Fluctuations of heavy rainfall association parameters over Bihar, India

Sk Hasane Ahammad[1], Rajesh Gogineni[2], T Raghavendra Vishnu[3], N Umakanth[4], MC Rao[5,*] and Y RamaKrishna[2]

[1]Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram–522502, India
[2]Department of ECE, Dhanekula Institute of Engineering and Technology, Vijayawada–521139, India
[3]Department of ECE, Priyadarshini Institute of Technology and Science For Women, Chintalapudi–522306, India
[4]Department of ECE, Kallam Haranadhareddy Institute of Technology, Chowdavaram–522019, India
[5]Department of Physics, Andhra Loyola College, Vijayawada-520008, India
*raomc65@gmail.com

Abstract

Heavy rains are not uncommon in India. A substantial amount of precipitation frequently falls in a short period of time, increasing the risk of severe flooding and landslides. These heavy rainfall events result in severe damage to crops, livestock, buildings and infrastructure. Forestry crops are at a high risk when there is heavy rainfall combined with strong winds. Strong winds, hail and torrential rain are among well-known effects of convective systems. In the Bihar region, convective systems are the main cause of precipitation during the monsoon season. Throughout the year, there are seasonal variations in where it rains. During the monsoon season, Bihar is frequently vulnerable to these systems. In recent years, there have been increasingly frequent heavy rainfall occurrences over North India. The characteristics associated with high rainfall are taken into consideration in our study to examine these systems. June, July, August and September months are known as the monsoon season (MNSS). The MNSS precipitation patterns are crucial because they affect many different crop-related operations across the nation. The mean rainfall for MNSS has been analyzed for the Bihar region for the year 2021. Total precipitable water (TPW), Show alter index (SWI), Total Totals Index (TTI), K index (KI), Excessive precipitation with enhanced convection (EPEC) are investigated over Bihar region during MNSS of 2021. A strong chance of convection is implied by these KI and TTI values. Over Bihar, all the months of MNSS displayed high EPEC values and low KI values.

Keywords: Convection, Index, excessive precipitation, show alter index.

Introduction

Numerous factors like the daily temperature and rainfall have an effect on people's lives. Surface temperature and rainfall are influenced by the geographical features of the area. The long-term structure of the monsoon season from 1951 to 2005, as shown by study done by Pattanaik and Rajeevan in 2010, indicates that a reducing tendency in low rainfall occurrences balances out an increasing trend in the contribution from extreme rainfall events. As a result, in recent years, extreme weather and climatic occurrences have received increasing amounts of attention (Karl and Easterling 1999). Since more than 80% of India's land area receives around 90% of its yearly rainfall during this season, the monsoon season (MNSS) is crucial for an agricultural country like India. The four-month South-West monsoon season, which contributes to approximately 75% of the nation's total rainfall, is essential because more than 55–60% of the country's territory is still rain-fed. In comparison to the post-monsoon season (November to February), India receives about 53% of its agricultural products during the monsoon season (June to September) (Naskar 2022). A weak or insufficient monsoon poses serious problems for the country in the form of crop loss, drought and more severe famine conditions. As a result, it is critical to monitor variations in rainfall (location and intensity) across the country on a daily, weekly, monthly and seasonal time scale.

Dash et al. (2009) looked into potential changes in the frequency of rain events in India in terms of their length and severity per day using daily gridded (1°X 1°) rainfall data from 1951 to 2004. They found that the frequency of moderate and low rain days over the entire country has significantly decreased during the previous 50 years. Past research by Dash et al. (2007), Lal (2003) and Goswami et al. (2006) reveals that while the number of rainy days and overall annual precipitation have decreased, the frequency of higher rainfall events has generally increased in many parts of Asia. Mason et al. (1999) claim that by focusing on changes in extreme occurrences rather than climatic variables, it is feasible to comprehend climate change projections more effectively. According to Pai et al. (2015), a rise in low-pressure monsoon days during the 1970s is the primary factor contributing to rising trends in heavy rainfall and very heavy rainfall weather events over Northern and Southern areas of India. North-east India's tendencies for these kinds of accidents decreased between 1956 and 2010. Goswami et al. (2006) observed that the frequency and size of extreme rainfall events were both moving increased in central India, while the frequency of moderate rainfall occurrences was trending decrease, using daily rainfall data from 1951 to 2000. When Kumar et al. (1992) examined total precipitation changes through time, they noted rising trends across the majority of the northwest and west coast regions of India. Joshi et al. (2006) examined the patterns of extreme rainfall indices over the Indian peninsula's northern and western coasts. On the state of Bihar, however, hardly any work has been done.

The state of Bihar is extremely vulnerable to natural disasters. Every year, the state suffers severe loss of life and property due to natural disasters like hailstorms, flash floods, cloudbursts and lightning. There have only been a few researches on these phenomena (Warwade et al. 2018). Its location in subtropical latitude, particularly in the centre of the landmass and the proximity of the Himalayas are the main causes of all these different aspects of its climate. Siwalik system offshoots like the Someshwar and Dun ranges have a small local impact on the pattern of the geographical distribution of rainfall incidence on its northern limit.

Examining the changes in MNSS precipitation-related variables over the Bihar region in 2021 is the goal of this study. First, we looked at the diurnal rainfall for the MNSS Bihar region using the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (GPM IMERG) dataset. We started by carefully examining the rainfall parameter. After creating many indices to look at the stability of the atmosphere, we later determined the effectiveness of each indicator for regulating rainfall. For this, we use temperature and humidity information from daily MNSS ERA5 reanalysis data at various vertical atmospheric levels.

Material and Methods

Study site

It covers 94,163 square kilometers in total. It covers the longitudes 83.20° E and 88.18° E, as well as the latitudes 24.2° N and 27.31° N. With an average elevation of 150 meters above sea level, it is an entirely landlocked nation. The state's borders with Nepal, West Bengal, Jharkhand and Uttar Pradesh are on the north, east, south and west, respectively. The Ganga divides the plain into two unequal halves as it travels through the heart of Bihar from west to east. The northern Himalayan Mountains have a substantial influence on the pattern of monsoon rainfall in Bihar. Bihar's primary industry is agriculture. With 76 percent of the workforce employed there, agriculture serves as the main economic pillar of rural areas. Bihar's agriculture depends heavily on the monsoon.

Data

This study looks at convection-related characteristics over the Bihar region during MNSS. The Global Precipitation measurement (GPM) half-hourly 0.1°x0.1° data obtained from the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG) method has been collected for the year 2021 at https://gpm.nasa.gov/data/directory. Temperature and relative humidity data were collected from 0.25° resolution ERA5 pressure level reanalysis data at https://cds.climate.copernicus.eu/#!/home (Hersbach and Dee 2020). The convection-related parameters are calculated using ERA5 temperature and relative humidity data.

Methodology

We have used the calculations below to determine the CAPE and TPW parameters using the above data.

(i). Total precipitable water (TPW)

The quantity of water that can be collected from the earth's surface to the topmost pressure level in the atmosphere is determined using TPW. When all of the water and water vapour has condensed into a liquid phase, this should satisfy. The formula is used to calculate it.

$$TPW = \frac{1}{g}\int_{P_1}^{P_2} W\ dP \quad \text{------------ (1)}$$

W is the mixing ratio and P_1 and P_2 are the two pressure levels (Carlson TN et al. 1990).

(ii) Showalter index (SWI)

The Showalter Index (Showalter 1953) assesses the buoyancy of an air parcel (atp) raised at 500 hPa and is based on the potential instability of the 850 hPa and 500 hPa layer. As a result, it gives an indicator of the layer's latent instability. A negative number indicates that positive buoyancy exists above the Level of Free Convection (LFC), reducing the likelihood of free convection.

SWI = att500 – atp500 ------- (2)

If SWI values are less than or equal to +3K, then there is a possibility of formation of small showers with thunder.

If SWI values are less than or equal to -3K, then a possibility for a strong convection occurs.

(iii). Total Totals Index (TTI)

Vertical Totals (VRT) and Cross Totals (CRT) are the two components of the Total Totals Index. The vertical lapse rate in the atmosphere is measured by VRT, whereas the amount of moisture in the atmosphere is measured by CRT. The lapse rate between 850 and 500 mb pressure levels can be investigated using TT (Miller 1967).

$CRT = dpt_{850} – att_{500}$; $VRT = att_{850} – att_{500}$

Total totals Index, $TTI = CRT + VRT = att_{850} + dpt_{850} – 2att_{500}$ ------- (3)

The values represented in the suffix of (1) are pressure level values.

The thunderstorm threshold fluctuates between 45 and 50 depending on geographic location, season and synoptic scenario and the TTI has proven to be very effective (Huntertrieser et al. 1996; Marinaki et al. 2006). A thunderstorm is more likely to occur when the TTI value is higher.

(iv). kindex (KI)

K index (KI) is an important parameter to estimate the intense rain occurring convective systems. It considers both moisture and temperature in its assessment. att values and dpt values can be estimated without using a "skew-T" diagram. If the att difference between 850 and 500 is more, it triggers the KI values that give a clear indication for high moisture incursion needed for the convection activity (George 1960).

$KI = (att_{850}-att_{500})+dpt_{850}-(att_{700}-dpt_{700})$ ------------ (4)

The values represented in the suffix of (4) are pressure level values.

The thunderstorm threshold varies between 288K and 313K depending on location, season and synoptic scenario and the KI has proven to be quite effective (Johnson, 1982). When the KI value is higher, a thunderstorm is more likely to form.

(v) Humidity Index (HI)

Litynska et al. (2005) developed this index. It helps the forecasters to analyze the wet and dry air masses which play a critical role in thunderstorm development. Moisture depth is the major assessment done at 850hpa pressure, 700hpa pressure and 500hpa pressure level.

$HI= (att_{850}-dpt_{850})+(att_{700}-dpt_{700})+(att_{500}-dpt_{500})$ ------------ (5)

The HI values go below 30K, there is a good possibility that thunderstorms may emerge in the vicinity.

(vi). Excessive Precipitation with Enhanced Convection (EPEC): It is a parameter that was developed to aid in the prediction of heavy rainfall combined with elevated convection. K-index (KI), 250-hPa divergence (Div250) and total precipitable water are the three metrics that make up EPEC (Foscato A 2016).

EPEC= KI+ TPW+ (Div250 x 100,000) ---------- (6)

Results and discussion

This study looked into the convection-related characteristics that affect the MNSS convective systems in the Bihar region.

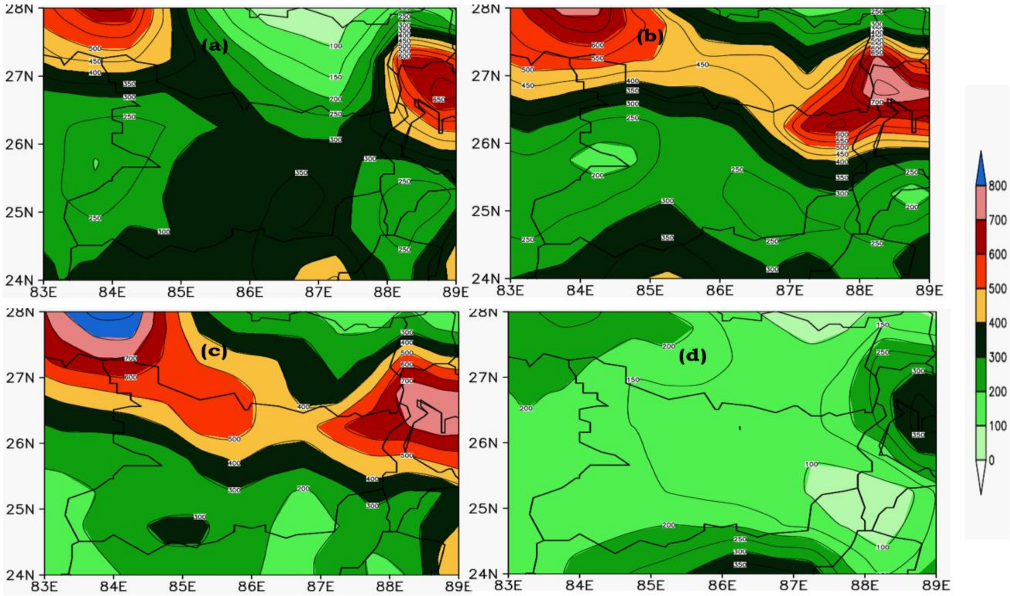

Fig.1 Spatial distribution of mean rainfall parameter for MNSS during the time period 2021.

We plotted the mean rainfall for each month over Bihar for the MNSS of 2021(Fig. 1). During the year 2021, the average rainfall in most parts of Bihar was between 400 and 700 mm. These rainfall amounts imply a significant likelihood of convection. During MNSS, the months of July and August showed considerable rainfall over Bihar. Rainfall in north-east Bihar ranges from 400 to 650 millimeters. During the southwest monsoon months and season, three districts in the northeast, Kishanganj, Arariya, Purnia and one in the northwest, West Champaran, receive the most rainfall. In June, these districts had roughly 200-350 mm of rain, followed by 400-600 mm in July, 400-650 mm in August and 100-200 mm in September. During the MNSS, regions in Bihar's southwest received less rainfall on average (675-900 mm). Kishanganj district has the highest mean MNSS rainfall (1850.1 mm), while Arwal district has the lowest mean MNSS rainfall (707.9 mm).

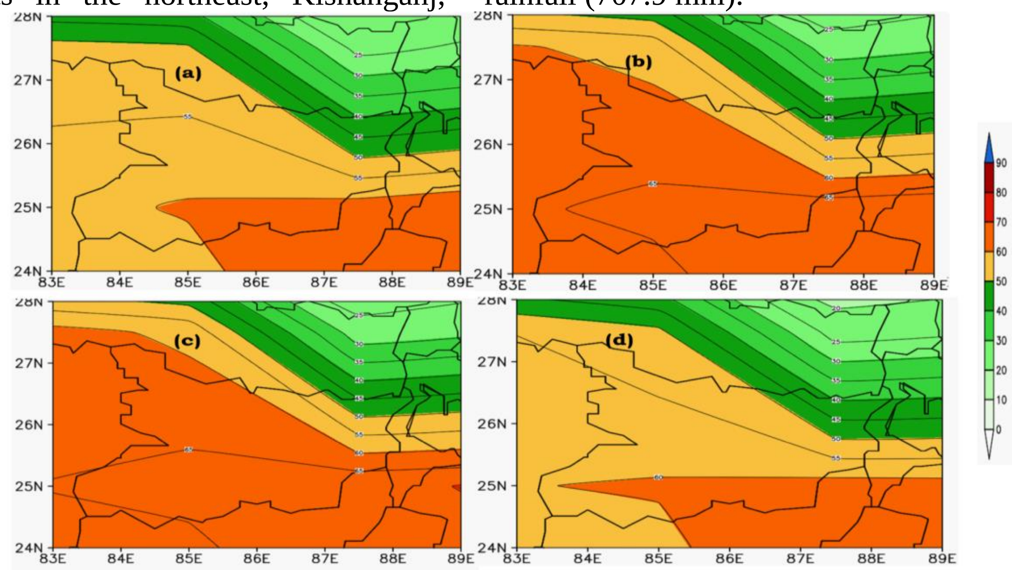

Fig. 2: Spatial distribution of mean LI parameter for MNSS during the time period 2021.

During the year 2021, the average total precipitable water values in most parts of Bihar were between 50 and 65 mm (Fig. 2). These total precipitable water values imply a significant likelihood of convection. During MNSS, the months of July and August showed high total precipitable water values over Bihar. TPW parameter in north-east Bihar ranges from 45 to 65 mm. In June, the districts had roughly 45-65 mm of TPW, followed by 50-69 mm in July, 50-72 mm in August and 40-65 mm in September. During the southwest monsoon season, regions in Bihar's Northeast indicated slightly less TPW on average (45-55 mm). The mean TPW values were high over all districts of Bihar during MNSS. Araria district has the lowest mean MNSS TPW (40-50 mm), while Arwal district has the highest mean MNSS TPW (50-65 mm).

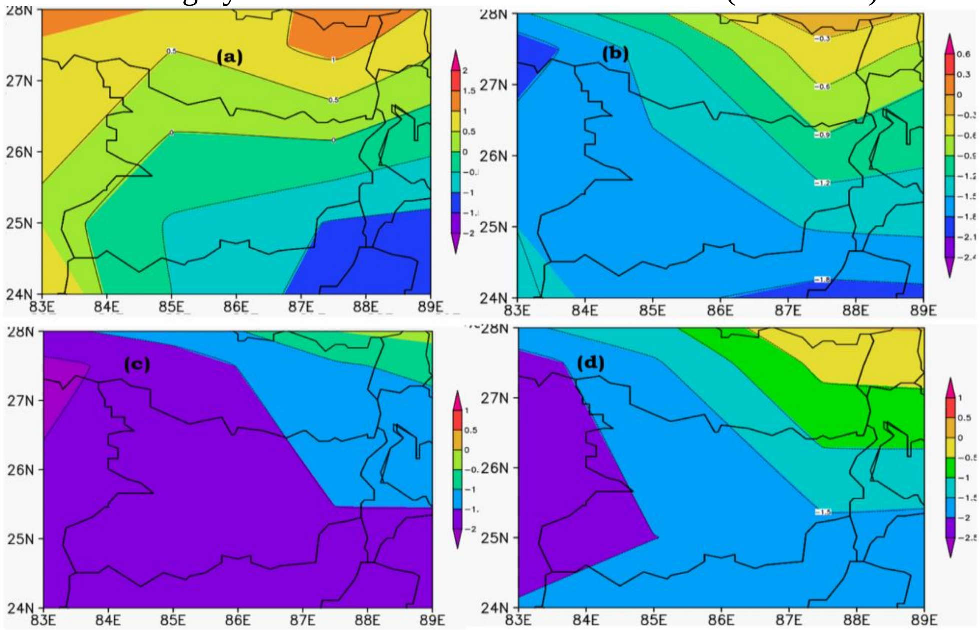

Fig. 3 Spatial distribution of mean TPW parameter for MNSS during the time period 2021.

During the year 2021, the average lifted index values in most parts of Bihar was between -2.5 and 0 K (Fig. 3). These lifted index values imply a significant likelihood of convection. During MNSS, the months of August and September showed low lifted index values over Bihar. In June, the districts had roughly -1 to 0.5 K of lifted index values, followed by -0.5 to -1.8 K in July, -1.5 to -2.5 K in August and -1 to -2.5 K in September. (During the MNSS, regions in Bihar's Northeast indicated a slightly less TPW on average -1.5 to 0 K). The mean lifted index values were high over all districts of Bihar during MNSS. Araria district has the lowest thresholds of lifted index parameter (-1 to 0 K), while Buxar district has the highest thresholds of lifted index (-2.65 to -0.9 K) parameter during MNSS.

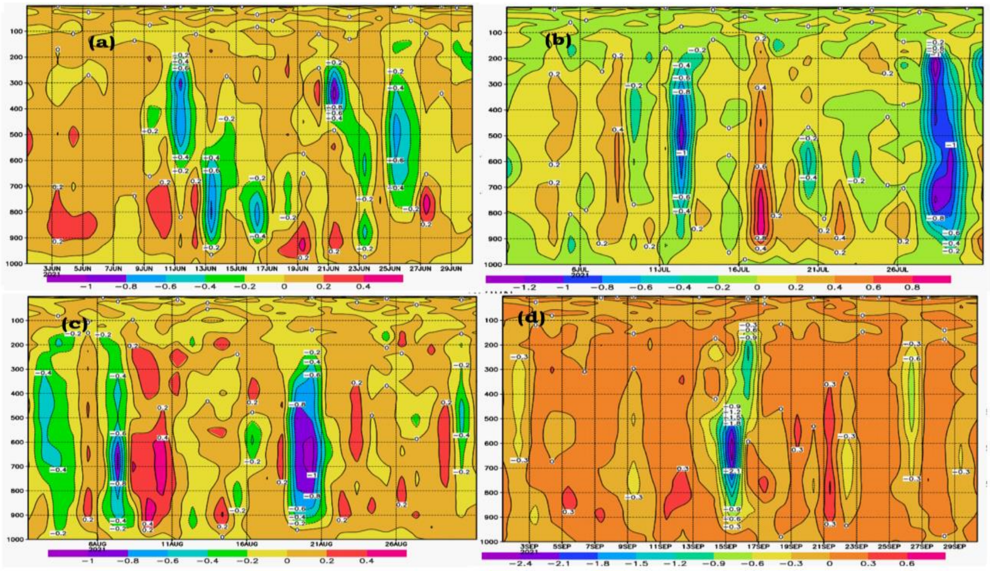

Fig. 4 Spatial distribution of mean KI (shaded) and TTI (contour) parameters for MNSS during the time period 2021.

During the year 2021 (Fig. 4), the average KI are represented in shaded and mean TTI values in contours. These KI & TTI values imply a significant likelihood of convection. During MNSS, the months of June and July showed high KI and TTI values over Bihar. Both KI and TTI parameters are showing reasonable good thresholds for severe convection over south-east, south-west and north-east Bihar regions. In June, the districts had roughly 316-319 K KI values whereas 41-43K TTI values are observed. In July, the districts had roughly 315-318 K KI values whereas 41-42K TTI values are observed. In August, the districts had roughly 314-316 K KI values, whereas 41-42K TTI values are observed. In September, the districts had roughly 316-318 K KI values, whereas 42-44K TTI values are observed. During the MNSS, regions in Bihar's Northeast indicated slightly high KI and TTI values. Buxar district has the highest mean KI and TTI during MNSS.

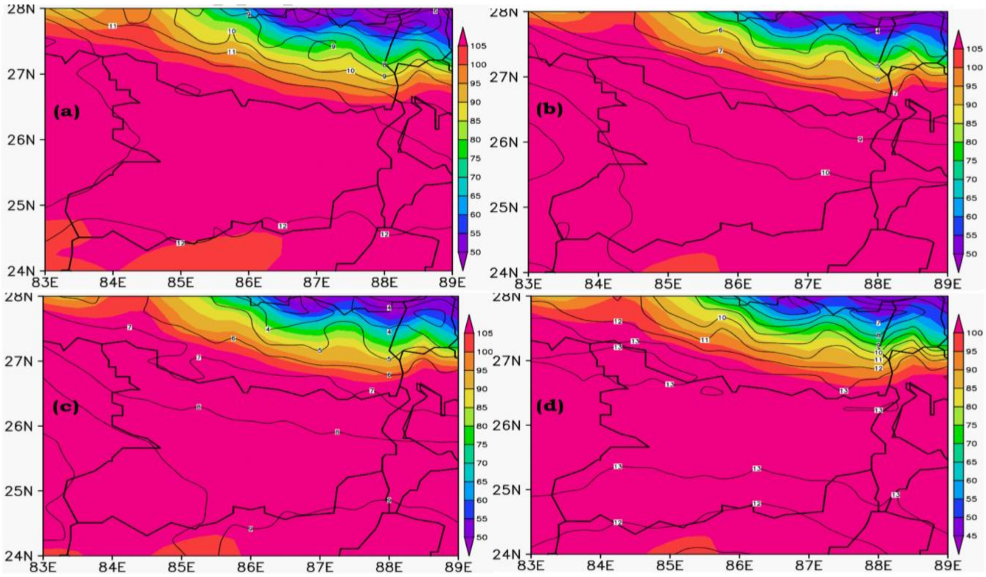

Fig. 5 Spatial distribution of mean EPEC (shaded) and HI (contour) parameters for MNSS during the time period 2021.

During the year 2021 (Fig. 5), the average EPEC are represented in shaded and mean HI values in contours. These EPEC & HI values imply a significant likelihood of convection. During MNSS, all the months showed high EPEC and HI values over Bihar. Both KI and TTI parameters are showing reasonable good thresholds for severe convection over north-east Bihar regions. Purnia, Araria districts has the highest mean EPEC and HI during MNSS.

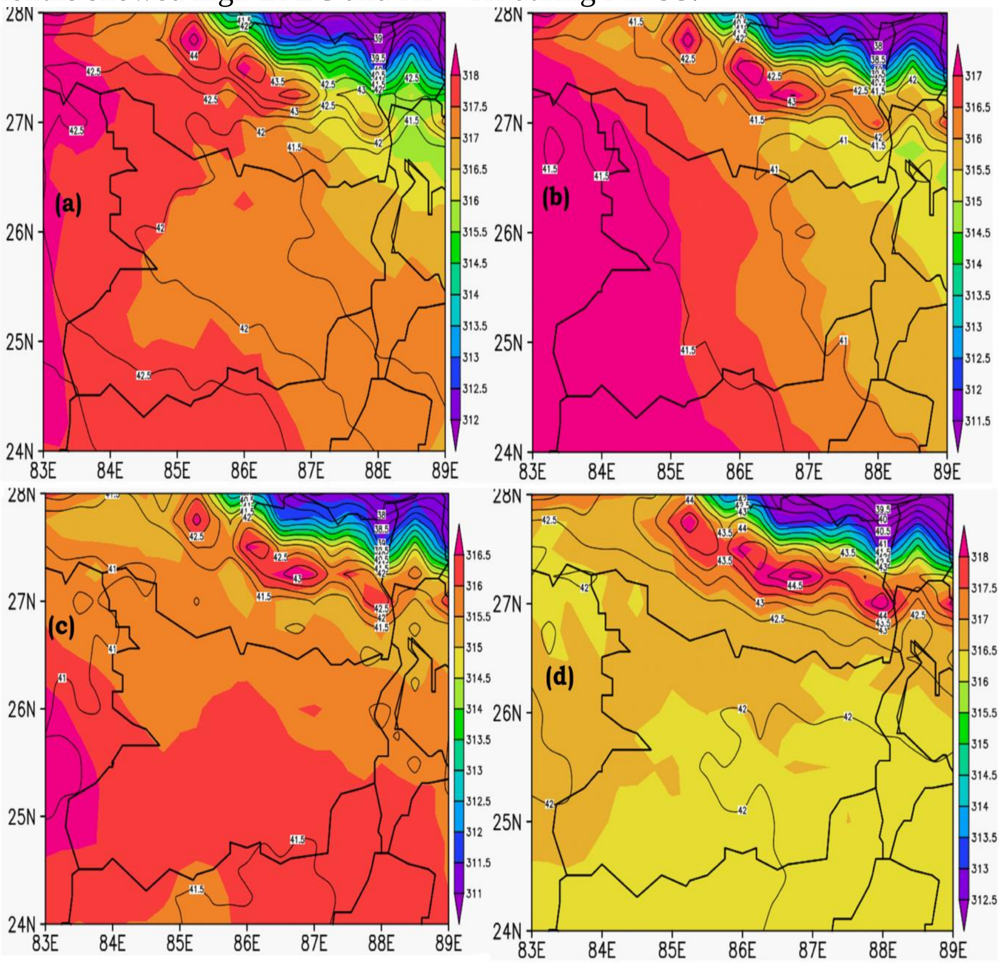

Fig. 6 Time-height sections of a vertical velocity parameter during the period 2021 of MNSS for Bihar region.

Fig. 6 shows a depiction of vertical velocity (VV) across the Bihar region. On days with a lot of convection, we saw large negative vertical velocity measurements. This shows that the lower atmosphere's air mass is going upward. With the exception of September, the other months displayed more negative VV values. When negative VV values are seen, the air mass is rising and ascending. Positive VV values show that the air mass is sinking downward when they are present. This is due to the fact that pressure decreases with height. These VV levels on days with significant precipitation are supported by the significant moisture build-up throughout the study area. September is the month where there are more positive VV readings.

Conclusion

The heavy rainfall related properties are studied over the Bihar region during the MNSS. The current study is being carried out for the MNSS for 2021. The months of July and August during MNSS showed significant rainfall throughout Bihar. Bihar's north-east experiences 400 to 650 millimetres of rainfall annually. The three north-eastern districts of Kishanganj, Arariya and Purnia, as well as one northwest district named West Champaran, indicated the highest rainfall during the MNSS. The mean MNSS TPW in Araria district is the lowest (40–50 mm), while the mean MNSS TPW in Arwal district is the highest (50-65 mm). During MNSS, Araria district has, the lowest thresholds for the LI parameter (-1 to 0 K), whereas Buxar district has the highest thresholds (-2.65 to -0.9 K). The north-eastern parts of Bihar showed somewhat elevated KI and TTI values during the MNSS. During MNSS, the Buxar district had the highest mean KI and TTI. The mean EPEC and HI during MNSS are highest in the Purnia and Araria districts. The air mass is rising and climbing when negative VV values are seen. When present, positive VV values indicate that the air mass is descending.

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