on 17th July close to the normal date (15th July).
- Monsoon withdrew from west Rajasthan on 23rd September (a delay of more than 3 weeks) against the normal date of 1st September and from entire country, Bay of Bengal and Arabian Sea on 18th October.
- As in the previous year, though number (3) of intense low pressure systems (depression or above) formed during the season was less than normal (6), the number (10) of low pressure areas was more than normal (6). The increase in the number of low pressure areas helped in receiving near normal rainfall after large rainfall deficiency experienced till first half of July.
- For the country as a whole, the rainfall for the season (June-September) was deficient (88% of LPA). Seasonal rainfall was 79% of its LPA over Northwest India, 90% of its LPA over Central India, 93% of its LPA over south Peninsula and 88% of its LPA over Northeast (NE) India.
- South Interior Karnataka was the only subdivision out of 36 subdivisions to receive excess rainfall. Four (4) subdivisions (i.e. Himachal Pradesh, west Uttar Pradesh, east Uttar Pradesh and Telangana) were deficient/scantly during all the four months of the season.
- Out of 615 districts in the country, the season rainfall was excess in 56 (9.1%) districts, normal in 279 (45.4%) districts, deficient in 223(36.3) districts, scanty in 56 (9.1%) districts and no rainfall in 1 (0.1%) district. During last 10 years, after 2009, the highest number of districts (46%) to receive deficient/ scanty/no season rainfall was 2014.
- Due to large rainfall deficiency during June (-42% of LPA) the rainfall during the first half of the monsoon season was deficient (78% of LPA). However, the rainfall during the second half was normal (97% of LPA).

- The data from IMD AWS network and imageries and products from newly launched INSAT-3D satellites helped better monitoring and prediction of various features of southwest monsoon.
- The short and medium range forecasts based on GFS T574 showed better skill than last year.
- The forecast for monsoon onset over Kerala for this year was correct, which is the tenth consecutive correct forecast for this event since issuing of forecast for the event was started in 2005.
- All the operational long range forecasts for the 2014 southwest monsoon season rainfall over the country as a whole and that over 4 broad geographical regions were within the limits of second forecast update issued in August. The forecasts for the monthly rainfall (for the months July and August) and that for the second half of the monsoon season over the country as a whole were also within the forecast limits.
- The large rainfall deficiency in June was resulted from the delayed progress of the monsoon over these areas. The delayed monsoon progress in turn was caused by the below normal heating of the Indian subcontinent during the pre-monsoon season resulting in weaker than normal monsoon flow into the region. Monsoon gained its normal strength around the middle of July.
- The conditions over the equatorial Pacific during prior and early part of the monsoon season were close to be classified as the border line El Niño. Forecasts from several global models were also indicating formation of weak El Niño during the middle of the monsoon season. However, subsequent weak air-sea coupling over the region led to the weakening of border lineEl Niño conditions from early July resulting in ENSO neutral conditions during remaining part of the monsoon season. This helped monsoon to remain more or less normal thereafter.
- The season also witnessed strong intra seasonal variation with a long spell of monsoon break in the middle of August caused by unfavourable phases of MJO and short active monsoon spells during middle of July and early part of August caused by passage of low pressure systems along the monsoon trough region. In the early part of September, the interaction between the western disturbances moving across north India and monsoon low pressure systems caused increased rainfall activity over north, northwest India and central India. The country received near normal rainfall (94% of LPA) during the period July to September period. But due to the large rainfall deficiency in June, the 2014 season rainfall over the country as a whole (88% of LPA) ended as deficient (<90% of LPA).
- The large temporal and spatial variation in the rainfall during the season had adverse impact on the productivity and production of major kharif crops over the country except rice.

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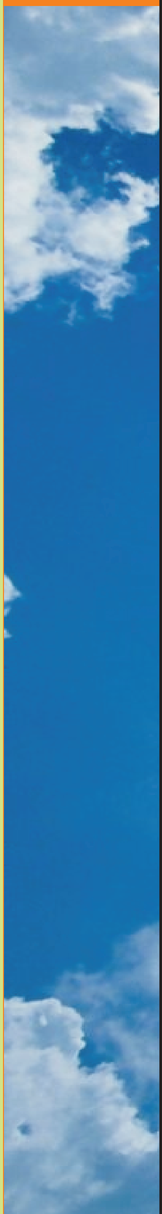

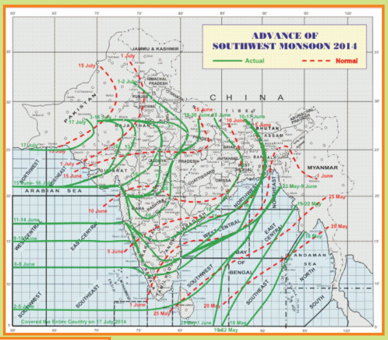

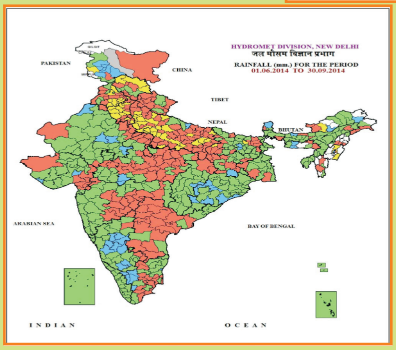

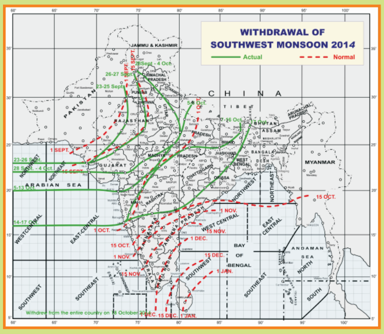

Monsoon 2014

A Report

DESIGNED & PRINTED AT
CENTRAL PRINTING UNIT,
OFFICE OF THE
ADDITIONAL DIRECTOR GENERAL
OF METEOROLOGY (RESEARCH),PUNE