Government of India
Ministry of Earth Sciences
India Meteorological Department

A report on heavy rainfall over Uttarakhand during 16-18 June 2013
(A draft report)

Lodi Road, New Delhi-110003
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1. Introduction

Wide spread very heavy to extremely heavy rainfall occurred over Uttarakhand and neighbouring states during 16-18 June 2013. This has caused severe floods, landslides, large scale loss of lives, properties and damages. Uttarakhand, formerly Uttaranchal, is a state in the northern part of India. Most of the state lies in the Greater Himalayas region. The region is renowned for its natural beauty, as well as pilgrimage sites which dot the upper reaches of the hills. The non-availability of abundant farmland makes the local people mostly dependent on seasonal activities, primarily tourism for their livelihood. The tourist season is primarily in summer season, when daily influx of a large number of pilgrims and tourists into the state, put a huge burden on the local infrastructure. This has also led to massive over-exploitation of the local environment, thereby loosening the top soil and making the region susceptible to landslides and flash floods. A major group of pilgrimage sites are located in the Uttarkashi and Rudraprayag districts of Uttarkashi. These include the Kedarnath and Badrinath temples, which are holy to the Hindus and Hemkunt Sahib which is holy to Sikhs. Together, these pilgrimage sites account for footfalls of tens of thousands of pilgrims from all over India everyday during the summer season.

During 16-18 June 2013, widespread very heavy rainfall activities with a few extremely heavy rainfall (more than 24.5 cm) were reported at many stations over Uttarakhand, as shown in **Table-1**. Heavy rainfall activities were also reported at some stations over Himachal Pradesh, Delhi & Haryana and Punjab during 16 June to18 June 2013 (Table-1). During the period, on 16 June 16 stations reported heavy rainfall with 11 stations ≥ 10 cm and 1 stations ≥ 20 cm; on 17 June 23 stations reported heavy rainfall with 18 stations ≥ 10 cm and 7 stations ≥ 20 cm and on 18 June 16 stations reported heavy rainfall with 9 stations ≥ 10 cm and 2 stations ≥ 20 cm . The rainfall distribution shows that heavy to extremely heavy rainfall occurred on 15 June and 16 June (reported at 0300 UTC of next day) over the western districts of Uttarakhand (Uttarkasi, Dehradun, Haridwar, Teri, Rudraprayag and Pauri) with a maximum rainfall of 37 cm reported on 17 June at Dehradun. Thereafter the heavy rainfall belt gradually shifted towards eastern part of Uttarakhand. Heavy to extremely heavy rainfall reported on 17 June and 18 June over the districts of eastern parts of Uttarakhand (Almora, Nainital, Udham sing nagar, Champawat, Bageshwar, Pithoragarh and Chamoli) with a maximum rainfall of 28 cm reported on 18 June at Haldwani of Nainital district. Despite prior information of the likelihood of disturbed weather, more than one lakh pilgrims were stranded in these pilgrimage sites . Numerous deaths took place due to

exposure and starvation. Countless others died due to flash floods and landslides in the Mandakini river, especially in the vicinity of Kedarnath temple.

Table-1. Chief amounts of observed rainfall (cm)

Date	**Chief amounts of rainfall in cm (24 hour rainfall) more than 6.5 cm (heavy rainfall)**
16 June	**UTTARAKHAND:** Dehra Dun-22, Purola-17, Deoprayag-13, Uttar Kashi-13, Tehri (CWC)-12, Tehri-12, Uttar Kashi (CWC)-12, Dunda-12, Barkot-11, Hardwar-11, Jakholi-11, Haldwani-9, Rudraprayag-9, Karnaprayag-9, Mukteshwar-8, Kotdwara-7. **HIMACHAL PRADESH:** Rajgarh-18, Una (AWS)-8, Una-7, Dharmpur-7, Bangana (Revenue)-7 **PUNJAB:** Muktsar-12, Balachaur-12, Hoshiarpur (AWS)-9, Sangrur-9, Phagwara-9, Mansa (AWS)-8, Balachaur (AWS)-8, Dhuri-8, Mahurana (ARG)-8, Ropar-7, Talwandi Sabo-7, Roopnagar (AWS)-7, Faridkot (AWS)-7, Anandpur Sahib-7, Kapurthala (AWS)-7. **HARYANA, CHANDIGARH & DELHI:** Jagadhari-11, Bilaspur-10, Rattia-7
17 June	**UTTARAKHAND:** Dehra Dun-37, Mukteshwar-24, Hardwar-22, Uttar Kashi (CWC)-21, Kosani-21, Haldwani-20, Nainital-18, Tharali-17, Tehri-17, Tehri (CWC)-17, Deoprayag-16, Bageshwar-16, Mussoorie-15, Roorkee-15, Joshimath-11, Jakholi-11, Champawat-10, Keertinagar-10, Rudraprayag-9, Karnaprayag-9, Almora-9, Pithoragarh-9, Chamoli-8. **HIMACHAL PRADESH:** Paonta Sahib-41, Kalpa-19, Renuka-15, Sangrah-11, Nahan-10, Jubbal-7. **HARYANA, CHANDIGARH & DELHI:** Chhachhrauli-27, Chhachrauli (ARG) -27, Bilaspur-27, Jagadhari-26, Delhi (Palam)-12, Delhi (Ayanagar)-9, Nilokheri-8, Delhi (Pitampura)-8, Naraingarh-7, Faridabad-7.
18 June	**UTTARAKHAND:** Haldwani-28, Champawat-22, Mukteshwar-18, Nainital-17, Ranikhet-12, Pithoragarh-12, Pantnagar-11, Almora-10, Chamoli-10, Kosani-8, Karnaprayag-8, Tharali-8, Joshimath-8, Deoprayag-7, Keertinagar-7, Jakholi-7.

Table 2: Heavy rainfall records (in mm) over Uttarakhand during Monsoon months (2008-2013)

2008		2009		2010		2011		2012		2013 (upto 13.07.13)	
Dehra Dun		Dehra Dun		Dehra Dun		Dehra Dun		Dehra Dun		Dehra Dun	
13-Jun	120.8	7-Aug	71.5	5-Jul	72.8	6-Jul	85.2	14-Jul	89.2	14-Jun	93.4
15-Jun	73.7	8-Aug	107.4	31-Jul	363.7	16-Jul	96.5	4-Aug	153.1	16-Jun	219.9
22-Jun	93.8	11-Sep	75.8	19-Aug	142.2	21-Jul	73.5	5-Aug	81.8	17-Jun	370.2
18-Jul	77.9	5-Oct	110.3	22-Aug	106.0	28-Jul	119.3	6-Aug	64.6	25-Jun	119.7
19-Jul	81.3	PANT NAGAR		24-Aug	67.6	1-Aug	91.1	18-Aug	79.5	8-Jul	129.6
31-Jul	161.1	18-Aug	142.6	25-Aug	78.5	16-Aug	138.7	19-Aug	190.3	PANT NAGAR	
3-Aug	79.4	12-Sep	110.2	26-Aug	92.3	17-Aug	74.8	18-Sep	137.8	18-Jun	113.0
11-Aug	116.2	6-Oct	138.8	2-Sep	95.1	19-Aug	118.6	PANT NAGAR		25-Jun	148.6
17-Aug	100.7	MUKTESHWAR		3-Sep	108.2	15-Sep	119.0	3-Aug	146.9	26-Jun	102.8
27-Aug	65.6	17-Aug	115.2	17-Sep	90.8	16-Sep	90.6	3-Sep	77.6	MUKTESHWAR	
PANT NAGAR		18-Aug	119.4	19-Sep	149.3	PANT NAGAR		MUKTESHWAR		16-Jun	78.5
10-Jun	88.4	10-Sep	94.1	20-Sep	72.9	1-Jul	149.8	4-Aug	10.9	17-Jun	236.8
18-Jul	88.1	12-Sep	79.5	PANT NAGAR		14-Jul	113.2	17-Sep	103.3	18-Jun	183.0
5-Aug	65.2	6-Oct	106.6	6-Jul	64.7	15-Jul	121.6	19-Sep	93.6	NEW TEHRI	
8-Aug	82.3			19-Jul	129.8	16-Aug	209.4	NEW TEHRI		16-Jun	121.9
15-Aug	80.0			20-Jul	71.6	17-Aug	79.4	5-Aug	86.0	17-Jun	168.9
20-Aug	212.8			21-Jul	146.2	18-Aug	105.4			25-Jun	96.0
20-Sep	161.0			19-Aug	95.4	9-Sep	104.6				
21-Sep	128.1			7-Sep	117.2	MUKTESHWAR					
MUKTESHWAR				16-Sep	66.1	1-Jul	78.5				
20-Sep	119.8			17-Sep	82.6	15-Aug	75.6				
21-Sep	122.3			18-Sep	116.2	16-Aug	234.3				
NEW TEHRI				19-Sep	112.0	NEW TEHRI					
17-Aug	67.3			20-Sep		16-Jul	65.8				
				MUKTESHWAR		16-Aug	132.0				
				21-Jul	102.6						
				19-Aug	100.0						
				18-Sep	102.0						
				19-Sep	235.8						
				NEW TEHRI							
				9-Feb	67.6						
				20-Jul	74.6						
				31-Jul	65.4						
				8-Sep	100.6						
				19-Sep	84.8						

Heavy rainfall events have a major impact in human affairs, particularly over the densely populated Indian subcontinent. Occurrence of heavy to very heavy rainfall over Uttarakhand during monsoon months is not uncommon. Records of heavy rainfall over Uttarakhand which occurred during last five years (2008-2013) are shown in **Table 2**. The Table shows that there

are number of occasions in the past that heavy to very heavy rainfall reported over Uttarakhand during monsoon months.

The forecasting of heavy rainfall, particularly over high complex terrain is one of the most challenging tasks for forecasters. Rainfall prediction has been one of the difficult areas in numerical weather prediction. This is due to the complex issues which involve impact of orography due to high complex terrain, treatment of synoptic scale and mesoscale system and their interactions, lack of good quality data over remote areas and large spatial and temporal variations of rainfall. In the past, synoptic methods have been the mainstay of tropical weather forecasting. Of late, NWP methods have acquired greater skills and are playing increasingly important role in the tropical weather prediction, through the progress of dynamical modeling efforts in the tropics has been rather slow as compared the extra tropics. This is because of some inherent problems associated with the dynamics of the tropical motion systems. The problems involved are much more difficult than in the middle latitudes. In the extra tropics, the primary energy source for the atmospheric motion is the zonal available potential energy associated with the strong temperature gradients, and there exists a satisfactory dynamical theory of these motions outside the tropics. In the tropics, on the other hand, the storage of available potential energy is very small due to the very small temperature gradients. Latent heat release in cumulus convection is the primary energy source. Parameterization of cumulus convection in tropical model is therefore very important and is a difficult problem. Added to this, there is the problem of large perennial data gaps in the tropical regions which are largely oceanic. The tropical numerical weather prediction system is required to address these problems adequately. Much progress has been made in recent years in the development of numerical models for low latitudes. The World Weather Watch, now supported by a variety of surface based and spaced based observing platforms has considerably enhanced the observational data base for numerical weather modeling. The availability of faster computers has enabled a large volumes of tests on analysis, initialization, sensitivity to physical parameterization and statistical evaluation of NWP, resulting an overall improvement in the skill of tropical dynamical models. Currently, Forecast Services are based on conventional Synoptic methods supplemented by use of Numerical Weather Prediction products.

This report analyses this extremely heavy rainfall episode with an objective of improving the predictability of such phenomena in the future. The report comprises of following five sections: **(a)** Description of the weather systems which caused this devastating rainfall activities, **(b)** Performance of operational NWP models of IMD to predict this event in short range tome scale (3 days), **(c)** Assessment of forecast and warnings issued by India

Meteorological Department to State Government and other user agencies and **(d)** Road map for the future.

2. Description of weather systems associated with this heavy rainfall event

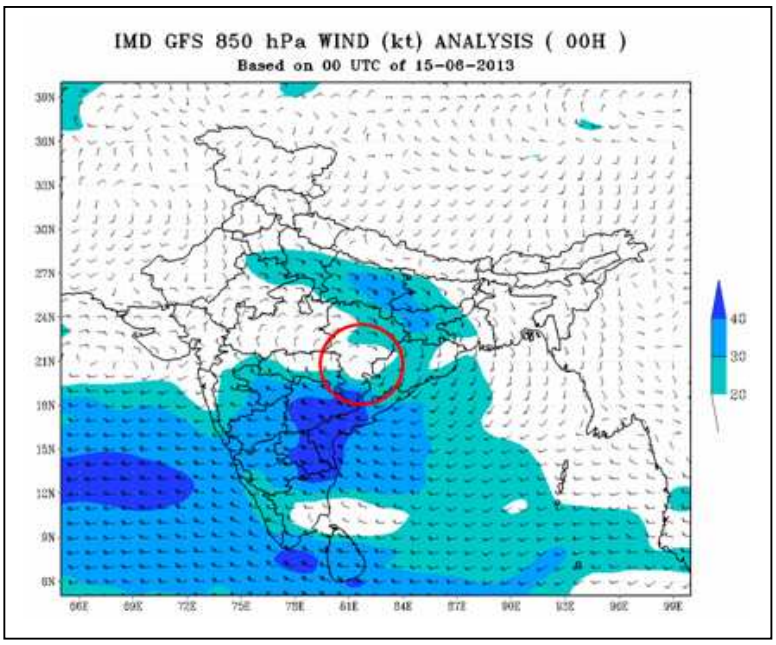
A monsoon low pressure area formed over northwest Bay of Bengal on 12 June 2013. The monsoon low had a general north-westward movement and reached up to northeast Rajasthan on 18 June 2013. The location of the low pressure system during its lifetime is shown in **Table-3**. The locations of low pressure system based on daily 0000 UTC model analysis fields of Global Forecast System (GFS) of IMD during 15 June to 18 June 2013 are shown in **Figure 1(a-d**). The analysis of the lower tropospheric wind and moisture fields suggests that progress of southeast monsoon current from south to northwest upto Uttarakhand and simultaneously movement of a western disturbance across north India from west to east during the period. The westerlies and the monsoon system virtually locked over the Uttarakhand and neighbouring regions during the period. The strength of the monsoon wind flow is relatively weaker in the Himalayan region but as a result of this system, a strong south easterly wind flow (> 40 kts) over Uttar Pradesh, Uttarakhand and Himachal Pradesh (as shown in Figure 1(a-d)) pumped moisture into the region from both the Arabian Sea and Bay of Bengal. The location of this strong, narrow current of wind and associated moisture flux, changed from day-to day in association with the position of the monsoon low. Initially, when the monsoon low was located over southeast Madhya Pradesh and adjoining Chhattisgarh at 0000 UTC of 15 June, the southeasterly current was strongest (20 kys -30 kts) over the northern plains of India at the northern periphery of the system. On 0000 UTC of 18 June the low pressure system became less marked and persisted over north Rajasthan as cyclonic circulation. The monsoon current significantly weakened to 5-10 kts over the region and there was no southeasterly component of monsoon current from the Bay of Bengal.

The analysis suggests that due to strong interaction between an oncoming trough in the westerlies and the strong southeasterly monsoon wind flow in association with a monsoon low pressure system over the North Indian region, resulting development of lower troposperic wind convergence over the Uttarakhand and neighbouring regions. This, with strong orographic effect due to high terrain when coupled by the strong moisture feeding from both the Arabian Sea and Bay of Bengal triggered heavy rainfall activity downstream of the trough, over the North Indian region. The episode was unique in that, the line of

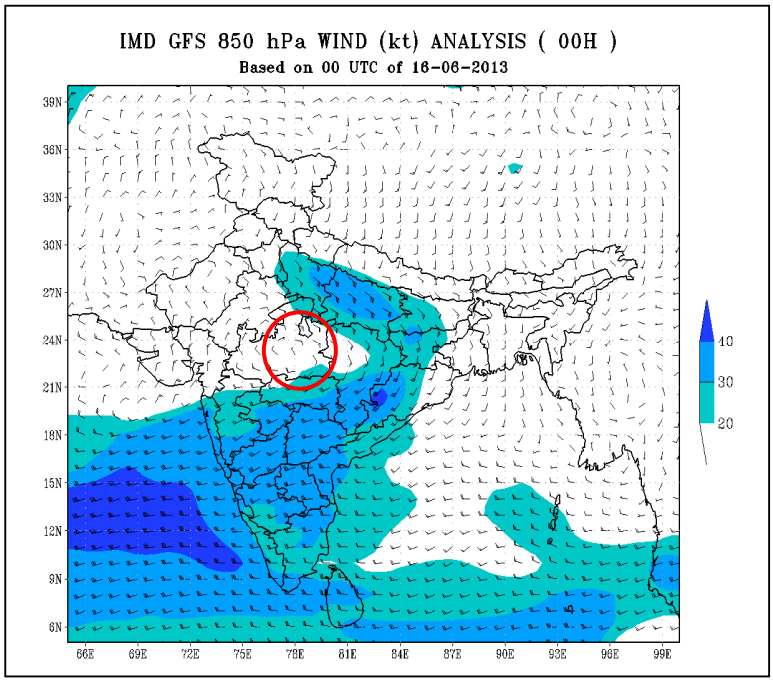
convergence of the two weather systems was nearly stationary for hours at a time, resulting in huge amount of accumulated rainfall over parts of North India causing widespread flooding.

Table-3 Location of the Low pressure Area

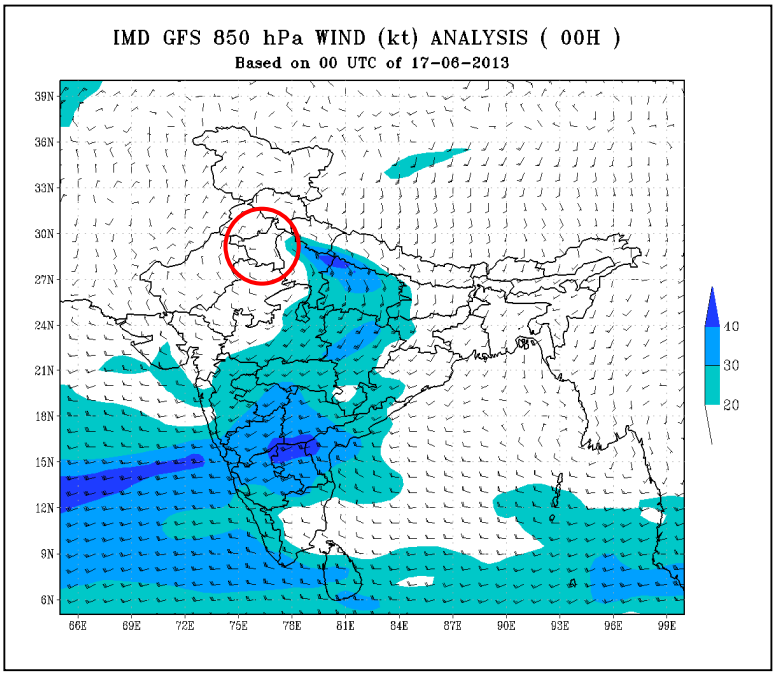
Date & Time	**Location of the Low pressure Area**
1200 UTC 12 June 2013	Northwest Bay of Bengal & adjoining Odisha and north coastal Andhra Pradesh
0000 UTC 13 June 2013	Northwest Bay of Bengal & adjoining Odisha and north coastal Andhra Pradesh
1200 UTC 13 June 2013	South Odisha and neighbourhood
0000 UTC 14 June 2013	Central parts of Odisha and neighbourhood
1200 UTC 14 June 2013	Chhattisgarh and adjoining Odisha
0000 UTC 15 June 2013	Southeast Madhya Pradesh and adjoining Chhattisgarh and Vidarbha
1200 UTC 15 June 2013	West Madhya Pradesh and neighbourhood
0000 UTC 16 June 2013	West Madhya Pradesh and neighbourhood
1200 UTC 16 June 2013	East Rajasthan & neighbourhood
0000 UTC 17 June 2013	East Rajasthan & neighbourhood
1200 UTC 17 June 2013	Northeast Rajasthan & adjoining area of Haryana
0000 UTC 18 June 2013	Became less marked and an upper air cyclonic circulation over north Rajasthan and neighbourhood
1200 UTC 18 June 2013	Upper air cyclonic circulation over Haryana and adjoining west Uttar Pradesh


IMD GFS 850 hPa WIND (kt) ANALYSIS (00H)
Based on 00 UTC of 15-06-2013
40
30
20

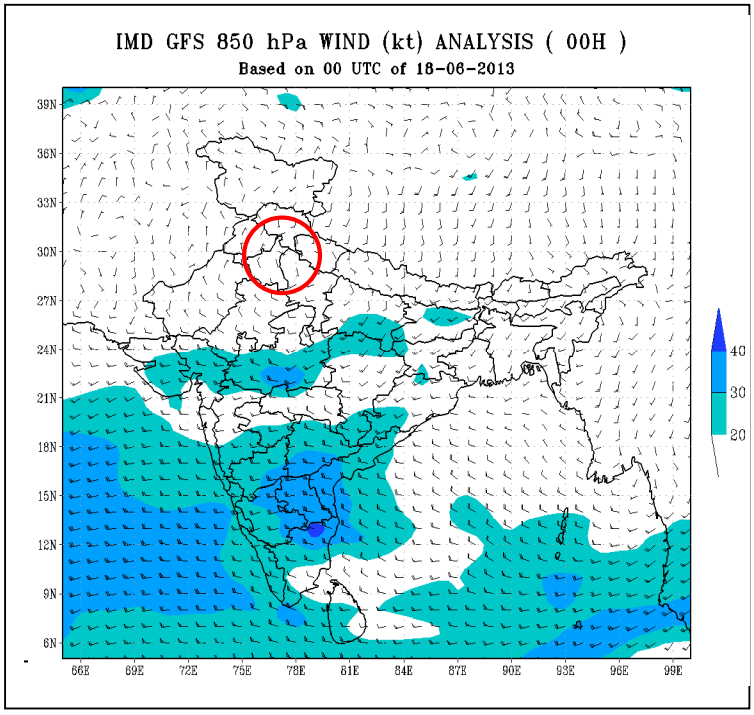
(a)


IMD GFS 850 hPa WIND (kt) ANALYSIS (00H)
Based on 00 UTC of 16-06-2013
40
30
20

(b)



(c)



(d)

Figure 1. The locations of low pressure system at 0000 UTC of (a) 15 June 2013, (b) 16 June 2013, (c) 17 June 2013, (d) 18 June 2013

3. Performance of Operational NWP Models

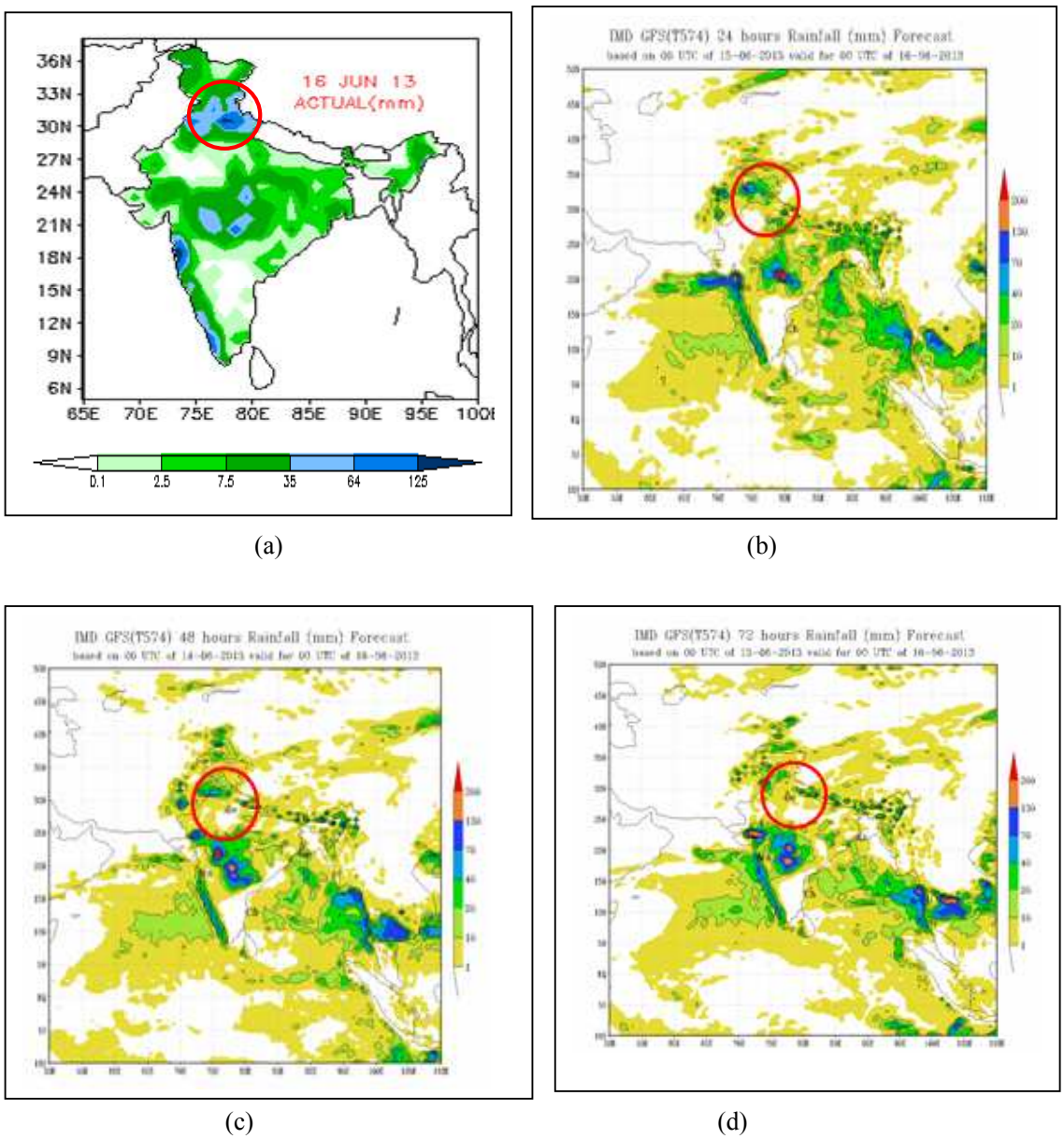
With the commissioning of High Performance Computing System (HPCS) , National Centre for Environmental Prediction (NCEP), USA based Global Forecast System (GFS T574/L64) has been made operation at the H/Q of IMD, incorporating Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to 7 days. Currently, it runs twice in a day (based on 0000 UTC and 1200 UTC observations). In addition to this, the meso-scale forecast system WRF (ARW) with 3DVAR data assimilation is being operated daily twice, at 27 km, 9 km and 3 km horizontal resolutions for the forecast up to 3 days using initial and boundary conditions from the IMD GFS-574/L64 (horizontal resolution over the tropics ~ 22 km)..

Figure **2(a-d)** shows the rainfall analysis and predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's GFS valid for 16 June 2013. The rainfall analysis is presented along with the model forecasts for better visualization of the performance of model forecasts. The figure shows that the model underestimated heavy rainfall over Uttarakhand and neighbouring states on 16 June. However the 24 h, 48 h and 72 h rainfall predictions valid for 17 June **(Figure 3(a-d))** and 18 June **(Figure 4(a-d))** clearly indicated heavy rainfall activity (more than 20 cm) over Uttarakhand on 17 June and 18 June 2013.

Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD WRF (9 km) valid for 16 June **(Figure 5(a-d))** shows that the model underestimated the heavy rainfall over Uttarakhand, Himachal Pradesh, Delhi&Haryana and Punjab. The model forecast shows a shifting of heavy rainfall belt towards northwest side of the observed heavy rainfall belt of 16 June. The 24 h, 48 h and 72 h rainfall predictions based on IMD WRF model (9 km resolution) clearly indicated heavy rainfall activity (more than 20 cm) over Uttarakhand and Himachal Pradesh on 17 June (**Figure 6(a-d))** and 18 June 2013 **(Figure 7(a-d))**.

District wise distributions of rainfall over Uttarakhand during 14 June -18 June 2013 are shown in **Table 4.** The observed rainfall analysis shows that heavy rainfall occurred during 16 June -18 June over Uttarakhand but higher rainfall occurred over western part of Uttarakhand on 16 June and 17 June and over eastern part on 18 June. Therefore, for quantitative verification the rainfall belt over Uttarakhand is divided in two parts (i) western part (consisting of Uttarkasi, Dehradun, Haridwar, Teri, Rudraprayag and Pauri districts) and (ii) eastern part (consisting of Almora, Nainital, Udham sing nagar, Champawat, Bageshwar,

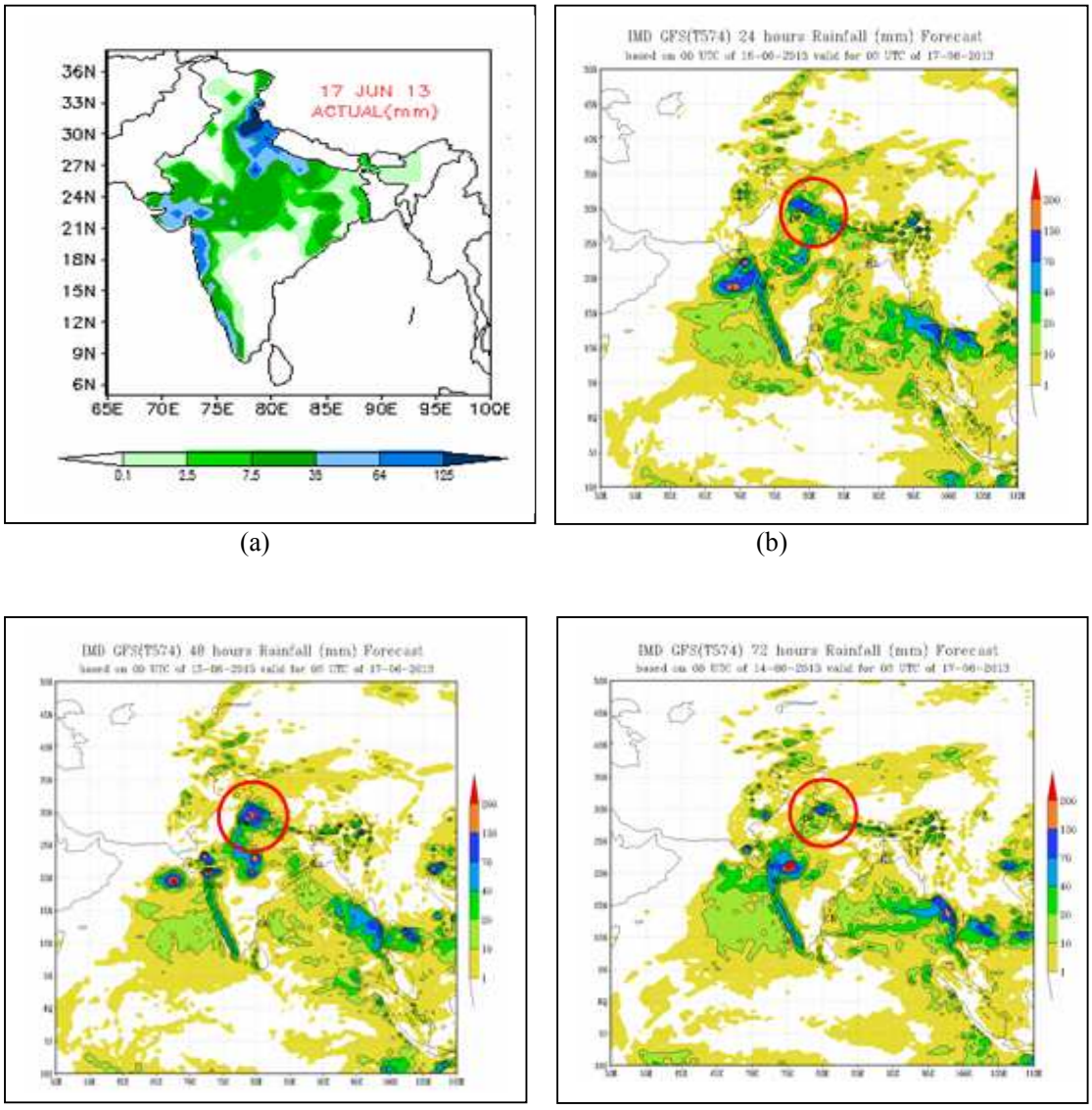
Pithoragarh and Chamoli districts of Uttarakhand (UK)). The quantitative forecasts (24 h, 48h and 72 h) along with analyzed rainfall (**Table-5**) shows that both the model correctly predicted heavy rainfall and very heavy rainfall over both the parts of Uttarakhand on 17 June and 18 June 2013. This improvement in forecast has been possible due to enormous improvement in the input data volume and assimilation techniques into operational NWP models.



(a) (b)

(c) (d)

Figure 2 Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's GFS valid for 16 June 2013.



(a) (b)

(c) (d)

Figure 3 Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's GFS valid for 17 June 2013.

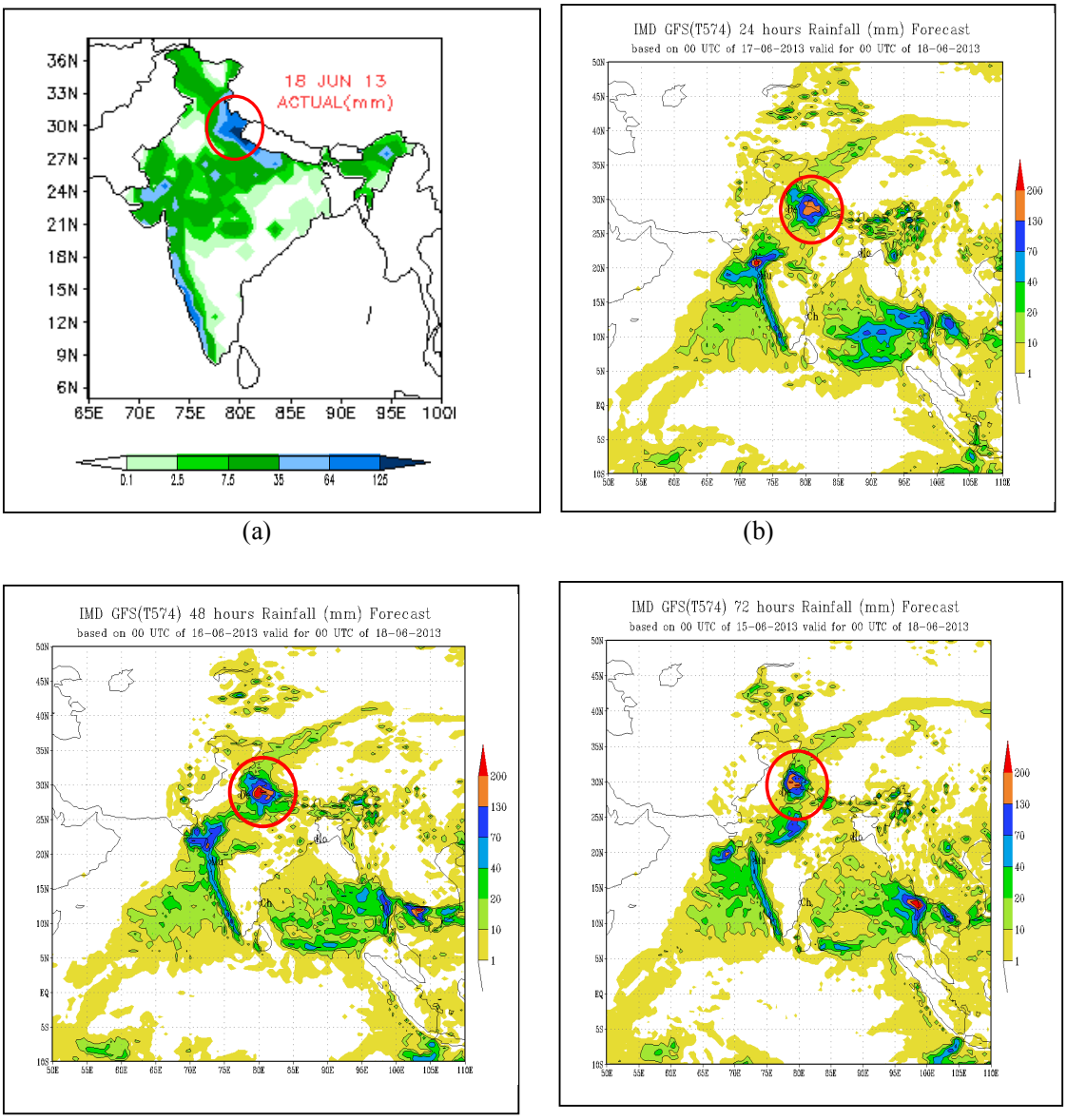


Figure 4. Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's GFS valid for 18 June 2013.

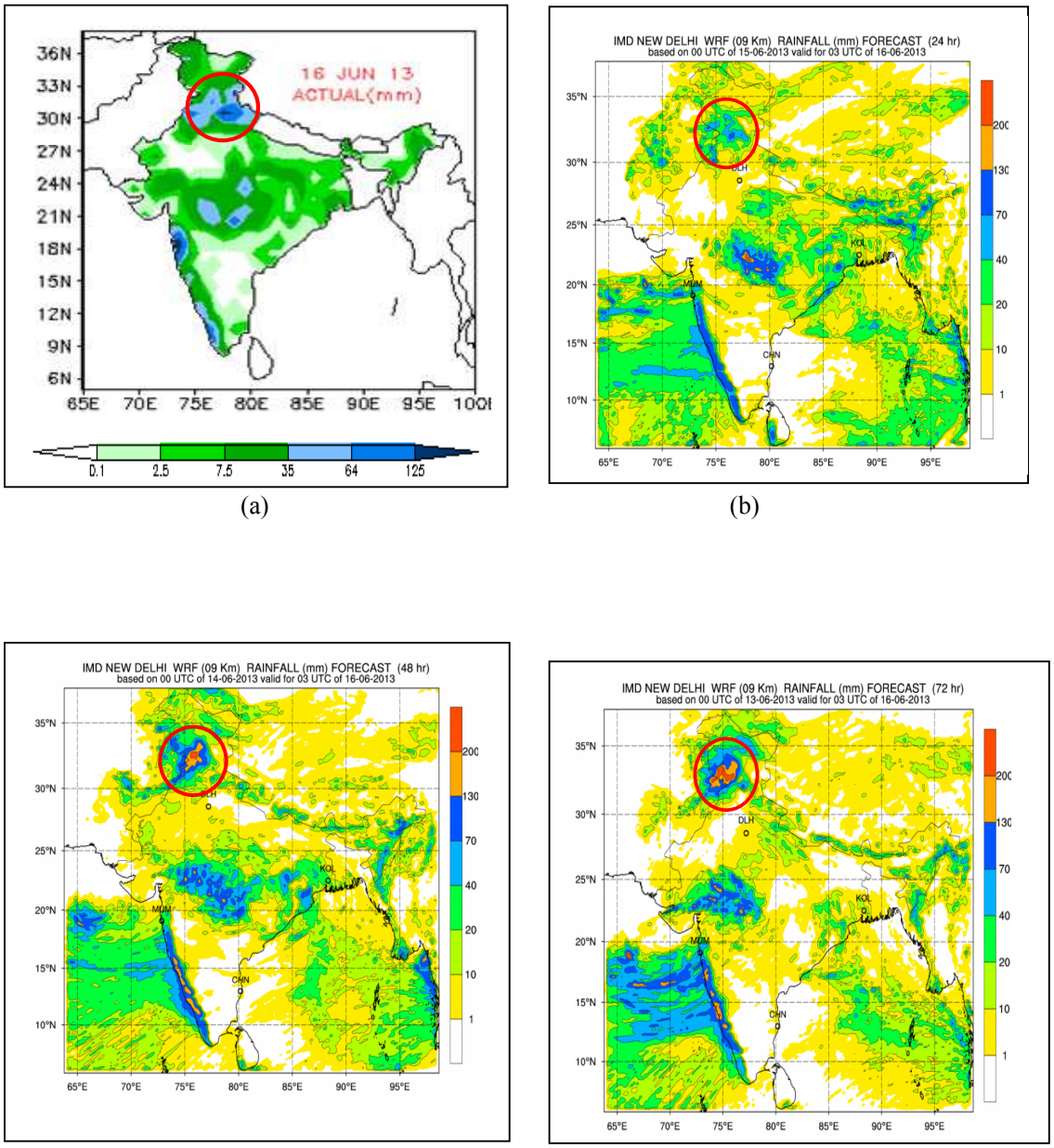


Figure 5. Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's WRF (9 km) valid for 16 June 2013.

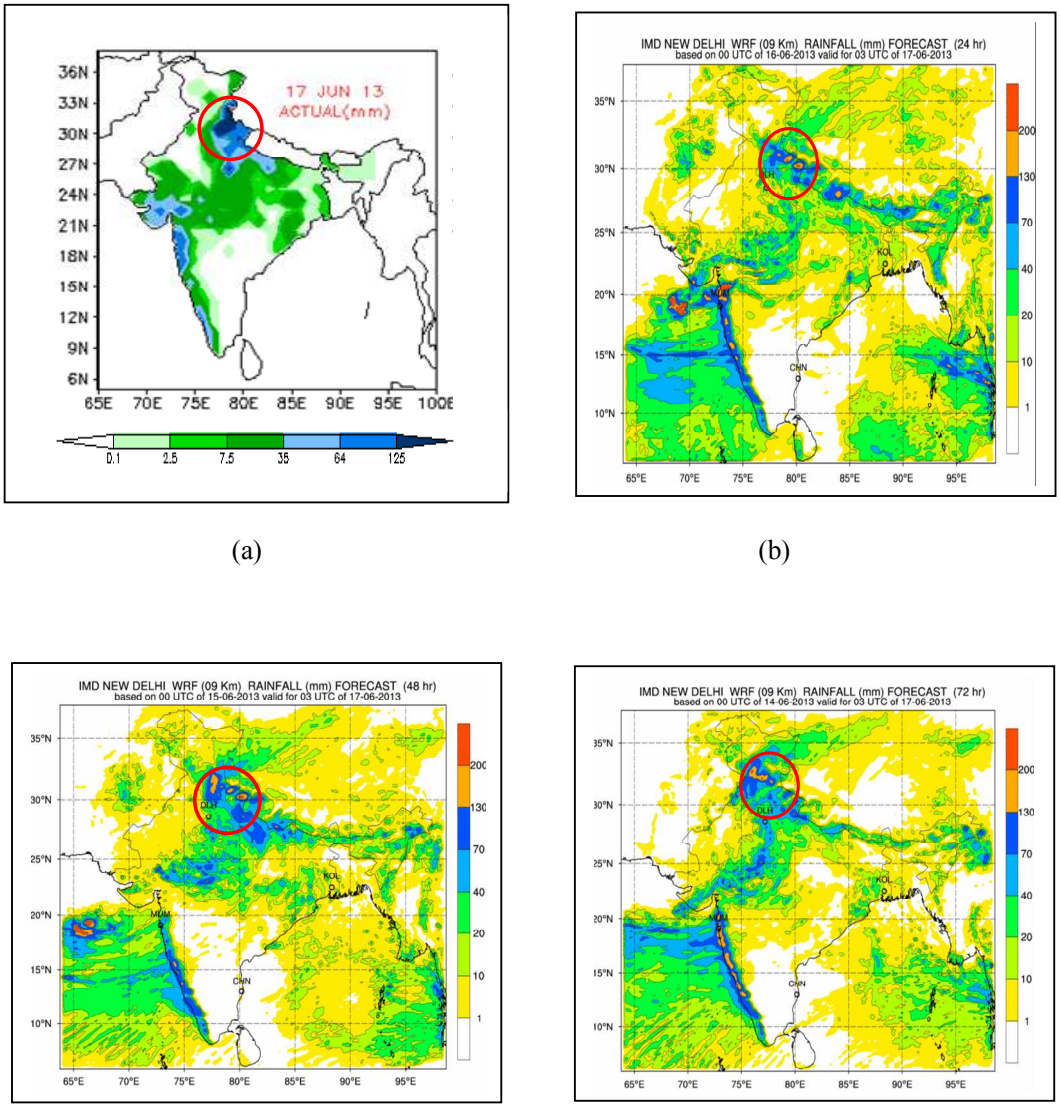


Figure 6. Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's WRF (9 km) valid for 17 June 2013.

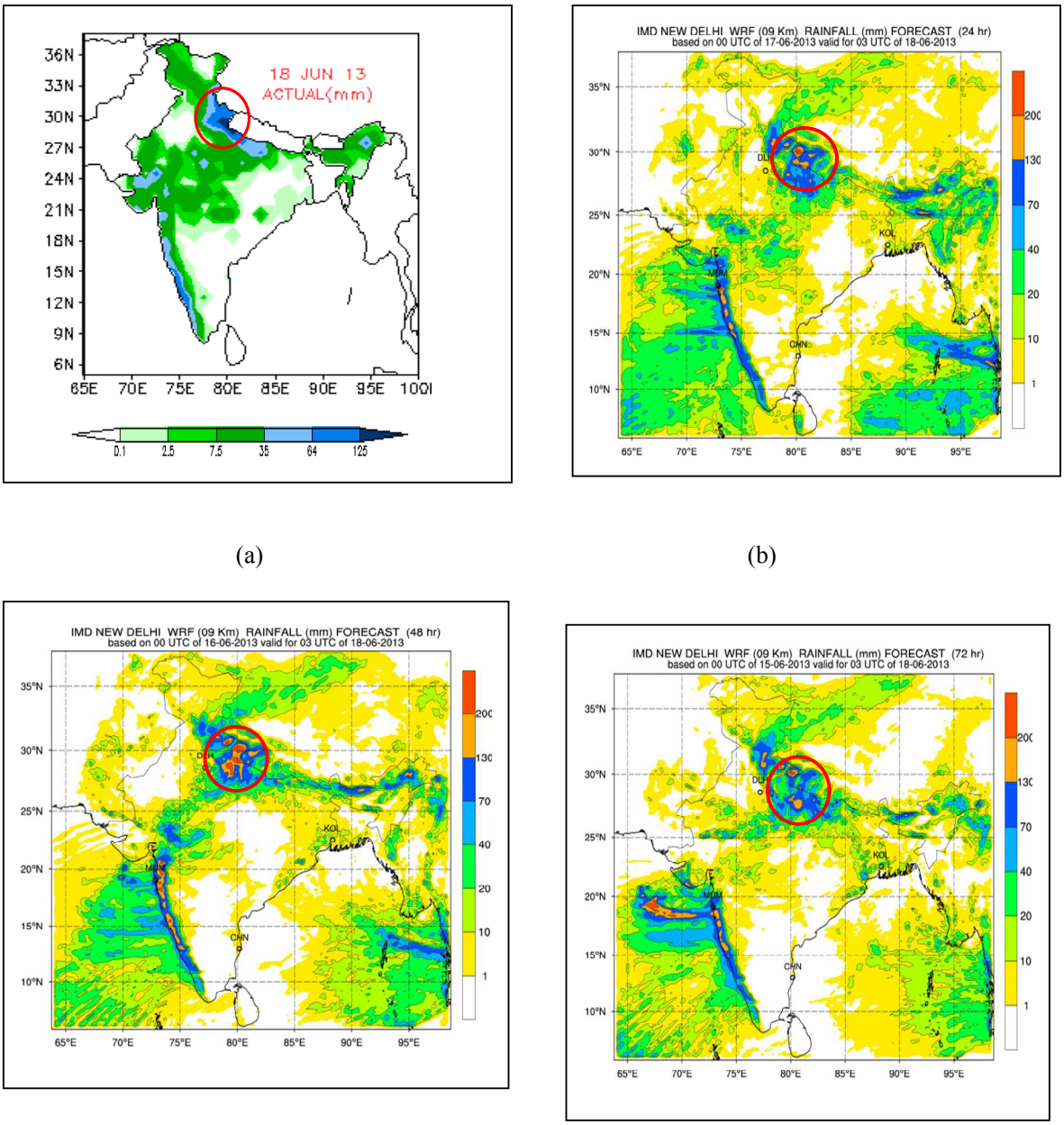


Figure 7 Rainfall predictions for day-1, day-2 and day-3 (24 h, 48 h and 72 h) based on IMD's WRF (9 km) valid for 18 June 2013.

Table 4. District wise rainfall (mm) over Uttarakhand during 14 June -18 June 2013

DATE	14 June	15 June	16 June	17 June	18 June
DISTRICT: ALMORA					
ALMORA	15.1	1.0	32.4	89.3	100.0
RANIKHET (G)	4.0	0.0	16.0	38.0	120.0
DISTRICT: BAGESHWAR					
BAGESHWAR (THMO)	15.0	3.0	61.0	161.0	63.0
KOSANI (U PROB)	43.2	20.2	105.0	205.0	83.2
DISTRICT: CHAMOLI					
CHAMOLI	1.0	37.0	58.0	76.0	100.0
JOSHIMATH	0.0	31.4	41.9	113.8	78.6
KARNAPRAYAG	8.2	7.0	88.0	89.6	82.3
THARALI	0.0	15.0	58.0	173.0	80.0
DISTRICT: CHAMPAWAT					
BAMBASA	0.0	0.0	3.0	99.0	230.0
CHAMPAWAT	0.0	1.0	34.0	97.0	222.0
DISTRICT: DEHRADUN					
DEHRA DUN	93.4	53.5	219.9	370.2	11.8
MUSSOORIE	16.0	44.0	137.0	155.0	8.0
DISTRICT: GARHWAL PAURI					
KOTDWARA	0.0	9.0	73.0	23.0	52.2
LANDSDOWN	16.0	0.0	64.0	51.0	28.0
PAURI	0.0	0.0	44.0	51.0	38.0
DISTRICT: GARHWAL TEHRI					
DEOPRAYAG	0.5	7.3	129.5	163.3	69.5
KEERTINAGAR	0.0	0.0	78.0	96.0	65.2
TEHRI	3.7	33.5	121.9	168.9	53.4
TEHRI (CWC)	0.2	0.0	124.0	168.4	17.6
DISTRICT: HARDWAR					
HARDWAR	10.0	20.0	107.6	218.0	14.0
ROORKEE	0.0	5.0	51.0	147.0	15.0
DISTRICT: NAINITAL					
HALDWANI	0.0	13.0	91.0	200.0	278.3
MUKTESHWAR	14.0	0.4	78.4	236.8	183.0
NAINITAL	14.8	18.6	43.6	175.6	170.2
DISTRICT: PITHORAGARH					
MUNSIYARI	4.0	25.0	44.0	85.0	75.0
PITHORAGARH	0.0	0.0	11.2	85.5	117.2
DISTRICT: RUDRAPRAYAG					
JAKHOLI	25.0	71.0	121.0	108.0	65.0
RUDRAPRAYAG	4.0	11.8	89.4	92.2	59.2
DISTRICT: UDHAM SINGH NAGAR					
KASHIPUR	0.0	65.0	2.0	31.0	35.0
PANTNAGAR	0.0	0.0	5.6	62.1	113.0
DISTRICT: UTTARKASHI					
BARKOT	10.0	15.4	112.6	20.0	20.0
BHATWARI	20.0	18.0	35.0	70.0	50.0
DUNDA	5.0	80.0	118.0	185.0	16.0
PUROLA	26.0	36.0	165.0	60.0	104.0
UTTAR KASHI	15.0	35.0	129.0	162.0	19.0
UTTAR KASHI (CWC)	4.2	48.2	121.8	207.4	21.2

Table-5 Analyzed and model forecast rainfall for 17 June and 18 June 2013

Date	Region	Analyzed rainfall	24 h Forecast		48 h Forecast		72 h Forecast	
			GFS	WRF	GFS	WRF	GFS	WRF
17 June	West UK	≥ 12.5 cm	13 cm	≥ 20 cm	≥ 20 cm	20 cm	13 cm	13 cm
	East UK	12.5 cm	7 cm	≥ 20 cm	13 cm	≥ 20 cm	7 cm	≥ 20 cm
18 June	West UK	12.5 cm	13 cm	13 cm	13 cm	≥ 20 cm	20 cm	≥ 20 cm
	East UK	≥12.5 cm	20 cm	≥ 20 cm	≥ 20 cm	≥ 20 cm	20 cm	≥ 20 cm

3. Verification of Operational forecasts

IMD provides operational weather forecasts and warnings to various users through a three-tier forecast set up of National Weather Forecast Centre (NWFC),New Delhi , Regional Weather Forecast Centre (RWFC) located at respective Regional Meteorological Centres and State Weather Forecast Centres (SWFC), located at respective Meteorological Centre. SWFC is responsible to provide weather forecast and warnings to the State Government for the respective states. Heavy Rainfall Warnings issued by Meteorological Centre (SWFC) Dehradun, RWFC New Delhi and NWFC New Delhi(HQ) for Uttarakhand and Himachal Pradesh during the period 14-17 June 2013 along with realised weather are presented in **Table-6** and **Table-7** respectively.

Table 6: Rainfall warnings issued for Uttarakhand

Forecast issued on	Warning by MC Dehra Dun	Warning by RWFC, New Delhi	Warning by NWFC, New Delhi	Realised Weather next day
14.06.2013	Isolated rather heavy to heavy rainfall during next 48 hours.	Nil	NIL	Dehradun-5, Tehri-3, Jakholi -7, Kashipur -6.5 Dunda -8.0
15.06.2013	**Isolated heavy to very heavy rainfall** during next 72 hours.	**Isolated heavy rainfall** would occur during next 48 hours.	**Isolated Heavy to very heavy** rainfall would occur during next 48 hours.	Dehradun-22 Purola-17 Deoprayag-13 Uttarkashi-13, Tehri-12
16.06.2013	**Havy to very heavy** rainfall at few places during next 36 hours.	**Isolated heavy to very heavy** rainfall may occur during next 48 hours.	**Heavy to very heavy** rainfall would occur **at a few places** during next 48 hours.	Dehradun-37 * Mukteshwar-24 Hardwar-22 Uttarkashi-21 Kosani-21
17.06.2013	**Isolated heavy to very heavy** rainfall during next 24 hours.	**Isolated heavy to very heavy** rainfall during next 48 hours.	**Heavy to very heavy** rainfall would occur at **a few places** during next 48 hours.	Haldwani-28, Champawat-22, Mukteshwar-18, Nenital-17, Ranikhet-12

Meteorological centre, Dehra Dun had specified the areas of heavy to very heavy rainfall in the char dham's and issued the following advisories.

Char dham yatra forecast issued on 15-06-13 (morning): Char Dham yatris are advised to postpone yatra by four days.

Char dham yatra weather forecast issued on 16-06-13 (morning): Char Dham yatris are advised to postpone yatra by three days.

Advisory (issued on 15-06-13) to DM RUDRAPRAYAG AND ITBP: Yatris are requested to get back to safer places.

Advisory (issued on 16-06-13) to Chief Secretary , Secretary , Disaster management , Executive director , Disaster management , DM's of respective districts and ITBP : People are advised to move to safer places and not to venture into hills with warning of landslides as well.

Table 7 Rainfall warnings issued for Himachal Pradesh

Forecast issued on	Warning by MC Shimla	Warning by RWFC, New Delhi	Warning by NWFC, New Delhi	Realised Weather next day
14.06.2013	Isolated heavy rainfall would occur on 15th June, 2013.	Nil	NIL	Nahan-9, Shimla-5, Sundernagar-4, Una-4, Dharamshala-2
15.06.2013	Isolated heavy rainfall would occur during next 72 hours.	Isolated heavy rainfall would occur during next 48 hours.	Isolated **heavy to very heavy** rainfall would occur during next 48 hours.	Rajgarh-18, Una-8, Dharampur-7, Bangana-7, Kalpa-6
16.06.2013	Isolated heavy rainfall would occur during next 48 hours.	Isolated heavy to very heavy rainfall may occur during next 48 hours.	**Heavy to very heavy** rainfall would occur at **a few places** during next 48 hours.	Paonta Sahib-41, Kapa-19, Renuka-15, Sangrah-11, Nahan-10
17.06.2013	Isolated heavy rainfall would occur during next 24 hours.	Isolated heavy to very heavy rainfall may occur during next 48 hours.	Isolated **heavy to very heavy** rainfall would occur during next 48 hours.	Kalpa-7, Sangraha-6, Renuka-5, Jubbal-4, Guler-3

4. Operational setup for Heavy Rainfall Warnings and Road map for future for increased synergy between different forecast offices in IMD

IMD provides operational weather forecasts and warnings for different weather parameters to various users through a three-tier forecast set up of National, Regional and State Weather Forecast Centres. The following sections, however, describe only the heavy rainfall/snowfall procedures.

1. Standard Operating Procedure (SOP)

1.1. Salient Features of the SOP

IMD brought out the **Standard Operation Procedure - Weather Forecasting and Warning (SOP-WFW)** during January 2012 to streamline and synergize the process of weather forecast and warning among the three tiers. The SOP-WFW describes in details the following aspects related to Heavy Rainfall Warning:

i. *Definition of Heavy Rainfall (HRF)*
ii. *Area of Responsibility and Organisation*
iii. *Heavy Rainfall Monitoring*
iv. *Heavy Rainfall Forecasting Heavy Rainfall Warning (HRW) for General Purpose*
v. *Stakeholders*
vi. *Warning Product Generation and Presentation*
vii. *Warning Dissemination*
viii. *Organisation and Area of Responsibility*
ix. *Inputs for HRW*
x. *Decision Making Process*
xi. *Timeline for Analysis, Forecast and Dissemination*
xii. *Directory/List of Warnees*
xiii. *Modes of Communication for HRW*
xiv. *Text of Heavy Rainfall Warning*
xv. *Visual Display*
xvi. *Documentation and Verification*

The SOP covers in details the inputs and procedures to be adopted at each stage of HRW and was an attempt towards uniformity in inputs, procedures and final warnings.

The operational heavy rainfall warnings issued by IMD include intensity and distribution of heavy rainfall/snowfall. The description of terms used for forecasts and warnings as described in the SOP are as below:

Spatial Distribution of Rainfall/Snowfall

Distribution Category	**Percentage of Places expected to receive heavy rainfall/snowfall**
Isolated (One or two Places):	<25% of stations gets rainfall
Scattered (At a few Places)	26–50% of stations gets rainfall
Fairly Widespread (At many Places):	51–75% of stations gets rainfall
Wide spread (At Most place):	76–100% of stations gets rainfall

Descriptive Term used for Intensity of Rainfall amount (in mm) for 24 hours

Heavy Rain:	64.5 – 124.4
Very Heavy Rain:	124.5 – 244.4
Extremely Heavy Rain:	>244.5
Exceptionally Heavy Rain:	When the amount is a value near about the highest recorded rainfall at or near the stationfor the month or season. However, this termwill be used only when the actual rainfall amount exceeds 12 cm.

Other Categories used for rainfall amounts are as follows

No Rain:	0.0
Very light Rain:	0.1- 2.4
Light Rain:	2.5 – 7.5
Moderate Rain:	7.6 – 35.5
Rather Heavy:	35.6 – 64.4

1.2. **Main Recommendations of the SOP and current practice:** Some of the recommended procedures and practices of the SOP are reproduced below (only selective portion and not the entire set of recommendations) along with the current practices:

1.2.1 Organisation and Area of Responsibility:

SOP Recommendation: *There will be a three tier organization for monitoring, prediction and warning services at the national level, NWFC will issue heavy rainfall warning valid for 48 hrs. based on 00, 03, 09 and 12 UTC observations. It will issue warning to national agencies, press & electronic media, public and users. While the bulletin based on 03 UTC will be main bulletin, others will be the update. The warning bulletin will be a part of the main bulletin. In addition the heavy rainfall*

warning will have visual presentation in multi hazard warning map generated by NWFC.

At regional level the warning bulletin will be issued for the concerned state(s) only like that issued by SWFC. This bulletin will contain the warning for the districts. For other states, the regional bulletin will contain the warnings at sub-divisional level and will be available in regional website. It will not issue warning bulletin for the states where there is SWFC.

At SWFC the HRW will be issued by duty officer under the supervision of SWFC In-charge for the state. At RWFC there should be round the clock duty headed by a Group-A officer if available, otherwise work may be managed by trained officials under the supervision of a Group-A Officer.

RWFC (RMC) and SWFC (MC) will issue district-wise HRW for their respective states. NWFC, New Delhi will issue HRW for the whole country on a meteorological subdivision scale.

The organisational map is shown in **Figure 8 below**

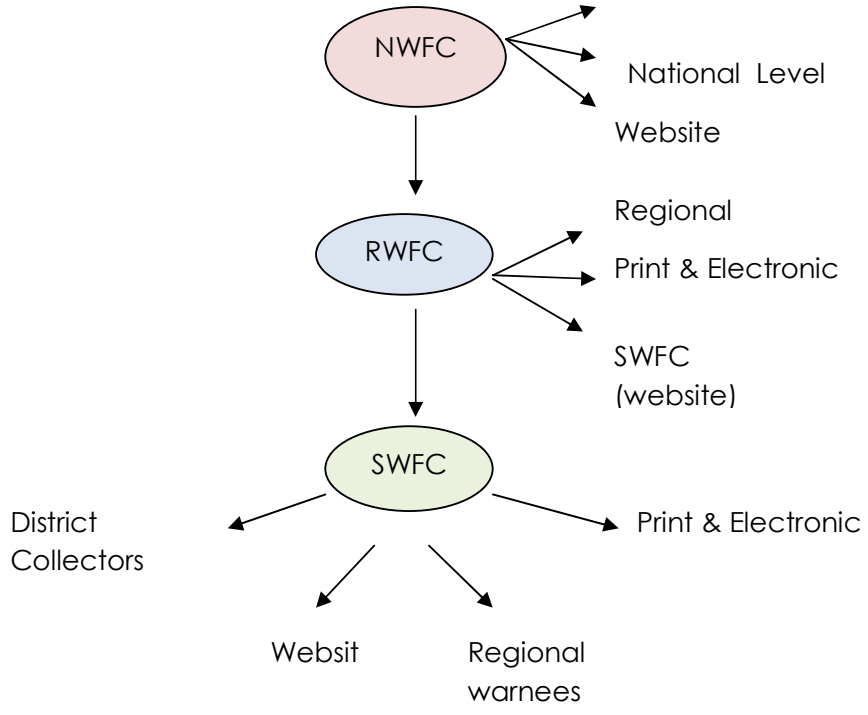


Fig. 8. Organisational Map for Heavy Rainfall warning

Current Practice: National Weather Forecast Centre(NWFC), New Delhi provides weather warnings (and also forecasts) valid for next 72 hours (instead of the recommended 48 hours) along with outlook for next four days. These forecasts are updated four times a day (based on 00, 03, 09 and 12 UTC data) around 09, 12, 16 and 20 hours IST. These forecasts/warnings are provided to All India Radio, Doordarshan, Press Information Bureau, NDMA Control Room and NDRF through e-mail and also posted on IMD website (www.imd.gov.in). The forecasts are issued for a meteorological sub-division as a whole.

Regional Weather Forecast Centres (RWFCs) at Regional Meteorological Centres at Regional Meteorological Centres Chennai, Guwahati, Kolkata, Mumbai, Nagpur and New Delhi) provide weather forecasts and warnings for next 48 hours with outlook for subsequent two days and are updated twice a day. Forecasts/warnings are provided for either for whole of meteorological sub-divisions or parts (north, south, east, west) in case the expected intensity /distribution are different for different parts of a sub-division. These forecasts are provided to different state level functionaries and also updated on website of respective Regional Meteorological Centres. Discussions with the RWFCs and a **survey of the website of Regional Meteorological Centres** (done on 04 July) reveal that warnings are being communicated to state level functionaries and **separate warning bulletins** are available on the regional websites **(except RMC Guwahati and New Delhi).** However, the HRW available in website of RMC, Nagpur is under the head Regional Weather and no separate link to warning is available. **RMC Guwahati and New Delhi are updating these forecasts/warnings in their websites only once a day in the form of Regional Daily Weather Reports only.** ***The recommendation that RWFCs will not issue warning bulletin for the states where there is SWFC is not being followed by RWFCs Chennai and Nagpur as their websites have warnings for states having SWFCs.***

State Weather Forecast Centres (SWFCs) at Meteorological Centres provide weather forecasts and warnings upto district level twice a day. These forecasts and warnings are provided to various decision makers at state level. As all the MCs do not have their websites, these are not available on the website for all the states. **Mention of warnings for these states, however, is found in the Regional Daily Weather Reports of concerned RMCs.**

1.2.2 Decision Making Process:

SOP Recommendation: *SWFC/RWFC will issue district-wise HRW for the respective state. NWFC will issue sub-division wise HRW for the whole county. Issue of heavy rainfall warning is the sole responsibility of the concerned SWFC/RWFC. However, they will discuss the matter with NWFC by 1030 hrs IST for issue of warning based on data of 0830 hrs IST of the day through* ***tele/video conferencing****.* ***In case of discrepancy, the view of SWFC/RWFC will prevail.***

Current Practice: SWFC/RWFC issue district-wise HRW for the respective state whereas NWFC issues sub-division wise HRW for the whole county. A practice of **video-conferencing** every day at 1030 hrs IST has been introduced from 2103 monsoon season for issue of HRW based on data of 0830 hrs IST of the day. However, the discussion is confined between RWFCs and NWFC as the conferencing facility is not available up to SWFC level. **However, cases of discrepancy between HRW issued by NWFC and RWFCs are still being noticed as is evident from forecasts issued for Uttrakhand during 13-17 June (Annexure I). A comparison of HRW issued by NWFC and RWFCs issued on 03 July (taken from Mid Day Bulletin of NWFC and RDWRs of RWFCs dated 03 July) show that differences continue to be there (Annexure II).**

1.2.3 Timeline for Analysis, Forecast and Dissemination:

SOP Recommendation: *The offices will issue HRW four times/two times a day (as given in* ***the Table 6*** *below) according to infrastructure/facilities available (like availability of Synergy) and depending upon requirements of various users.*

Table 6. Preparation & dissemination time of various charts/products

Charts/Product Time	Preparation Time	Dissemination Time
0000UTC	0300UTC	0400UTC
0600UTC	0900UTC	1000UTC
1200UTC	1500UTC	1600UTC
1800UTC	2100UTC	2200UTC

Current Practice: Weather Forecasts and HRWs are issued by NWFCs four times a day and by NWFC and twice a day by RWFCs/SWFCs as recommended. **However, the timings are not as per the recommendation**. NWFC issues HRWS four times a day around 04, 07, 11 and 15 UTC; and the RWFCs/SWFCs twice a day around 10 UTC and 15 UTC.

Recommendations for HRW Procedures in IMD:

In view of observations in the preceding section, following specific recommendations are made

1. Recommendations made in the **SOP-HRW** brought out by IMD in January 2012 should be implemented by all Forecast Offices across the country. However, in view of observations in the preceding sections, following specific recommendations are made

2. Significant differences have been noticed in the HRWs issued by different tiers of the warning system of IMD. Following recommendation is made for further streamlining the consultation process among various forecast offices.
   a. Tele-conferencing/ Video-conferencing facility should be extended up to all SWFCs on priority basis.
   b. Till the above stated facilities are not available at all SWFCs, the existing system of holding video-conferencing at 1030 IST among NWFC and RWFCs may continue. However, RWFCs should consult the SWFCs in their region before

1030 IST and present views of SWFCs also in the video-conferencing at 1030 IST. The consensus arrived at in the video-conferencing should be conveyed by RWFCs to the SWFCs in their region immediately after the meeting is over and their views should be obtained (preferable through a fax message/e-mail for records). This exercise should preferably be completed by 1130 IST. **In case the SWFCs do not agree to the consensus arrived between the NWFC and the concerned RWFC views of the SWFC should prevail as SWFC is finally responsible for the forecast issued for the state/s under their jurisdiction.** In such cases, RWFCs and NWFC should issue the same warning as issued by the SWFC.

c. NWFC should prepare a short note daily based on the discussions highlighting the consensus arrived, divergence in views, if any and major considerations which have gone into the final decision making. This note along with the final warnings should be brought to notice of the DGM daily by 1230 IST.

3. The timeline recommended in the SOP are not being followed by any of the forecast tier. Also the procedure suggested above (Recommendation 2b) does not permit issue of HRW before 07 UTC. At the same time, it is considered that 07 UTC will be too late for first warning bulletin for any area as half of the day will be over by the time HRW reaches the user. Keeping in view the above statement and other operational aspects, following recommendation is made

a. The main warning bulletins may be issued by the forecast centres at 07 UTC based on the procedure under recommendation 2b above. This may be followed by update bulletins around 14 UTC on the same day and 03 UTC next day.

b. Validity of all the HRW bulletins should be 48 hours from time of origin clearly stating the validity period (from ---- hrs IST to --- hrs IST). In case the HRW is different for 0-24 and 24-48 hours, it should be mentioned accordingly.

4. Users demand warnings for a longer validity for very obvious reasons. At the same time, accuracy of NWP models (particularly for extreme weather events) is limited beyond 48 hours. Keeping both the above aspects in view, it is recommended that a new terminology by name of Advisory or Alert should be introduced. These

Heavy Rainfall Advisories or Alerts may be issued for the validity period of 48-96 hours. **This would, however, necessitate appropriate sensitization of the end users and media about uncertainty attached to Advisory/Alert; and that this is an Advisory/Alert only and actual Warning (if needed) shall be issued only 48 hours in advance. A footnote may be given with every HRW bulletin mentioning the indented meaning of HRW and Heavy Rainfall Advisory/Alert.**

5. As rainfall in the immediate past few days may have significant role in modulating the impact/s of any heavy rainfall event, the following recommendations are made

   a. A mention of significant rains during past few days should accompany the HRW bulletin. In case an area has already received significant rains during past few days, the warning may be phrased as follows: **There have been rather heavy/heavy/very heavy/extremely heavy rains ranging from 4-6, 7-12, 12-25 or >25 cm during last two (or one/three/four/five days) and the area is expected to receive further heavy/very heavy/extremely heavy rains ranging from 7-12, 12-25 or >25 cm during next 24/48 hours.**

   b. In case of continued significant rains (**rather heavy/heavy/very heavy/extremely heavy)** during past few days, a **warning** or a **special mention o**f even **rather heavy rainfall** may be made in the HRW message/s keeping in view the impact of cumulative rains.

6. De-warning is also important for certain tactical decision making. A de-warning message should also be issued for an area in case it has been under HRW for two days or more.

7. The SOP under reference has the following recommendations for list of the warnees

   i. Complete up to date list of HRF warnees, with address and telephone numbers to be kept. List of warnees to be updated in the month of March every year.

   ii. The duty officer will ensure that HRW has been issued and has been passed on to all concerned.

   iii. Highest authorities of the State (Chief Secretary, Military, Relief commissioners etc.) to be kept informed telephonically by D/O or class I officer.

iv. A log book to be maintained for this purpose.

It is recommended that the above mentioned recommendations should strictly be adhered to with following modifications/additions.

a. The list of warnees of **SWFCs should be available with concerned RWFCs**; and that of **RWFCs and SWFCs should be available with NWFC**.
b. Instead of updating the list only once a year (in March), it should be **updated twice a year in April and October**. Mid-term changes, if any, should be shared immediately among all tiers of the forecast offices.
c. The list should, preferably be **arranged based on PRIORITY of the warnees**.

8. It is pertinent to mention here that the difference in views of NWFC/RWFC/SWFC on HRW for an area might, on occasions, be arising out of the difference in the inputs available to these offices as Forecast Work Stations are not available with all these offices. The SOP-HRW has also mentioned the inputs required for decision making on HRW. The following recommendations are made in this regard

a. NWFC may review the list of inputs (both observations/charts and NWP model outputs) suggested in the SOP-HRW. The review should also include the frequency at which each input is required to be generated.
b. Concerned divisions may make arrangements for timely preparation of these inputs and disseminate through IMD website/FTP/e-mail to all forecast offices as some of these offices are not equipped with basic facilities of preparing even the synoptic weather charts.
c. Some of the NWP model products (flow pattern, rainfall, thermo-dynamic outputs etc.) are available in IMD website/FTP. These, however are available at 24 hours time step. These products are required at more frequent time steps for better appreciation of evolution of the flow pattern and thermodynamic structure of the atmosphere. Therefore, it is recommended that **the already available products and those suggested by NWFC as recommended under 8a above should be generated at 6 hourly time step for GFS and 3 hourly time stem for WRF. NWP division may immediately start generating the**

current products at above suggested time steps and make these available through website/FTP.

9. At present, there is a link on 'Severe Weather Warnings' inside the 'weather Forecasts' link on IMD HQs website (www.imd,gov.in). This link provides the same information as given in the 'All India weather Forecast Bulletins' issued by NWFC. Therefore, the district-wise warnings issued by SWFCs are not available on the IMD HQs website (www.imd,gov.in). AS this is the most used website by the users, **it is recommended that a separate link for HRW (and also for other warnings) should be created on home page of the website. The newly created link should have district-wise warnings issued by SWFCs. Facility to upload the warnings should be given to the SWFCs and RWFCs which should upload the district-wise warnings for the state/UT under their jurisdiction (**RWFCs should not upload warnings for a state catered to by an SWFC). **The page should clear show to separate district-wise warnings for 0-24 and 24-48 hours; and advisory/alert for 48-96 hours. The page should also provide information on significant rainfall in the state during last one week (date wise).** There could be a separate link for each state or the information can be appended in one page. The same warnings should be uploaded on websites of RMC and also of MCs (which ever have their own websites). ***This will ensure common warnings across the websites and a user will not have separate information through different websites of IMD as some-times happens in the present case.*** *This will also facilitate monitoring timely update of warnings by RWFCs/SWFCs. A mechanism for automatic* ***monitoring, reminding RWFCs and SWFCs of any delay and periodic report generation for each RWFC/SWFC*** *should also be made.*

10. As nowcasts being issued on IMD website are also kinds of weather warnings, a link of nowcast page may be given on the HRW page with an appropriate disclaimer that this is warning for thunder storm/intense rainfall during next few hours only; and may or may not lead to accumulated heavy rains.