Intraseasonal Variability and Possible Causes of Large Scale and Convective Precipitations Over the Gangetic Plain of India

Pradhan Parth Sarthi (drpps@hotmail.com)
Central University of South Bihar https://orcid.org/0000-0001-7254-1576
Praveen Kumar
Ministry of Earth Sciences, Mausam Bhawan

Research Article

Keywords: Large Scale rainfall, Convective rainfall, Meteorological Subdivisions, Outgoing Long Wave Radiation, Zonal Wind, Relative Humidity

Posted Date: September 7th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-782707/v1

Version of Record: A version of this preprint was published at Theoretical and Applied Climatology on January 7th, 2022. See the published version at https://doi.org/10.1007/s00704-021-03881-w.

Abstract

In India, summer monsoon rainfall during June-July-August-September (JJAS) along the river Ganga is the lifeline. Since its variability predominantly affects the agriculture production, drought and flood over the densely populated meteorological subdivisions of the Gangetic West Bengal, Jharkhand, Bihar, East and West Uttar Pradesh. Owing to its importance, a large number of research on the variability of Indian Summer Monsoon Rainfall (ISMR) has been conducted. However, the types of rainfall (or precipitation), i.e. Large Scale Precipitation (LSP) and Convective Precipitation (CP), is less discussed. The LSP is precipitated out from the stratus or nimbostratus clouds, while CP occurs from the cumulus and cumulonimbus clouds, and both of them coexists during summer monsoon months. The current research aims to know the climatological characteristics and possible cause of occurrence of these two types of precipitation over the meteorological subdivisions. For this purpose, the data of LSP, CP, zonal, meridonal (u and v component) wind and Relative Humidity (RH) at the spatial resolution of 0.25° x 0.25° (25km) for the period of 1980-2019 are taken from the European Centre for Medium-Range Weather Forecasts (ECMWF), UK. The Outgoing Longwave Radiation (OLR) data at a surface resolution of 1° x 1° for the same months and periods are obtained from the National Centre for Environmental Information (NOAA), USA. The observed rainfall data of the India Meteorological Department (IMD) at the same resolution and period is considered and compared with ERA data. The spatial and temporal distribution of both types of precipitation is analyzed as well as their linkage with OLR, zonal winds and RH at pressure levels of 1000, 850 and 700hPa is examined.

1. Introduction

The Indian Summer Monsoon Rainfall (ISMR) is the lifeline for the populations of India and its economy. A substantially large number of researches on ISMR have been carried out on observational data. Based on station or gridded data, the variability of ISMR has been examined on regional and national scales (Koteswaram and Alvi, 1969; Jagannathan and Parthasarathy,1973; Raghavendra,1974; Hastenrath and Rosen,1983; Mooley and Parthasarathy,1984; Sarker and Thapliyal,1988; Kripalani et al., 1991; Kulkarni et al. 1992; Parthasarathy et al, 1994; Goswami et al, 2001; Singh and Sontakke 2002; Krishnamurthy and Shukla, 2007; Dash et al., 2007; Guhathakurta, 2007; Guhathakurta and Rajeevan, 2008; Sontakke et al. 2008; Kumar and Jain, 2011; Guhathakurta et al., 2015). However, the occurrence of types of precipitation (i.e. rainfall) during the summer monsoon season is less discussed, although LSP and CP co-occur. The LSP occurs from the stratus or nimbostratus clouds, while convective precipitation happens from cumulus or cumulonimbus clouds. These two types of clouds are found either separately or entangled in the same cell of cloud. According to Houze (1997), the large scale or stratiform cloud region is a group of convective cloud cells arranged horizontal, and the LSP is associated with a group of deep convection. The CP is started due to the heating of the earth's surface, and the heated ground surface warms the air above it, and such layer of air becomes lighter and rises rapidly into the atmosphere. The rising air cools, and water vapour in the air condenses into clouds and precipitate further. So, in the case of CP, the strong vertical motion or convection and updraft/downdraft in a single or group of convective clouds allow the droplets and ice particles to grow in size within the cloud. In LSP, the convection will not be strong, and rainfall particles concentration occurs through the incursion of water vapour. The mechanism of LSP and CP has already been discussed in the context of cloud microphysics (Tokay and Short, 1996). The microphysical process of moisture particles and, consequently, the latent heat is released in both types of precipitations. However, studies have shown that stratiform rainfall may occur in mesoscale convective systems (Schumacher and Houze, 2003), and CP may be present within LSP (Gregory et al., 1990; Houze, 1993; Matthew et al., 2000).

During the development stage of a convective cloud, CP is dominant. However, when a convective cloud matures and finally decays, the LSP replaces the CP (Shen et al., 2012). Researchers suggested that the relative contribution of CP and LSP varies with time and space over the tropical region (Cheng and Houze, 1979; Houze and Rappaport 1984; Johnson, 1984; Leary 1984; Chong and Hauser 1989; Goldenberg et al. 1990). Berg et al (2013) have shown that the CP is more sensitively to temperature increases than that of LSP, and therefore events of extreme precipitation events are increasing with temperature rise. During the LSP, the maximum heating due to latent heat is found at the height of 3km. However, the maximum heating is found at 7–8 km height in the case of convective cloud (Schumacher and Houze, 2003). The latent heat released (Houze, 2004; Schumacher et al., 2004; Choudhury and Krishnan, 2011) and the growth process of precipitation particles (Mapes, 1993; Kodama et al., 2009) in convective and stratiform clouds have been discussed.

In India, the CP and LSP in Tropical Rainfall Measuring Mission (TRMM) data of rainfall (1998–2010) during JJAS over Central India, the Bay of Bengal is found almost equal to the total rain (Pokhrel and Sikka, 2013). Chattopadhyay et al. (2009) has discussed the vertical profile of stratiform and convective heating within the summer monsoon season of India. The domination of CP over northern and central India and LSP over the southern peninsular of India has already been discussed for 1998 to 2013 (Ghosh et al, 2016). The LSP did not show a trend in the spatial variability, whereas a clear increasing trend in the spatial variability of CP is observed since the convective activity over the equatorial Indian Ocean is also increasing (Prakash et al., 2013).

Since both types of precipitation are associated with convective activity, the LSP and CP may relate with the Outgoing Longwave Radiation (OLR). Earlier researchers (Heddinghaus and Krueger, 1981; Prasad and Verma, 1985; Muthuvel and Arkin, 1992; Xie and Arkin 1998; Prasad et al., 2000; Prasad and Bansod, 2000; Kumar et al, 2021) have shown that the low value of OLR corresponds to intense convection whereas a high value of OLR shows cloud-free regions and therefore used for the study of the variability of precipitations. Therefore there may be the possibility of a link between the OLR and the variability in CP and LSP. In addition, water vapour is one of the critical factors for forming convective clouds (Battan and Kassander, 1960) because the latent heat released by the moisture is absorbed at different levels and enhances the condensation process. It is believed that the deep convection clouds have more liquid water than that in stratiform clouds (Taylor and Ghan, 1992) and a large number of supercooled water droplets in the deep convective cloud (Rosenfeld and Woodley, 2000). So, more moisture in the atmosphere may enhance CP through deep moist convective activity and vice versa. It is believed that the CP and LSP during summer monsoon months over these meteorological subdivisions of the Gangetic plain take place when surface easterly winds are more robust and the RH become more than 70% (Ramachandran and Kedia, 2013; Acosta and Huber, 2017). During JJAS, the moisture inflow is taken from ocean to land by southeasterly flow from the Bay of Bengal towards eastern and central India (Maussion et al. 2014; Kobayashi et al., 2015; Acosta and Huber, 2017). In the absence or weakening of this low-level easterly wind and associated moisture, the atmosphere may contain less moisture (Hastenrath 1976; Lamb 1978; Sikka 1980; Jaswal and Koppar 2011) and may reduce LSP and CP.

Based on the above-cited literature and discussion, it aims to (a) analyze the spatial and temporal distribution of LSP and CP and (b) their relation with OLR, zonal wind and RH by using more than 30 years of data. In the past research, these issues are not discussed over the meteorological subdivision of the Gangetic plain of India. In this paper, the literature survey and the basic idea is kept in the Introduction section. Section 2 describes the study area, data and methodology. Section 3 presents the results and discussion, respectively, while Sect. 4 concludes the proposed work.

2. Study Area And Data

Figure 1 shows the study area comprising the meteorological subdivisions of the Gangetic West Bengal (GWB), Jharkhand (JHA), Bihar (BR), East Uttar Pradesh (EUP), and West Uttar Pradesh (WUP). These meteorological subdivisions are located adjacent to the river Ganga. These regions are densely populated and largely depend on agriculture, especially on rainy crops. Hence precipitation is essential for agriculture cultivation and therefore selected as the study area. The LSP and CP, zonal (u component of wind) and meridional wind (v-component of wind), and RH available at the spatial resolution of 0.25° x 0.25° (~ 25km) are taken for Indian summer monsoon months of June, July, August, and September for 1980 to 2019 from the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA5), UK (Hoffmann et al., 2018; Hersbach et al., 2020). The detail of CP and LSP in ERA5 is given on the official website of ECMWF, UK. The OLR data at a surface resolution of 1°x1° for the same periods are obtained from the National Centre for Environmental Information (NOAA). The observed rainfall data of India Meteorological Department (IMD) is taken at resolution of 0.25° x 0.25° for the period of 1980–2019 for comparing with ERA5 data. The OLR data has been widely used in the qualitative estimation of the convective activity over the region of interest (Chelliah and Arkin, 1992).

3. Results And Discussion

3.1 Convective and Large Scale Precipitation

The spatial distributions of mean monthly values of CP and LSP in June, July, August, September, and mean JJAS for the period of 1980–2019 in ERA5(0.25˚x 0.25˚) data over the study area is shown in Fig. 2 and Fig. 3, respectively. The CP dominates in July and August compared to June and September (Fig. 2) over each meteorological subdivision. In Fig. 3, the spatial distribution of mean monthly values of LSP is well spread in July, and August followed by September and June. However, its value is comparatively less than that of the CP. The daily climatology of total precipitation i.e. CP plus LSP in ERA5, is plotted and compared with IMD observed precipitation in Fig. 4a,b since IMD records only total precipitation, not CP and LSP individually. The total precipitation in ERA5 has followed the pattern of IMD observed precipitation, although both differ in magnitude. The climatology (for 1980–2019) of the relative frequency of daily values of CP and LSP is shown in Fig. 5a,b. The interval of precipitation is kept on the X-axis while Y-axis represents the relative frequency (in %) of occurrence of CP (Fig. 5a) and LSP (Fig. 5b). In the case of CP, the percentage of 6.1-8 mm/day is 62% and 28% over the Gangetic West Bengal and West UP. The percentage of occurrence of 0-2mm/day (minimum range) and 8.1-10mm/day (maximum range) is lowest over each sub-divisions. In Fig. 5b, the LSP is found in the 0–2 mm/day (minimum range) and 6.1-8 mm/day (maximum range) during 1980–2019. The percentage occurrence of 2.1-4 mm/day is 63% over the Gangetic West Bengal and 42% over the Bihar and West UP. The relative frequency of CP is found in the range of 8.1-10mm/day, but it is absent in the LSP. The relative frequency of LSP does not show much variation among subdivisions, while such variation is seen in CP.

In the above discussion, the large value of CP compared to the LSP over these meteorological subdivisions has also been supported in the earlier research (Saikranthi et al, 2014). The considerable activity of deep convection (Zuidema, 2003) and associated precipitation (Zuluaga et al., 2010), as well as the stratiform precipitation associated with prevailing weak wind system (Romatschke and Houze, 2011) may be the possible cause of enhancing the value of CP and suppressing the value of LSP over the Gangetic West Bengal and adjoining meteorological subdivisions. The meteorological subdivisions of West and East UP located over the north and west India are the dry region, and large values of OLR are noticed there (Zipser et al., 2006) and is the possible cause of occurrence less amount of CP and LSP over West and East UP. However, other than these meteorological subdivisions in India, a significant LSP or stratiform precipitation has been observed (Houze, 2007).

3.2 Outgoing Longwave Radiation (OLR)

It has already been stated that low values of OLR corresponds to strong convective activities in the lower atmosphere and maybe the possibility of precipitation (Prasad and Verma 1985; Arkin et al. 1989; Xie and Arkin 1998; Prasad et al.2000; Prasad and Bansod 2000; Kumar et al. 2021). So, the inverse relation between OLR and precipitation could be a tool to understand the behaviour of CP and LSP. Thus, the spatial distribution of mean monthly OLR in June, July, August, and September and the mean JJAS OLR is shown in Fig. 6a,e, respectively. The spatial distribution shows a high value of OLR over the East and West UP while comparatively lower values of OLR, especially in July and August, is observed over West Bengal, Jharkhand, and Bihar. The spatial value of mean JJAS OLR is increased from West Bengal to West UP. A similar pattern of OLR is observed in earlier researches (Mahakur et al. 2013; Hazra et al 2017). The daily climatology of OLR for the period of 1980–2019 over West Bengal, Jharkhand, Bihar, East UP and West UP is shown in Fig. 7. The daily climatology of OLR is found comparatively higher over the West UP and East UP, while lower values are received over the West Bengal, Jharkhand and Bihar. It also reveals that the OLR remains high in June and September compared to the rainy months of July and August over these meteorological subdivisions.

3.3 Relation between OLR and Convective/Large Scale Precipitation

It is believed that the low (high) value of OLR is indicative of enhanced (suppressed) convection and hence more (less) cloud coverage (Prasad and Bansod, 2000). Researchers (Liu, 2003; Hu et al, 2011; Kumar et al, 2017) have shown that the large value of OLR is associated with large turbulence in the lower atmosphere while small values of OLR correspond to less turbulence. So, the LSP originated from the stratiform cloud may have less turbulence while CP from convective clouds would have strong updrafts of air mass and more turbulence. Further, near the Inter Tropical Convergence Zone (ITCZ) position over these meteorological subdivisions in July and August, the convective activity is enhanced, and OLR gets lower values (Gadgil, 2003) which may control the occurrence of CP and LSP. Therefore, the scatter diagrams between OLR and LSP as well as in between OLR and CP in June, July, August, and September and in mean JJAS for the period of 1980–2019 over the study area are shown in Fig. 8, Fig. 9, Fig. 10, Fig. 11 and Fig. 12, respectively. The LSP and CP show an inverse relation with OLR over the considered meteorological subdivisions; however, the relationship is more stronger (large value of R^2) in the case of CP and OLR.

Over the Gangetic West Bengal (Fig. 8), the values of CP is more concerning LSP in the individual months, especially in July and August, as well as in JJAS when OLR lies in between 190–240 watts/m2. The relation between OLR and CP is much better (high values of R^2) than the relation between OLR and LSP (low values of R2). These results suggest that the occurrence of convective activity supports large value of CP over the Gangetic West Bengal because the deep convective activity has occurred over the BoB and adjoining areas, and stratus cloud formation would be restricted, and less value of LSP is observed. In Figs. 9 and 10, over the meteorological subdivisions of the Jharkhand and Bihar, the values of CP show more consistency and dependency on OLR; the relation is relatively better in terms of R^2 in July and August. It means the Jharkhand and the Bihar regions get a large amount of rainfall through convective activity and due to the position of ITCZ (Gadgil 2003). Over Bihar, the relation between LSP and OLR in the individual months and JJAS reveals the occurrence of less amount of LSP. The meteorological subdivision of East UP and West UP shows large values of OLR (Fig. 11a,e and Fig. 12a,e) i.e. 200–290 Watts/m2 over the East and West UP in comparison to the other meteorological subdivisions where OLR lies in the range of 190–240 Watts/m2. Therefore, LSP and CP are relatively low over East and West UP compared to other meteorological subdivisions. The OLR and LSP are shown a relatively poor relation (low values of R2), and a low value of LSP is observed throughout the season. It may be summarized that the meteorological subdivisions of the Gangetic West Bengal, Jharkhand and Bihar get the lower side of OLR while East and West UP is receiving higher values of OLR, and this is the probable cause of lower values of LSP and CP over the meteorological subdivisions of East and West UP.

It may be visualized that during the summer monsoon season, the large scale or stratiform cloud, generally seen as a sheet of clouds, is recognized as a group of individual convective cloud cells arranged one by one in the horizontal and the LSP occurs when all the convective cells are merged in a single sheet, and deep convection is reduced. The variation in the high activity of deep convection (i.e. low value of OLR) over the adjacent area of BoB (Zuidema, 2003) and the variability of moisture inflow from BoB may be the possible cause of occurrence of a large fraction of CP in comparison to the LSP during individual months over the Gangetic West Bengal and adjoining areas of Jharkhand. However, both type of rainfall is suppressed over the Jharkhand. Over the meteorological subdivision of Bihar, the summer monsoon winds reach in the middle of June. In July and August, the position of monsoon trough over the Gangetic plain of Bihar enhances the convective activity (corresponds to low values of OLR) (Choudhury and Krishnan, 2011), and the value of CP is increased significantly in July and August over Bihar. Further, the larger values of OLR reduces the convective activity, as well as atmosphere, remains relatively free from the cloud over the East UP and West UP (Zipser et al., 2006), and that could be the possible justification of reduced values of CP and LSP in compare to that over the others meteorological subdivisions.

3.4 Possible causes of variability in Convective/Large Scale Precipitation

The inflow of moisture and presence of easterly wind over the Gangetic plain (Bavadekar and Mooley, 1981; Ramachandran and Kedia, 2013; Acosta and Huber, 2017) are essential for the occurrence of LSP and CP. In Fig. 13, the zonal wind and RH at the vertical pressure levels of 1000, 850 and 700hPa are shown for the Gangetic West Bengal, Jharkhand, Bihar, East UP and West UP. In June, the lower atmosphere shows the small values of RH and regime of westerly over the meteorological subdivision. In July, and August, RH attain the maximum value at 850hPa over all meteorological subdivisions, but it is 80–90% over the Gangetic West Bengal, Jharkhand and Bihar and is in between 75–85% over the East and West UP. During these two rainy months (July and August), the Gangetic West Bengal and Jharkhand subdivisions are under the grip of purely easterly and westerly wind in alternative at vertical pressure levels of 1000, 850 and 700hPa. These also get a large amount of RH and possibly set up the condition to initiate moist convection. It has been established that vertical wind shear and moisture may initiate atmospheric moist convection and convective cloud cells (Cotton and Anthes 1989; Houze 1993; Anber et al, 2014), and therefore this is the possible cause of larger values of CP over these subdivisions. Simultaneously, there is no direct moisture incursion through the easterly wind from the BoB, and as a consequence, the LSP shows lower values. The meteorological subdivision of Bihar receives relatively stronger easterly wind at the pressure levels of 1000hPa to 700hPa and RH of greater than 80% in July, August and September so that this subdivision may have a combination of stratiform and convective clouds.

Consequently, an almost equal proportion of LSP and CP is found (as shown in Fig. 10). Over the East UP, a weak easterly wind is prevailing throughout the pressure levels (1000hPa to 700hPa) with restricted vertical wind shear, and RH is reduced. Therefore LSP and CP are suppressed. Over the meteorological subdivision of West UP, the wind changes the direction from easterly to westerly in vertical levels of 1000 to 700hPa and initiate vertical wind shear, but low values of RH does not allow to enhance the moist convective activity, and therefore LSP and CP are reduced in comparison to other meteorological subdivisions of the Gangetic West Bengal, Jharkhand, Bihar and East UP. It may be summarized that LSP is reduced when a weak easterly flow and the reduced RH exists at a lower level of the atmosphere and vice versa (Hastenrath 1976; Lamb 1978; Sikka 1980; Jaswal and Koppar 2011). The change of zonal wind direction in the vertical levels (1000hPa to 700hPa) and increased value of RH could be favourable for enhancing moist convective activity and maybe the possible cause of the occurrence of relatively larger values CP over these meteorological subdivisions. The above analysis is carried out based on zonal wind and RH; however other meteorological variables may also explain the variability in LSP and CP.

4. Conclusions

In India, the precipitation during the summer monsoon season, i.e. in JJAS, over the meteorological subdivisions of the Gangetic West Bengal, Jharkhand, Bihar, East UP and West UP is very important. During JJAS, the LSP precipitated from the stratus or nimbostratus clouds, while CP occurs from the cumulus and cumulonimbus clouds, and both of them coexists. In the spatial distribution, the large values of CP over the LSP are revealed over the Gangetic West Bengal, Jharkhand and Bihar; however, both types of precipitations are suppressed over the East and West UP. During the period of 1980–2019, the relative frequency of daily climatological values of CP (LSP) is relatively higher (lower). The frequency of occurrence of 6.1-8 mm/day of CP is highest (lowest) over the Gangetic West Bengal (West UP). Similarly, in the case of LSP, the frequency of occurrence of 2.1-4 mm/day is 63% (42%) over the Gangetic West Bengal (West UP). The lower values of OLR (180–220 watt/m^2) is found over the Gangetic West Bengal, Jharkhand, and Bihar higher values of OLR (240–290 watt/m^2) lie over the East and West UP. The lower side of OLR (especially in July and August) is conducive for convective activities and vice versa. To know the supportive condition for convective activities, the zonal wind and RH are analyzed on a monthly scale. The change in the direction of zonal wind, i.e. easterly to westerly and vice versa, from the 1000hPa to 700hPa pressure levels and a large amount of RH (> 80%) could be the possible justification of triggering moist convective activity, which leads to precipitating the larger values of CP over the Gangetic West Bengal, Jharkhand, and Bihar during the months. The relatively stronger zonal wind of easterly and the larger value of RH, i.e. 80–95% over the Bihar, is probably responsible for a good amount of LSP. Over the subdivisions of West and East UP, the weak easterly in the lower level and small values of RH may be a possible cause of lower values of CP and LSP. Such analysis of LSP and CP over the meteorological subdivisions along the Gangetic plain may be used for various purposes.

Declarations

Acknowledgement

Authors are thankful to IMD (India), ECMWF (UK) and NOAA (USA) for providing the observed and reanalyzed data for the current analysis.

Conflict of Interest: There is no conflict of interest.

Funding Statement: There is no funding support for the current research.

Author's Contribution: Pradhan Parth Sarth (PPS) did conceptualize the idea for this research. Praveen Kumar (PK) plotted the figures and drafted the manuscript.

Ethics approval: The authors confirm that this research is original and has not been published in any journal (in whole or in part).

Consent for publication: Authors have consented to publish this research

Availability of data and material: Models simulated outputs, Reanalysis and observed data are freely available.

Code availability: Code used for this research may be available upon genuine request from corresponding author

Consent to participate: None

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Figures

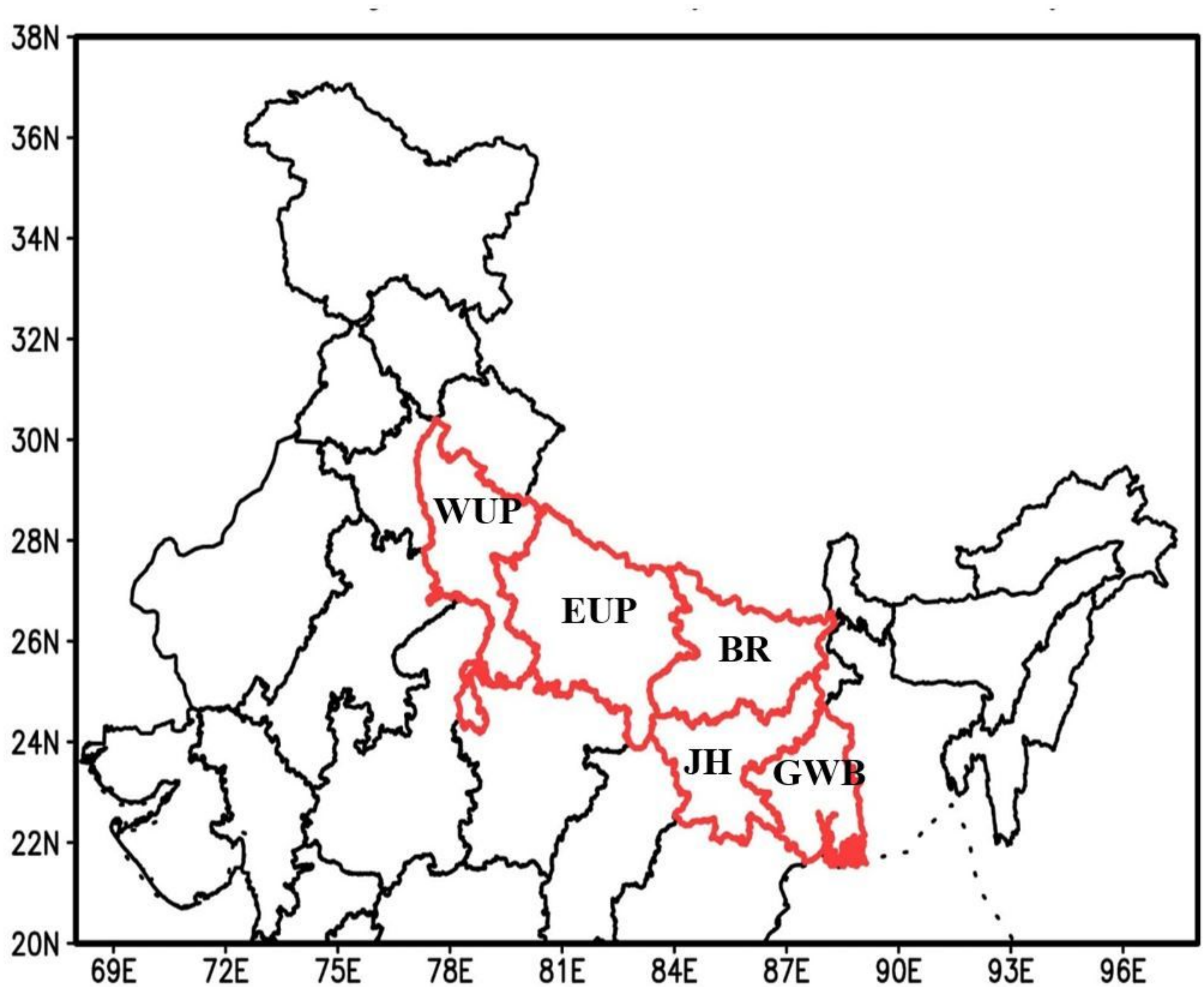

Figure 1

Study area comprising the meteorological sub division of India (Red Boundary) namely WUP–West Uttar Pradesh; EUP–East Uttar Pradesh; BR–Bihar; JH–Jharkhand; and GWB – Gangetic West Bengal, in India

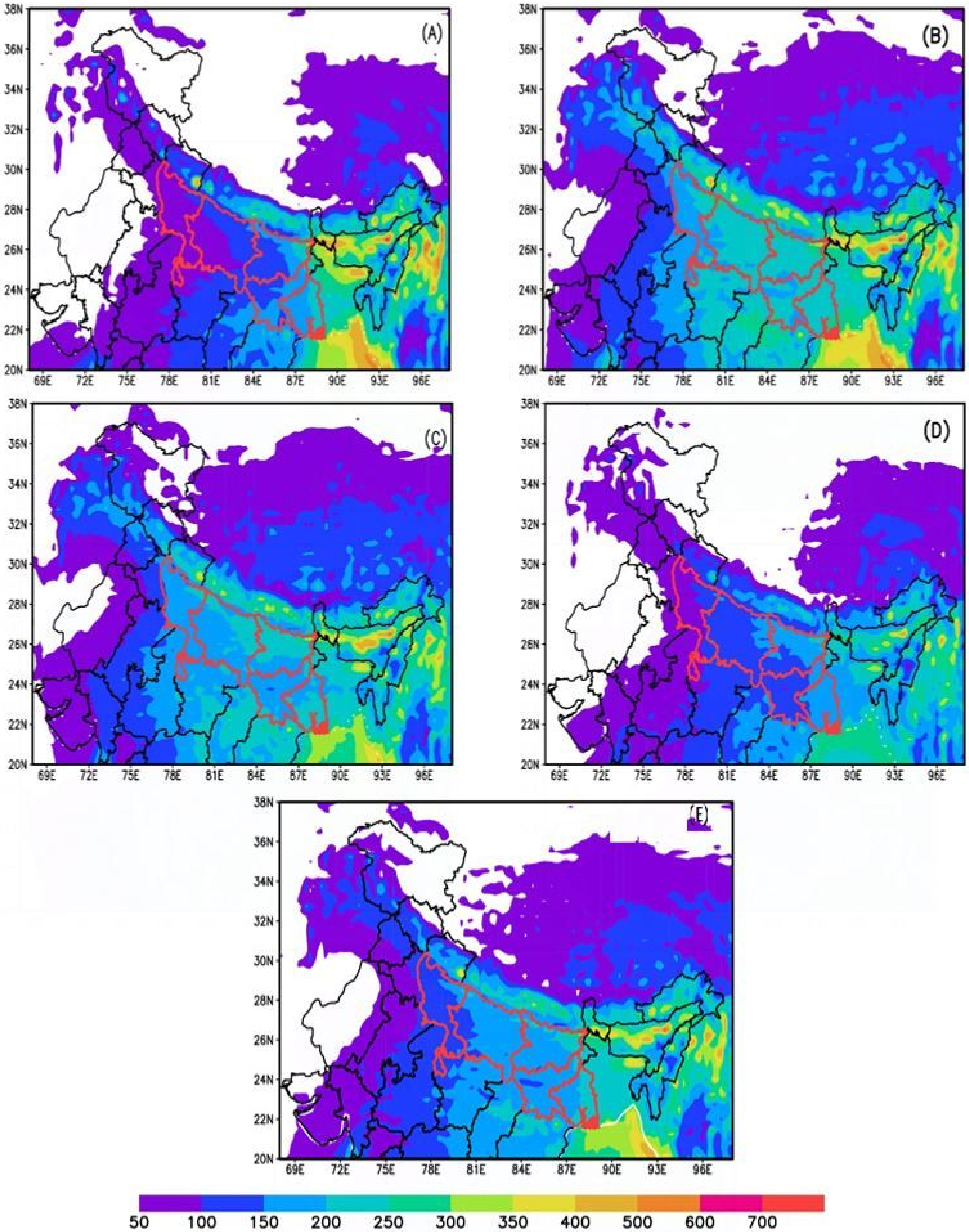

Figure 2

Spatial distribution of mean monthly Convective Precipitation (CP) in the months of (A) June, (B) July, (C) August, (D) September; and (E) during JJAS for the time period of 1980-2019 in ERA5(0.25˚x 0.25˚) data

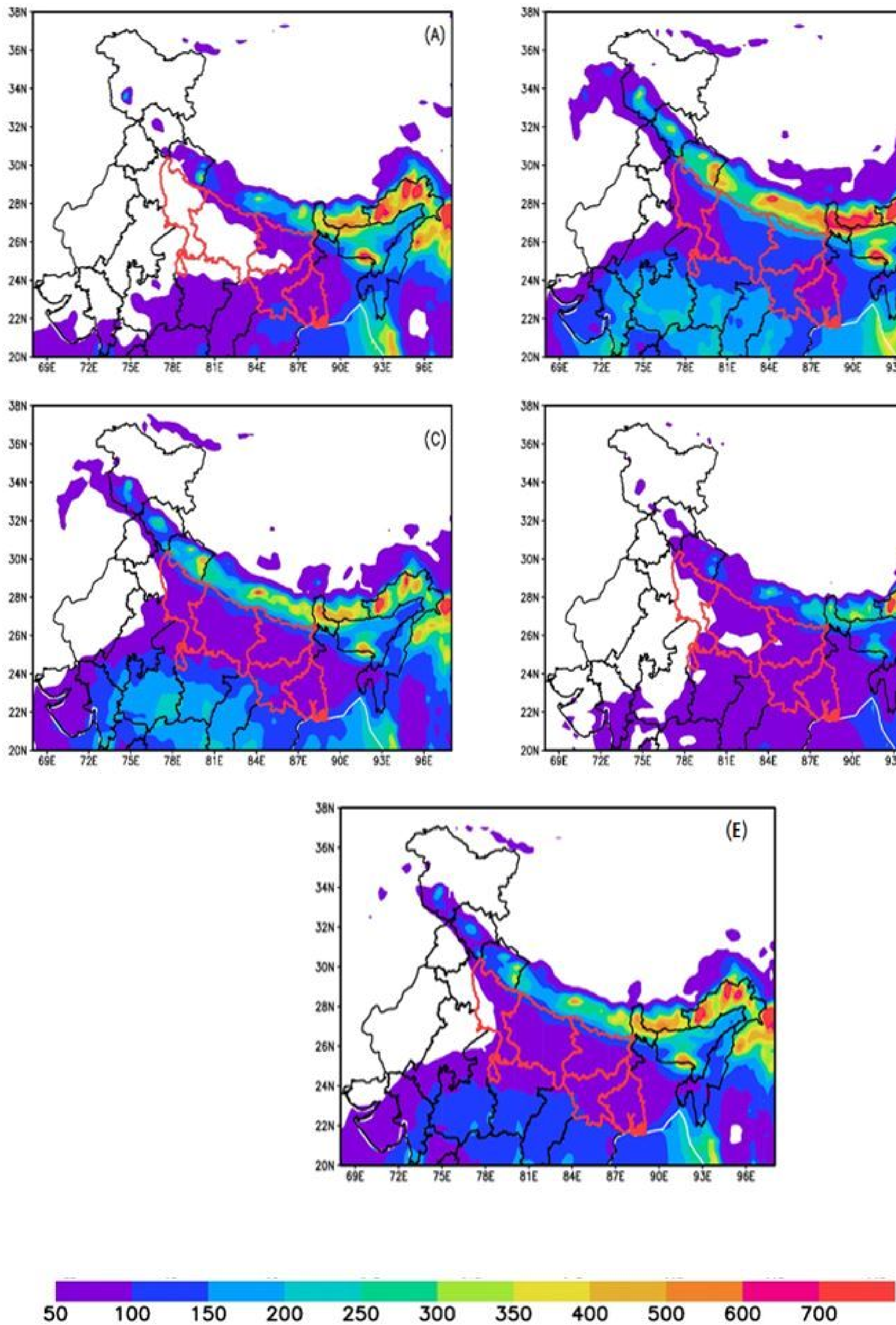

Figure 3

Spatial distribution of mean monthly Large Scale Precipitation (LSP) in the months of (A) June, (B) July, (C) August, (D) September; and (E) during JJAS for the time period of 1980-2019 in ERA5(0.25˚x 0.25˚) data

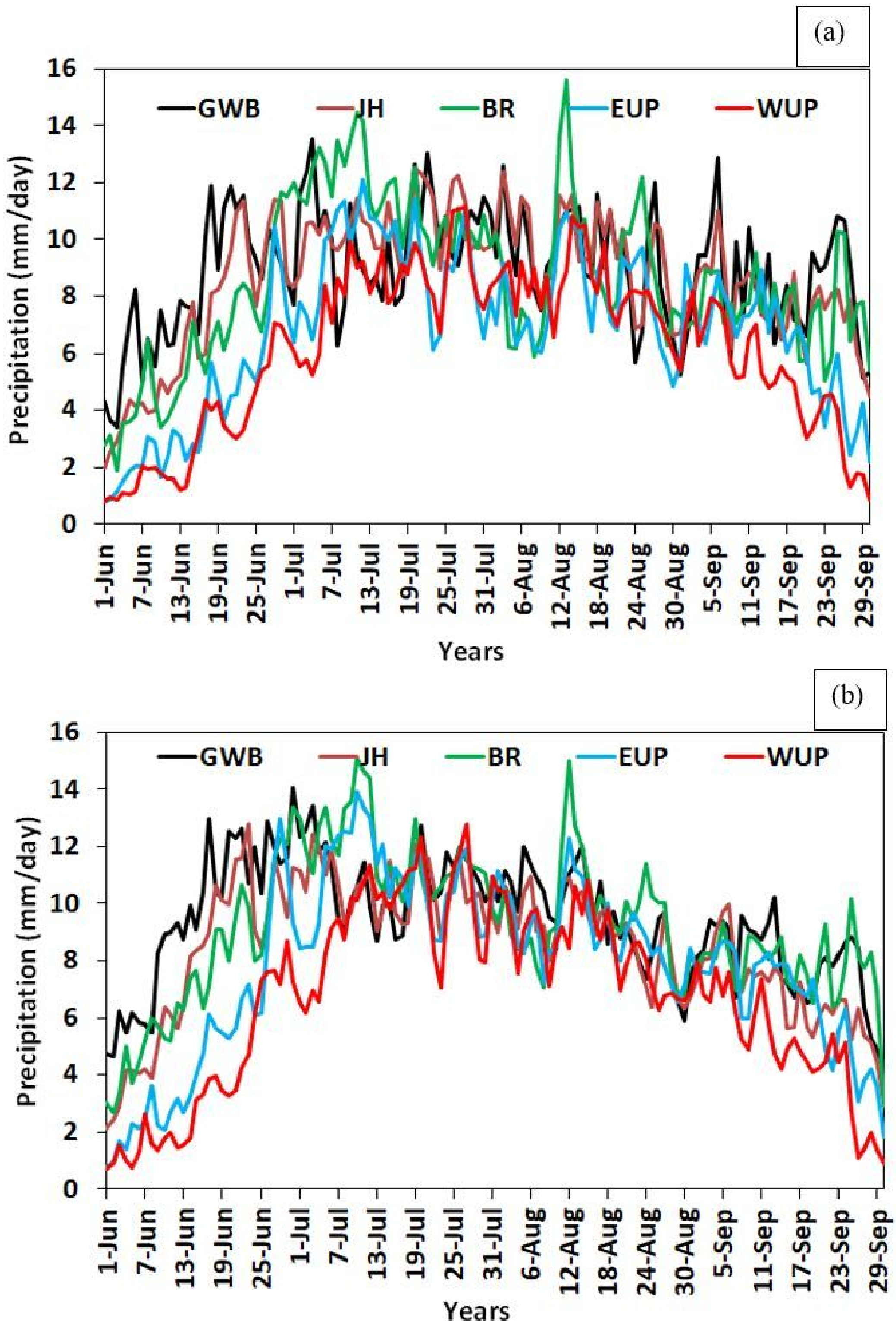

Figure 4

Total precipitation (mm/day) over meteorological subdivisions of the Gangetic West Bengal (GWB), Jharkhand (JH), Bihar (BR), East UP (EUP) and West UP (WUP) in (a) IMD, and (b) ERA5, respectively

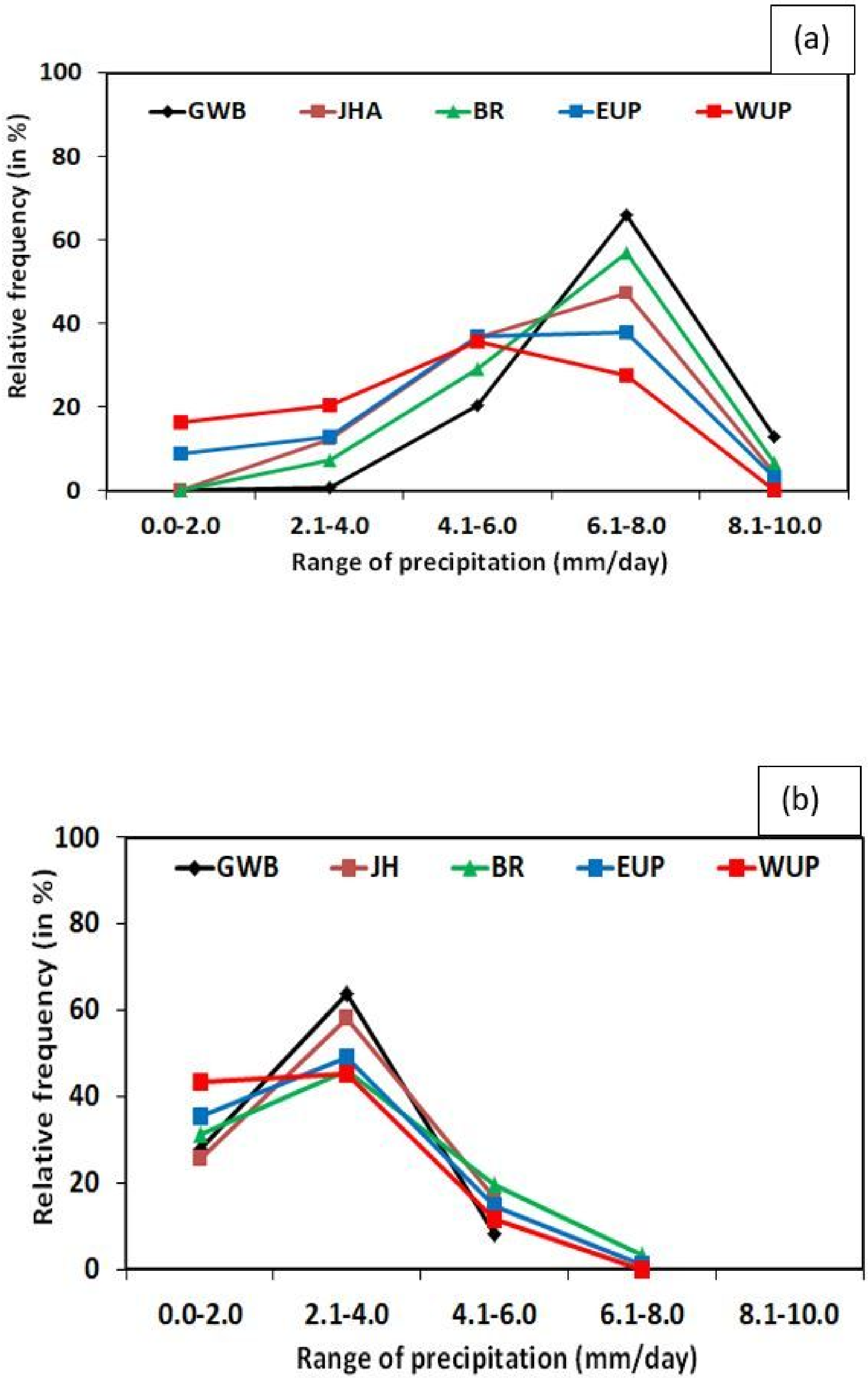

Figure 5

Relative frequency (in %) of (a) Convective Precipitation (CP) and (b) Large Scale Precipitation (LSP) for the time period of 1980-2019 in ERA5 (0.25˚x0.25˚) data over West Bengal, Jharkhand, Bihar, East UP, and West UP, respectively

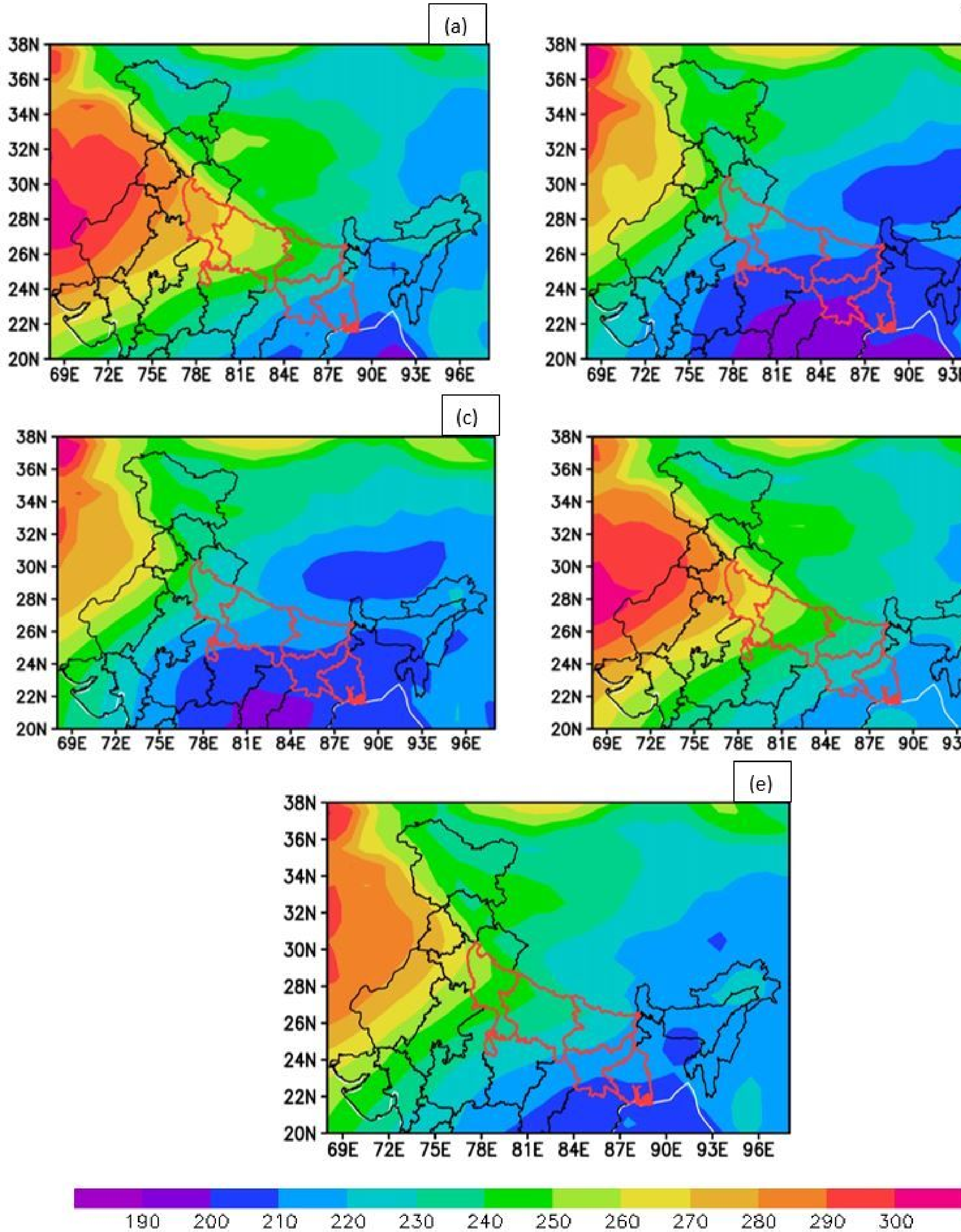

Figure 6

Spatial distribution of Outgoing Longwave Radiation (OLR) (Watts/m2) in monthly mean of (a) June, (b) July, (c) August, (d) September and in mean of (e) JJAS for the time period of 1980-2019

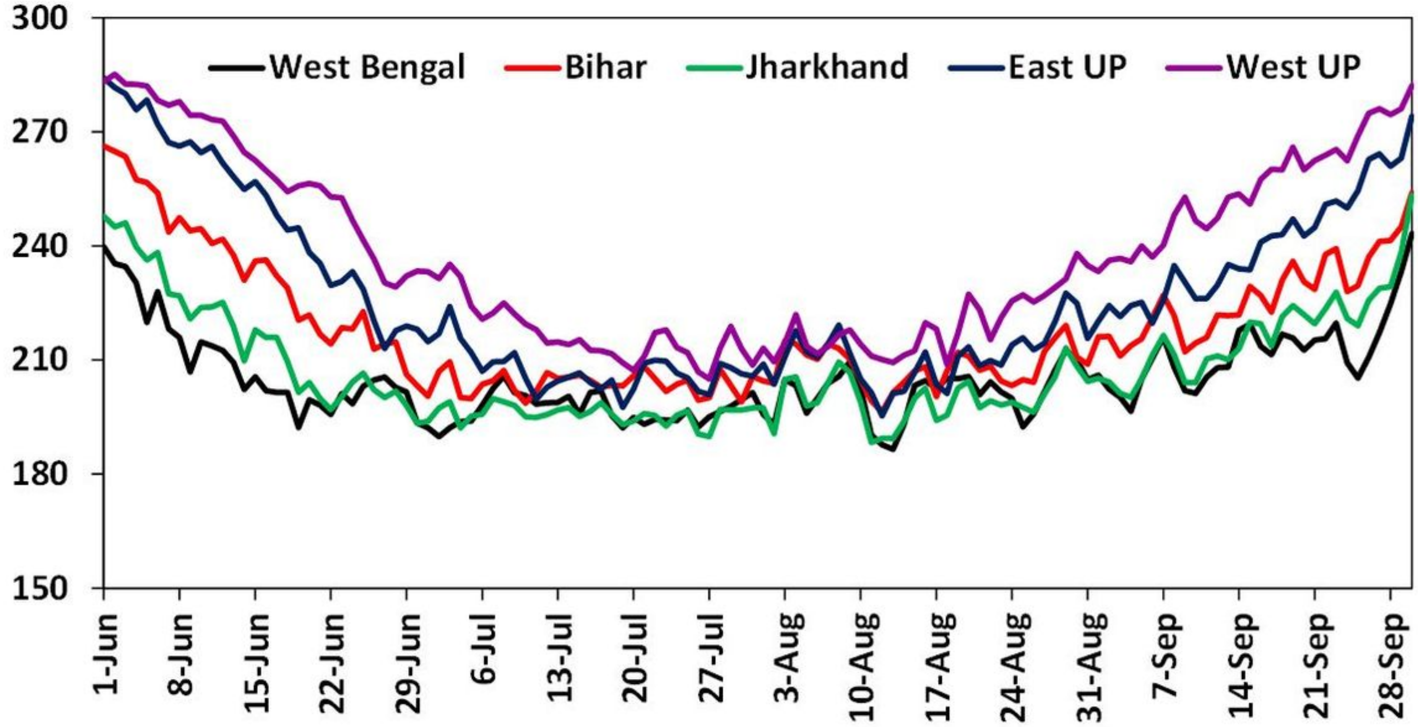

Figure 7

Temporal variation of daily climatology (June to September) of Outgoing Longwave Radiation (OLR) (Watts/m2) during JJAS for the time period of 1980-2019

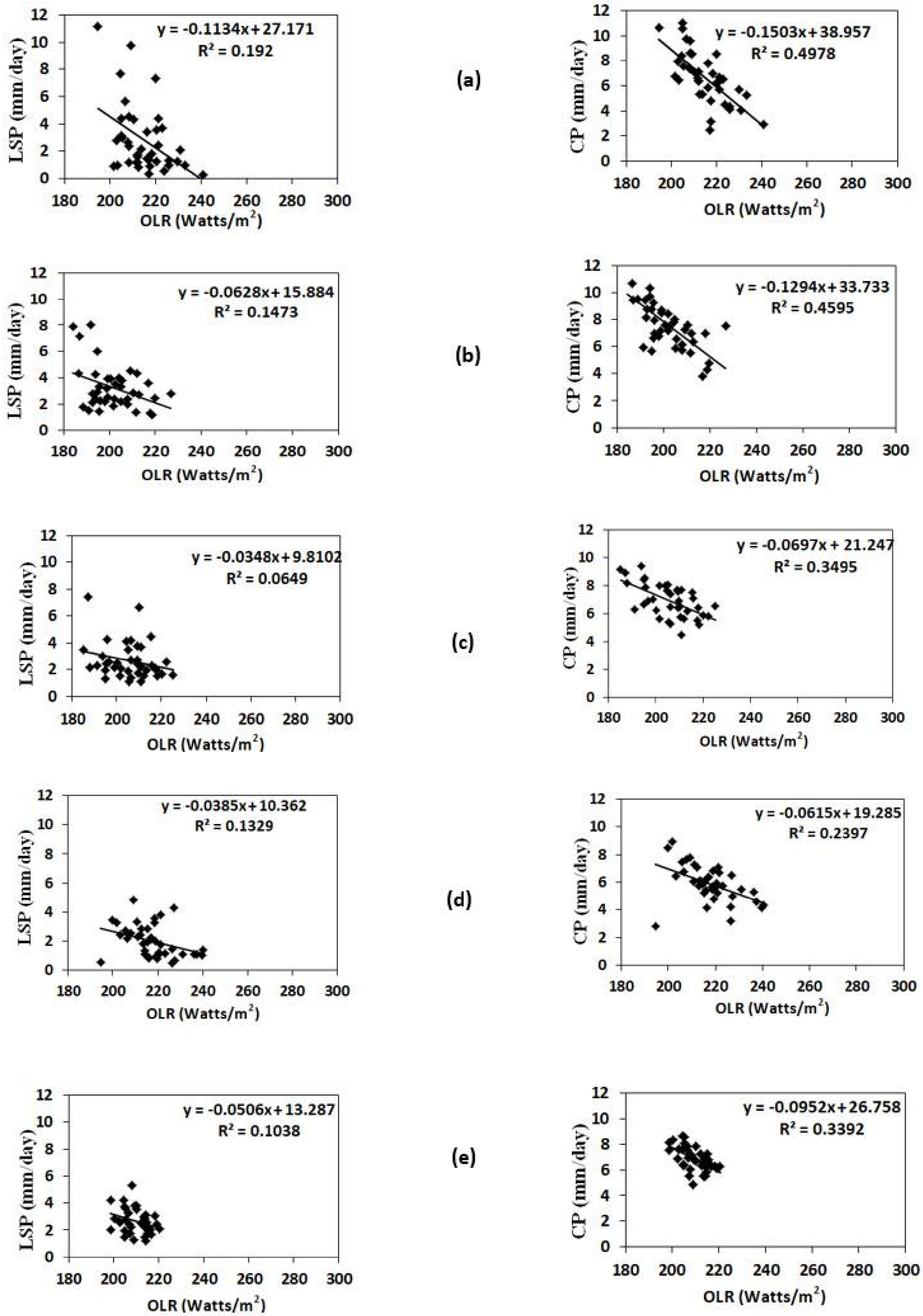

Figure 8

Scatter diagram between Large Scale Precipitation and OLR as well as Convective Precipitation and OLR (from left to right) during the time period of 1980-2019 over the Gangetic West Bengal in the months of (a) June; (b) July, (c) August; (d) September and (d) JJAS, respectively

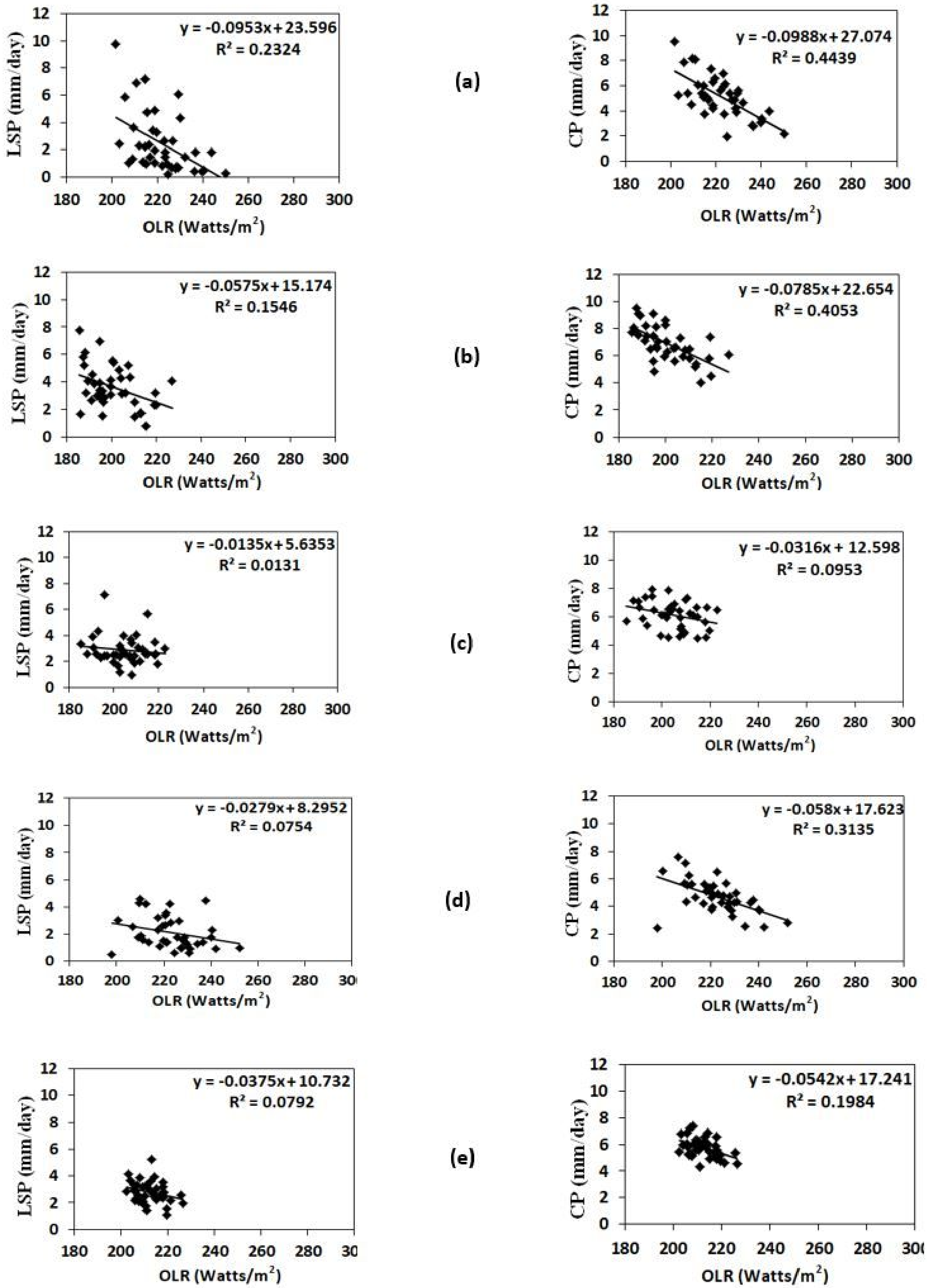

Figure 9

Scatter diagram between Large Scale Precipitation and OLR as well as Convective Precipitation and OLR (from left to right) during the time period of 1980-2019 over the Jharkhand in the months of (a) June; (b) July, (c) August; (d) September and (d) JJAS, respectively

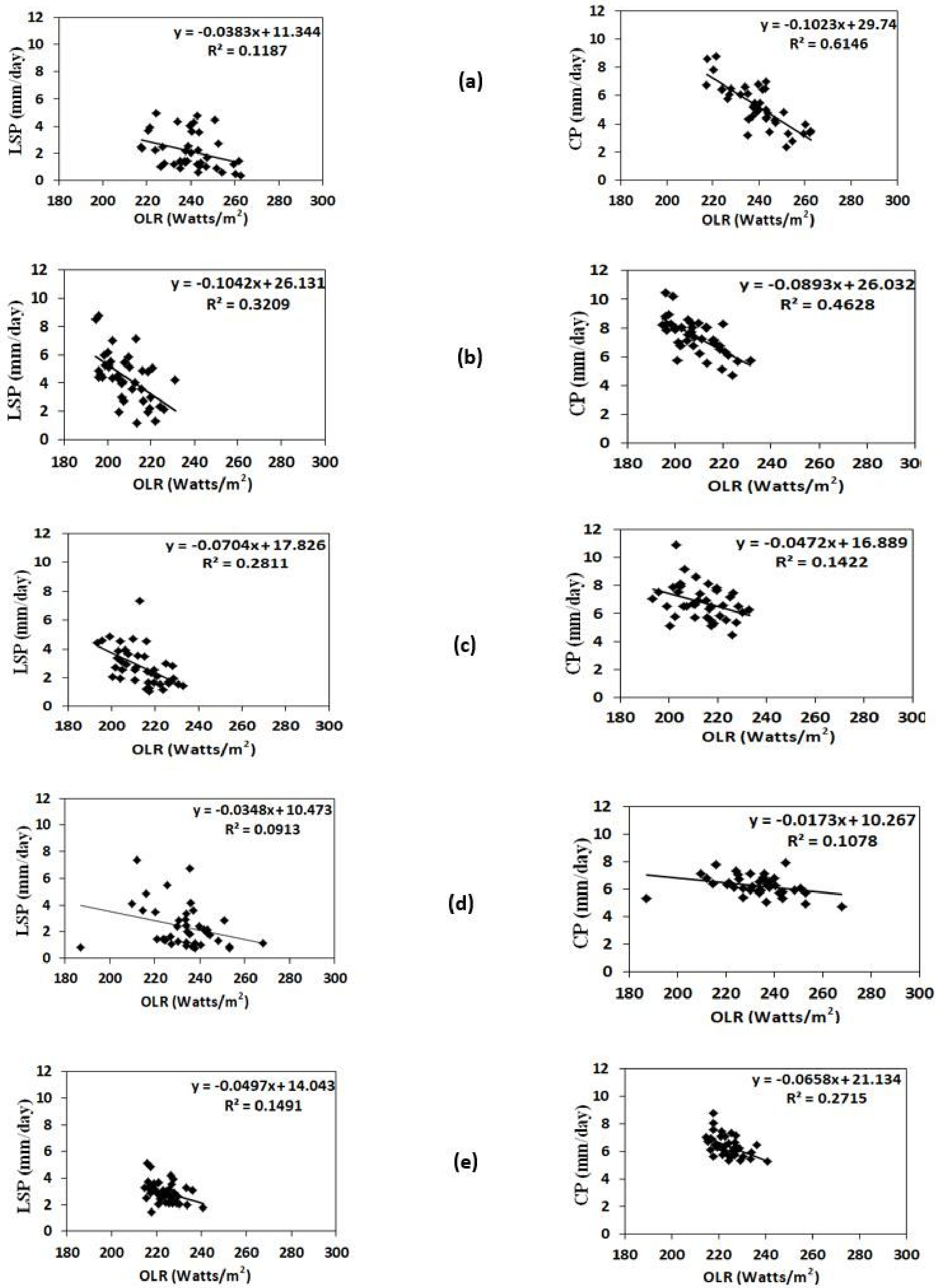

Figure 10

Scatter diagram between Large Scale Precipitation and OLR as well as Convective Precipitation and OLR (from left to right) during the time period of 1980-2019 over Bihar in the months of (a) June; (b) July, (c) August; (d) September and (d) JJAS, respectively

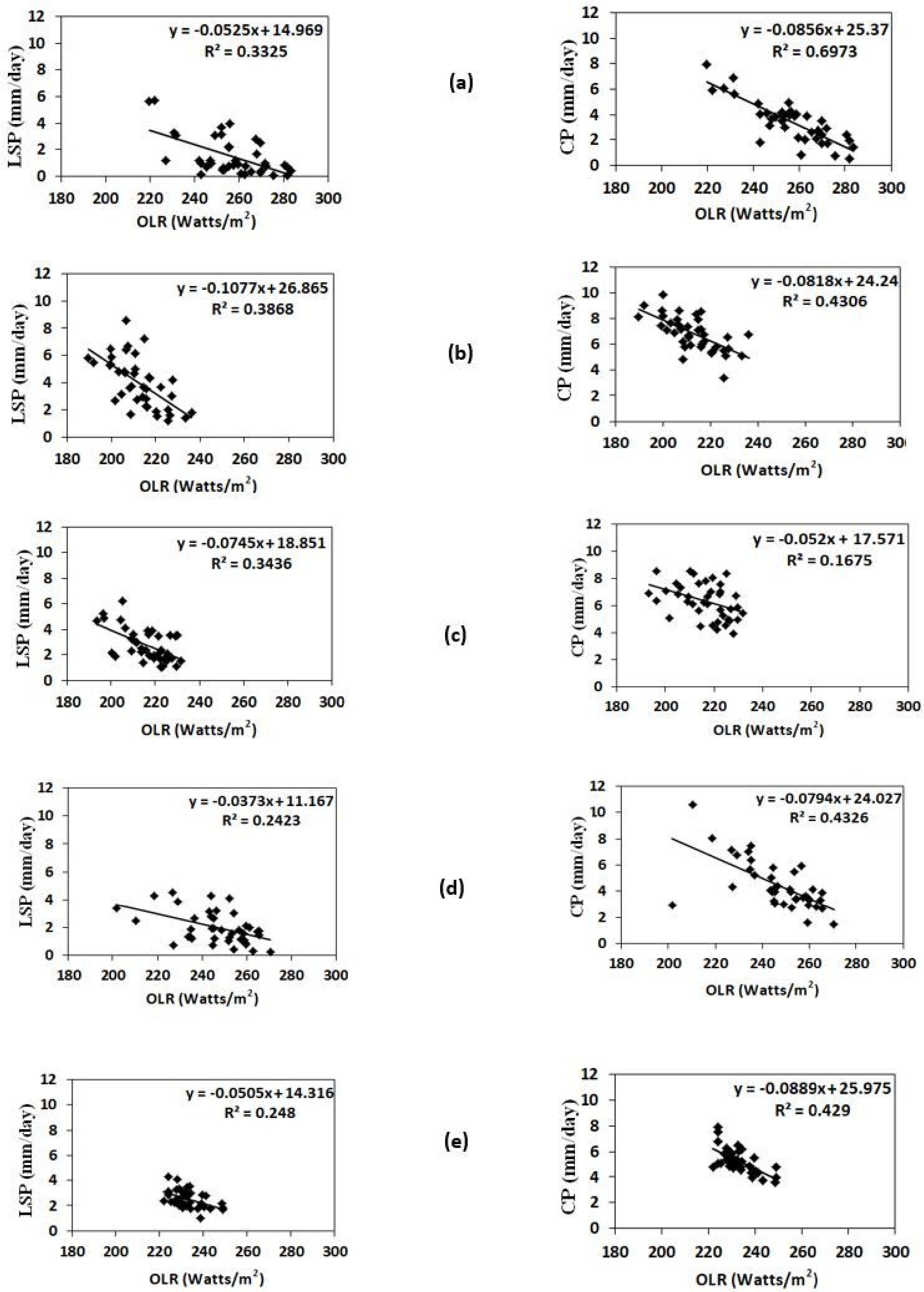

Figure 11

Scatter diagram between Large Scale Precipitation and OLR as well as Convective Precipitation and OLR (from left to right) during the time period of 1980-2019 over East UP in the months of (a) June; (b) July, (c) August; (d) September and (d) JJAS, respectively

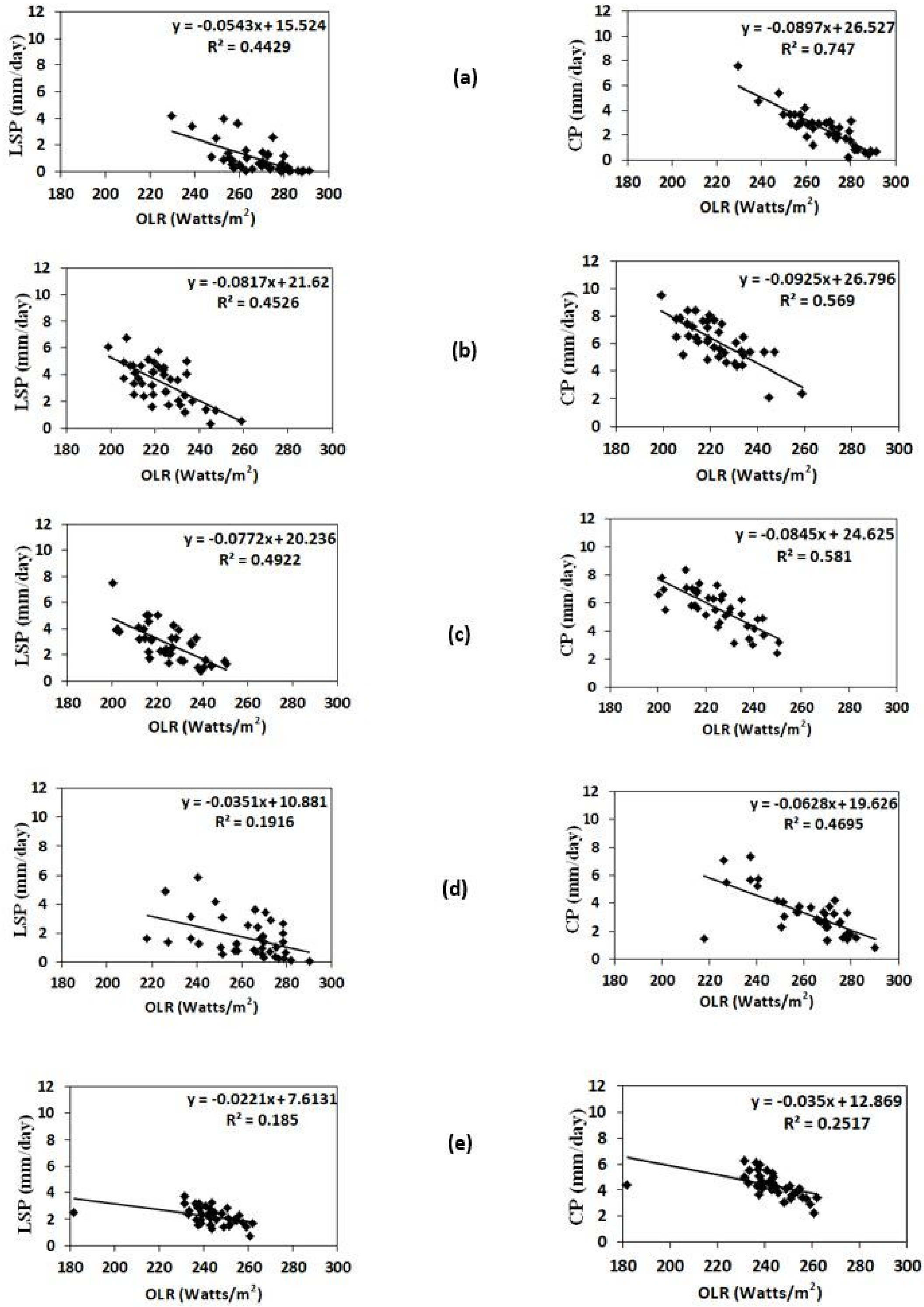

Figure 12

Scatter diagram between Large Scale Precipitation and OLR as well as Convective Precipitation and OLR (from left to right) during the time period of 1980-2019 over West UP in the months of (a) June; (b) July, (c) August; (d) September and (d) JJAS, respectively

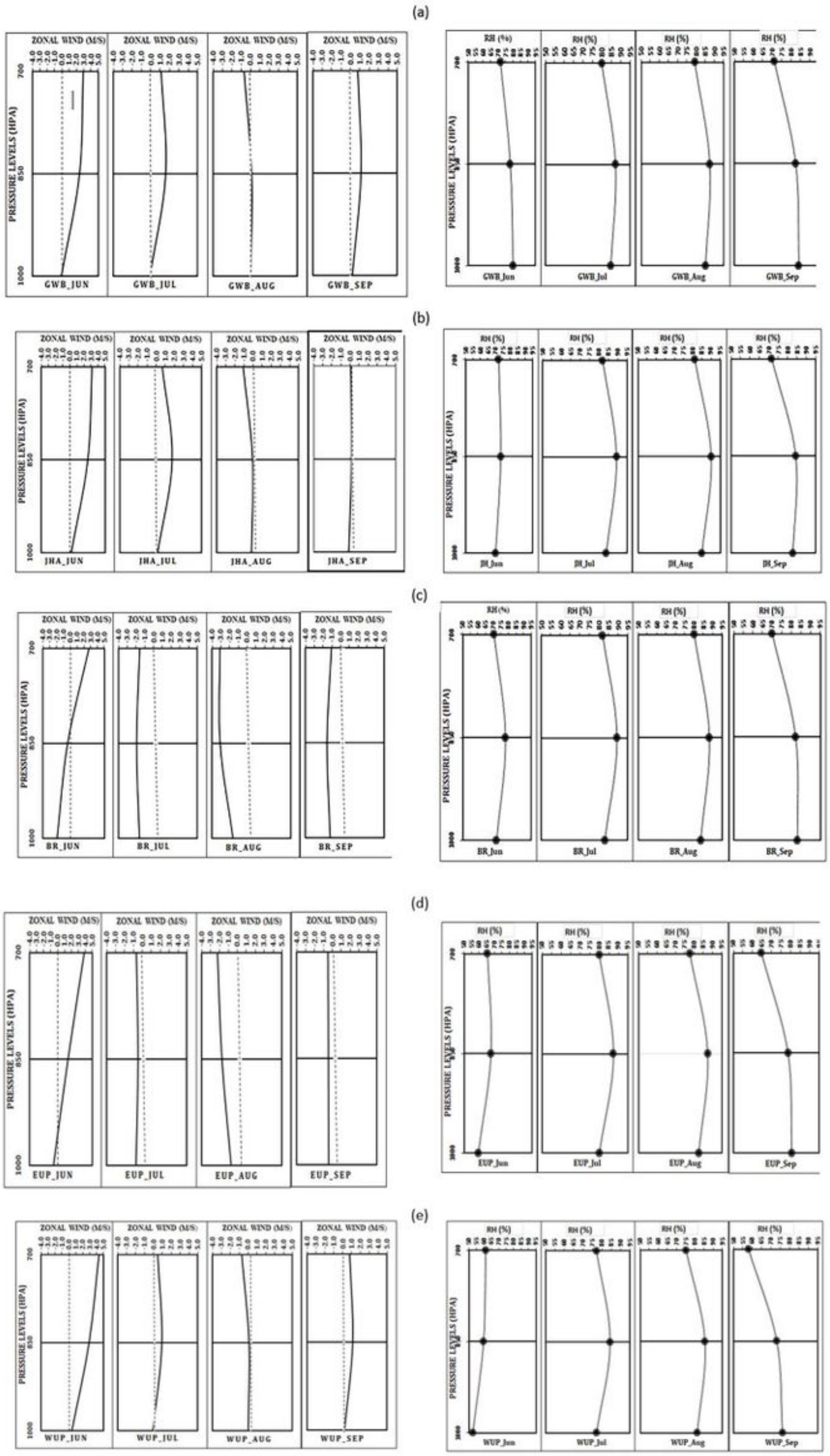

Figure 13

Vertical profile (1000hpa to 700hPa) of the zonal wind (m/s) and RH (%) in June, July, August and September during 1980-2019 over the meteorological subdivisions of the (a) Gangetic West Bengal (GWB), (b) Jharkhand (JHA), (c) Bihar (BR), (d) East UP (EUP) and (e) West UP (WUP), respectively