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A study of extremely heavy rainfall in Chhindwara, Betul and Hoshangabad districts of Madhya Pradesh in India during 28-30 August 2020

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Abstract
There was extremely heavy rainfall in Madhya Pradesh in Central India during 28th to 30th August 2020 in the monsoon season. Chhindwara, Betul and Hoshangabad are the three districts of M.P. which recorded extremely heavy rainfall at a number of stations. Chaurai station in Chhindwara district reported exceptionally heavy rainfall of 414.4mm on 29th August 2020 which is a record for the district, on 30th August on Hoshangabad station also recorded extremely heavy rainfall 340.4mm rainfall and district average rainfall of 250.6 mm was recorded on 29th August 2020 in Chhindwara which is also a new record. There was continuous rain for 3days in these districts which was very heavy to exceptionally heavy for 2 days which led to severe flood in the catchment area and downstream of river flowing through the area. Therefore a study has been made in this paper to find out the reason for such an exceptionally heavy rainfall. In the study prevailing synoptic situation, dynamics like convergence-divergence, satellite data, RADAR data and geography of the area were analyzed. The conclusion shows that the Well-Marked Low pressure area passing through Odisha to Rajasthan and Monsoon Trough also passed through this system during 27-30 August 2020 brought huge amount of moisture and their confluence region was central India so strong convergence and extremely heavy rainfall occurred on 28th Aug 2020 and caused extreme and exceptionally heavy rainfall recorded on 29th over three districts (Chhindwara, Betul & Hoshangabad) that fall in the Southwest quadrant of the passing system. Moisture incursion took place from both Arabian Sea and Bay of Bengal. During the said period, significant lower level convergence, upper level divergence and high positive vorticity were observed over the region intensifying the system. Due to the sluggish movement of the system the region under study got widespread rainfall for 3days. Chhindwara, Betul and Hoshangabad districts are situated on the Satpura range of mountains so orography was also very important factor for such extremely heavy rainfall.

Keywords: Extremely heavy rainfall, exceptionally heavy rainfall, well-marked low pressure area, convergence, divergence

1. Introduction
Madhya Pradesh is located in central India. It is divided into two meteorological subdivisions - East Madhya Pradesh and West Madhya Pradesh. In present study, Chhindwara, Betul and Hoshangabad (Now Narmadapuram) districts shown in Fig 1, are considered due to highlighted extreme heavy rainfall. These districts are situated on the Satpura Range of mountains and Tropic of Cancer being close to this area, this hilly region is richest in forests of good quality of teak wood and biodiversity. There are major rivers like Narmada, Tapi, Kanhan, Pench and Wainganga which flow through this region. Wainganga catchment is close to the area and National Highways (NH 47) for transports. Pench dam, Totaladoh water dams and Goshikhurd dam are importance project in these districts. Normally, Weather of this region is affected by the weather systems developed in the Bay of Bengal and passes through M.P.

Fig 1: District Map of Madhya Pradesh

The extremely and exceptionally heavy rainfall experienced over this region during 28th to 30th August 2020 (Fig 2) caused floods over Southeast Madhya Pradesh and adjoining Vidarbha. It damaged agriculture, disturbed transports, damaged infrastructures and affected daily routine life of people. 11 people died in the floods and 3 died from lightning. Table 1 shows that rainfall recorded in Chaurai of Chhindwara district was the highest rainfall of 414.4 mm on 29th August 2020 which is all time record followed by Parasia which recorded 331.0 mm. In Betul district**,** Shahpur and Ghodadongri recorded 193.2 mm and 182.0 mm respectively. On 29th Sohagpur of Hoshangabad district and on 30th Hoshangabad recorded 340.4 mm and 241.6 mm rainfall respectively.

Very high district average rainfall was recorded on 29thAugust 2020, 250.6 mm and 142.4 mm rainfall in Chhindwara and Betul districts respectively and on 30th August 2020, 120.3 mm in Hoshangabad district, due to favourable weather situations developed over the region during the period. It is seen that these figure has crossed the previous records as shown in Table 1.

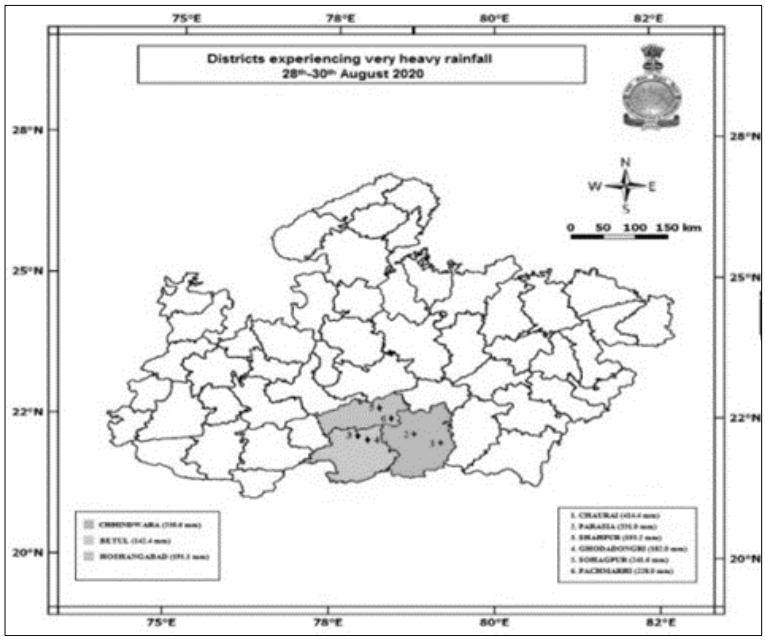


Fig 2: Districts with extremely heavy rainfall

Table 1: Heaviest Rainfall Record

Districts / Average	District Average R/F (mm)	Monthly r/f (mm)	Annual r/f (mm)	Highest rainfall in mm in 24 hours (mm)	Cumulative rainfall in mm during 28-30th August 2020 (mm)	Heaviest fall in 24 hrs of rainfall in mm during 28-30th August 2020 (mm)
Chhin4wara	250.6	229.2	946.2	160.3 (1997)	348.0	414.4 (Chaurai) On 29.08.2020
Betul	142.4	371.7	1191.0	253.6 (1979)	199.8	193.2 (Shahpur) on 29.08.2020
Hoshangahad	120.3	419	1250.0	380.0 (2006)	393.2	340.4 (Hoshangabada) on 30.08.2020

Goldar (1996) [7] pointed out that high intensity rainfall occurring during two successive days caused too much damages to the public utility services, infrastructures and agriculture. Desai *et al*. (1998) [5] found that very heavy to exceptionally heavy rainfall (*i.e*., 204.4 mm and more in 24 hours and ever recorded rainfall) in northwest India particularly in the months of August and September occurred when the upper level westerly trough lay over the lower-level easterly trough. Shyamla and Shinde (1999) [4] concluded that the cyclonic circulation over Saurashtra, South Gujarat region and adjoining northeast Arabian Sea at 925 and 850 hPa gives rise to widespread rainfall activity in north Konkan, South Gujarat and Saurashtra. Singh (2019) [3] concluded that the strong southwesterly flow in lower levels over northeast Arabian Sea which was converging over Saurashtra transports the large amount of moisture from Arabian Sea over to Saurashtra area. The sluggish movement of the system from the Arabian Sea for a considerable period contributed in exceptionally heavy rainfall over the district of Amreli. The location *vis-a-vis* the moisture sources in its proximity *viz*., Arabian Sea, Gulf of Kutch and Gulf of Khambhat contributed in exceptionally heavy rainfall. Raha (2020) [6] found that monsoon trough or trough of low on sea level chart passing through SHWB-S and (iii) Upper air cyclonic system over Bihar with trough passing through SHWB-S and persistence of these conditions for two or more days may cause disastrous flood situation in this area. Ali *et al*. (2013) [1] suggested that if the system is accompanied by local ascending conditions, it will certainly cause intensive rain. Dubey (1998) [2] found that Sagar and Jabalpur division received very heavy rainfall when the system is over the Northeast Madhya Pradesh or over the Head Bay.

In view of foregoing studies regarding reasons of extremely heavy rainfall in SE Madhya Pradesh especially Chhindwara, Betul and Hoshangabad districts is yet not done. Secondly, in view of the importance of these districts as stated above, this study will be very useful for forecasting disaster events of flood and preparedness for it.

Therefore, the synoptic situations and dynamic conditions that contributed to extremely heavy rainfall event are discussed on the basis of surface and upper air synoptic data, the radar data and Numerical Weather Prediction (NWP) model outputs. It may be very useful to forecasters, government planners and general public for safety of life and property point of view.

2. Methodology and Data Collection

For compilation of this study, rainfall data of various stations including departmental and DRMS of Chhindwara, Hoshangabad and Betul districts of Madhya Pradesh on daily and monthly basis and other concerned data i.e. daily inferences, weekly weather report of IMD, information of synoptic & dynamic situations prevailing during 28th-30th August 2020 were considered and dynamic conditions were also analyzed, RADAR & satellite images and NWP & WRF charts were collected from NWP section of IMD New Delhi. Some information has also been collected from CR&S, IMD Pune. The data obtained was tabulated and scrutinized in required format for discussion and presentation of results.

3. Results and Discussions

3.1 Synoptic situations observed during 28 th-30th August 2020

3.1.1 The analysed Surface Level Charts

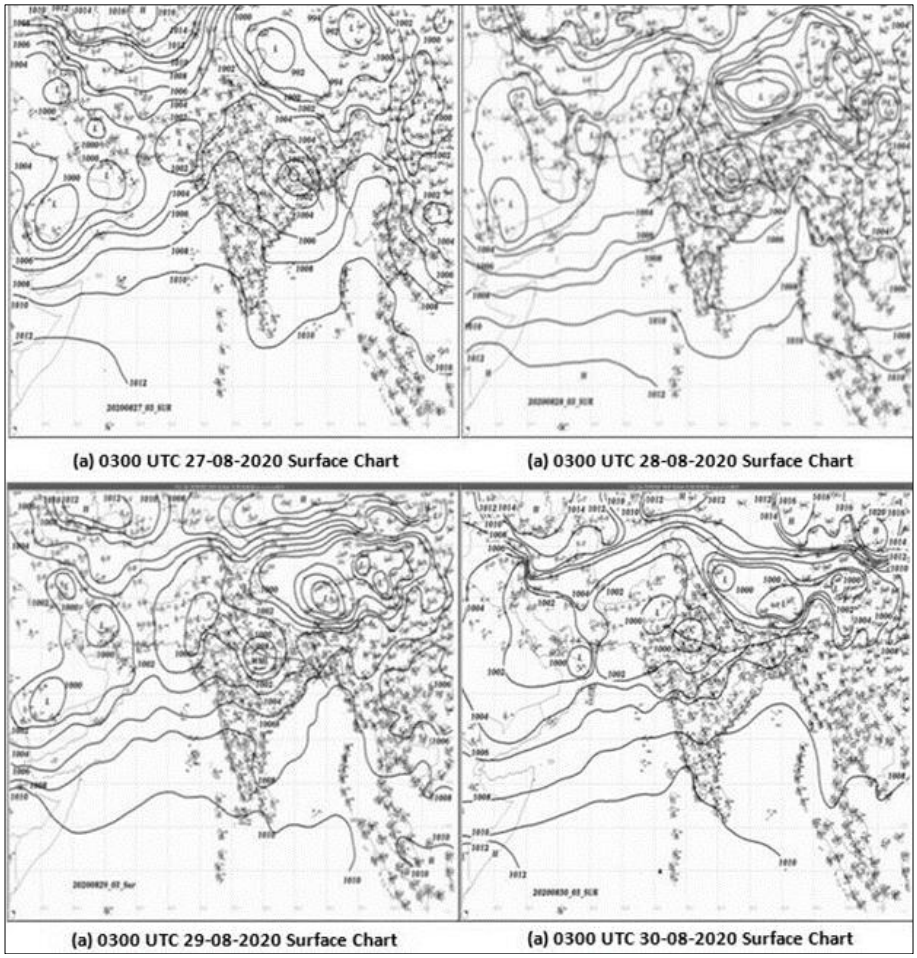


Fig 3: (a) to (d): 0300 UTC Surface Charts

3.1.2 Analysed Upper Air Charts at 400 hPa (Fig 4) shows that associated upper air cyclonic circulation extends upto 7.6 Km amsl.

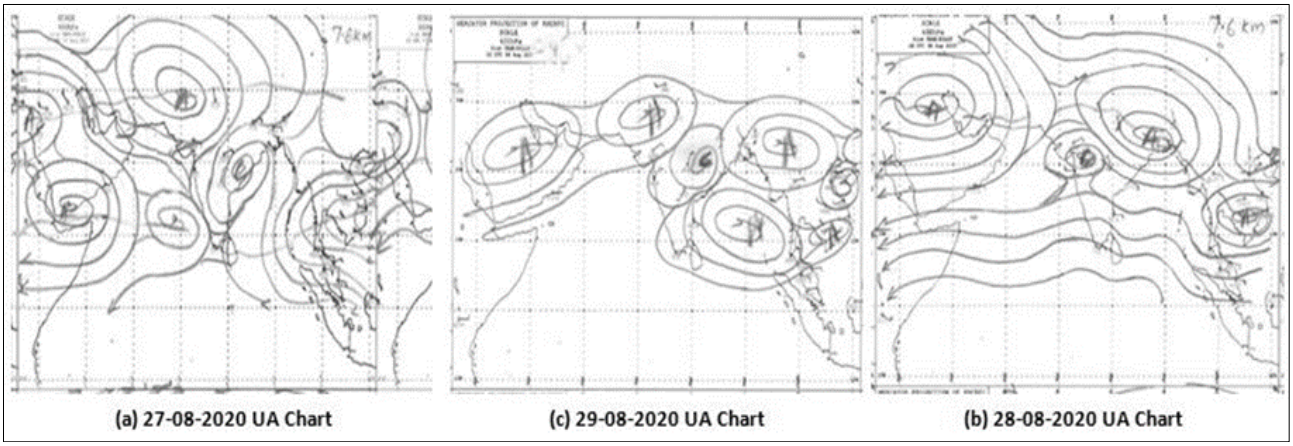


Fig 4: (a) to (c): Analysed Upper Air Charts at 400 hPa

3.1.3 Analysed Upper Air Charts at 200 hPa (Fig 5) shows anti cyclonic circulation and ridge line at upper level+

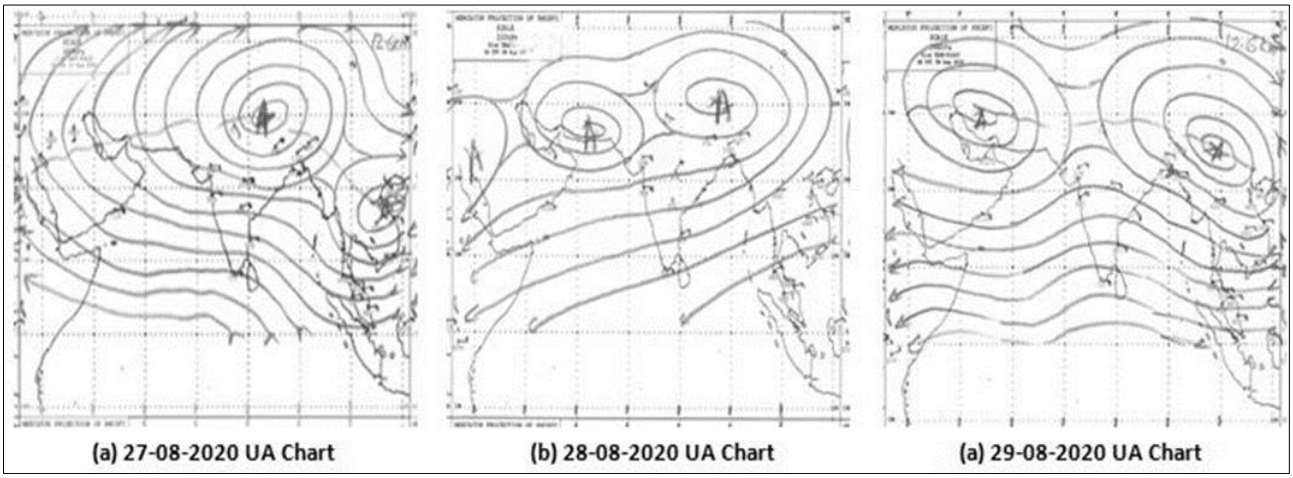


Fig 5: (a) to (c): Analysed Upper Air Charts at 200 hPa

From Fig 3 (a-d), Fig 4 (a-c) and Fig 5 (a-c), it can be seen that movement of system and its intensity and analysed charts of IMD of 7.6 km level during 27th-30th August 2020. The well-marked low pressure area over north interior Odisha & neighbourhood laid over southwest Jharkhand & neighbourhood with the associated cyclonic circulation extended upto 7.6 km above mean sea level tilting southwestwards with height on 27th and anticyclonic circulation was seen in upper atmosphere at 200 hPa which indicates that there was strong lower level convergence & upper level divergence. The monsoon trough at mean sea level was passing through Ganganagar, Narnaul, Shivpuri, centre of well-marked low pressure area over north Chhattisgarh & adjoining east Madhya Pradesh, Jamshedpur, Midnapore and thence southeastwards to north Bay of Bengal. The synoptic condition was most favourable to keep system intensified. These synoptic conditions pulled ample moisture over the area. On 28th, the well-marked low pressure area laid over north Chhattisgarh & adjoining east Madhya Pradesh and associated cyclonic circulation extended upto 7.6 km above mean sea level tilting southwestwards with height and at 200 hPa divergence was prevailed as anticyclonic circulation and monsoon trough at mean sea level continued to pass through same region. On 29th, it laid over central parts of north Madhya Pradesh & adjoining South Uttar Pradesh with associated cyclonic circulation extending upto 7.6 km above mean sea level tilting southwestwards with height and the well-marked low pressure area over west Madhya Pradesh & adjoining east Rajasthan and monsoon trough at mean sea level continued to pass through centre of well-marked low pressure and on 30th, it moved over Rajasthan region as a low pressure area and the associated cyclonic circulation extended upto 7.6 km above mean sea level tilting southwestwards with height and divergence was continued at 200 hPa and monsoon trough continued to pass through low pressure area.

3.2 GFS Model Charts Observation

GFS model charts observed at 00 UTC during 27 th -30th August 2020

3.2.1 GFS model charts of Mean Sea Level Pressure at 00 UTC

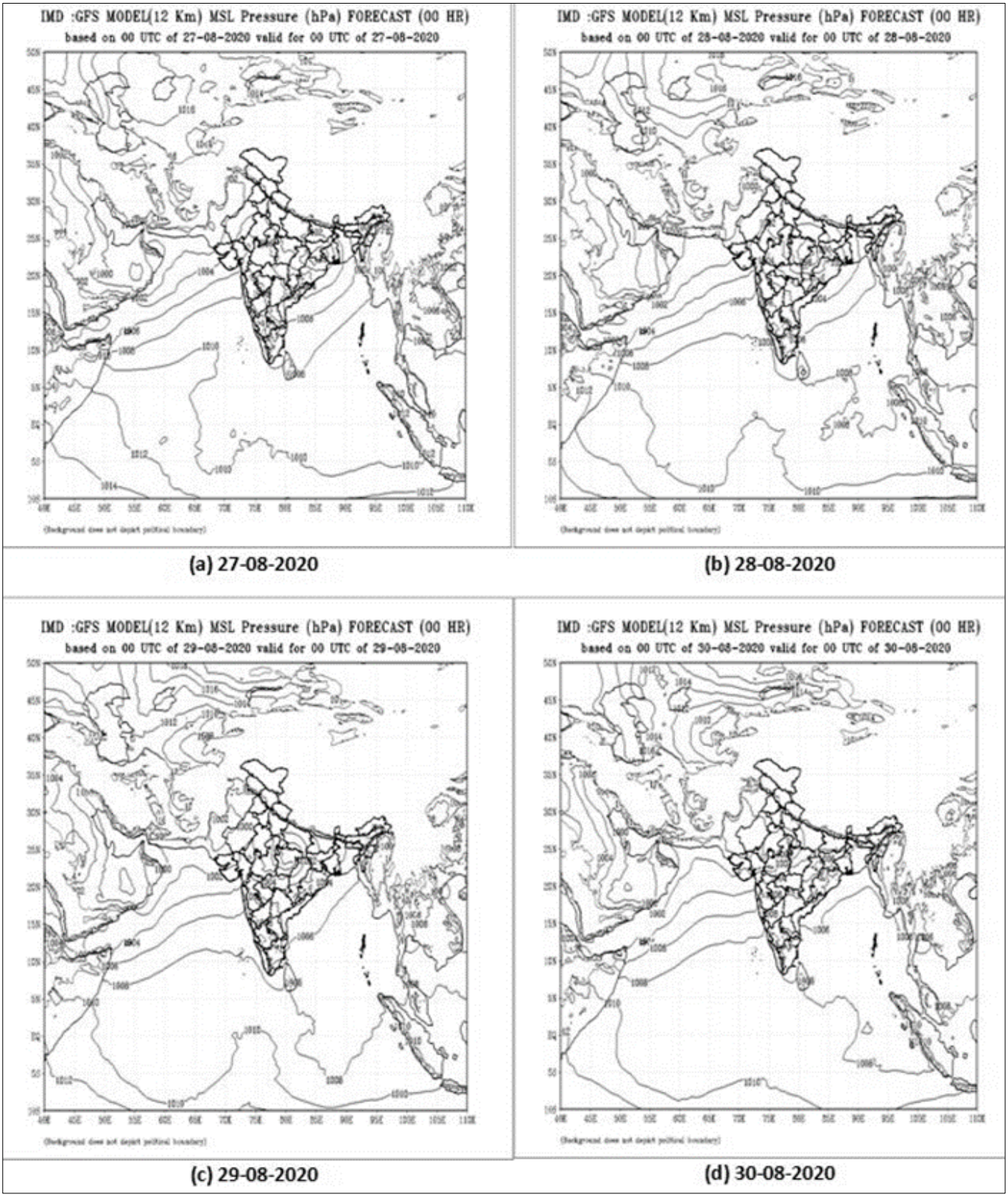


Fig 6: (a) to (d): Mean Sea Level Pressure at 00 UTC

3.2.2 GFS model charts of Wind at 00 UTC of 925 hPa

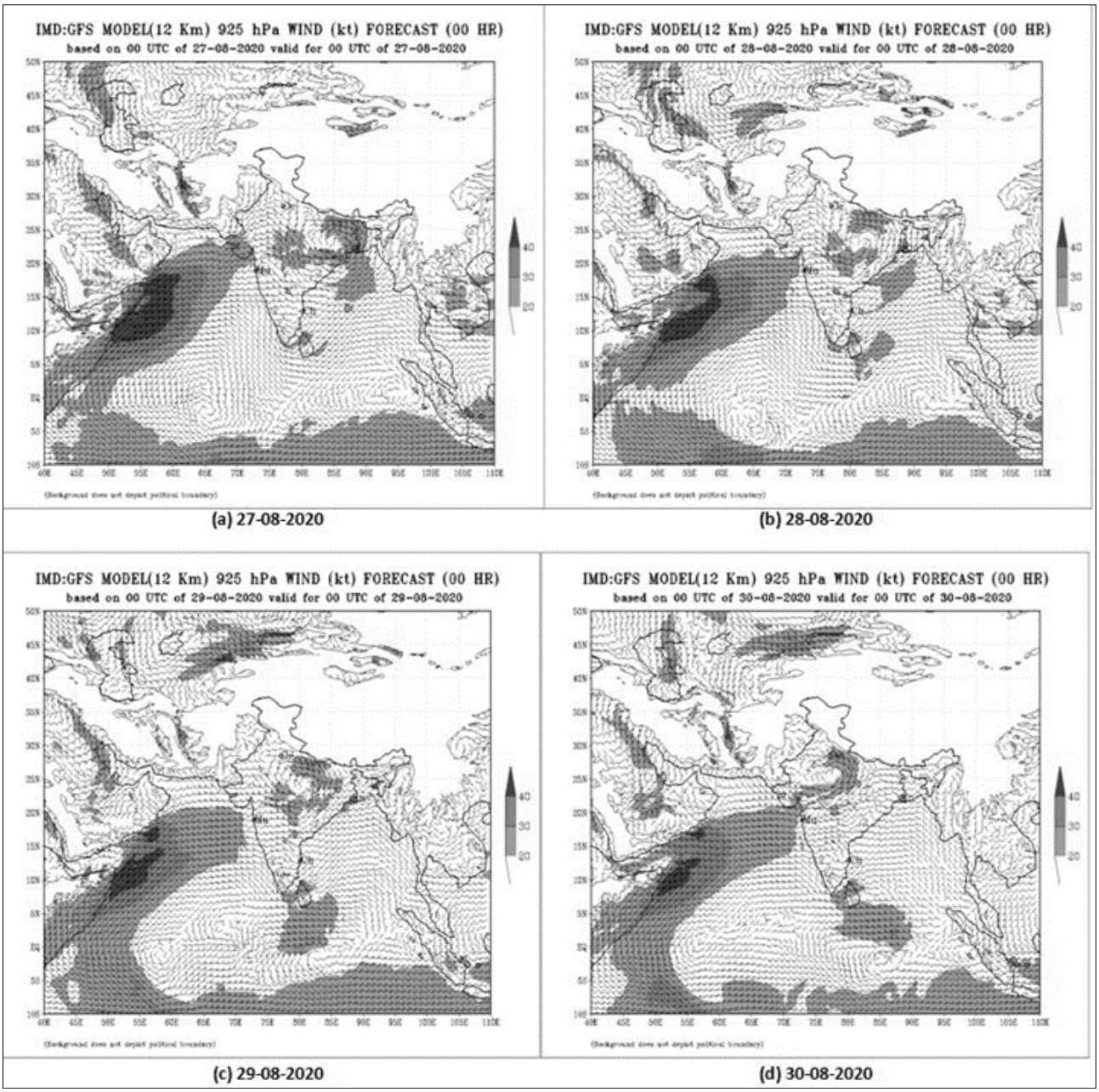


Fig 7: (a) to (d): Wind at 00 UTC of 925 hPa

3.2.3 GFS model charts of Wind at 00 UTC of 200 hPa

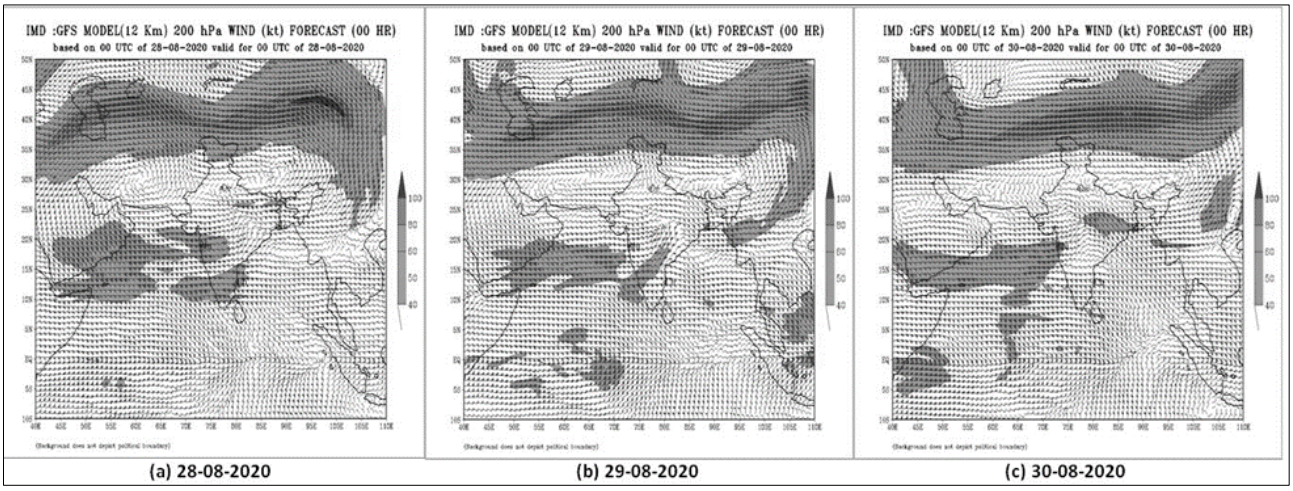


Fig 8: (a) to (c): Wind at 00 UTC of 200 hPa

3.2.4 Observations of synoptic charts in Fig 6 to Fig 8
It has been observed that the IMD's 03 UTC analysed charts of surface level and visualised movement of the synoptic system during 27th-30th and upper air level of 925 hpa, 400 hPa & 200 hPa, shows that associated cyclonic circulation extended upto 400 hPa (7.6 km). It was also observed that it mostly resembled with the WRF & GFS models of 00 UTC charts. It is seen that system was observed ahead at 03 UTC at analysed charts of IMD at surface level and 7.6 km at upper level with associated cyclonic circulation in comparision with 00 UTC charts of WRF & GFS models. It determines that WRF & GFS models charts can be used in advance for forcasting.

3.4 Dynamic factors contributing to rainfall during 27th-30th August 2020
3.4.1 Convergency at 850-925 hPa and Divergence at 150-300 during 28-29th August 2020 at 1200 UTC are shown in Fig 8 and Fig 9 respectively.

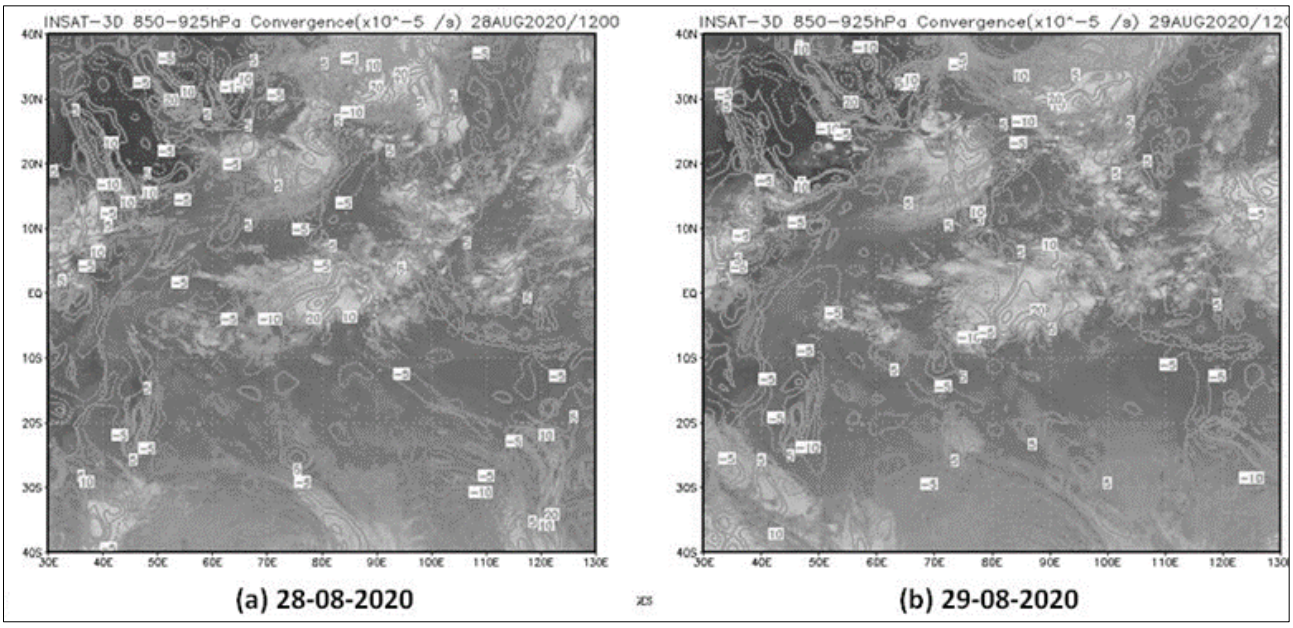


Fig 9: (a) & (b): Convergence

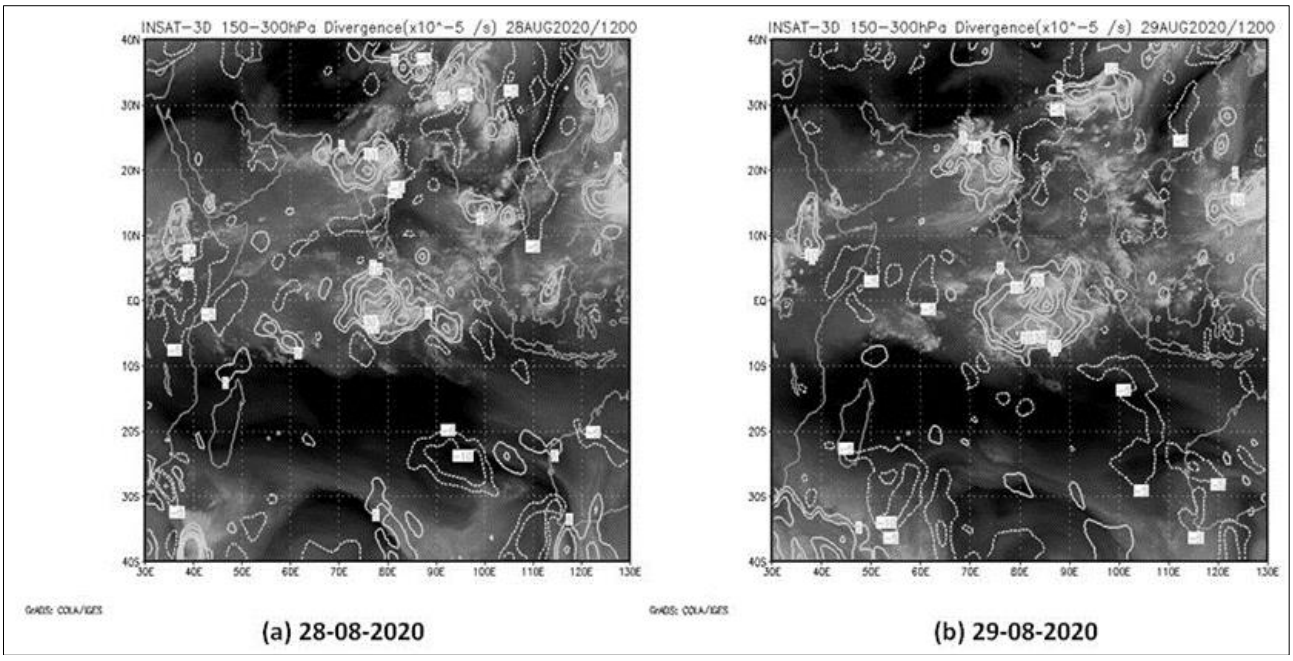


Fig 10: (a) & (b): Divergence

Fig 9 (a) & (b) & Fig 10 (a) & (b) show convergence and divergence at 850-925 hPa and 150-300 hPa respectively during 28th-29th August 2020. It reveals strong positive convergence area located over central parts of Madhya Pradesh with value 20 X 10^{-5} S^{-1} at 1200UTC on 28th and on 29th, the location of convergence shifted towards west M.P. and adjoining area. Positive divergence of 25 X 10^{-5} S^{-1} was also seen over central part of M.P. on 28th and which shifted to West M.P. on 29th. So, strong lower level convergence and upper level divergence was present in the region on 28th and 29th August.

3.4.2 Vorticity at 850-925 hPa during 28th-29th August 2020 at 1200 UTC

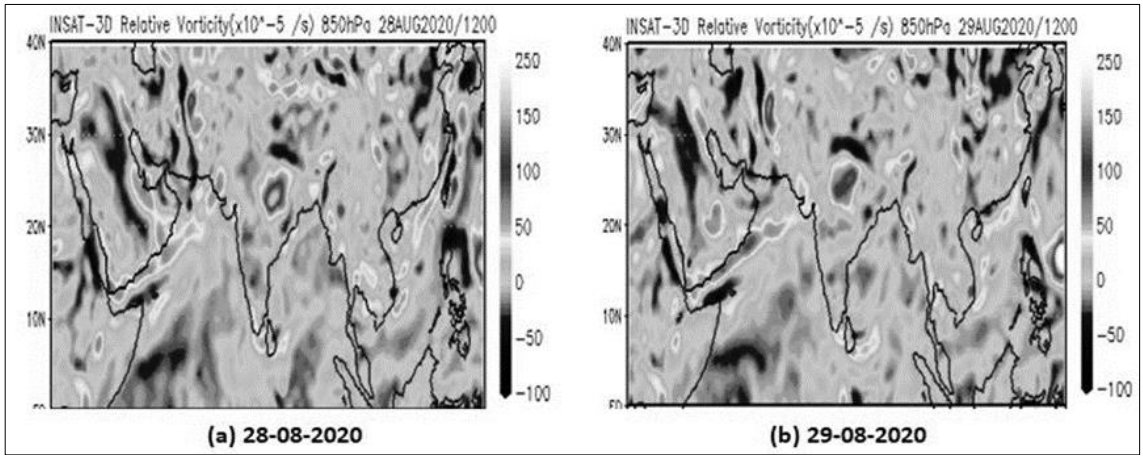


Fig 11: (a) & (b): Vorticity

Fig 11 (a) to (b) depict the values and locations of relative vorticity by INSAT-3D imagery. It shows positive and highest value of 150 X 10^{-5} S^{-1} at 1200 UTC located at east and central parts of M.P. on 28th and on 29th, highest relative vorticity reduced to 100 X 10^{-5} S^{-1} at 1200 UTC with its location in west M.P. and adjoining area.

3.5 RADAR imageries during 28th August 2020

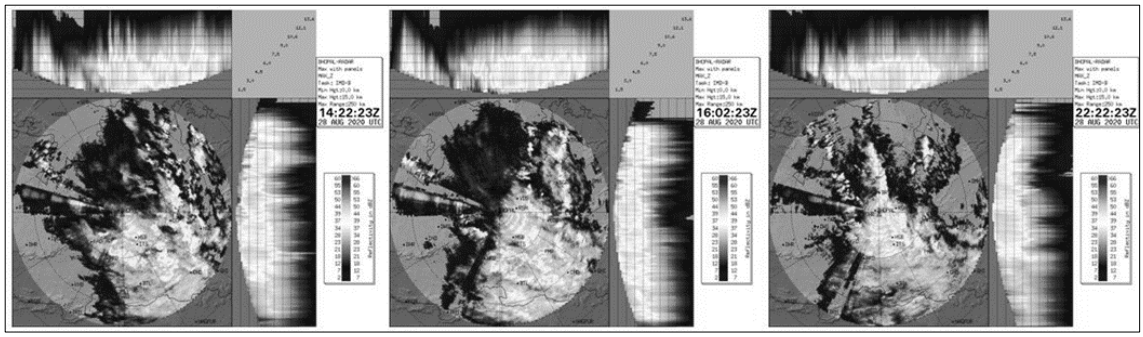


Fig 12: Radar images of DWR Bhopal

Fig 12 reveals radar images MAX_Z of the clouds of thunderstorm activity and lightning observations. Animations of images can be monitored for the direction and location that can be used for prepardness and disasterous warnings. Images of radar on 28th shows reflectvity around 50 dBZ at 1422 UTC, 1602 UTC & 2222 UTC over the region. These high reflectivity of clouds witnesses that there was strong convection which help the extremely heavy rainfall.

3.6 Satellite imageries during 28th-30th August 2020

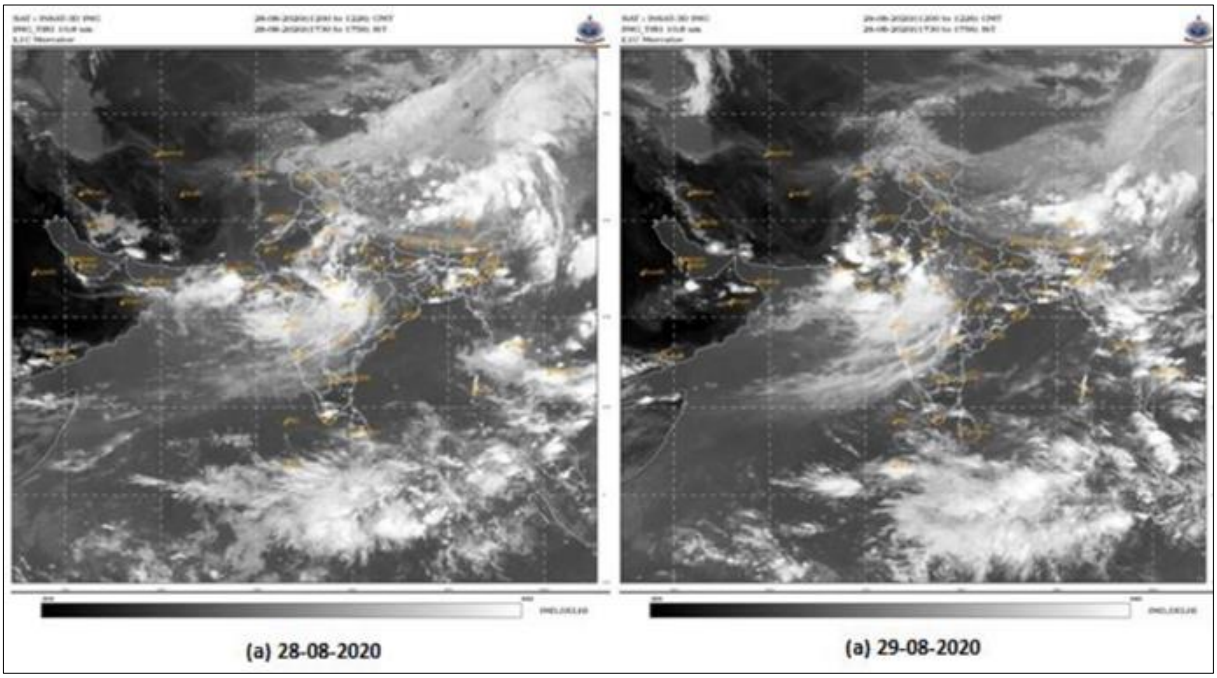


Fig 13: (a) & (b): INSAT-3D imagery at 1200

Fig 13 (a) & (b) depict INSAT-3D imagery at 1200 UTC on 28th, dense cloud mass with brightness and progressive movement and development of multiple deep convective clouds was observed over most parts of M.P. region. In the visible imagery, clouds which appear brighter and most prominent can help to predict convective activities. It is seen that on 29th at 1200 UTC, cloud patch was shifted towards West MP, East Rajasthan and North Maharashtra.

3.6.1 Rainfall, Synoptic & Dynamic situations

It has been observed that rainfall recorded over Chhindwara, Betul and Hoshangabad districts during 28th-30th tallied with the synoptic & dynamic situations during 28th-30th. The charts of GFS were indicating possibility of extremely heavy rainfall during the period and thus these models would be very helpful for prediction.

3.7 Rainfall and Orography

The Fig 14 shows Satpura Range of mountains at 450-900 meters elevation a.m.s.l. and more than 900 meters elevation a.m.s.l. and water body, rivers & dams are also located in the map. System of Well-Marked Low pressure areas moving towards WNW direction carrying huge mass of moistures during 27th-30th. On 28th, the Well-Marked Low pressure area laid over North Chhattisgarh & adjoining East Madhya Pradesh and associated cyclonic circulation extended upto 7.6 km above mean sea level tilting southwestwards with height and Chaurai (Lat. 2202 and Long. 7924, altitude 646 m) is located at the SW sector of system and in the NNE direction of Range of mountain of more than 900 meters elevation a.m.s.l. in the Chhindwara district. As Chaurai is situated in the windward side of the mountains, the mass of clouds & huge moisture carried through the system interacted with hilly areas resulting in exceptionally heavy rainfall recorded at Chaurai (414.4 mm) on 29th. System was moving towards WNW crossing Betul & Hoshangabad district with huge mass of moisture. Again, system was active giving large mass of moisture to SW sector which interacted with mountain ranges also seen at the boundary of Hoshangabad district 900 meters elevation a.m.s.l., thus, resulting in extremely heavy rainfall at Shahpur (193.2 mm) in Betul district and Hoshangabad in Hoshangabad district. Due to this peculiar situation of three districts, it helped to retain large amount of moisture and convective activities from 27th-30th August 2020 giving widespread heavy to very heavy rainfall and isolated extremely heavy rainfall over the area.

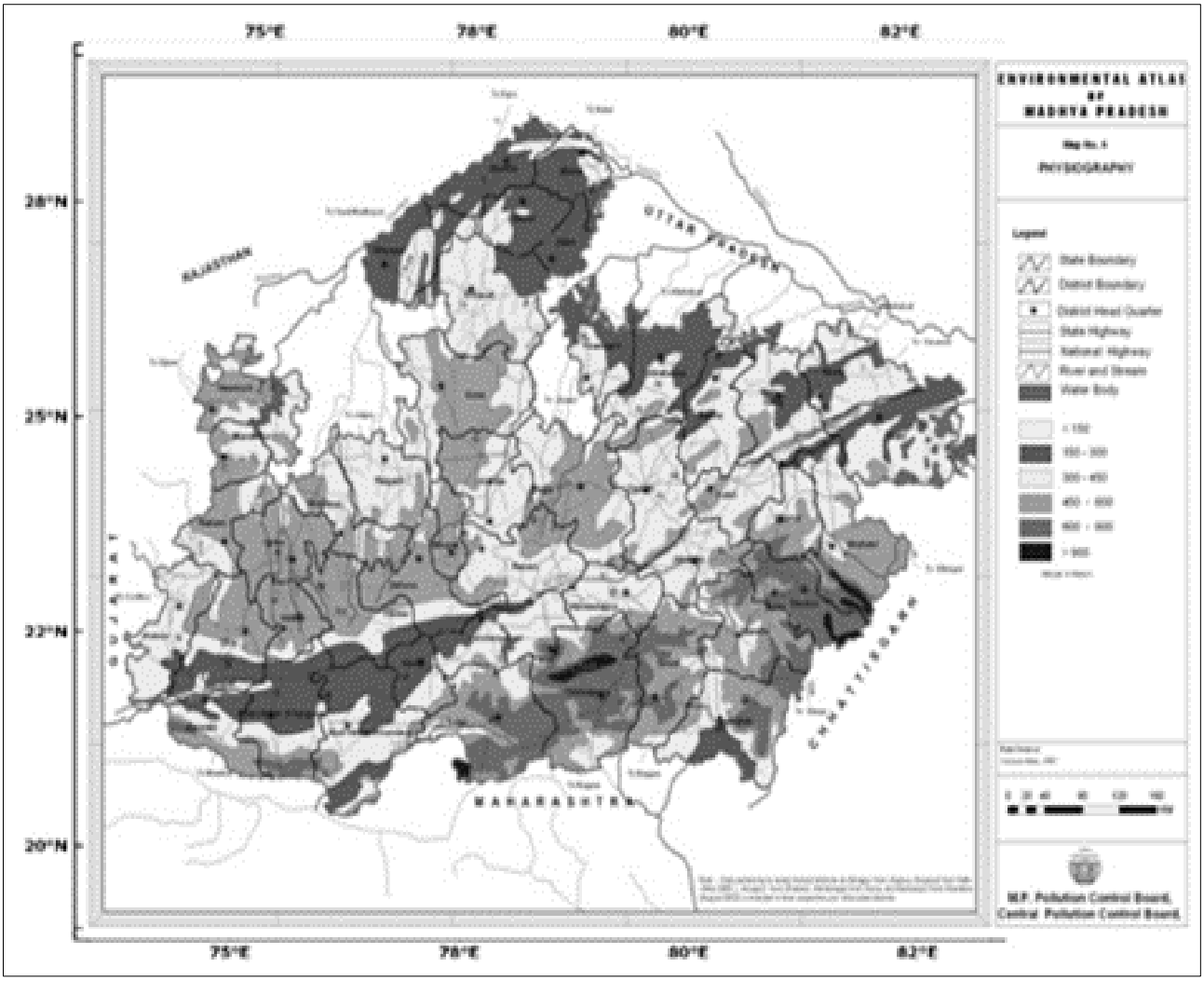
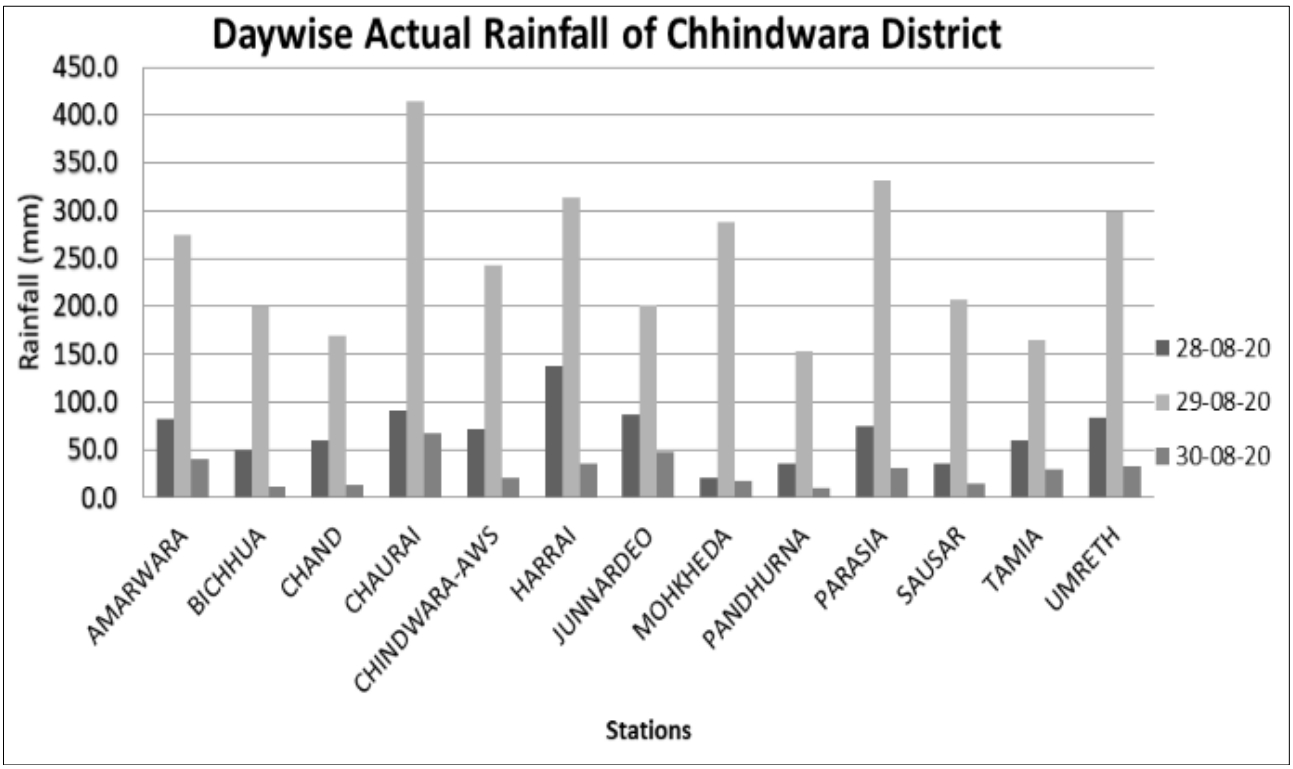


Fig 14: Orographic Map of Madhya Pradesh

Table 2: Rainfall in mm recorded at various stations of Chhindwara district during 28th-30th August 2020

Stations	28-08-20	29-08-20	30-08-20	Average
Amarwara	82.2	274.2	40.2	132.2
Bichhua	49.0	199.6	12.0	86.9
Chand	60.3	170.1	13.4	81.3
Chaurai	91.4	414.4	67.6	191.1
Chindwara-aws	72.2	242.4	20.2	111.6
Harrai	137.2	313.0	36.2	162.1
Junnardeo	87.4	201.2	47.8	112.1
Mohkheda	20.2	288.4	18.4	109.0
Pandhurna	36.4	153.2	10.2	66.6
Parasia	75.2	331.0	31.2	145.8
Sausar	35.2	206.3	15.0	85.5
Tamia	60.0	165.0	30.0	85.0
Umreth	84.4	299.2	32.8	138.8

Table 2 & Graph 1 reveal that Chhindwara district recorded widespread rainfall during 28th-30th. On 29th, Chaurai, Parasia, Harrai, Umreth, Mokheda, and Chhindwara recorded extremely heavy rainfall and Chaurai (414.4 mm) reported exceptional rainfall.

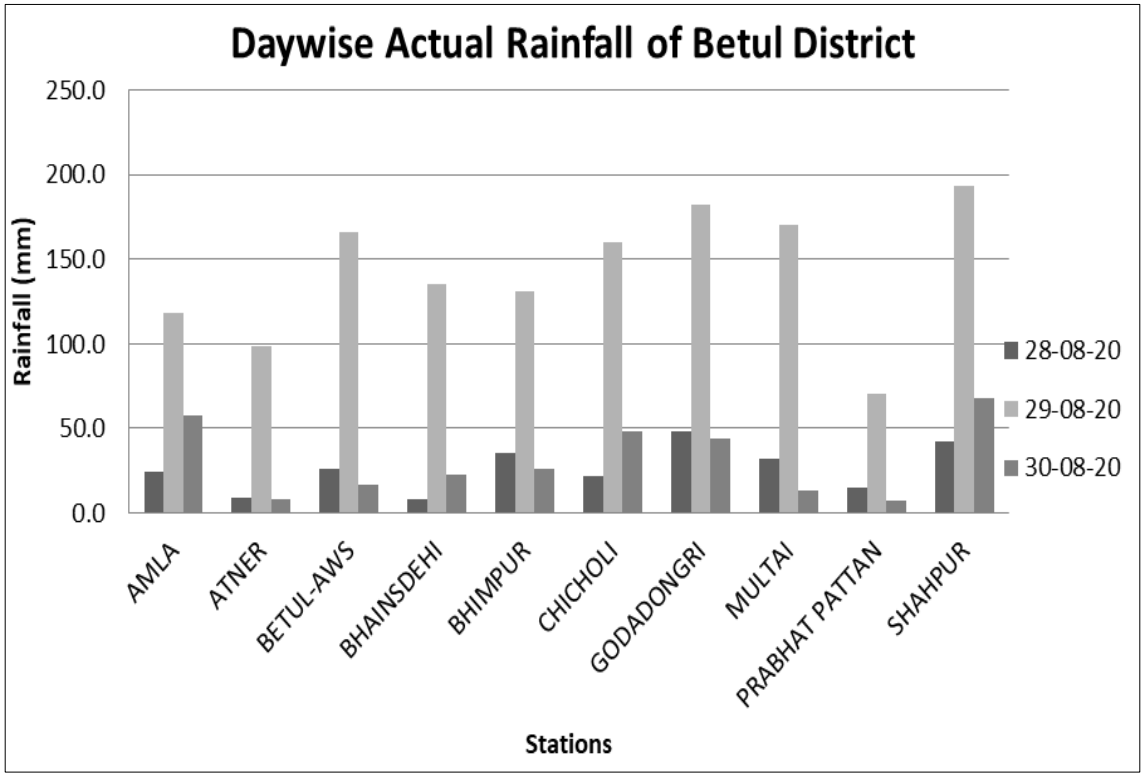


Graph 1: Graphical representation of Rainfall in mm recorded at various stations of Chhindwara district during 28th-30th August 2020

Table 3: Rainfall in mm recorded at various stations of Betul district during 28th-30th August 2020

Stations	28-08-20	29-08-20	30-08-20	Average
Amla	24.0	118.0	58.0	66.7
Atner	9.0	98.2	8.4	38.5
Betul-aws	26.2	166.4	16.4	69.7
Bhainsdehi	8.0	135.0	23.0	55.3
Bhimpur	35.0	131.0	26.0	64.0
Chicholi	22.1	160.2	48.3	76.9
Godadongri	48.0	182.0	44.0	91.3
Multai	31.8	170.0	13.2	71.7
Prabhat pattan	15.3	70.2	7.2	30.9
Shahpur	42.0	193.2	67.8	101.0

Table 3 & Graph 2 reveal that Betul district recorded widespread rainfall during 28th-30th. On 29th, Shahpur, Godadongri, Chicholi, Betul, Multai, Bhainsdehi, Bhimpur and Amla recorded very heavy rainfall and on 28th, Atner district recorded heavy rainfall.

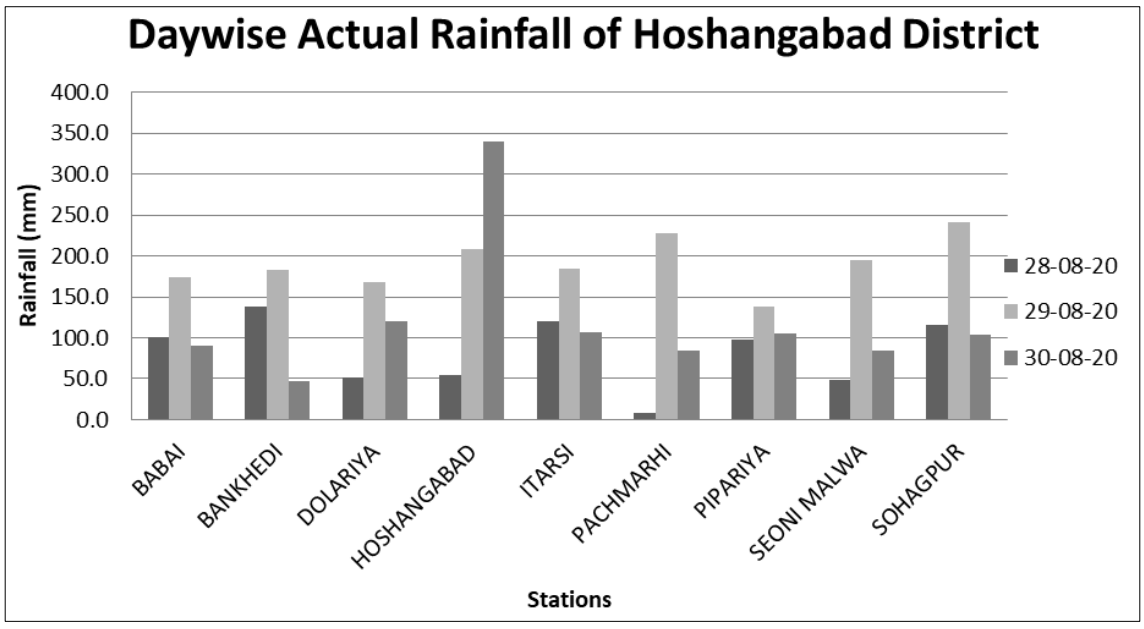


Graph 2: Graphical representation of Rainfall in mm recorded at various stations of Betul district during 28th-30th August 2020

Table 4: Rainfall in mm recorded at various stations of Hoshangabad district during 28th-30th August 2020

Stations	28-08-20	29-08-20	30-08-20	Average
Babai	101.0	174	90.0	121.7
Bankhedi	138.8	182.2	47.6	122.9
Dolariya	52.0	168	120.0	113.3
Hoshangabad	54.4	208.8	340.4	201.2
Itarsi	120.6	184.4	107.4	137.5
Pachmarhi	8.0	228	83.8	106.6
Pipariya	97.2	138	105.8	113.7
Seoni malwa	48.0	195	84.4	109.1
Sohagpur	116.3	241.6	103.4	153.8

Table 4 & Graph 3 reveal that Hoshangabad district recorded widespread rainfall during 28th-30th and all 9 stations recorded very heavy rainfall on 29th and heavy rainfall on 30th August 2020. Hoshangabad recorded extremely heavy rainfall on 30th.



Graph 3: Graphical representation of Rainfall in mm recorded at various stations of Hoshangabad district during 28th-30th August 2020

Table 5 shows the location with lat-long of heaviest rainfall at Chhindwara, Betul and Hoshangabad districts during 28th-30th August 2020.

Table 5: Location and heaviest fall at Chhindwara, Betul and Hoshangabad districts during 28th-30th August 2020

District	Station	Rainfall (mm)	Lat	Long	Altitude
Chhindwara	Chaurai	414.4	2202	7924	646 m (2119 feet)
	Parasia	331.0	2211	7844	785 m (2575 feet)
Betul	Shahpur	193.2	2212	7755	248 m (814 feet)
	Godadongri	182.0	2207	7800	413 m (1355 feet)
Hoshangabad	Hoshangabad	340.4	2246	7746	278 m (912 ft)
	Sohagpur	241.6	2242	7812	336 m (1102 feet)

During the three days, Hoshangabad district reported the most rain followed by Chhindawara and Betul. Chhindwara district towards east, Betul in Southwest and Hoshangabad in west direction and hilly ranges covered in south west, they helped to retain more moisture during three days, resulting in more rainfall in this three districts. It indicates that system was approaching from east and passing towards west with high intensity pulling of moisture. Due to this spell of rain and Pench River originated from this area got flooded and increased the water level of Kanhan & Wainganga rivers located in downstream also flooded and it affected agriculture and property loss in Bhandara districts in Vidarbha.

4. Conclusions

1. The Well-Marked Low pressure area passing from north interior Odisha to Rajasthan through Madhya Pradesh during 27th-31st August 2020 carried huge amount of moisture that caused extremely and exceptionally heavy rainfall during 28th-30th August 2020. The WML situated over N Chhattisgarh and adjoininig East M. P. is very favourable location of system to give extremely heavy rain to exceptionally heavy rain over south central M.P. in the district of Chhindwara and Betul. On 29th, the well-marked low pressure area over northern parts of east Madhya Pradesh & neighbourhood laid over central parts of north Madhya Pradesh & adjoining South Uttar Pradesh with associated cyclonic circulation extending upto 7.6 km above msl was favourable location for extremely heavy rainfall at Hoshangabad district of M.P.
2. The region falls in the Southwest quadrant of the passing WML system and support of monsoon trough at surface level was also there which laid over the area lead to extremely heavy rainfall in the region.
3. Moisture incursion took place from both Arabian sea and Bay of Bengal and their confluence region was central India so strong lower level convergence and upper level divergence was observed and this situation gave extremely heavy rainfall occurred on 28th and 29th Aug 2020.
4. It is observed that influence of the orography due east west oriented Satpura hills with maximum height 900m a.m.s.l. in the southwest direction of Well-marked Low pressure region that helped to further lift the moisture resulted in widespread and extremely heavy rainfall and convective activities helped to increase intensity of rainfall.
5. It is found that the system continued intensifying due to existing significant dynamic factors such as lower level convergence & upper level divergence and strong positive vorticity of order of 50-150 X 10^{-5} S^{-1}.
6. The satellite and radar imageries respectively showed dense cloud patch and very high reflectivity that indicated development of intense weather system which is useful to predict weather forecast in advance that can help disaster management systems in preventing massive destructions.
7. Sluggish movement of system which shows it took 3 days to pass Madhya Pradesh is one of reason for widespread and extremely heavy rainfall over the region for continuously 3 days. The slow movement of WML is very favourable condition for extremely heavy rainfall because convergence area does not change much.
8. GFS models can be used as tools for preparation of advance weather forecasting with increasing preparedness.
9. Location of Chaurai is at windward side i.e. on eastern side of the Satpura hilly range of altitude more than 900m and it laid in southwest sector of the system which caused exceptionally heavy rainfall over the station due to lifting of strong moisture inflow upward due to orography effect.

Thus, we may conclude that combination of multiple factors e.g. well-marked low pressure system, slow movement of system, strong moisture incursion, strong lower level convergence and upper level divergence and orography was the reason for such extremely heavy rainfall over the region.

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