

Synoptic & climatological aspects of extreme rainfall over western Himalayas towards end of 2014 southwest monsoon season

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सार - 2 से 5 सितम्बर 2014 के दौरान जम्मू-कश्मीर राज्य में असामान्य रूप से वर्षा के क्रियाकलाप के कारणों का विश्लेषण और समझने के लिए निदानात्मक अध्ययन किया गया। भारत मौसम विज्ञान विभाग में उपलब्ध ऐतिहासिक वर्षा आँकड़ा का सावधानीपूर्वक परीक्षण करने पर पता चला कि पिछले सभी आँकड़ों को तोड़कर सितम्बर 2014 के पहले सप्ताह के दौरान क्षेत्र के अनेक स्टेशनों पर 24, 48 और 72 घंटे में संचयी वर्षा हमेशा से अधिकतम हुई थी परिणामस्वरूप प्रदेश के अधिकांश भागों में बाढ़ आ गई थी जिसके कारण जान माल की बहुत बड़ी हानि हुई थी। असामान्य घटना की सतही विवेचना के अध्ययन में बहुत ही अनुकूल मौसम परिस्थितियों की पुष्टि होती है जैसा कि मध्य क्षोभमंडलीय स्तर पर चक्रवातीय परिसंचरण/ द्रोणी के रूप में पश्चिमी विक्षोभ था जो 2 से 5 सितम्बर 2014 तक उत्तर पाकिस्तान और जम्मू एवं कश्मीर से सटे हुए भागों पर व्यवहारिक रूप से स्थाई रहा और इसी समय के दौरान उत्तरी पश्चिमी तथा सटे हुए मध्य भारत के मॉनसून निम्न दाब के साथ मिल गया। इसके अलावा इस असामान्य वर्षा के लिए बंगाल की खाड़ी के साथ-साथ अरब सागर के क्षेत्र में 60-80 नोट्स स्तर के जेट चरमबिन्दु और अधिकतम नमी का अभिगमन भी जिम्मेदार था।

ABSTRACT. A diagnostic study has been carried out to analyse and understand the causes of unusual rainfall activity over Jammu & Kashmir (J&K) State during 2nd to 5th September, 2014. The careful examination of available historical rainfall data of India Meteorological Department (IMD) network reveals that many stations in the region received ever-highest 24, 48 & 72 hours cumulative rainfall during first week of September in 2014, breaking all previous records. In result, there was flooding in most parts of the State, which has caused loss of human lives and huge loss of property. The synoptic interpretation of this unusual event carried out in the study confirms very favourable meteorological conditions, as there was a western disturbance (WD) in form of cyclonic circulation/trough in mid-tropospheric level, which remained practically stationary over north Pakistan and adjoining Jammu & Kashmir from 2nd to 5th September, 2014 and its interaction with a monsoon Low-Pressure Area (LPA) over northwest & adjoining central India during the same period. In addition, jet maxima of the order 60-80 knots and high moisture advection from the Bay of Bengal as well as from Arabian Sea over the region were also responsible for this unusual rainfall.

Key words – Unusual rainfall, Jammu & Kashmir, Low-pressure area and western disturbance.

1. Introduction

Southwest monsoon normally starts withdrawing from region of northwest India during first week of September. This is associated with the development of anti-cyclonic circulation over western Rajasthan in the lower tropospheric levels leading to sharp reduction in water vapour and rainfall activity over the region. However, during first week of September 2014, Jammu & Kashmir State and adjoining areas received heavy to very heavy with extremely heavy (>244.5 mm) rainfall. The

rainfall was exceptionally heavy as reported on 5th & 6th September. Also, many of the stations received more than 300 mm rainfall in 3 days period. Due to continuous heavy rainfall, local rivers broke out into the streets and caused flood situation in the region. Jhelum and Chenab River was observed to flow above danger mark in some areas. This triggered flooding and landslides in the State causing loss of life and huge loss of property. The aim of present study is to understand the synoptic and thermodynamical parameters associated with unusual rainfall event over Jammu & Kashmir state.

TABLE 1(a)

All-time 24 hours record rainfall (in mm) over Jammu & Kashmir

Station	Previous Record			2014		All time records in 2014
	Period	24 hrs (in mm)	Date	24 hrs (in mm)	Date	
Anantnag	1901-1982	149.4	01 Sep, 1928	180	04 Sep, 2014	All time record
Kukernagh	1979-2013	135.8	25 Feb, 1987	149.5	05 Sep, 2014	All time record
Qazigund	1962-2013	160.9	09 Sep, 1966	206	05 Sep, 2014	All time record
Banihal	1962-2013	205.6	28 Aug, 1997	188.8	05 Sep, 2014	-
Batote	1979-2013	255.4	23 Aug, 1996	207.8	05 Sep, 2014	-
Katra	1980-2013	292.4	25 Sep, 1988	279.2	05 Sep, 2014	-

TABLE 1(b)

All-time 48 hours record rainfall (in mm) over Jammu & Kashmir

Station	Previous Record			2014		All time records in 2014
	Period	48 hrs (in mm)	Date	48 hrs (in mm)	Date	
Anantnag	1901-1982	186.7	13 Jan, 1903	330.2	04 Sep, 2014	All time record
Kukernagh	1979-2013	176.1	27 Aug, 1997	268.9	04 Sep, 2014	All time record
Qazigund	1962-2013	282.3	27 Aug, 1997	362.7	04 Sep, 2014	All time record
Banihal	1962-2013	310.4	18 Feb, 2003	295.6	04 Sep, 2014	-
Batote	1979-2013	363.6	23 Aug, 1996	339.8	05 Sep, 2014	-
Katra	1980-2013	418.4	22 Aug, 1996	488.6	05 Sep, 2014	All time record

TABLE 1(c)

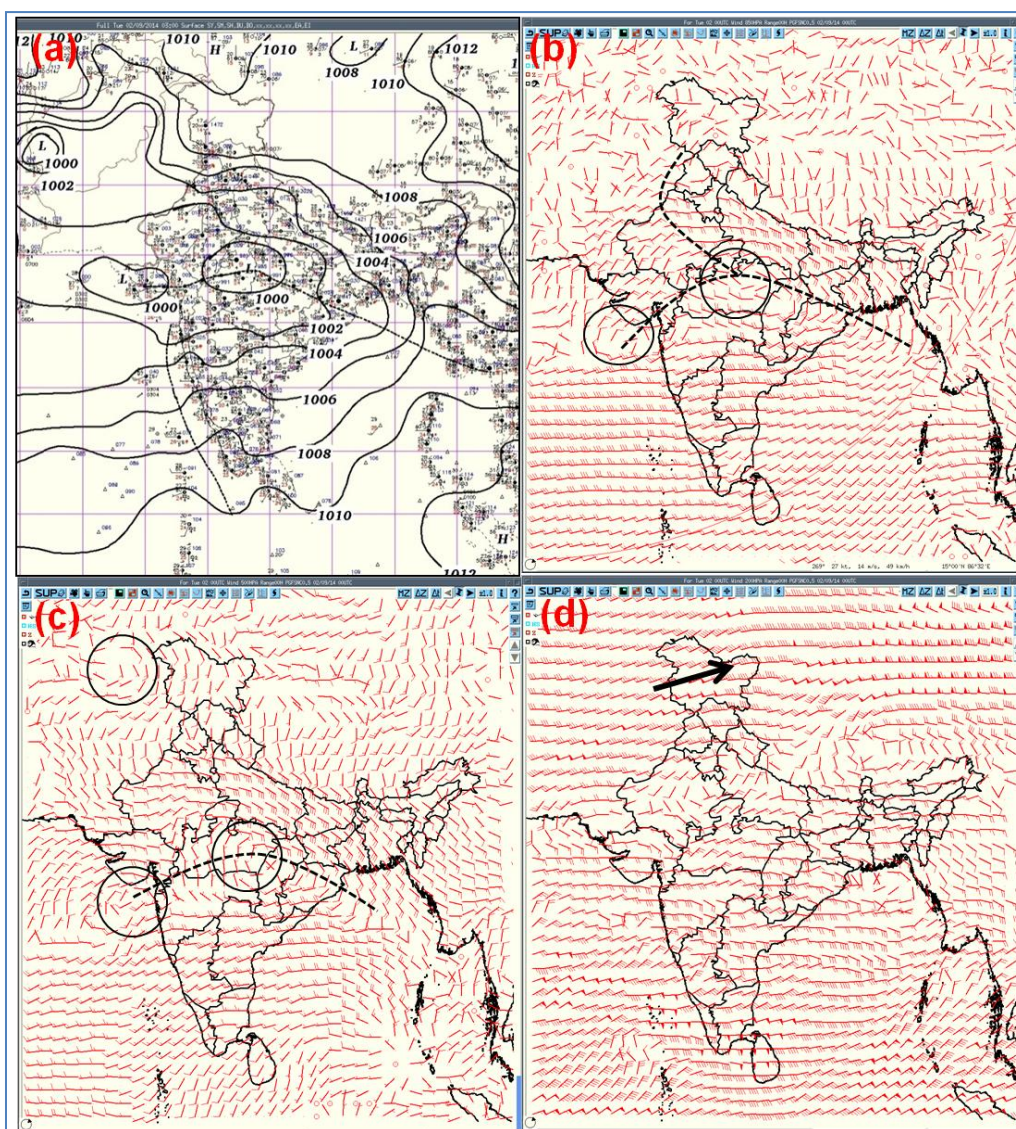
All-time 72 hours record rainfall (in mm) over Jammu & Kashmir

Station	Previous Record			2014		All time records in 2014
	Period	72 hrs (in mm)	Date	72 hrs (in mm)	Date	
Anantnag	1901-1982	210.8	16 Sep, 1950	410.6	04 Sep, 2014	All time record
Kukernagh	1979-2013	194.5	26 Jul, 1995	357.5	04 Sep, 2014	All time record
Qazigund	1962-2013	300.7	17 Feb, 2003	465.4	04 Sep, 2014	All time record
Banihal	1962-2013	392.5	17 Feb, 2003	389.3	03 Sep, 2014	Near all time record
Batote	1979-2013	434	22 Aug, 1996	433.2	04 Sep, 2014	Near all time record
Katra	1980-2013	544.2	22 Aug, 1996	556.0	04 Sep, 2014	All time record

2. Earlier Studies

In literature, there are limited studies related to WDs and its interaction with easterlies systems. Hatwar *et al.*

(2005) studied the synoptic aspects of WDs that have caused extreme weather over western Himalayan region. They found that extreme weather occurs due to active WDs and along with good amount of moisture incursion



Figs. 1(a-d). (a) Mean sea level chart of 0300 UTC of 2nd September, 2014 (b) 850 hPa wind chat (c) 500 hPa wind chat and (d) 200 hPa wind chat based on 0000 UTC of 2nd September, 2014

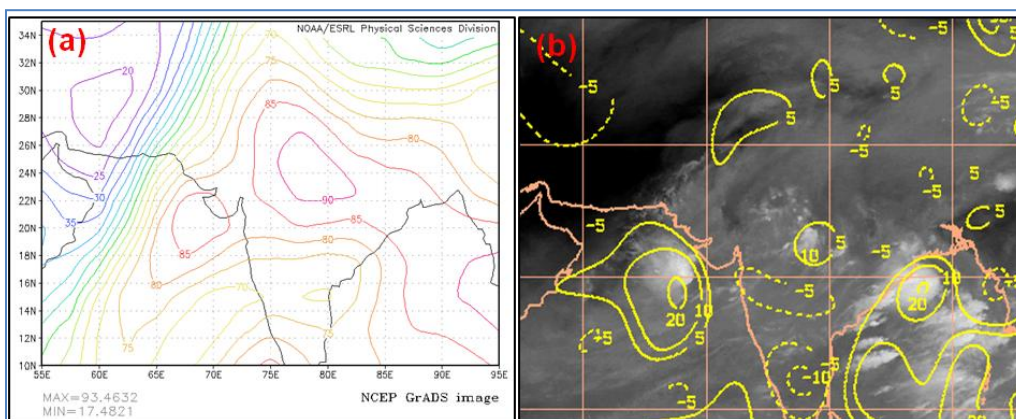


Fig. 2(a&b). (a) 700 hPa Relative Humidity and (b) METEOSAT-7. 150-300 hPa divergence of 2nd September, 2014

TABLE 2
Station-wise rainfall* (in mm) over Jammu & Kashmir

Stations	3 rd September	4 th September	5 th September	6 th September
Anantnag	58.4	180.0	150.2	80.4
Kukernag	57.7	119.4	149.5	88.6
Pahalgam AWS	47.0	68.0	52.0	50.0
Baramulla AWS	8.0	65.0	84.0	28.0
Gulmarg R.S.	34.0	106.6	128.0	98.2
Badarwah	29.2	81.4	138.8	100.6
Jammu	9.0	39.3	101.4	218.3
Kathua	1.4	33.8	65.6	93.8
Kulgam AWS	49.0	82.0	138.0	77.0
Qazigund	80.4	156.7	156.7	206.0
Kupwara	2.8	45.6	68.2	15.4
Awantipur I.A.F.	39.1	51.0	51.0	67.0
Malangpura AWS	37.0	61.0	102.0	66.0
Banihal	93.7	106.8	188.8	86.1
Batote	67.8	102.4	207.8	123.0
Govindpura AWS	52.0	71.0	202.0	102.0
Katra	21.8	67.4	279.2	209.4
Shopian AWS	42.0	68.0	140.0	85.0
Rambagh AWS	18.0	51.0	52.0	19.0
Srinagar	20.0	51.8	52.4	19.5
Kawa AWS	14.0	64.0	152.0	260.0

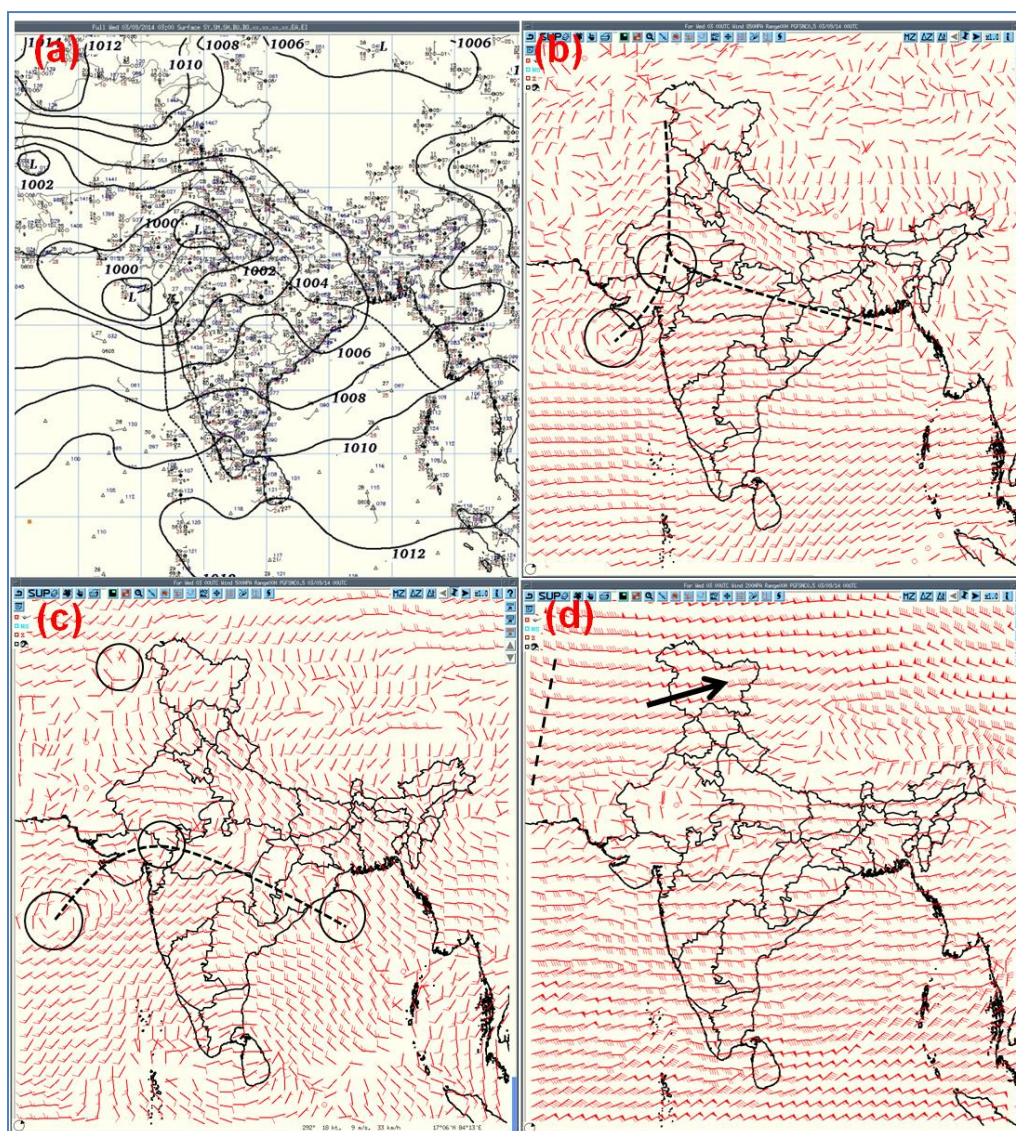
*24 hours rainfall from 0830 hours IST of previous day till 0830 hours of the day

from Arabian Sea or Bay of Bengal or both over western Himalayan region. Yadav & Bhan (2010) studied the meteorological conditions associated with July, 2005 floods in river Jhelum in J&K State. They found interaction of a westwards moving monsoon disturbance over plains of northwest India and an eastwards moving trough in mid tropospheric level over Pakistan was the major cause of flooding in river Jhelum. Aleem-ul-Hassan *et al.* (2010) have done a diagnostic study of heavy downpour in the central part of Pakistan. They found that heavy rainfall occurred under the influence of monsoon depression, westerly trough over Kashmir & surrounding Himalayan region and its interaction with the upper air easterly wave. Houze *et al.* (2011) studied the anomalous atmospheric events that caused summer 2010 floods in Pakistan. Raju *et al.* (2011) have carried out study about kinetic energy aspects related to intense WD and found that strong flux convergence and adiabatic production of

kinetic energy has caused widespread precipitation over northwest India. Very recently, Kotal *et al.* (2014) studied the causes of widespread very heavy to extremely heavy rainfall activity over Uttarakhand during 16-18 June 2013. They concluded that the exceptionally heavy rainfall occurred due to strong interaction between mid-tropospheric trough in westerlies and strong lower levels south-easterly wind flow in association with a low-pressure area over northern parts of India. Kumar *et al.* (2015) have studied the WDs which have caused extreme weather in form of precipitation over Himachal Pradesh during winter months.

3. Data used

The wind analysis charts are collected from NCMRWF GFS model (27 km resolution) and mean sea level charts is plotted through Synergie system installed at



Figs. 3(a-d). (a) Mean sea level chart of 0300 UTC of 3rd September, 2014 (b) 850 hPa wind chat (c) 500 hPa wind chat and (d) 200 hPa wind chat based on 0000 UTC of 3rd September, 2014

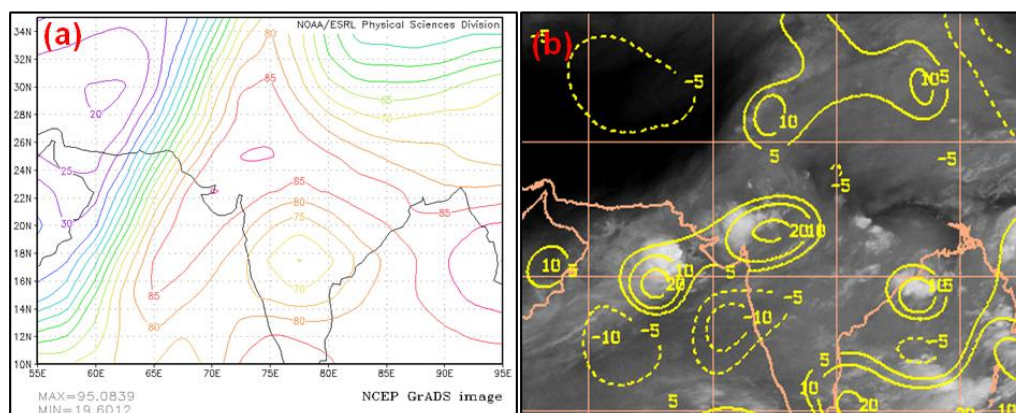
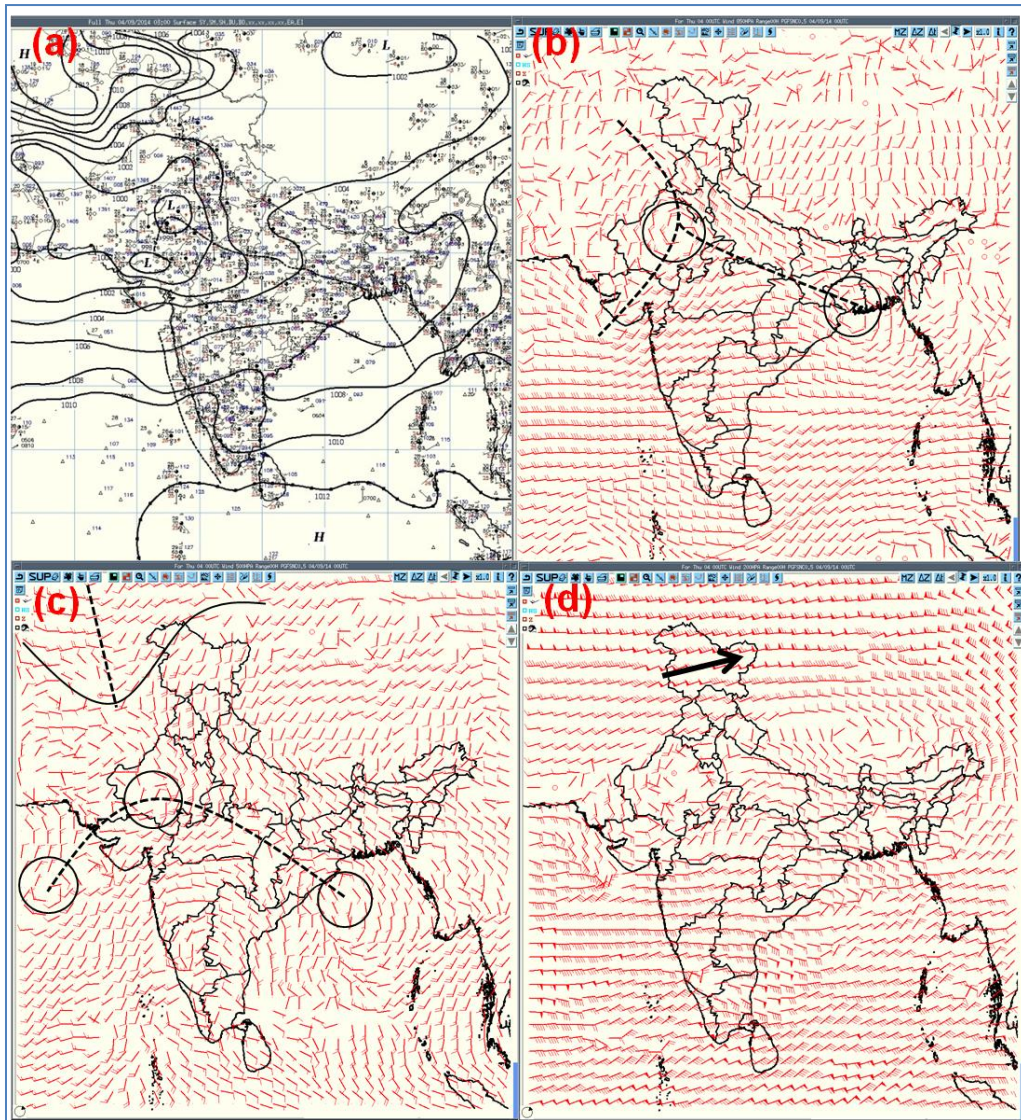


Fig. 4(a&b). (a) 700 hPa relative humidity and (b) METEOSAT-7 (150-300 hPa divergence of 3rd September, 2014)



Figs.5(a-d). (a) Mean sea level chart of 0300 UTC of 4th September, 2014, (b) 850 hPa wind chat, (c) 500 hPa wind chat and (d) 200 hPa wind chat based on 0000 UTC of 4th September, 2014

IMD, Pune. Meteosat-7 derived relative vorticity products are also used in the study. To see the historical records, daily rainfall data of all the meteorological observatories of J&K are collected from National Data Centre, Pune and Meteorological Centre, Srinagar.

4. Results and discussion

4.1. Historical perspective

Careful examination of available historical precipitation data of IMD network reveals that during this period, many stations of the region received ever-highest 24, 48 & 72 hours cumulative rainfall during first week of September in 2014, breaking all previous records for any

time of the year. Details of these stations are given in following Tables 1(a-c). It is found that the three stations of Kashmir Valley of Jammu & Kashmir State for which long-term data is available have received ever-highest 24, 48 & 72 hours cumulative rainfall. However, in Jammu Division, it is only Katra which has got ever highest 24, 48 & 72 hours cumulative rainfall where as rainfall received at other two stations namely Batote and Banihal was just near to all-time previous records.

4.2. Synoptic and thermo-dynamic analysis of unusual rainfall situation

After a prolonged break-like situation during August, the southwest monsoon revived with the formation of a

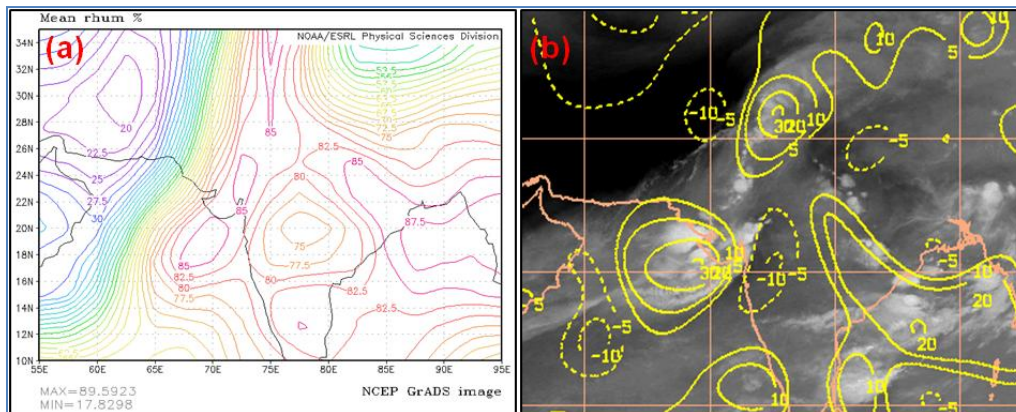


Fig. 6(a&b). (a) 700 hPa relative humidity and (b) METEOSAT-7 (150-300 hPa divergence of 4th September, 2014)

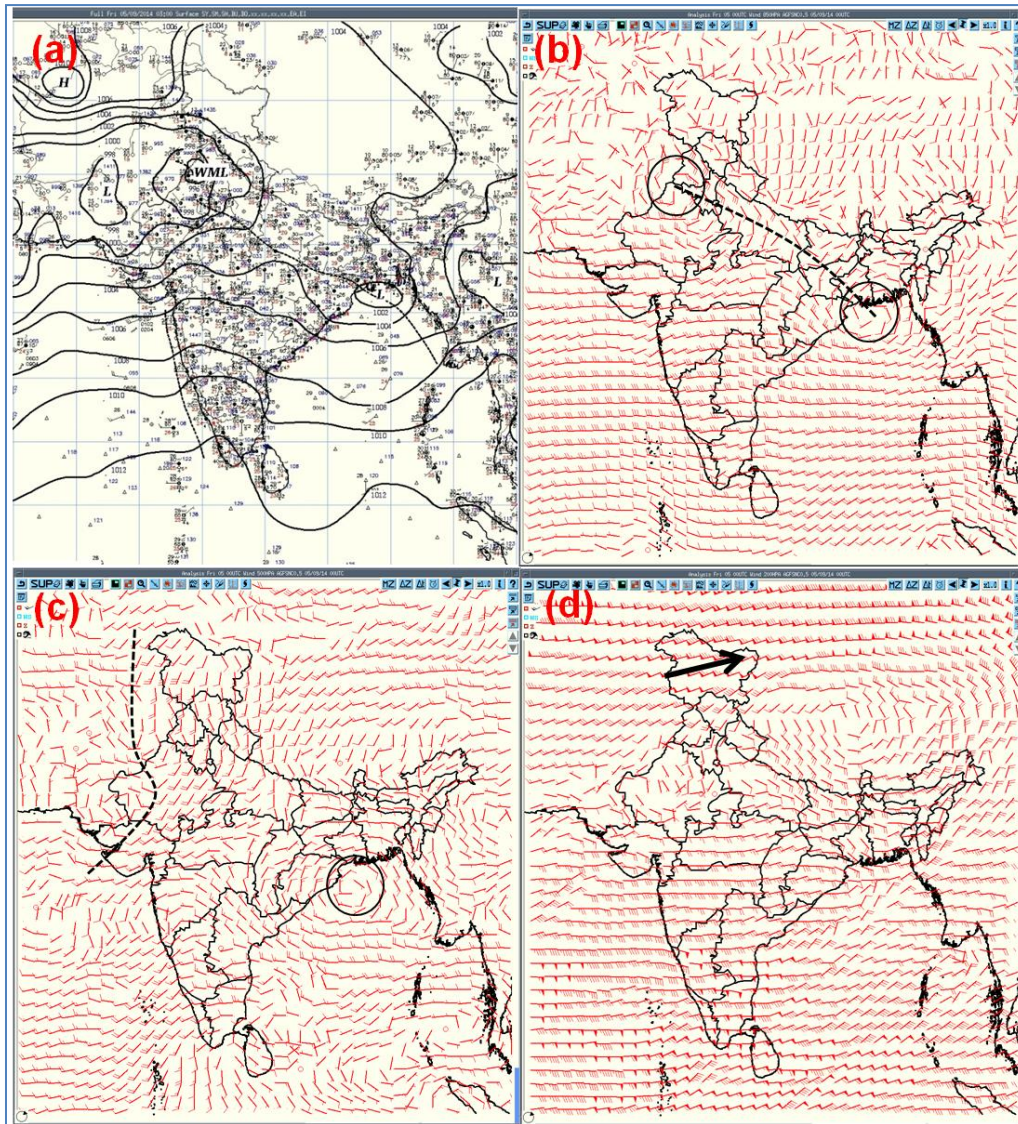
LPA over west-central & adjoining northwest Bay of Bengal (BoB) off north Andhra Pradesh -south Odisha coasts on 27th August. It moved across south Chhattisgarh, Vidarbha and laid over northwest Madhya Pradesh on 2nd September [Fig. 1(a)]. Another LPA formed over Saurashtra & Kutch and adjoining northeast Arabian Sea on the same day [Fig. 1(a)]. At 850 hPa, there were two upper air cyclonic circulations associated with these LPAs. There were two troughs, one from north Bay of Bengal to south J&K across cyclonic circulation (CC) over northwest Madhya Pradesh (extended upto 600 hPa level) and another from northeast Arabian sea to CC over northwest Madhya Pradesh, thereafter, it merged with 1st trough [Fig. 1(b)].

Consequently, there was heavy moisture incursion over J&K region both from the BoB and from Arabian Sea [Fig. 2(a)]. At 500 hPa, a CC laid over north Pakistan in association with a Western Disturbance (WD) [Fig.1(c)].

There was a jet maxima of the order 60 knots over J&K region which caused upper level divergence over the region [Fig. 1(d), Fig. 2(b)]. Relative vorticity at 500 hPa was also positive and of the order more than $25 \times 10^{-5} \text{ sec}^{-1}$ over north Pakistan, northeast Arabian Sea and Central India. At 700 hPa, a positive relative vorticity patch was seen extending from BoB to J&K region and it was nearly neutral at 850 hPa over north Pakistan and adjoining J&K. Hence, due to CC over north Pakistan in mid-tropospheric westerlies, good amount of moisture incursion over J&K region from BoB upto 600 hPa and jet maxima over J&K region provided favourable meteorological conditions for widespread rainfall with isolated heavy to very heavy falls over J&K region on this day (Table 2).

On 3rd September, the 1st LPA moved over to southeast Rajasthan & neighbourhood and 2nd persisted over Saurashtra & Kutch and adjoining northeast Arabian Sea [Fig. 3(a)]. At 850 to 600 hPa, a trough extended from BoB to J&K region across CC over southeast Rajasthan and another trough extended from Arabian Sea upto north Pakistan & adjoining J&K region and it merged with 1st trough over southeast Rajasthan [Fig. 3(b)]. It caused moisture incursion over J&K region upto 600 hPa level [Fig. 4(a)]. At the same time, there was a CC over north Pakistan & neighbourhood in mid-latitude westerlies at 500 hPa and wind confluence was observed over J&K region [Fig. 3(c)]. At 200 hPa, there was a jet maxima of the order 60 knots over J&K and adjoining region along with a trough roughly along Long. 60° E which further increased the divergence over the region [Fig. 3(d), Fig. 4(b)]. In 500 hPa relative vorticity chart, positive vorticity of order around $25 \times 10^{-5}/\text{s}$ was seen over north Pakistan & neighbourhood. However, it was nearly neutral at 850 hPa. Thus, under the influence of WD as a CC over north Pakistan & neighbourhood, wind confluence & moisture feeding over J&K region from BoB as well as Arabian Sea and jet maxima over J&K region. As combined effect of these synoptic cum thermodynamic conditions, there was widespread rainfall activity along with heavy to very heavy falls at few places over J&K region on this day (Table 2).

On 4th September, the 1st LPA over southeast Rajasthan & neighbourhood persisted and 2nd LPA laid over Kutch & neighbourhood [Fig. 5(a)]. At 850 hPa, a trough extended from BoB to north Pakistan and adjoining J&K region across CC over southeast Rajasthan and another trough extended from Arabian Sea and merged with 1st trough over southeast Rajasthan [Fig. 5(b)]. Both the troughs extended upto 600 hPa and provided very good moisture incursion over the region

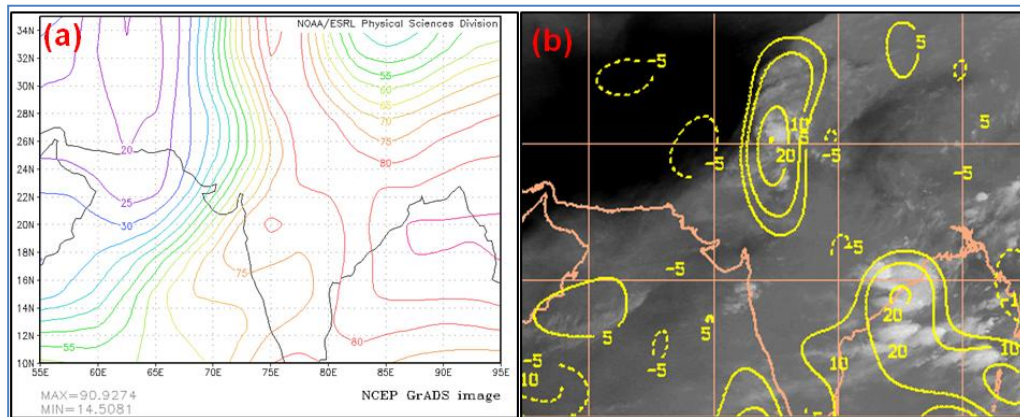


Figs. 7(a-d). (a) Mean sea level chart of 0300 UTC of 5th September, 2014 (b) 850 hPa wind chat (c) 500 hPa wind chat and (d) 200 hPa wind chat based on 0000 UTC of 5th September, 2014

on 4th September [Fig. 6(a)]. At 500 hPa, there was a trough from northeast Arabian Sea to north BoB across CC over southeast Rajasthan and a trough in westerly over Afghanistan & adjoining Pakistan extended upto 30° N [Fig. 5(c)]. At 400 hPa, a trough extended from Afghanistan & adjoining Pakistan to northeast Arabian Sea with strong wind convergence from Arabian as well as BoB. At mid-tropospheric level, there was strong moisture feeding over the region. In addition, jet maxima of order upto 80 knots provided strong divergence over the region [Fig. 5(d) & Fig. 6(b)]. In addition, there was continuous patch of positive vorticity from Arabian Sea to

Jammu & Kashmir region both at 500 & 850 hPa relative vorticity chart of the order of $50 \times 10^{-5}/s$.

On 5th September, the 1st LPA area concentrated into a well-marked low pressure area over northwest Rajasthan & adjoining areas of Haryana & Punjab. However, the 2nd LPA over Kutch & neighbourhood became less marked [Fig. 7(a)]. At 850 hPa, there was a trough from northwest BoB to CC over northwest Rajasthan [Fig. 7(b)]. At 700 & 600 hPa, there was a trough extended from North Pakistan & adjoining Jammu division of Jammu and Kashmir to Arabian Sea. At 500 hPa also, the trough



Figs. 8(a&b). (a) 700 hPa relative humidity and (b) METEOSAT-7 (150-300 hPa divergence) of 5th September, 2014)

extended from north Pakistan to Arabian Sea [Fig. 7(c)]. On 5th, the moisture feeding was very high from Arabian Sea [Fig. 8(a)]. Consequently, Jammu & Kashmir received widespread precipitation along with extremely heavy falls at isolated places reported as reported on 5th (Table 2). Jet maxima of the order 60-80 knots was seen over northern parts of Jammu & Kashmir [Fig. 7(d) & Fig. 8 (b)]. At 500 hPa relative vorticity, there was continuous positive vorticity patch from North Rajasthan & neighbourhood upto North Pakistan & neighbourhood. Positive vorticity of the order more than $100 \times 10^{-5}/s$ was seen mainly at 850 hPa. On this day, Jammu & Kashmir received widespread precipitation along with extremely heavy falls as reported on 6th (Table 2).

5. Conclusions

The study very clearly suggests that the rainfall over Jammu & Kashmir during first week of September 2014 was an extreme and exceptional event. Analysis of available data reveals that 24, 48 & 72 hours cumulative rainfall at many of the stations of the State was ever-highest breaking all previous records for any time of the year. The favourable synoptic scale environment was provided by a low-pressure area over extreme northwest India and a deep westerly trough/ circulation in middle & upper troposphere over north Pakistan & neighbourhood, both persisted for 3-4 days. Interaction of tropical easterly (monsoon low) & extra tropical westerly (western disturbance) air masses, confluence of winds from Arabian Sea & Bay of Bengal and high moisture feed over Jammu & Kashmir region from Bay of Bengal and particularly from Arabian Sea has contributed in cloud development and heavy rainfall. In addition, other parameters like high magnitude divergence caused by jet maxima and anomalous stronger & westward located

Tibetan high may also have caused favourable atmospheric conditions. This typical weather situation and the resultant exceptionally heavy rainfall during withdrawal phase of monsoon 2014 was much severe than that the recent disaster which also occurred over Himalyan region in Uttarakhand but during the onset phase of monsoon 2013. The Uttarakhand heavy rainfall episode during 16-18 June, 2013 was also mainly due to interaction of mid-tropospheric westerlies due to WD and strong south-easterly monsoon current developed due to low pressure area over central & adjoining northwest India (Kotal *et al.*, 2014) but a persisting western disturbance, its interaction with two low pressure systems, both merging and then moving over to Northwest Indian plains steered by a westward located stronger Tibetan High might be reason for the severity of Jammu and Kashmir event.

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