MAUSAM, **64**, 2 (April 2013), 265-280

551.577.37 : 556.51

Synoptic study of extremely heavy rainfall events over lower Yamuna catchment : Some cases

MEHFOOZ ALI*, U. P. SINGH D. JOARDAR and NIZAMUDDIN

**Airport Meteorological Office, Jaipur, India*

India Meteorological Department New Delhi – 110 003, India

(*Received 17 March 2011, Modified 3 April 2012*)

e mail: mehfoozali.syed@gmail.com

सार – अत्यधिक वर्षा होने के कारण भूस्खलन होता है अक्समात बाढ़ आ जाती है और फसल को क्षति पहुँचती है। समाज, अर्थव्यवस्था और पर्यावरण पर इसका बहुत दुष्प्रभाव पड़ता है। पर्यावरणीय और सिनॉप्टिक स्थितियों के उत्पन्न होने से अत्यधिक अथवा बहुत भारी वर्षा होने के कारण भारत में दक्षिण पश्चिमी मानसून ऋतु के दौरान अधिकाँशतः बाढ़ आती है। इस शोध पत्र में प्रमुख सिनॉप्टिक कारणों का पता लगाने का प्रयास किया गया है जो लघु अवधि पूर्वानुमान के क्षेत्र में विकसित पूर्वानुमान तकनीक और आधुनिक प्रेक्षणात्मक प्रौद्योगिकी पर आधारित वर्ष 1998–2010 की अवधि की इस वर्षा और वायुमंडलीय प्रणालियों के मध्य संबंधों के विश्लेषण के माध्यम से यमुना के निचले जलग्रहण क्षेत्र (एल.वाई.सी.) में अत्यधिक भारी वर्षा की घटनाओं के लिए उत्तरदायी है। इस अध्ययन से यह पता चला है कि इस क्षेत्र में बंगाल की खाड़ी में निम्न दाब प्रणालियों का बनना प्रमुख कारक है निस्संदेह यदि स्थानीय स्थितियाँ प्रभावी हो जैसें कि गर्मी का बढ़ना तो वहाँ पर भारी वर्षा होती है। सामान्यतः बंगाल की खाड़ी में निम्न अबदाब प्रणालियाँ (चक्रवात, अवदाब, निम्न अवदाब क्षेत्र आदि जैसे (एल.पी.एस.) विकसित हुई जो पश्चिम से उत्तरी पश्चिमी दिशा की ओर बढ़ी तथा यमुना के निचले जलग्रहण (एल.वाई.सी.) क्षेत्र में पहुँची। ऐसी घटनाओं के लिए उत्तरदायी उपरितन वायु चक्रवाती परिसंचरण (साइसर) के प्रभाव से वहीं पर एल. पी. एस. भी बन सकता है। ऐसी प्रणाली से इक्के–दूक्के स्थानों पर अत्यधिक भारी वर्षा की घटनाएँ (सामान्यतः प्रणाली के दक्षिण पश्चिम क्षेत्र में) और कुछ स्थानों पर भारी से बहुत भारी वर्षा हुई जिसके कारण बाढ़ आई। यदि यमुना के निचले जलग्रहण (एल.वाई.सी.) क्षेत्र में एल.पी.एस. निष्क्रिय या धीमा पड़ जाता है तो इस प्रकार की वर्षा की घटनाओं की संभावना बढ़ सकती है। एल.पी.एस. के आगे बढ़ने का सही पूर्वानुमान देने के लिए आर.एस.एम.सी. (भारत मौसम विज्ञान विभाग) नई दिल्ली के पूर्वनुमान रूप रेखा के एन.डब्ल्यू.पी. उत्पाद/72, 48 और 24 घंटों के पवन चार्ट सही साधन पाए गए हैं। अत्यधिक वर्षा की घटनाओं के पूर्वानुमान में इस प्रकार की सूचना देने से पूर्वानुमानकताओं को निश्चित रूप से सही पूर्वानुमान मिलेगा ताकि जिला प्राधिकारी समय रहते आपदा की तैयारी के लिए आवश्यक मूलभूत सुविधाएँ उपलब्ध करा सकें।

ABSTRACT. Extreme rainfall results in landslides, flash flood and crop damage that have major impact on society, the economy and the environment. During southwest monsoon season, flood mostly occurs in India due to extremely or very heavy rain that originates from environmental and synoptic conditions. An attempt has been made to identify the main synoptic reasons, which are responsible for extremely heavy rainfall events over Lower Yamuna catchment (LYC) through the analysis of the relationship between this rainfall and atmospheric systems for the period 1998-2010 based on modern observational technology and developed forecasting technique in the field of short range prediction. The finding of this study show that the major factor have is the arrival of Bay of Bengal low pressure systems in this region, of course if the ascent local conditions such as heat occur, causing the heaviest rains there. The low pressure systems (LPS like, Cyclone, depression, low pressure area etc.) developed generally over Bay of Bengal moved in west to north-westwards direction and reached over the LYC region. Also LPS may be formed *in situ* under the influence of upper air cyclonic circulation (cycir) responsible for such events. Such system yield extremely heavy rainfall events **(**generally in the south-west sector of the system) at isolated places and heavy to very heavy rainfall at a few places and there by caused flood situation. The possibility of occurrence of such type of rainfall would be higher if the LPS is either stagnate or slow over LYC region. The NWP products of RSMC (IMD) New Delhi forecast contours / wind charts for 72, 48 & 24 hrs were found good tool for accurate forecast position of the movement of the LPS**.** Such information certainly facilitate to forecaster in prediction of extreme rainfall events more accurately so that district authorities may set up necessary infrastructures for disaster preparedness in time.

Key words – Synoptic systems, Atmospheric systems, Extremely heavy rainfall events, Low pressure systems, Floods.

1. Introduction

The southwest monsoon rainfall over India is characterized by heavy to very heavy rainfall events and in some cases extremely very heavy rainfall leading to floods over different parts of the country. Such type of rainfall events are caused by the interaction of basic monsoon flow with the orography and the synoptic

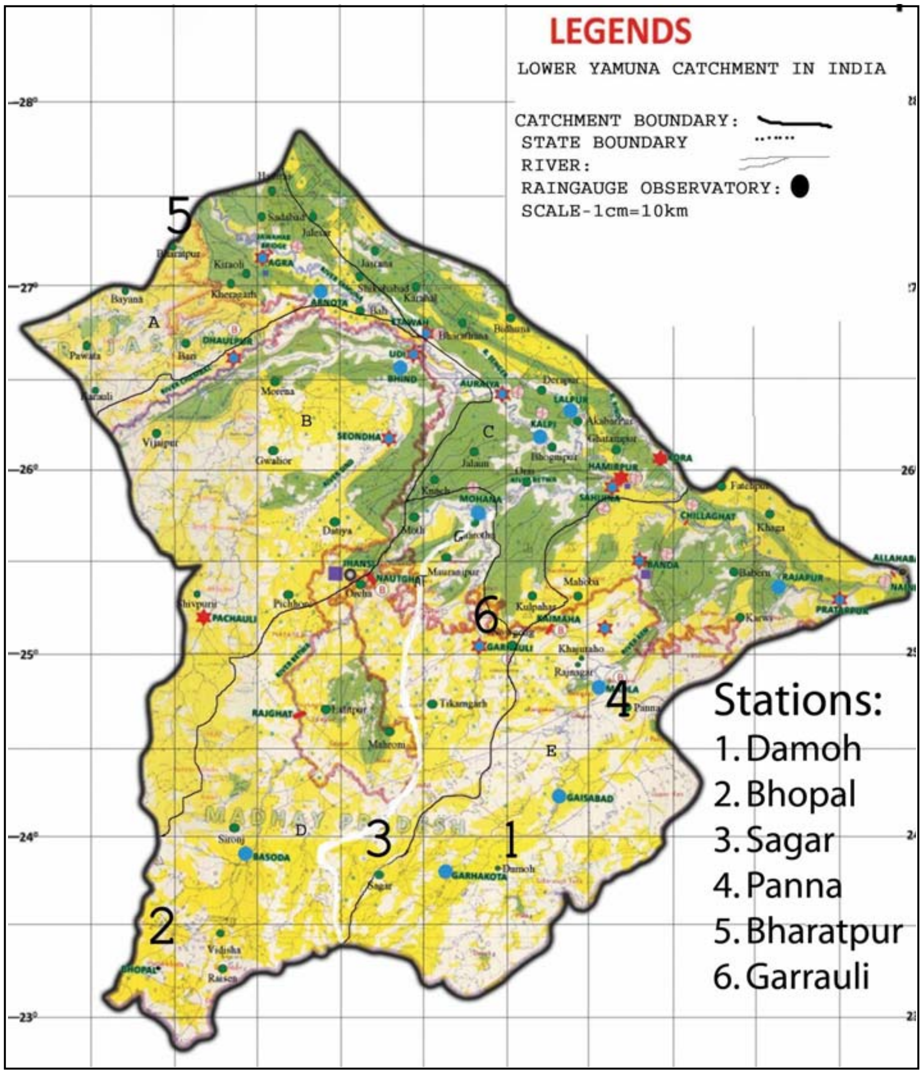


Fig. 1. Location of stations of case studies in Lower Yamuna catchment

disturbances developing over Indian regions. From the meteorological point of view, a flood is defined as a quantum of rainfall received over an area in excess of its long period average over that area during the period when it is expected to occur. Flood events often occur rather suddenly so there may not be enough time to implement disaster mitigation measures. A good understanding of the causes of individual floods is therefore crucial in increasing the lead time for issuing warnings. From the insurance perspective, such an understanding could provide a better estimate of the possible losses. Flood in India mostly occur during southwest monsoon season due to extremely or very heavy rain caused by synoptic scale monsoon disturbances. Most of such cases have been noticed in July and August months. By definition synoptic climatology is the scientific study of the connection between atmospheric circulation and superficial environment, since it is geared to elucidating important interaction between atmospheres and superficial environment, it has theoretical and applied value. The synoptic disturbances are the low pressure systems (LPS, like cyclonic storms, depression, low pressure episodes etc.), generally formed over Bay of Bengal, and played a notable role during southwest monsoon season. These systems yield copious rainfall over a wide area through convergence and vertical motion associated with them. A large proportion of these systems formed over Bay of Bengal moved west-north-westwards, crossing coast, reached over Madhya Pradesh and adjoining Uttar Pradesh, Rajasthan, either as depression or lopar/or an upper air cyclonic circulation, causing heavy to very heavy rain in some areas with isolated extremely heavy rain during their movement. Dasggupathy and Sikka (1977) found that westward movement of monsoon depression is due to production of vorticity in western sector. Murkami (1977) made spectrum analysis of monsoon lows while Sarkar and Chowdhary (1988) had a diagnostic study of monsoon depression. Godbole (1977) studied structure and movement of the monsoon depression. Kalsi (2003) documented the flow features, which are associated with the important synoptic systems that affected the Bay of Bengal and its neighbourhood and controlled the convective activity during BOBMEX that commenced on 15 July, 1999 and continued to first week of August 1999. De *et al*., (2005) presented a factual and a brief review of the extreme weather events that occurred in India during the last 100 years (1901-2004), discussed specially the major rainstorms causing havoc flood situation. Floods are a major disaster in India in term of occurrences (41% of total disasters) as well as in casualties (De *et al*. 2002). Extreme rain are becoming more common in India as more moderate rains decline, increasing the risk of flooding, according to various studies. Gandomkarr (2007) concluded in his investigation that crossing of Mediterranean cyclone and westerly winds are main reasons for the rainfall in headstream of Zayandehrood basin. Extreme rainfall results in landslides, flash flood and crop damage that have major impact on society, the economy and the environment. Although the prediction of such extreme events is still fraught with uncertainties, a proper study would certainly facilitate to forecaster and to district authorities in setting up infrastructures for disaster preparedness.

There has been many studies on heavy rainfall over different regions. Ganeshan and Prasad (1985) examined synoptic features responsible for the occurrence of heavy spells in and around Jaipur. Gupta (1984) discussed unprecedented floods in July in south Rajasthan. Dubey and Balakrishnan (1992) have studied the frequency distribution of very heavy rainfall days over different stations in Madhya Pradesh and the causatives systems of these very heavy rainfall events. Desai *et al*. (1996) studied some cases of very heavy rainfall over Punjab, Himachal Pradesh and Haryana during 24-27 September 1988. Loe *et al*., (2005) discussed some typical cases of synoptic situations which caused onset over Rajasthan with heavy rainfall there. Rakhecha and Pisharoty (1996) have studied point and spatial distribution of heavy rainfall over India during monsoon season. Jayashree and Anil Kumar (1997) studied some aspects of daily rainfall distribution over a high range river basin in Central Kerala pointed out that half of the seasonal rainfall which contributes 80% of the total rainfall is of low intensity. Sengupta (1986) studied synoptically some cases, which caused localized floods in Rajasthan due to exceedingly heavy rain associated with intense upper air anticyclonic circulation. Ali *et al*., (2011) discussed some cases of heavy rainfall synoptically and concluded that QPF model over LYC may predict accurately the extreme rainfall events. In this study there is an attempt to recognize the atmospheric systems that cause extremely heavy rainfall (rainfall amount ≥ 245 mm) events over some stations *viz*., Damoh, Bhopal, Sagar, Panna, Bharatpur and Garrauli (depicted in Fig. 1) in LYC region during the period 1998-2010 and to forecast the placement of these systems and rainfall in order to warn executives and help them in crisis management and prevention of massive destruction. It will certainly facilitate to forecaster to predict QPF for extreme rainfall.

Ali *et al*., (2011) described fully the Lower Yamuna Catchment (LYC). Here it is summarized that LYC region comprises of land area in three States *i.e*., Uttar Pradesh, Rajasthan and Madhya Pradesh in which lower Yamuna flows from Agra to Naini (Allahbad) whose main tributaries are Chambal, Ken, Sind and Betwa. Basin of Ken river covers the areas of Sagar, Damoh, Panna, Satna, Chhatarpur and Raisen districts of Madhya Pradesh and Hamirpur and Banda districts of UP in LYC. The Betwa river covers the areas the Malwa plateau and the Vinhyan scrap lands in the districts of Tikamgarh, Sagar, Vidisha, Raisen, Bhopal, Guna, Shivpuri and Chhatarpur, of MP and Hamirpur, Jalaun, Jhansi and Banda districts of UP in LYC region.

2. Data

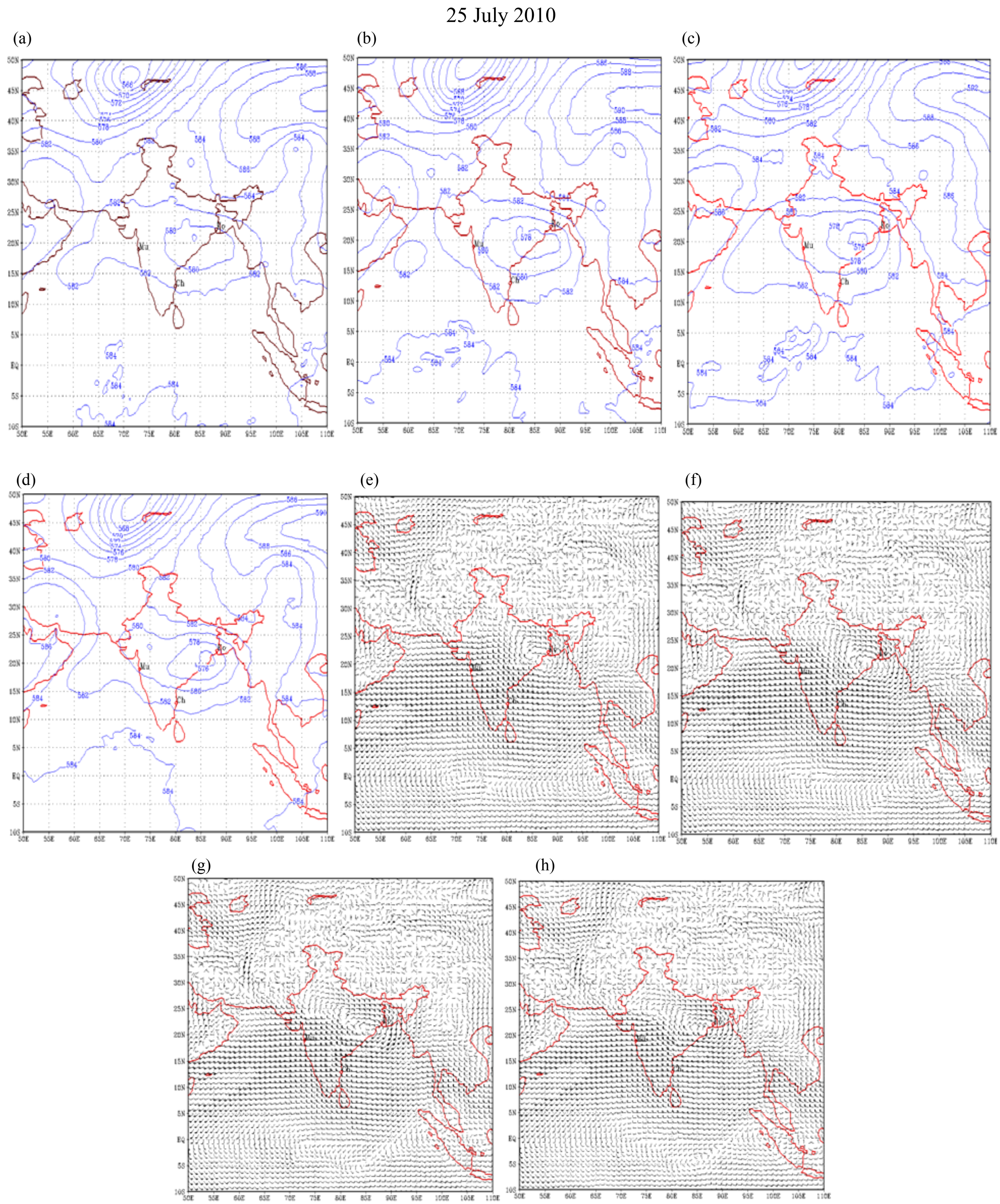
From the period 1998-2010, the daily rainfall accumulated in 24 hours recorded at 0830 hrs (IST) over different rainguages in LYC region during monsoon month (June-September) were analysed and some cases of rainfall ≥ 245mm were extracted. Afterwards the corresponding Synoptic charts and Indian Daily Weather Reports and IMD publication journal Mausam for the period were analysed.

3. Discussion of results

Some cases of extremely heavy rainfall

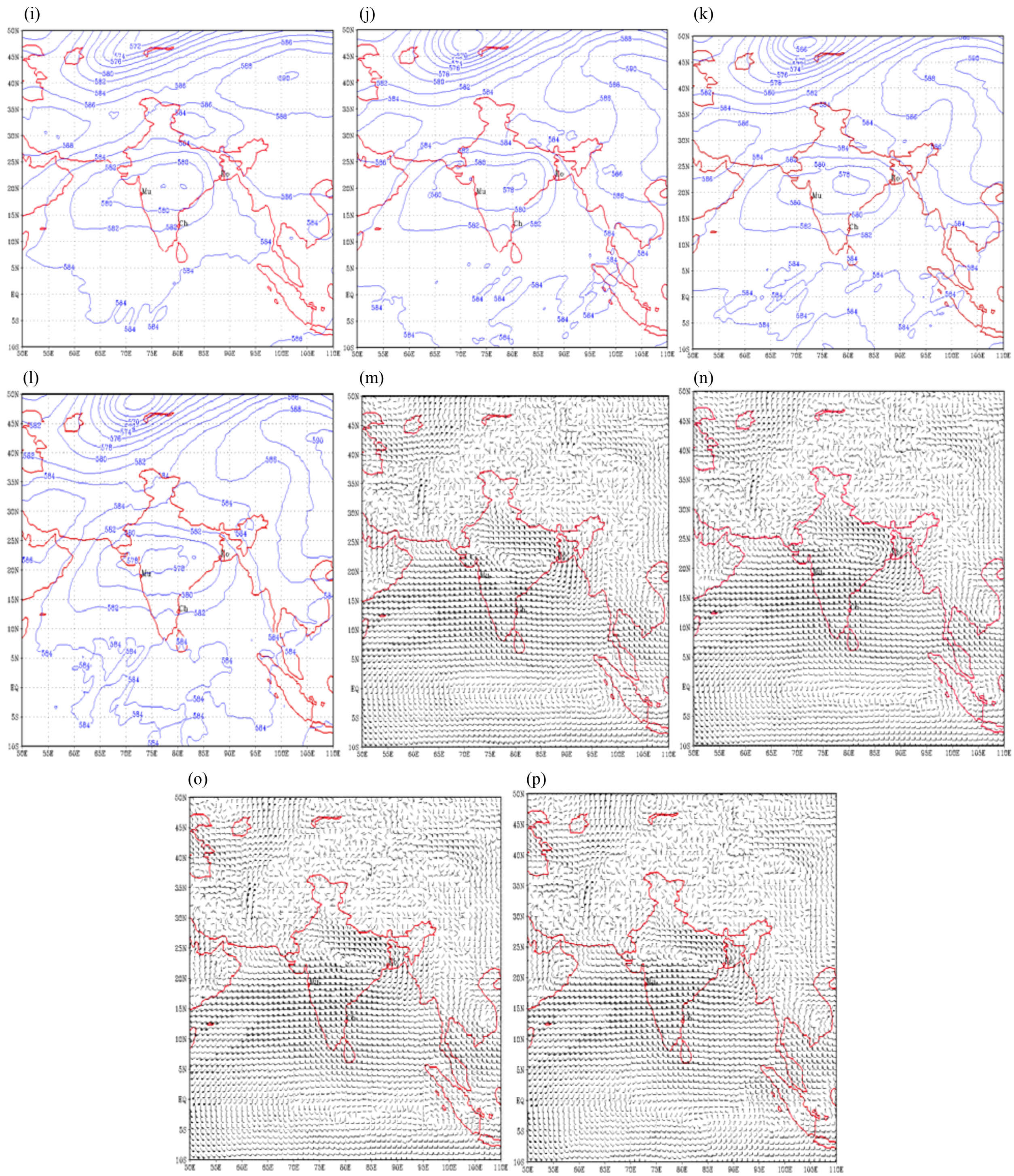
3.1. *Extremely heavy rain in Damoh (west-MP) in 2010*

(*i*) Damoh (station no.1, Fig. 1) is a place in Sagar division of northeast Madhya Pradesh lies 260 km east of Bhopal. Its lies at Lat. 24° 24′ N and Long. 79° 45′ E at elevation of 595 meters above mean sea level (a.m.s.l). The annual normal rainfall (r/f) is 1270 mm and in south-west monsoon season is 1130 mm. In July month, r/f is 391 mm.

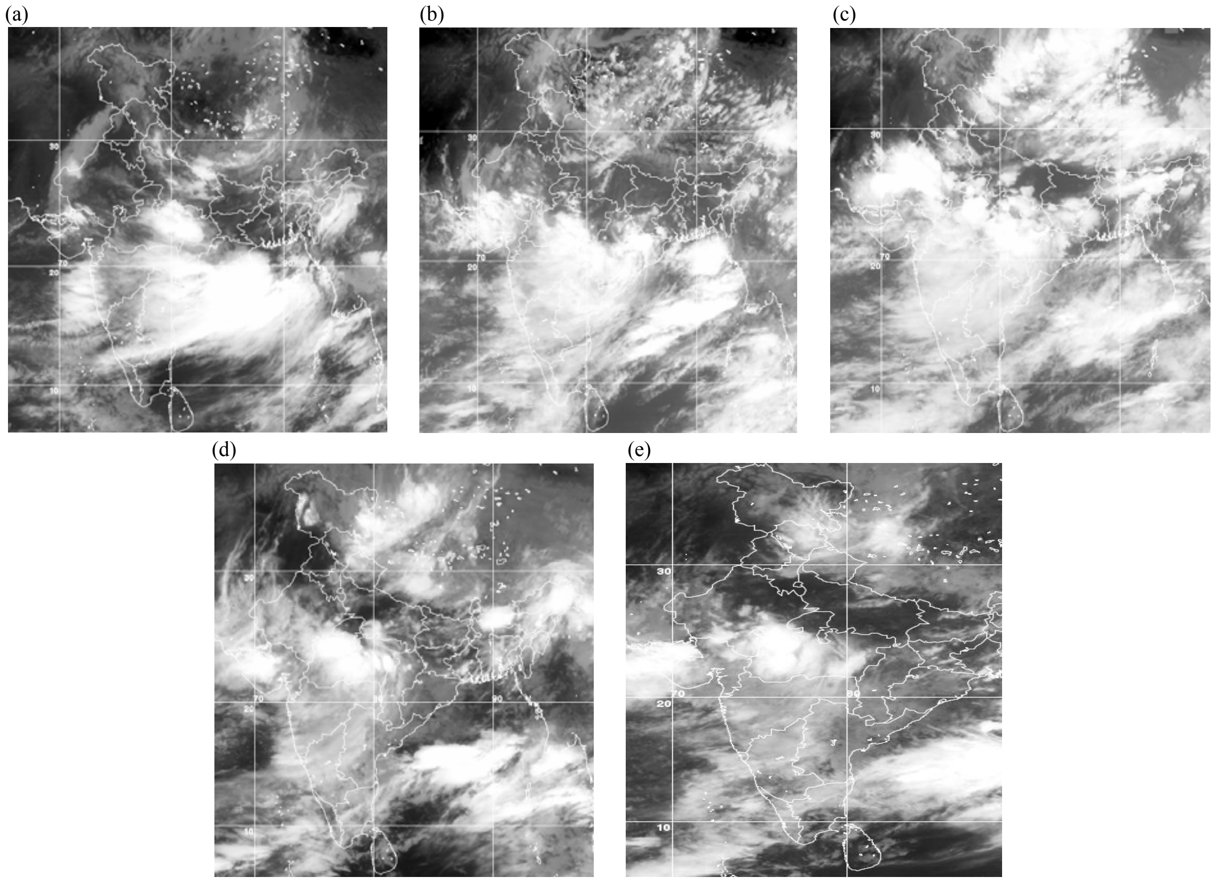


Figs. 2 (a-h). (a) ECMWF 500 hPa, 72 hrs Forecast (f/c); valid for 0000 UTC 25 July, 2010, (b) ECMWF 500 hPa 48 hrs forecast; valid for 0000 UTC 25 July, 2010, (c) ECMWF 500 hPa 24 hrs forecast ; valid for 0000 UTC 25 July, 2010, (d) ECMWF 500 hPa, analysed chart 0000 UTC, 25 July, 2010, (e) ECMWF 850 hPa forecast wind, 72 hrs valid for 0000 UTC, 25 July, 2010, (f) ECMWF 850 hPa forecast wind, 48 hrs, valid for 0000 UTC 25 July, 2010, (g) ECMWF 850 hPa wind, 24 hrs, forecast for 0000 UTC, 25 July, 2010 and (h) ECMWF 850 hPa wind, Analysed chart of 0000 UTC, 25 July, 2010

26 July 2010



Figs. 2(i-p). (a) ECMWF 500 hPa, 72 hrs forecast; Valid for 0000 UTC 26 July, 2010, (j) ECMWF 500 hPa, 48 hrs forecast; Valid for 0000 UTC 26 July, 2010, (k) ECMWF 500 hPa 24 hrs forecast; Valid for 0000 UTC 26 July, 2010, (l) ECMWF 500 hPa, Analysed chart of 0000 UTC, 26 July 2010, (m) ECMWF 850 hPa forecast wind, 72 hrs valid for 0000 UTC, 26 July, 2010, (n) ECMWF 850 hPa forecast wind, 48 hrs valid for 0000 UTC, 26 July, 2010 (o) ECMWF 850 hPa forecast wind, 24 hrs valid for 0000 UTC, 26 July, 2010 and (p) ECMWF 850 hPa wind, Analysed chart of 0000 UTC, 26 July, 2010

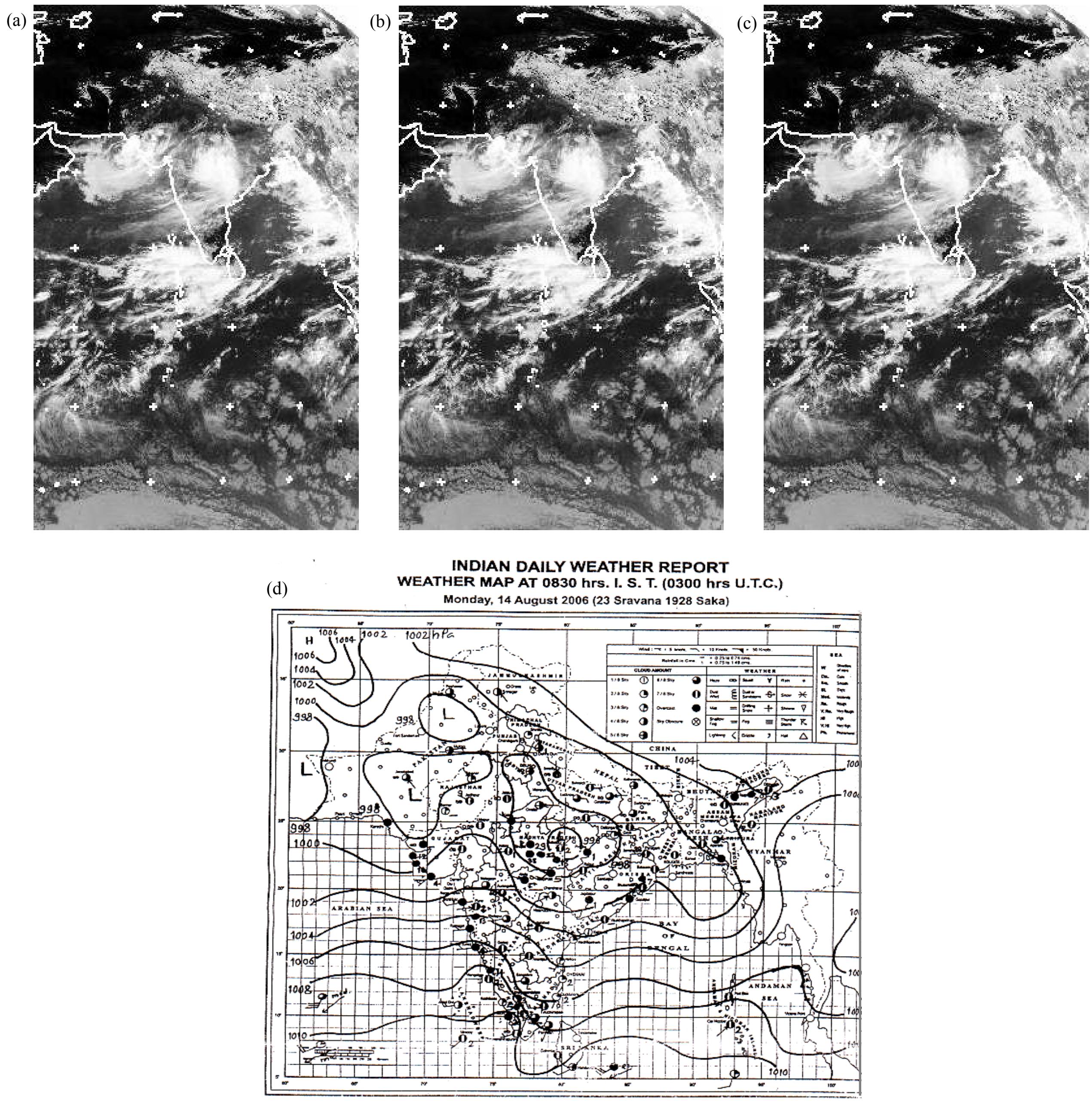


Figs. 3(a-e). Sat-Kalpana-1, (a) IR 0300 UTC, 24 July, 2010, (b) IR 0600 UTC, 25 July, 2010, (c) IR 1200 UTC, 25 July, 2010, (d) IR 2100 UTC, 25 July, 2010 and (e) Kalpana-1, I R, 0300 UTC, 26 July, 2010

(*ii*) Synoptic situation : Low pressure area (24-28 July 2010).

A low pressure area formed over northwest Bay on 24 morning. It intensified as well marked low pressure area and lay over Orissa and adjoining northwest Bay on 25 morning, it extended up to 500 hPa as depicted in Fig. 2(d). The associated upper air cyclonic circulation (cycir) at 850 hPa was shown in Fig. 2(h). Moving north-westwards, it lay over northern parts of Madhya Pradesh as a low pressure area on 26 morning as, it's extension up to 500 hPa shown in Fig. 2(f). The associated cycir at 850 hPa was presented in Fig. 2(p). ECMWF contour chart at 500 hPa and 850 hPa wind forecast charts for 72, 48 and 24 hr. valid for 0000 UTC of 25 and 26 July, 2010 are presented in Figs. 2 (a) to 2(c), 2(e) to 2(g), 2(i) to 2(k) & 2(m) to 2(o) respectively and observed mostly resemblance with the analysed charts and visualized movement of the synoptic system in north-westwards direction. It moved north-westwards and lay over southeast Rajasthan & adjoining Gujarat on 27 morning. Moved westwards, it lay over Kutch & adjoining southeast Pakistan on 27 evening and merged with monsoon trough on 28 morning. On 26 morning the axis of monsoon trough at m.s.l. passes through Jaisalmer, Jodhpur, centre of lopar, Ambikapur, Sagar and thence south-eastwards to east-central Bay. It extended up to mid-tropospheric level (MTL) tilting southward and passes through Bhuj, Indore,, Jabalpur, Jamshedpur, Digha & thence south-eastwards in to Bay. The associated cyclonic circulation (cycir) extended up to MTL.

The progressive movement & development of multilayered deep convective clouds towards northeast MP including station Damoh may be seen in IR imageries of Sat-Kalpana-1 in Fig. 3(a) 0300 UTC of 24 July, in Fig. 3(b), 0600 UTC of 25 July, in Fig. 3(c), 1200 UTC of 25 July, in Fig. 3(d), 2100 UTC of 25 July, Fig. 3(e), 0300 UTC of 26 July, 2010 associated with the synoptic systems.



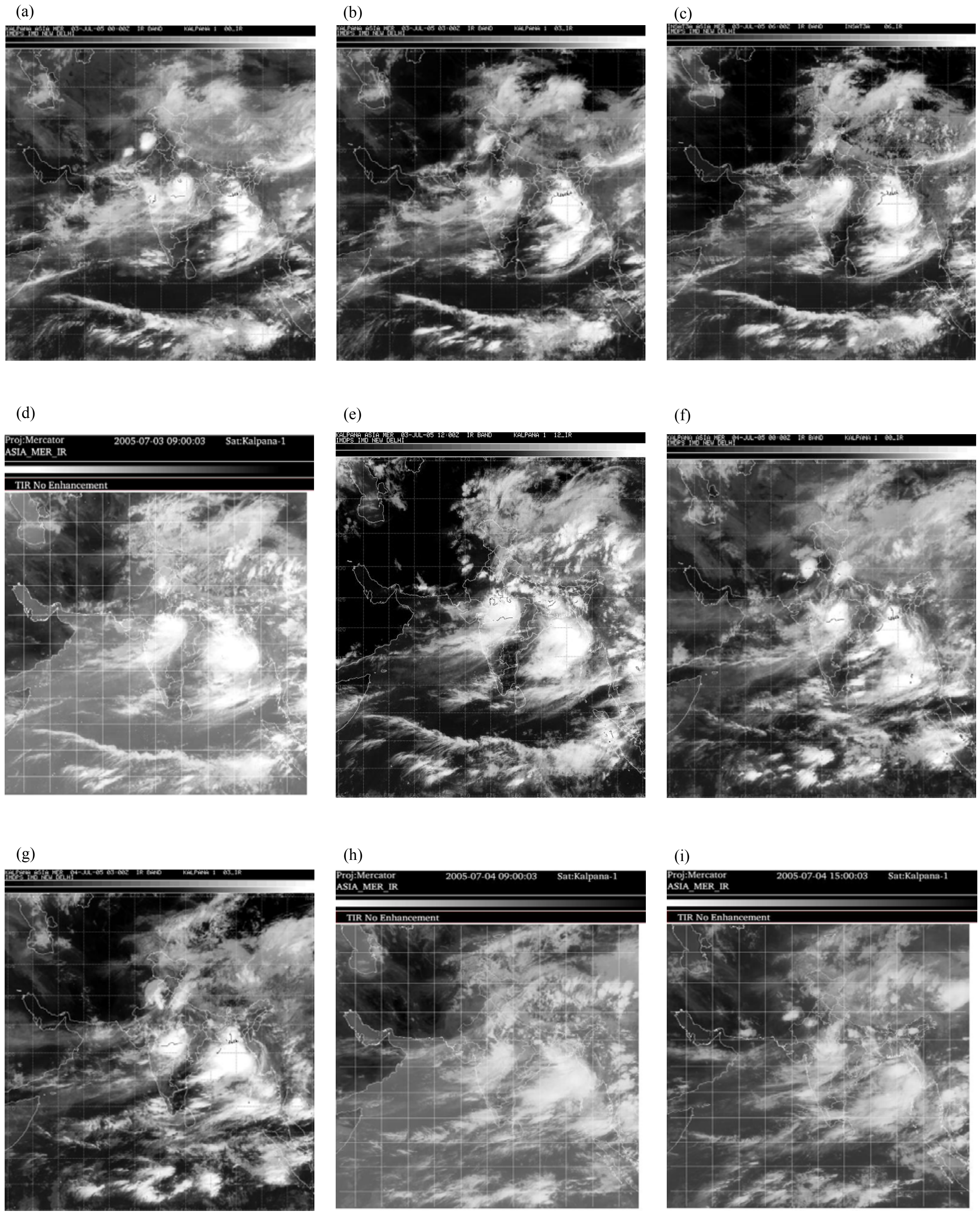
Figs. 4(a-d). (a) Image, 0600 UTC, 13 August, 2006, (b) Dundee, IR, 1200 UTC, 13 August 2006, (c) Dundee, IR, 0000 UTC, 14 August 2006 and (d) 0300 UTC, Surface weather chart, 14 August, 2006

Under the influence lopar & associated cycir extending up to MTL, Damoh (it was in the southwest sector of lopar) with the orography effect recorded 253.6 mm of rainfall on 26 July at 0300 UTC in 24 hours. The previous rainfall record was 247.7 mm on 3 August 1900 and on 18 July 1973 225.1 mm.

On 26 July, 2010 at 0300 UTC the other stations in LYC reported rainfall amount (in mm) in 24 hours as follows: (*i*) Very heavy rainfall in Mahroni : 139 and Sagar : 130.4, and heavy rainfall in Sironj : 120 and Shivpuri : 74

3.2. *Extremely heavy rain in Bhopal (west-MP) in 2006*

(a) Bhopal (station no.2, Fig. 1) is located at Lat. 23° 16′ 11″ N and Long. 77° 20′ 23″ E with an average



Figs. 5(a-i). (a) Sat. Kalpana-1 IR 0000 UTC / 03 July, 2005, (b) Sat. Kalpana-1 0300 UTC / 03 July, 2005, (c) Sat. Kalpana-1 IR 0600 UTC / 03 July, 2005, (d) Kalpana-1 IR 0900 UTC / 03 July, 2005, (e) Kalpana-1, IR 1200 UTC / 03 July, 2005, (f) Kalpana-1, IR 0000 UTC / 04 July, 2005, (g) Kalpana-1, IR 0300 UTC / 04 July, 2005, (h) Kalpana-1, IR 0900 UTC / 04 July, 2005 and (i) Sat. Kalpana-1, IR 1500 UTC, 04 July, 2005 elevation of 499 meters (1637 ft) a.m.s.l. Bhopal is capital of Madhya Pradesh, lies in the central part of India, and is just north of the upper limit of the Vindhyan mountain ranges. Located on the Malwa plateau, it is higher than the north Indian plains and the land rises towards the Vindhyan range to the south. The city has uneven elevation and has small hills within its boundaries. The major hills in Bhopal comprise of Idgah hills and Shyamala hills in the northern region and Arera hills in the central region.

In Bhopal, the monsoon starts in late June and ends in late September. These months see about 1023 mm of precipitation, frequent thunderstorms and flooding. While its annual normal rainfall is about 1123 mm.

(b) From the night of 13 August till morning 14 August 2006, Bhopal received 291.6 mm in (with a span of 5 hours at night, in a heavy downpour) that caused havoc to the city & its dwellers. 22 people dead, several area submerged, major trains halted outside the city and Army was called to cop with the situation. More than 1.05 lakh people were affected and 600 heads of cattle & poultry perished. Before the recent incidence it was in 22 July, 1973, city received 27 cm rainfall in 24 hours.

(c) Synoptic situations : Depression over the north Bay (12-13 August 2006) under the influence of an upper air circulation over the north Bay, a low pressure area formed there by 1200 UTC of 11, which concentrated in to a Depression and lay centered at 0300 UTC of 12 near Lat. 21.0° N / Long. 87.5° E (about 100 km east-southeast of Balasore) and at 1200 UTC near Lat. 21.0° N / Long. 87.5° E. It crossed Orissa coast, close to Balasore around 1500 UTC of 12, weakened into a well marked low and lay over Chhatisgarh and neighbourhood on 0000 UTC of 13. It moved north-westwards and lay over east Madhya Pradesh and neighbourhood on 0000 UTC of 14, as shown in Fig. 4(d) and as a low pressure area over west Madhya Pradesh and adjoining southeast Rajasthan on 0000 UTC of 15 & 16. Saurashtra & Kutch and adjoining northeast Arabian sea during 17-19 and became less marked on 20 [(Mausam, (2007)].

Due to low pressure area with associated cycir extending up to MTL and orography effect, on 14 August 2006 in 24 hours, extremely heavy rainfall 291.6 mm was occurred in Bhopal [it was in the southwest sector of well marked lopar at 0000 UTC of 14, as depicted in Fig. 4(d)]. In Fig. 4(a) IR imageries, 0600 UTC & Fig. 4(b) 1200 UTC of 13 August, Fig. 4(c) 0000 UTC of 14 August visualised the movement of the intense convective cluster of clouds (*Courtesy* : University of Dundee) over Bhopal region and neighbourhood, associated with the system.

The other stations in LYC rainfall recorded (in mm) in 24 hours as follows: Very heavy rainfall in Raisen:209 and Sironj:130 and heavy rainfall in Vidisha:110.

3.3. *Extremely heavy rain in Sagar,(west-MP) and Panna (east-MP)in 2005*

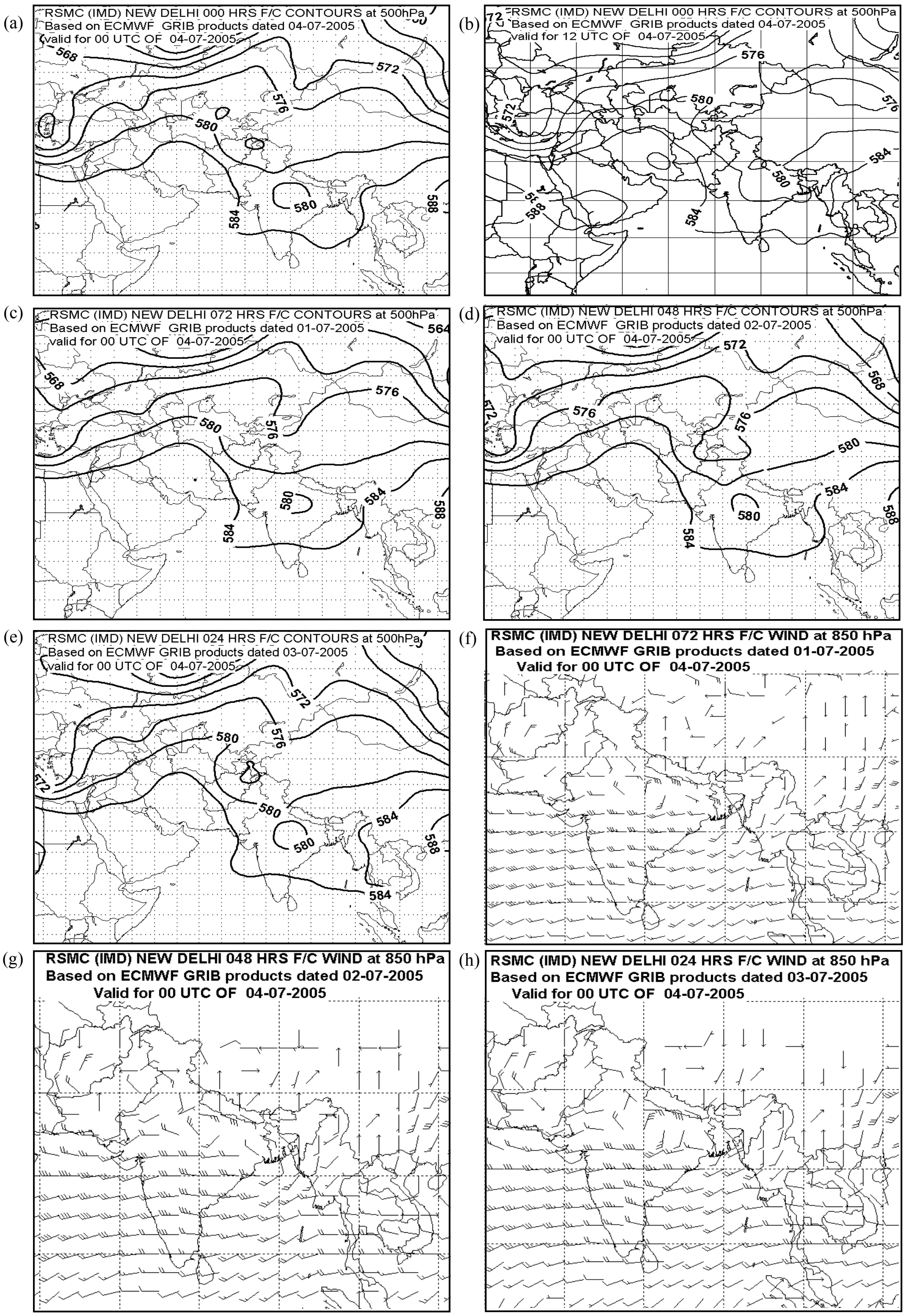
(a) Panna (station no.4, Fig. 1) is situated in the Vindhyan range Lat. 24.72° N and Long. 80.2° E at an elevation of 433 meters a.m.s.l. and spreads over Panna and Chhatarpur districts in the northern part of the Madhya Pradesh state of India. The Ken river, which flows through the National Park from south to north.

The terrain of the Reserve is characterised by extensive plateaus and gorges. The topography in the Panna district part of the Reserve can broadly be divided into three distinct tablelands - the upper Talgaon Plateau, the middle Hinouta Plateau and the Ken valley while there are series of undulating hills and plateaus on the other side of Ken river in the Chhatarpur district. The annual normal rainfall is 1215.5 mm and in south-west monsoon season is about 1086.3 mm. The previous record of rainfall was 365.3 mm on 8 August 1919.

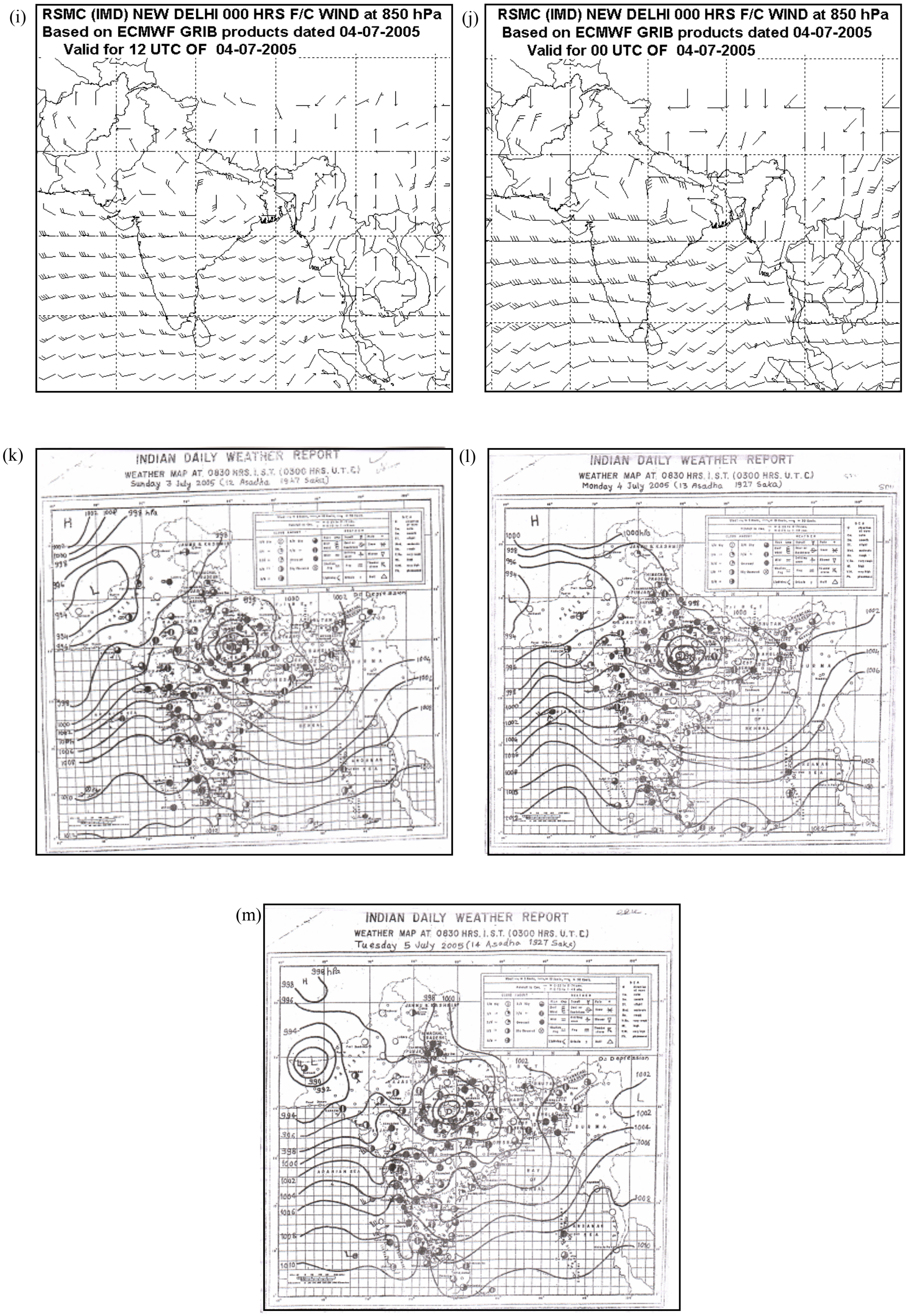
Sagar (station no.3, shown in Fig. 1) is known as city of lakes, is a city in Madhya Pradesh in a picturesque situation on a spur of the Vindhya range at 594 meters elevation a.m.s.l. The annual normal rainfall of Sagar is 1229.4 mm and in south-west monsoon season is about 1112.5 mm. The previous record of highest rainfall was 284.5 mm on 10 July 1904.

(b) Synoptic system: Depression (27 June - 5 July 2005)

A depression formed over Gangetic West Bengal and adjoining northwest Bay centred close to Kolkata at 1200 UTC of 27. Moving west wards, it lay over Jharkhand, centred near Jamshedpur till 0300 UTC of 29. Subsequently moving in a west-north-westerly direction it lay close to Ranchi at 1200 UTC of 29. It lay close to Daltonganj at 0300 UTC of 30; Sidhi at 1200 UTC of 30 June; Rewa at 0300 UTC of 1 July; Khajuraho from 1200 UTC of 1 to 4 and near reached over east Madhya Pradesh, and near Nowgong on 5, extended up to 500 hPa as shown in Figs. 6(a&b) analysed contour at 500 hPa. In Figs. 6(i&j) presented wind at 850 hPa of 0000 & 1200 UTC of 4 July respectively showing cyclogenesis. It weakened in to a well marked low pressure area over northwest Madhya Pradesh & adjoining west Uttar Pradesh & east Rajasthan on 6 morning. It moved over to west Uttar Pradesh & neighborhood on 7. Associated Cycir was extended up to to 7.6 km above m.s.l.



Figs. 6(a-h). (a) 0000 UTC analysed chart of 500 hPa of 04 July, 2005, (b) 1200 UTC, analysed chart of 500 hPa of 04 July, 2005, (c) 72 hours forecast contours at 500 hPa based on 01 July, 2005, (d) 48 hour forecast contours at 500 hPa based on 02 July, 2005, (e) 24 hour forecast contours at 500 hPa based on 03 July, 2005, (f) 72 hrs forecast wind at 850 hPa valid for 0000 UTC 04 July, 2005, (g) 48 hrs forecast wind at 850 hPa valid on 0000 UTC, 04 July, 2005 and (h) 24 hrs forecast wind at 850 hPa valid on 0000 UTC, 04 July, 2005



Figs. 6(i-m). (i) Wind at 850 hPa valid on 1200 UTC, 04 July, 2005, (j) wind at 850 hPa valid on 0000 UTC, 04 July, 2005, (k) 0300 UTC, Surface weather chart, 03 July, 2005, (l) 0300 UTC, Surface weather chart, 04 July, 2005 and (m) 0300 UTC, Surface weather chart, 05 July, 2005

RSMC contour at 500 hPa forecast charts for 72, 48 and 24 hrs valid for 0000 UTC of 4 July, 2005 are presented in Figs. 6 (c-e) & and 850 hPa wind f/c charts in Figs. 6(f-h) respectively and observed identical approximately with the analysed charts showed in Figs. 6(a&b) contour at 500 hPa and 850 hPa wind showed in Figs. 6(i&j) valid for 0000 UTC & 1200 UTC of 4 July respectively.

The track of this depression was presented by Ali *et al*., (2011). The land depression had a very slow translatory movement on 30 June. It remained stationary near Khajuraho during 1 evening to 4 July and near Nowgong on 5 July, the location of depression may be seen in Surface weather maps in Fig. 6(k), 0300 UTC of 3 July, Fig. 6 (l), 0300 UTC of 4 July and Fig. 6(m), 0300 UTC of 5 July. This was typical monsoon depression, being embedded in an environmental of westerlies to the south and easterlies to the north. The upper level easterlies also had been quite weak. The system caused persistent exceptionally heavy rainfall. Sixty two people dead and 1 million people in six towns and 358 villages were severely affected. Sagar, Chattarpur, Damoh, Sahra, Riva and Katni were the worst affected areas [(Mausam, (2006)].

In addition an upper air cycir extending up to MTL, lay over north Pakistan and adjoining Jammu & Kashmir from 1 to 4 July, causing moisture incursion from Arabian sea also simultaneously from Bay.

With the association of the system, the development and intensification of organized convective clouds with vortex over Sagar and neighbourhood can be seen in satellite IR imageries of 0000, 0300, 0600, 0900 & 1200 UTC of 3 July, in Figs. 5 (a-e) and convection weakening as showed in imageries of 0000, 0300, 0900, 1500 UTC of 4 July, in Figs. 5(f-i) respectively.

Under persistency of depression (from 1200 UTC of 1 to 0000 UTC of 4 July) with associated cycir extending up to 7.6 km a.m.s.l. and orography influence, on 3 July, station Panna (it was in the southern sector of depression) recorded extremely heavy rainfall of amount of 255.0 mm in 24 hours, the other stations in catchment recorded as follows: Very heavy rainfall in Madla:211.6 and Damoh : 132.4, heavy rainfall in Sagar : 117.3, Khajuraho:74.7 and Nowgong : 74.

On 4 July, under the influence of the persistency of depression (from 1200 UTC of 1 to 0000 UTC of 4 July) with associated cycir extending up to 7.6 km a.m.s.l. and orography effect, Sagar (it was in the southwest sector of the depression) recorded extremely heavy rainfall 475.6 mm in 24 hours, the other stations recorded very heavy rainfall (in mm) in Damoh : 240.4 mm and Raisen : 131.6 and heavy rainfall in Lalitpur : 116.0, Guna : 73.5, Kaimaha : 73.0, Mahroni : 70.0 and Pichchore : 73.0.

On 5 July very heavy rainfall recorded (in mm) in Damoh : 188.4, Raisen : 152.0, and heavy rainfall in Mahroni : 110.0, Sironj : 86.0, Bhopal : 85.7 and Sagar : 71.8.

From 3 to 5 July, Sagar Damoh and Panna recorded cumulative rainfall 664.7 mm, 561.2 mm and 336 mm respectively.

3.4. *Extremely heavy rain in Bharatpur (east-Rajasthan) in 2003*

(a) Bharatpur (Station no.5, Fig. 1) is located on the fringes of the Thar desert lying at Lat. 27° 13′ N and Long. 77° 28′ 60″ E at eastern boarder of Rajasthan. There are only three main seasonal rivers in this district, namely Chambal, Ban Ganga, and Gambhir. Ban Ganga starts from Ramgarh Dam of Jaipur District, flow through the places of Swaimadhopur, Bharatpur and then finally meets to Yamuna. Gambhir River starts from Pachana Dam of Karauli, the river finally falls in the river Yamuna. Bharatpur is also popular for its Birds Sanctuary. The annual normal rainfall of Bharatpur is 650 mm and in monsoon season 587 mm (90% of annual).

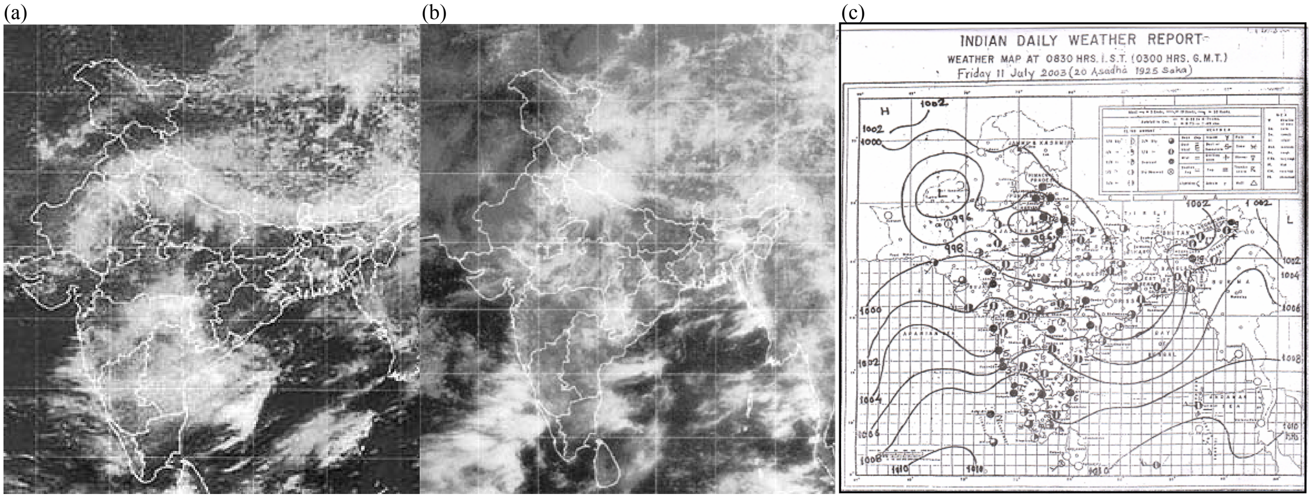
(b) *Synoptic system: Low pressure area (10-13 July, 2003)*

A lopar formed over Haryana and adjoining areas of east Rajasthan and west Uttar Pradesh on 1200 UTC of 10 under the influence of a cyclonic cycir over central parts of Rajasthan and adjoining areas on 0000 UTC of 10. The lopar may be seen at 0300 UTC in surface weather map of 11 July, 2003 in Fig. 7 (c). The associated cycir was extending up to MTL. It persisted till 13 and became less marked on 14. In addition an upper air cycir extending up to MTL, lay over north-Pakistan and adjoining Jammu & Kashmir persisted from 9 to 12 and moved away on 13 to western Himalayas. [Mausam, (July, 2004)]. Sat-Kalpana-1, VIS imagery showed scattered to broken medium clouds with convection over east Rajasthan on 10 & 11 July respectively in Figs. 7(a&b).

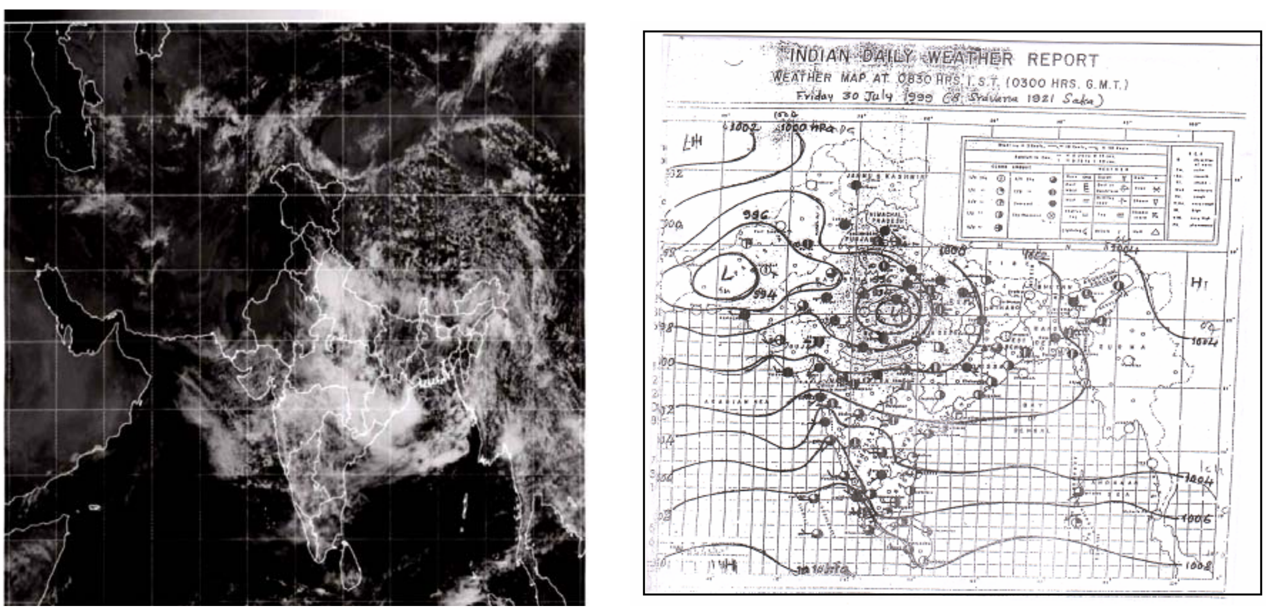
(c) Under the influence of lopar and western disturbance as described above, Bharatpur (it was in the southern sector of the lopar) recorded 269.4 mm rainfall (r/f) on 10 July, 2003 in 24 hours (normal r/f of July of Bharatpur is about 201 mm) which is all time record since 1900.

The other stations in LYC recorded rainfall (in mm) as follows: Heavy rain in Agra: 79.0, Hathras: 92.0, Iglas: 82.0, Khurja: 97.0.

(a) (b) (c)



Figs. 7(a-c). Kalpana-1, VIS., 0600 UTC / 10 July, 2003, (b) Kalpana-1, VIS., 0600 UTC / 11 July, 2003 and (c) 0300 UTC, Surface weather chart, 11 July, 2003



Figs. 8(a&b). (a) INSAT VIS 0600 UTC, 27 July, 1999 and (b) 0300 UTC, Surface weather chart, 30 July, 1999

Also the system caused rain / thunder showers at most places in Rajasthan and west-Uttar Pradesh with heavy to very heavy rainfall at a few places in the remaining parts of east Rajasthan.

3.5. *Extremely heavy rain in Garauli (east-MP) in 1999*

(a) The station Garauli (Station no.6, Fig. 1) lies in the district of Chhatarpur (west-Madhya Pradesh), at Lat. 25° 05′ N and Long. 77° 28′ 60″ E and an elevation of 215 meter a.m.s.l.

The average annual normal rainfall is 873.3 mm and in southwest-monsoon season is 808.3 mm. The previous highest rainfall recorded in 24 hours was 170.4 mm on 27 July, 1917.

(b) *Synoptic system: Deep depression (27-29 July, 1999)*

A low pressure area formed over northwest Bay and adjoining West Bengal coast on 24 morning. It became well marked on 26 evening. It concentrated into a depression at 0300 UTC of 27 and lay centered near Lat.

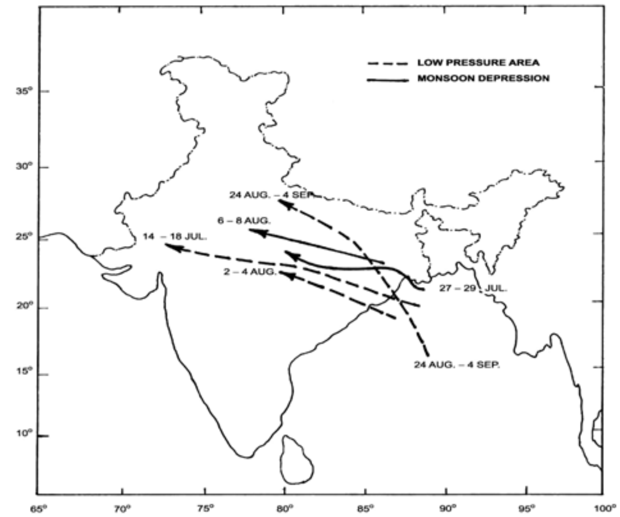
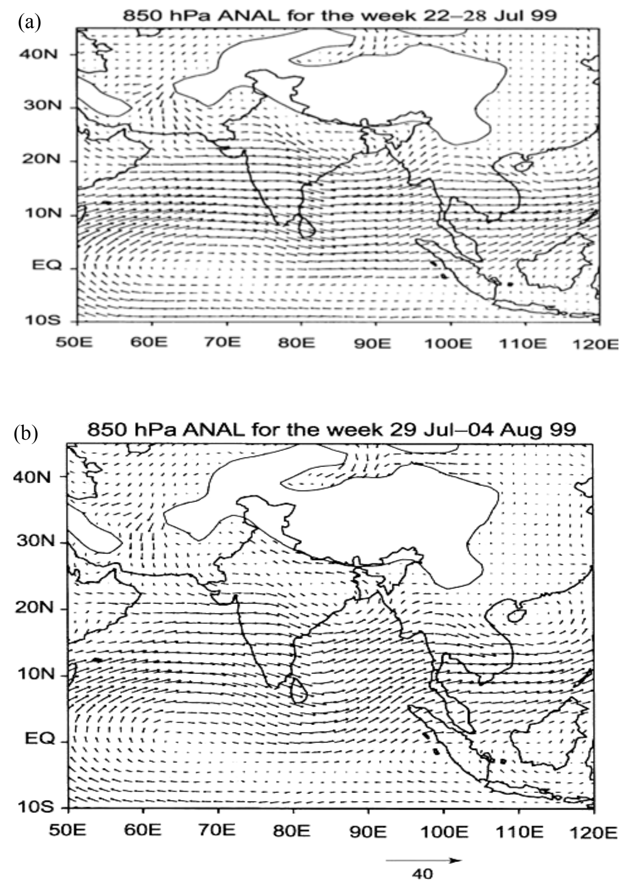


Fig. 9. Track of depression in southwest monsoon season 1999 (*Courtesy* : Kalsi)

21.0° N / Long. 89.0° E, about 200 km south-southeast of Kolkata. It further intensified into a deep depression at 1200 UTC of 27 and lay centered near Lat. 21.0° N / Long. 88.5° E. It crossed Orissa & West Bengal coast in the early morning hours of 28 and lay as Deep Depression at 0300 UTC of 28 near Lat. 23.0° N / Long. 86.5° E, about 50 km southeast of Purlia. It moved in a northwesterly direction and weakened into a depression at 1200 UTC of 28 and lay near Lat. 23.5° N / Long. 84.5° E, about 50 kms northwest of Ranchi. It further moved in a west-northwesterly direction and lay centered at 0300 UTC of 29 near Lat. 24.5° N / Long. 81.0° E, very close to Satna. Subsequently it weakened into a well marked low pressure area in the evening of 29 over northwest MP and neighborhood and into a low pressure area on 31 morning over northeast Rajasthan and neighborhood. In Fig. 8 (b) depicted location of well marked lopar at 0300 UTC on 30 July over west Madhya Pradesh & adjoining area. It later merged with the monsoon trough over extreme west Rajasthan and neighborhood on 3 August. [(Mausam, July, 2000)]. 850 hPa analysis for the week 22-28 Jul 1999 and 29 July - 04 August 1999 showed in Figs. 10 (a&b) in which cycir might be seen over Bay and east MP & neighborhood respectively caused cyclonic genesis there, however it was weak current [*Courtesy* : Kalsi (2003)]. In Fig. 8 INSAT VIS. imagery over the Bay at 0600 UTC, of 27 July, Bay and adjoining region showed a deep layer cluster about 2° in the extent to the west of the circulation centre of depression. These clouds clusters moved towards LYC region and under the influence of the well marked lopar with associated cycir up to MTL, Garauli (it was in southwest sector of lopar) recorded 308.2 mm rainfall on 30 July, 1999 in 24 hours.



Figs. 10(a&b). 850 hPa wind analysis for the week (a) 22-28 July, 1999 and (b) 29 July - 04 August 1999 (*Courtesy*:Kalsi)

The system became weak rapidly, so heavy rainfall (in mm) was occurred over other stations in LYC region in 24 hours as follows : Madla : 66.0, Mohana : 60, Kaimaha : 58.3 and Khajuraho : 57.0.

During BOBMEX in 1999, there were several spells of active and suppressed convection which were controlled by development of 4 lopar systems, out of which two became depressions. Fig. 9 showed the tracks of two monsoon depression during 27-29 July & 6-8 August and two lopar 22-28 July & 2-4 August during BOBMEX 1999 [*Courtesy* : Kalsi (2003)]. Both the depressions were the weak systems. Out of these lopar/depressions, only depression 6-8 August caused isolated heavy rain over LYC, rainfall recorded in mm at 0300 UTC, are as follows. On 7 August : Kaimaha : 119 & on 8 August : Kalpi : 68 & Etawah : 68.

4. Conclusions

Forecasting heavy rainfall especially extremely heavy rains can help planners and disaster management authorities in preventing massive destruction. Using synoptic analysis is the best and well known method to predict heavy rain. For this purposes, first atmospheric system that cause heavy or heaviest should be recognized and the exact time of their placement should be predicted as well. The present study of extremely heavy rainfall events over LYC region based on synoptic situations for a period 1998-2010 emerged that:

(*i*) In southwest monsoon season the LPS (Cyclone, depression and low pressure episodes etc.) over Bay of Bengal and adjoining area moved generally in west-northwestwards direction and reached to the LYC region either as Cyclone or depression or lopar, causing extremely heavy rain over the region (which lay generally in the southwest sector of the system) at isolated places and heavy to very heavy rainfall at a few places in association with orography influence during there movement. Also the lopar may be formed *in situ* over the region under the influence of cycir. If the LPS either stagnate or slow over LYC region, the possibility of such type of rainfall would be higher.

(*ii*) The NWP products of RSMC (IMD) New Delhi forecast (f/c) charts for 72, 48 & 24 hours specially contours at 500 hPa & wind at 850 hPa were found generally matched with the real time analysed charts, thus give accurate f/c position of the movement of the LPS. In addition to synoptic charts, and their prediction, satellite informations and Radar products facilitate to forecaster for predicting accurately extreme events in advance.

Thus investigating the status of atmospheric systems before and after the rainfall shows that the heavy/ extremely heavy rain is caused by mostly by Bay of Bengal low systems that enter in the LYC region. If the system is accompanied by local ascending conditions, it will certainly cause intensive rain.

Acknowledgement

The author expresses his heart felt thanks to Dr. (AVM) Ajit Tyagi DGM India Meteorological Department New Delhi for encouraging and fruitful guidance. Thanks also to Dr. O. P. Singh Scientist-F, DDGM (RMC New Delhi) for providing facilities for presenting this study. Thanks also to Shri Arvind Kumar Verma, Scientific Assistant and Shri C. S. Parashar, Flood Met. Office, Agra for their assistance in data processing and manuscript preparation.

References

Ali, Mehfooz, Singh, U. P. and Joardar, D., 2011, "QPF Model for lower Yamuna catchment, Synoptic analogue method", *Mausam,* **62**, 1, 27-40.

Dasggupathy, S. M. and Sikka, D. R., 1977, "On the vorticity budget and vertical velocity distribution associated with the life cycle of monsoon depression", *J. Atmos. Sc.,* **33**, 773-792.

De, U. S., Dube, R. K. and Rao Prakasa, G. S., 2005, "Extreme Weather Events over India in the last 100 years", *J. Ind. Geophys. Union (July),* **9**, 3, 173-187.

De, U. S., Guhathakurta, P. and Dandekar, M. M., 2002, "Hydrological Disasters in India", Proc. TROPMET 2002, 202-209.

Dubey, D. P. and Balakrishnan, T. K., 1992, "A study of heavy to very heavy rainfall over Madhya Pradesh for the period 1977 to 1987", *Mausam*, **43**, 326-329.

Desai, D. S., Thade, N. B. and Huprikar, M. G., 1996, "Very heavy rainfall Punjab, Himachal Pradesh and Haryana during 24-27 September, 1988 - Case Studies", *Mausam,* **47**, 269-275.

Gandomkarr, A., 2007, "Synoptic study of flood rain in middle zone of Zayandehrood basin", *Water resources management*, October, 240-249.

Ganeshan, G. S. and Prasad, M. C., 1985, "Astudy of heavy rainfall in and around Jaipur", *Mausam,* **36**, 1, 101-106.

Godbole, R. V., 1977, "The composite structure of monsoon depression", *Tellus,* **29**, 25-30.

Gupta, H. N., 1984, "Unprecedented floods in south Rajasthan in July", *Mausam,* **35**, 4, 548-549.

Jayashree, V. and Anil Kumar, K. G., 1997, "Some aspects of daily rainfall distribution over a high range river basin in Central Kerala", *Mausam*, **48**, 1, 71-76.

Kalsi, S. R., 2003, "Synoptic weather conditions during BOBMEX" *Indian Acad. Sci. (Earth Planet. Sci.)*, **112**, 2, 239-253.(www.ias.ac.in/jess/jun2003/Esblu57.pdf)

Loe, B. R., Ali, Mehfooz and Joardar, D., 2005, "Synoptic systems associated with onset of southwest monsoon over Rajasthan", *Mausam*, **56**, 4, 857-872.

Mausam, India Meteorological Department, July, 2000, "Weather in India", *Mausam*, **51**, 3, 285-318.

Mausam, India Meteorological Department, July, 2004, "Weather in India", *Mausam*, **55**, 3, 515-548.

Mausam, India Meteorological Department, July, 2006, "Weather in India", *Mausam*, **57**, 3, 527-566.

Mausam, India Meteorological Department, July, 2007 "Weather in India", *Mausam*, **58**, 3, 409-458.

Murkami, M., 1977, "Spectrum analysis of monsoon lows", *J. Met. Sc. Japan*, **55**, 26-35.

Rakecha, P. R. and Pisharoty, P. R., 1996, "Heavy rainfall during monsoon season : point and spatial distribution", *Current Science*, **71**, 179-186.

Sarkar, R. P. and Chowdhary, A., 1988, "A diagnostic study of monsoon depression", *Mausam*, **39,** 1, 9-18.

Sengupta, S., 1986, "Localised floods in Rajasthan owing to exceedingly heavy rains: case study of small scale accentuations the Indian summer monsoon fields associated with intense upper anticyclonic shear zones", *Mausam*, **37**, 3, 385-390.