Widespread Rainfall Activity with Isolated Heavy Falls over Himachal Pradesh and Uttarakhand during 15-19th, July 2014

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ABSTRACT

The present study has been carried out to determine the causes of widespread rainfall activities that were held during 15-19, July 2014. The sluggish movement of the low pressure area over north Odisha coast and the off-shore trough over the west coast observed over the country accumulated a large amount of moisture. This synoptic situation caused the widespread rainfall over both the states during 15-19th, July 2014. It has been seen that the vertical shear and orographic uplifting lead to a short lived intensified precipitation in this area, which caused landslides and flood activities. IMD GFS model reveals a superimposed amount of precipitation and incursion of moistures which has resemblance with the synoptic systems. It is also inferred that satellite and DWR radar imageries might be useful to issue the forecasts. This situation has created disturbance of life due to natural disaster on one hand and making up of the deficient rainfall on the other.

Keywords: *Synoptic and dynamic weather conditions, Orography, Monsoon trough and Low pressure area.*

1. Introduction

Himachal Pradesh and Uttarakhand states are situated in the western Himalayan region. Due to its geo-climatic and socio-economic conditions, these states are the most natural disaster prone states of the country. Natural hazards like earthquakes, landslides, avalanches, cloudbursts, hailstorms, glacial lakes, flush floods, lighting, forest fire, and extreme rainfall are witnessed in these states. According to the recent scientific researches, climate change is aggravating the frequency of high intensity rainfall and cloud bursts causing floods /flash floods and landslides. It is pointed out that increasing population has enhanced ecological & socio-economical vulnerability. According to NIDM report (2013), Uttarakhand suffered its worst disaster in the living memory with huge loss of lives and widespread destruction on 16th June, 2013. In this event, a total of 680 people died and over 4117 people were reported missing. In the both states houses and other infrastructures were damaged extensively. The high-intensity rainfall spells caused this type of severe devastating flood situation which sustained for a long duration and surpassed all the previous records in the flood history particularly of Uttarakhand State. Heavy rainfall occurred during 15-19, July 2014 amounting to 167 cm over Himachal Pradesh and 423 cm over Uttarakhand. Station wise rainfall of Himachal Pradesh and Uttarakhand are given in Table 1.

Many authors have studied the occurrence of the vertical lifting necessary for the formation of convective clouds and the torrential rainfall of high intensity from cumulus clouds leading to flash floods and landslides in the hilly region. Bhan et al. (2004) and Kulandaively (1996) pointed out that sudden cloud bursts in the hilly areas of Himachal Pradesh caused heavy rainfall over a small area leading to landslides during the southwest monsoon season. Das et al. (2006) pointed out that the low level convergence of south easterlies and northwesterly along the foothills coupled with vertical shear and orographic uplifting leading to a short-lived, intensifying precipitation at the rain rate of about 10 cm/hour (generally known as cloudburst) steered by the mean flow and travelling away from the high hilly regions. Litta et al. (2007) concluded that the localized heavy rainfall which occurred over Santacruz (Mumbai) might be due to the subsidence of the mid-tropospheric mesoscale vortex. This meso-scale vortex is superimposed on

Table 1. Cumulative rainfall in cm of various stations recorded during 16-20 July, 2014 of Himachal Pradesh and Uttarakhand.

Sr.no.	Himachal Pradesh		Uttarakhand	
	Stations	Rainfall (cm)	Stations	Rainfall (cm)
1	Bilaspur	6	Almora	27
2	Chamba	3	Bageshwar	26
3	Dharmshala	12	Chamoli	16
4	Hamirpur	2	Champawat	39
5	Kangra	6	Dehradun	8
6	Kinnaur	2	Deopryag	30
7	Kullu	5	Haldwani	58
8	Lahul & spliti/keylang	2	Haridwar	20
9	Mandi	15	Nainital	58
10	Solan	21	Pauri/Kotdwar	33
11	Sirmaur/nahan	24	Pithoragarh	26
12	Shimla	11	Rudraprayg	15
13	Renuka	43	Roorkee	16
14	Una	15	Tehri	21
15	-	-	Utarkashi	13
16	-	-	Udhampur/Kashipur	17

the active monsoon conditions over the region. Pradhan (2012) inferred that the system which could not be predicted synoptically or decisively by satellite images was very well observed and tracked by Doppler Weather Radar.

In the Western Himalayan region, Himachal Pradesh and Uttrakhand are located between (Lat. 30°.22' N - 33°.12' N and long. 75°.45'- 79°.04'E) and between (Lat. 28°.43' N - 31°.27' N and Long. 77°.34'- 81°.02'E) respectively. These states are well known as disaster prone states while both are also popular for tourists as well as pilgrimage. The knowledge of weather information and awareness of weather and climate of the region are needed for development and safe life. Because of the above, the present study has been made to understand contributing weather factors that were observed / experienced over Uttarakhand and Himachal Pradesh during 15-19, July 2014. The information on these weather systems have been collected from various units of IMD. The required data of rainfall during 16-20, July 2014 have been arranged in the required format for interpretation and analysis. Due to limitation of space, the synoptic systems occurred on 15 July 2014, selected radar and satellite imageries, charts of IMD GFS models and images of vorticity have been included in this text. The utility of numerical weather prediction models, satellite and radar imageries have also been considered. The orography of both the states including their valleys, ranges and elevations have been taken into account to find out the causes of landslides and floods. The conclusions drawn based on the discussions of the results may be useful to forecasters, administrators, planners, and the common public for the betterment of life.

2. Data Collection and Methodology

To complete the present study, the required information on rainfall, radar images and satellite pictures, visualised movement of the synoptic systems taken from the synergies system, daily inferences of the weather forecast of the considered period have been obtained from different divisions of IMD, New Delhi. The NWP charts of synoptic systems were provided by the NWP section and Vorticity images are collected from the CIMSS website, and the information on valleys, ranges, and

Table 2. The percentage deviation of actual rainfall (mm) from the normal, and the percentage deviation of seasonal monsoon total rainfall (from 1st June in mm) and seasonal monsoon normal rainfall (mm) in Himachal Pradesh and Uttarakhand.

Date	Himachal Pradesh			Uttarakhand		
	Actual	**Normal**	**Percentage**	**Actual**	**Normal**	**Percentage**
16.07.2014	23.1	10.8	**113%**	47	13.4	**251%**
01.06.2014-16.07.2014	156.5	230.8	-32%	225.9	372.4	-39%
17.07.2014	13.2	11.5	15%	21.4	14.2	51%
01.06.2014-17.07.2014	170.2	242.3	-30%	246.7	386.6	-36%
18.07.2014	12.7	12.5	2%	38.5	16.0	140%
01.06.2014-18.07.2014	182.8	254.8	-28%	284.2	402.6	-29%
19.07.2014	13.1	13.3	-2%	74	13.3	**457%**
01.06.2014-19.07.2014	195.1	268.1	-27%	356.6	415.9	-14%
20.07.20014	13.0	10.1	29%	32.7	14.8	121%
01.06.2014-20.07.2014	205.9	278.2	-26%	389.4	430.7	-10%

elevations are taken from the physical map of Himachal Pradesh and Uttarakhand. The percentage deviation of actual rainfall from normal has been calculated for five days of rainfall. The cumulative rainfall during 16-20, July 2014 in both the states were calculated and analysed.

3. Synoptic Systems

3.1 Rainfall over Himachal Pradesh and Uttarakhand

Table 2 shows the percentage deviation of actual rainfall from the normal, and that of actual rainfall (from 1st June) and monsoon seasonal normal rainfall of Himachal Pradesh and Uttarakhand. It has been observed that during 16-20, July 2014, the highest percentage of rainfall of 457% was reported on 19 July 2014 in Uttarkhand and 113% was reported on 15 July 2014 in Himachal Pradesh. During these five days total rainfall, Uttarakhand received 423 cm and Himachal Pradesh 167 cm. It indicates that Uttarakhand received more amount of rainfall than Himachal Pradesh. The cumulative rainfall for five days has been calculated for both the states and shown in Figure 1. It reveals that there was more rainfall at the lower longitude in the southwest sector of both the states.

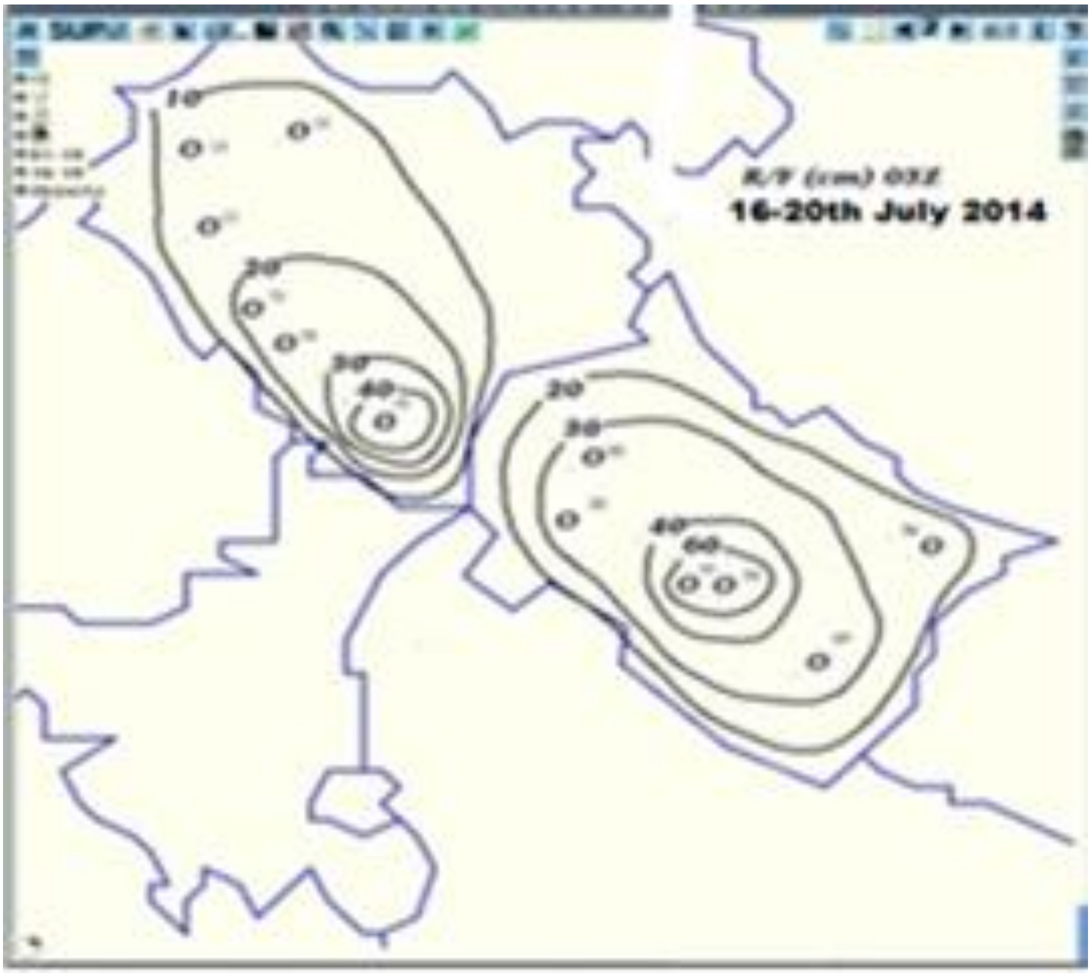

Figure 1: Cumulative rainfall during 16-20, July 2014 over Himachal Pradesh and Uttarakhand.

Figure 2 shows the percentage deviation of actual rainfall from its normal during 16-20, July 2014 in Himachal Pradesh. It has been observed that the actual rainfall was higher than the normal on all five days during 16-20, July 2014. A negative percentage of -2% of rainfall was reported on 19 July 2014. It has been also seen that a positive percentage of rainfall was recorded in the remaining days. On 16 July 2014, the actual rainfall recorded was more than the normal rainfall. It indicates that the system was more effective on 16 July 2014 in Himachal Pradesh. Figure 3 shows the percentage deviation of actual rainfall from the normal during 16-20, July 2014 in Uttarakhand. Thus the actual rainfall recorded was more than the normal on all days during 16-20, July 2014. The highest percentage of 457% of rainfall was there on 19 July 2014. It indicates that the system was more effective on 19 July 2014 over Uttarkhand. Hence, it is inferred that the system was more effective in Uttarakhand than in Himachal Pradesh on 19 July 2014.

3.2 Synoptic chart and inferences

Figure 4 shows synoptic charts of 15 July 2014. It depicts that the low pressure area lay over the north interior part of Odisha on 15 July 2014 and the eastern end of the monsoon trough deepened to the North Bay of Bengal. The western end of the monsoon trough has shifted northwards and remains close to foothills of the Himalayas which worked as a source of moisture supply over the western Himalayan region. In the same chart, it is seen that pressure gradient and surface winds along with the west coast were also significant strength of the monsoon activity. There seems to have an interaction of easterly and westerly winds over the region. Further, low level circulations reached in the north direction, pulled adequate moisture and intensified the system in favour of heavy rain. These synoptic situations were sustained during 15-19, July 2014, over Uttarakhand and Himachal Pradesh that caused widespread rainfall. A similar result was obtained by Chaudhury (1961). From the

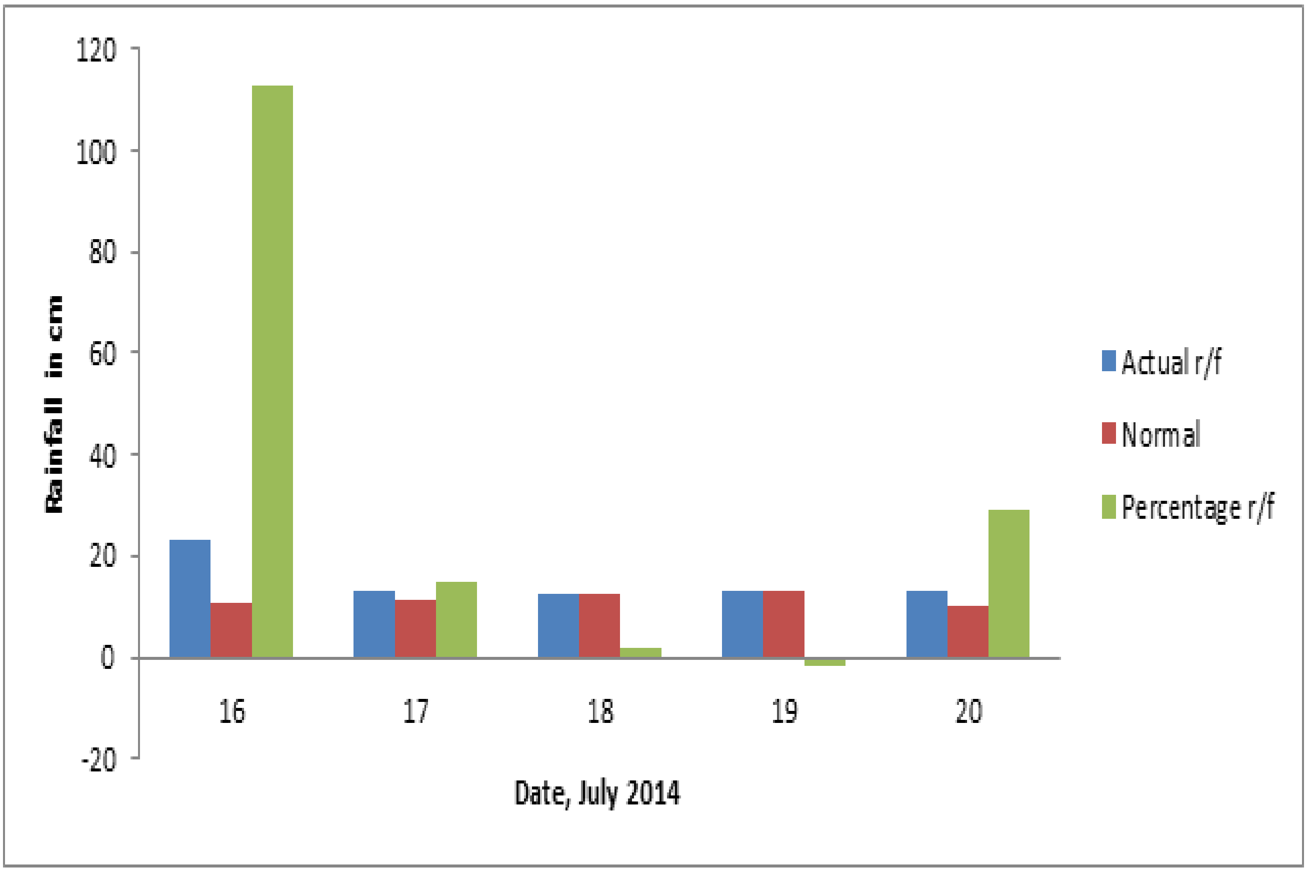

Figure 2: Graphical representation of actual, normal and percentage of rainfall in cm recorded during 16-20, July 2014 over Himachal Pradesh.

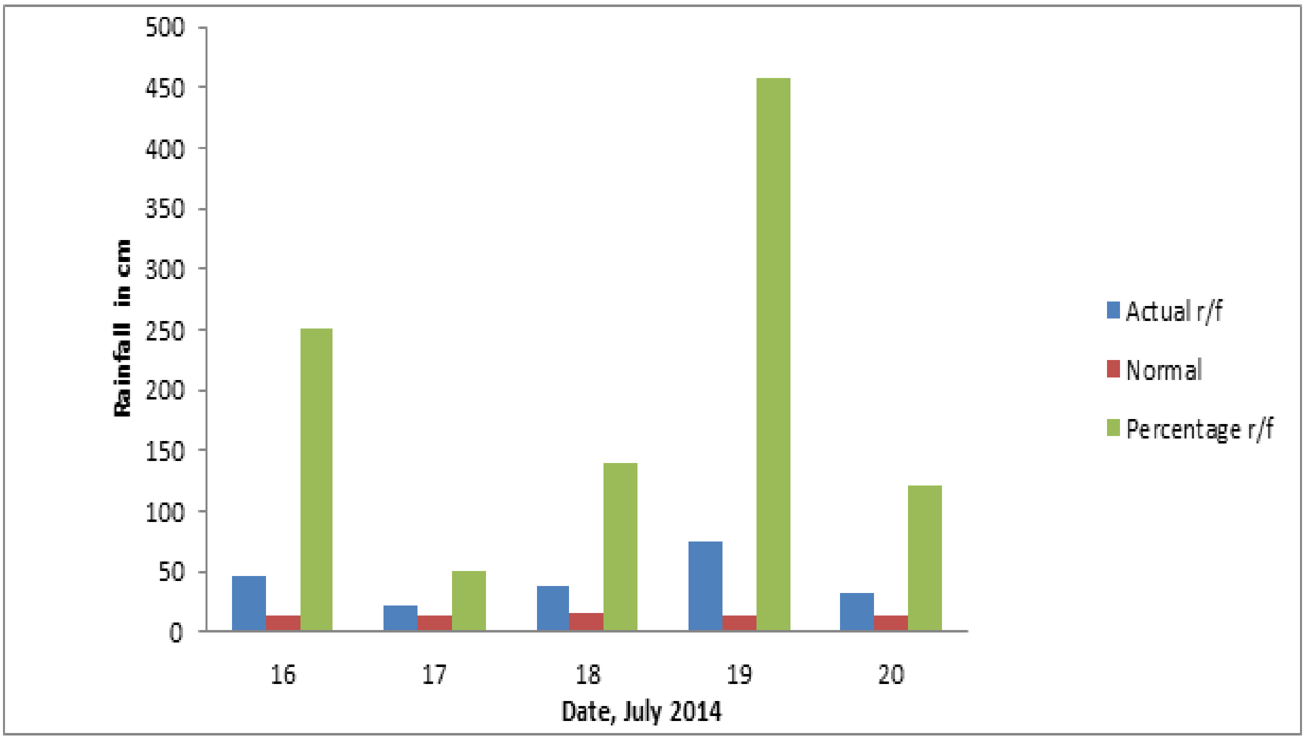

Figure 3: Graphical representation of actual, normal and percentage of rainfall in cm recorded during 16-20, July 2014 over Uttarakhand.

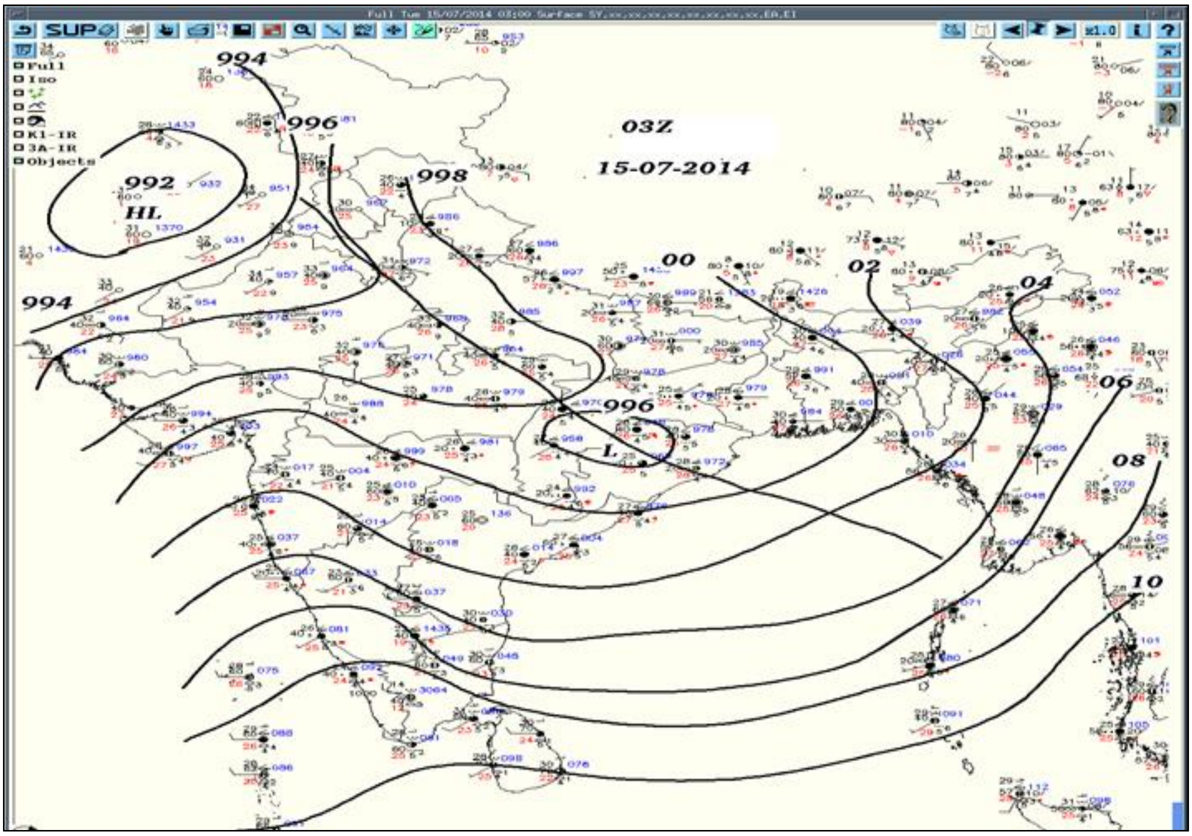

Figure 4: Synoptic charts of 15, July 2014.

weekly report of daily inferences of the weather forecast of IMD, it is seen that on 16 July 2014, the low pressure area had moved to North Madhya Pradesh which continued to supply moisture over the western Himalayan region. Further, on 19 July 2014, the system shifted to over west Uttar Pradesh across central India. In addition to the above synoptic situations, off-shore trough has passed over Gujarat coast to Kerala coast, which also pulled moisture from the Arabian Sea and accumulated over the region. The position of the monsoon trough was noticed across Haryana, north Madhya Pradesh, the center of low pressure area extending up to 1.5 km above MSL. On the 15 July 2014, it passed through Ganganagar, Narnual, Hamirpur, Churk, Daltanganj, Bankura, canning and thence south eastwards to east central Bay of Bengal extending up to 1.5 km above MSL on 19 July 2014. Upper air circulation lay over the North West Bay of Bengal and neighborhood between 5.8 and 7.6 km above MSL, and another upper air circulation over North East Arabian Sea and adjoining Gujarat extending between 3.1 and 5.8 km above MSL shifting to Gujarat & neighborhood during 15-17, July 2014. In addition to these systems, the development easterly winds along the foot hills of Himalaya that approached up to eastern parts of Jammu & Kashmir, and a simultaneous trough in the mid level westerly moved over to the western Himalayan region. All the above synoptic situations were found very conducive for widespread rainfall with heavy floods over the region. Because of the slow movement of the system and ample amount of prolonged moisture supply during 15-19' July 2014, enhanced rainfall activity along with landslides and floods occurred over the region.

3.3 Mascarene high & Tibetan high

Normally, the Mascarene high is located at 30^0 S / 50^0 E and its intensity is 1030 hPa. The above normal intensity was observed during 15-16 and 17-19 in July 2014, while slightly shifting north-eastwards to its normal position. The normal position of the Tibetan high is at 28^0 N /80^0 E. It shifted south-eastwards from its normal position during 15–19, July 2014. Both the observed positions and intensities of Tibetan high and Mascarene high were in favour of good monsoon activity.

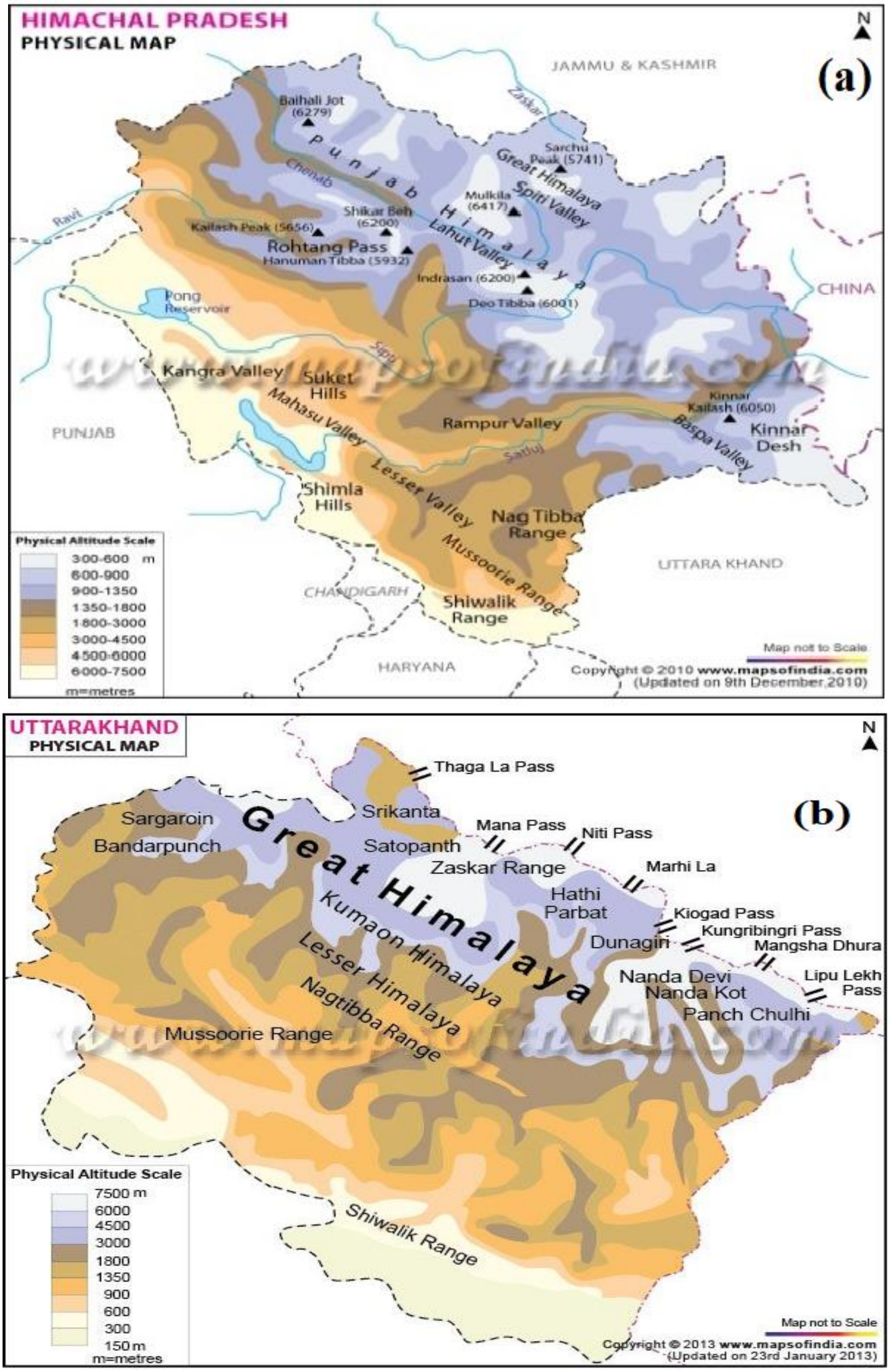

Figure 5 (a&b): Valleys, Ranges and Elevations of the Himachal Pradesh and Uttarakhand.

3.4 Orography

Figure 5 (a&b) shows elevation of Uttarakhand and Himachal Pradesh, and Figure 1 represents cumulative rainfall in cm recorded over Himachal Pradesh and Uttarakhand during 16-20, July 2014. Figures 1&5 reveal that the intensity of rainfall was high over the SW sector of Himachal Pradesh. In Sirmaur district, Renuka (30.6^0 N and $77.5\,^0$ E), 762 meters above MSL recorded 43 cm. of rainfall and

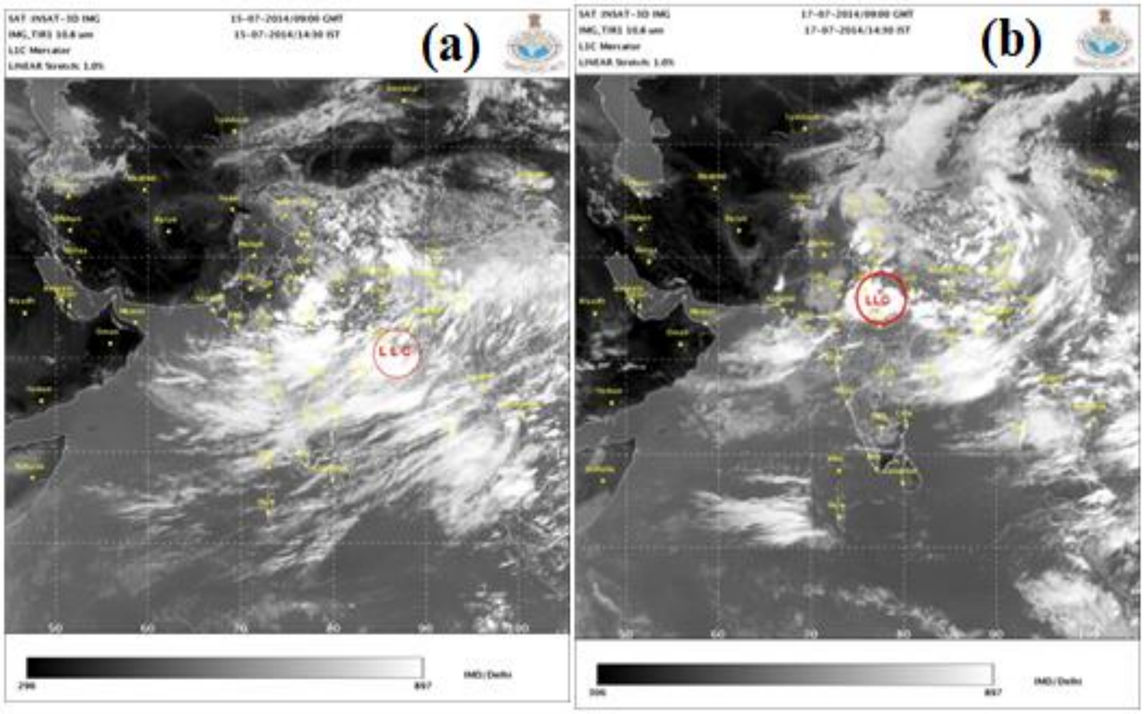

Figure 6 (a&b): Satellite imagery of 15th & 17th, July 2014.

all other stations Shimla (11 cm), Sirmaur (24cm), Unna (15cm) and Mandi (15cm) are situated on the windward side of the elevation of 3000 above MSL. In Uttarakhand, Haldwani (29.2^{0}N, 79.5^0 E), 474 meters above MSL recorded 58 cm rainfall and Nainital (29.3^0 N, 79.5^0 E), above 2084 meters recorded 58 cm rainfall in SW sector of Uttarakhand. Figure 1 shows the stations located at the foot of a hilly area, where maximum rainfall was recorded; which reveals that easterly and westerly winds and atmospheric situations have interacted with hilly areas that resulted in good amount of rainfall. It has been inferred that orography plays an important role to enhance low level convergence; which supported the formation of intense convection that resulted in much rainfall.

3.5 Landslides and floods

A landslide is defined as the movement of the mass of rock, soils, debris or earth down a slope. It encompasses slope movement falls, topples, slides, spreads and flows. Figure 5 (a&b) reveals many ups and downs that create valleys and ranges in both the states. Rainfall is the main reason that causes landslides and floods in these states. Due to the heavy rainfall over the hilly area, forcibly water flows down with soil and rocks causing landslides and floods. In these uncertain situations, many people and cattle lose their lives. It has been seen that human activities such as roads and structures without adequate grading of slopes and poorly planned constructions cause these miseries.

4. Dynamic Situation

4.1 Satellite imagery

Figure 6 (a&b) depicts the position of cloud mass and low pressure area. The bulletin of the Satellite Division of IMD, New Delhi of 15-19, July 2014 indicates the position and intensity of convective clouds, precipitation index and location of low level circulation. This information given in the above mentioned bulletin, explains the intensification of the system. Figure 6(a) shows satellite imagery of 15 July 2014, indicating intense to very intense convection of cloud mass and the location of the low pressure area over the north Odisha coast that incurred ample amount of moisture. The cloud cluster moved northward. Figure 6(b) of 17 July 2014 depicts the dense cloud mass with brightness and progressive movement and development of multiplied deep convective clouds. It was observed over most parts of the foothills of Himachal Pradesh and Uttarakhand. The satellite images also help to locate the position and intensity of convective clouds and precipitation index. It is

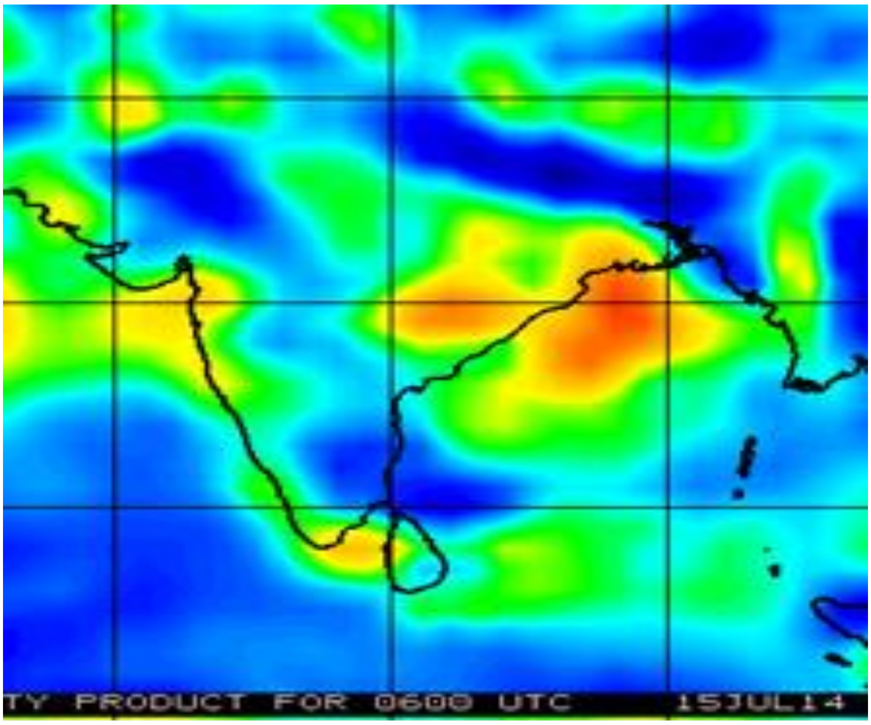

Figure 7: Vorticity at 850 hPa on 15, July 2014.

inferred that the satellite imagery and the bulletin were useful to predicate rainfall activity and intensity. It was also pointed out earlier by Goyal (2014).

4.2 Vorticity conditions

Figure 7 shows the vorticity conditions at 850 hPa on 15 July 2014. It depicts the relative vorticity at 850 hPa with a positive and higher value of 50 - 120 X 10^{-5} S^{-1} at 03 00 UTC on 15 July 2014. It may be inferred that the maximum convergence over Odisha coast and neighborhood and the positive and strong vorticity at 850 hPa contributed in intensifying the system. The positive vorticity indicates an adequate moisture incursion towards the western Himalayan region that caused the heavy rainfall over Himachal Pradesh and Uttarakhand.

4.3 Doppler Weather Radar imagery

Patiala is located in the west of Uttarakhand and southwest of Himachal Pradesh. The DWR of Patiala is the nearest station that can cover the cloud images of the region of Himachal Pradesh and Uttarakhand. Figure 8 shows the imagesof the meso-scale convective system (MCS) that came under the surveillance of Patiala DWR at 06:12:22z on 17 July 2014. The MCS convective system with the cloud top reaching more than 4 km high with reflectivity of about 52 dBz is associated with high precipitation. The higher reflectivity is a favourable signal for the formation of convective clouds. This also indicates that moisture incursion from the system favours heavy rainfall activity. The animations of images can be monitored for the direction and location that can help in disastrous warnings in advance and subsequent prepardness. Thus DWR images can be very useful for nowcast forecasts in advance. Pradhan (2012) had pointed out earlier that radar images help to predicate rainfall activity. Ray (2015) suggested that nowcasting requires accurate specification of the current weather condition with a resolution of a few kilometers.

4.4 The Output of GFS Model

With the advancement of numerical weather prediction techniques, the demand for NWP models is increasing in the improvement of forecasting skills in the prediction of precipitation. Pattanaik (2021) suggested that an extended range forecast can be useful to predict about two weeks in advance. In this study, Figure 9 shows the GFS (T574) model rainfall forecast for 72 hours based on 12 UTC of 15 July 2014 and valid on 12 UTC of 19 July 2014. This model reveals a superimposed

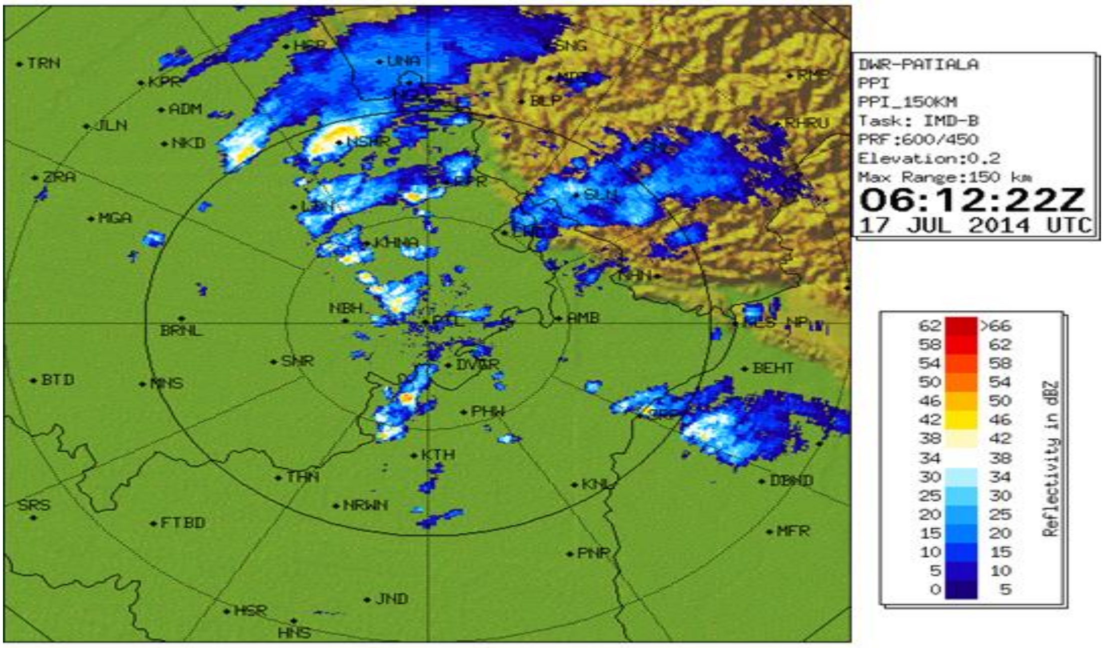

Figure 8: Radar imagery on 17, July 2014.

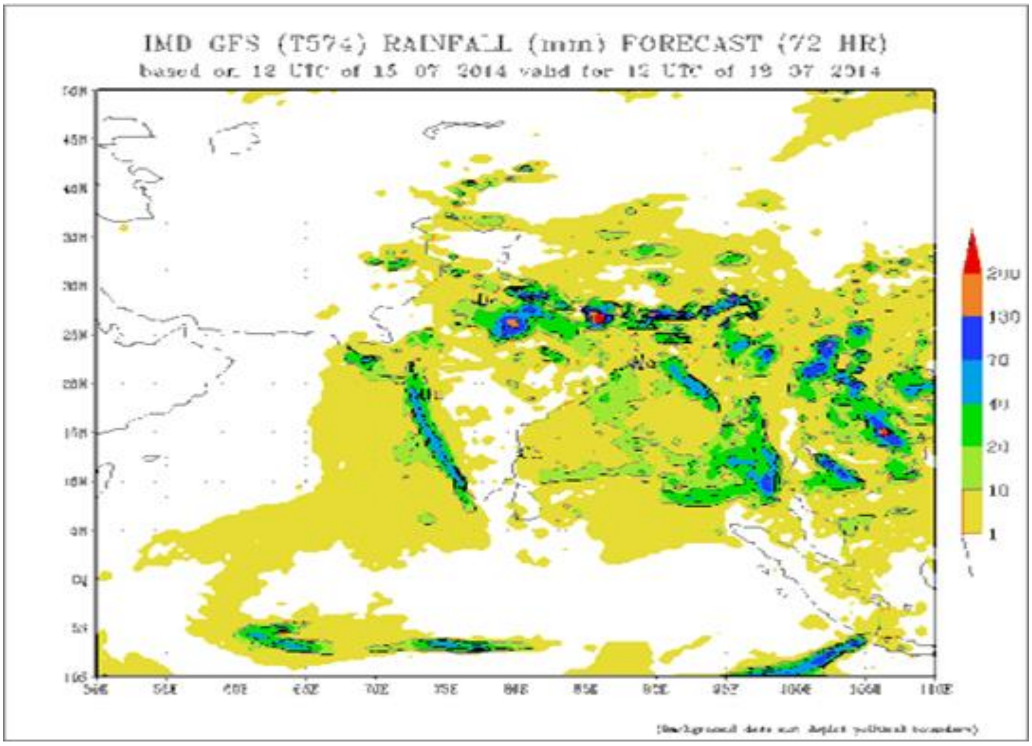

Figure 9: IMD GFS (T574) model charts of rainfall forecast at 12 UTC of 15th July, 2014.

amount of precipitation of more than 40 mm (Figure 9) and the incursion of moistures, which has a resemblance with the synoptic system (Figure 4) between (Lat. 25 & 30°N and Long. 75 & 82°E) over both the states of Himachal Pradesh and Uttarakhand. It has been seen that the rainfall forecasted by model (Figure 9) on 15-19, July 2014 compares well with the actual rainfall (Tables 1& 2). It is inferred that IMD GFS model charts might be used for forecasting and increasing preparedness.

4. Conclusions

The major findings of this study are summarised below:

1. The sluggish movement of low pressure area from the north interior part of Odisha towards the

northwest direction interacting with the westerly wind of Arabian sea pulled adequate moisture, which in conjunction with the orography and vorticity supported intensifying the system. All these dynamic and synoptic conditions caused widespread rainfall with isolated heavy spell over Himachal Pradesh and Uttarakhand.

2. It is concluded that vertical shear and orographic uplifting lead to short lived, intensifying precipitation in this area. Heavy rainfall over the hilly area in both the states generated the strong current of rainy water that caused landslides and intense floods.

3. IMD GFS model reveals a superimposed amount of precipitation and incursion of moistures which has a resemblance with the observed synoptic systems. DWR radar and satellite imageries are very useful for prediction of rainfall activity.

4. It is well known that disaster event such as heavy rainfall cause disturbances in normal life of local people and inconvenience to tourists and pilgrims on one hand and on the other hand, rainfall during five days converted the deficiency from -50% to -10% in Uttarakhand and from -39% to -26 % in Himachal Pradesh.

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