Intraseasonal variability and possible causes of large-scale and convective precipitations over the Gangetic plain of India

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Abstract
The occurrence of Indian summer monsoon rainfall (ISMR) during June to September, especially over the eastern Gangetic plain of India, is the lifeline for densely residing people. The intraseasonal and interannual variability in ISMR provokes drought and flood conditions and largely affects agriculture practices. Owing to its importance, several studies on the variability of ISMR over the meteorological subdivisions, namely West Bengal (WB), Jharkhand (JH), Bihar (BR), East Uttar Pradesh (EUP), and West Uttar Pradesh (WUP), respectively, have been conducted; however, the contribution of large-scale precipitation (LSP) and convective precipitation (CP) in ISMR needs to discuss. The LSP is precipitated out from the stratus or nimbostratus clouds, while CP occurs from the cumulus and cumulonimbus clouds, and both of them coexist in ISMR during summer monsoon months. The objective of this paper is to analyze and discuss the climatological characteristics and possible causes of occurrence of LSP and CP over the meteorological subdivisions. For this purpose, the data of LSP, CP, zonal, meridional (u and v components) wind, and relative humidity (rh) at the spatial resolution of 0.25° × 0.25° for the period of 1980–2019 are taken from the European Centre for Medium-Range Weather Forecasts (ECMWF). The outgoing longwave radiation (OLR) data at a surface resolution of 1° × 1° for the same periods are obtained from the National Centre for Environmental Information (of NOAA). The observed rainfall data of the India Meteorological Department at the same resolution and period is considered and compared with ECMWF Reanalysis (ERA5) data. The spatial and temporal distribution of both types of precipitation is analyzed, and their linkage with OLR, zonal winds, and rh at pressure levels of 1000 hPa, 850 hPa, and 700 hPa (in lower troposphere) is examined. The daily climatological values of CP (LSP) are relatively higher (lower) in each meteorological subdivision. The associated lower values of OLR are noticed over the Gangetic West Bengal, Jharkhand, and Bihar, while higher values of OLR are seen over the East and West UP. From the pressure levels of 1000 to 700 hPa, the change in the zonal wind, i.e., easterly to westerly and vice versa, and occurrence of a large amount of rh (>80%) may be possibly initiated moist convective activity for more precipitating out CP over the Gangetic West Bengal, Jharkhand, and Bihar in comparison to East and West Uttar Pradesh.

1 Introduction

A large number of research on Indian summer monsoon rainfall (ISMR) have been carried out on observational station or gridded data, and the variability has been examined on regional and national levels (Koteswaram and Alvi 1969; Jagnnathan and Parthasarathy 1973; Raghavendra 1974; Hastenrath and Rosen 1983; Mooley and Parthasarathy 1984; Sarker and Thalpiyal 1988; Kripalani et al. 1991; Kulkarni et al. 1992; Parthasarathy et al. 1994; Goswami and Ajaya Mohan 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). Researchers also examined the relationship between sea surface
temperature (SST) and El Niño southern oscillation (ENSO) with ISMR (Pradhan et al. 2016; Yu et al. 2021). 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 vapor in the air condenses into clouds and precipitates 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 vapor. 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 sensitive 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 3 km. 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 to 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 vapor is one of the critical factors for forming convective clouds (Battan and Kassander 1960) because the latent heat released by the moisture is absorbed in 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

![Figure 1](image-url) Study area comprising the meteorological subdivision (red) of India, namely, West Uttar Pradesh (WUP), East Uttar Pradesh (EUP), Bihar (BR), Jharkhand (JH), and Gangetic West Bengal (GWB) in India
more robust and the \( rh \) becomes more than 70\% (Ramachandran and Kedia 2013; Acosta and Huber 2017). During June, July, August and September (JJAS), the moisture inflow is taken from ocean to land by southeasterly flow from the Bay of Bengal toward eastern and central India (Maussion et al. 2014; Kobayashi et al. 2015; Acosta and Huber 2017). In the absence or presence of a weak low-level easterly wind, there may be lesser transport of moisture, and therefore, the atmosphere over land would 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 analyze (a) 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

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**Fig. 2** Spatial distribution of mean daily convective precipitation (CP, mm day\(^{-1}\)) 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° \( \times \) 0.25°) data.
plain of India. In this paper, the literature survey and the basic idea are kept in the “Introduction” section. The “Study area, data, and methods” section describes the study area, data, and methodology. The “Results and discussion” section presents the results and discussion, respectively, while the “Conclusions” section concludes the proposed work.

2 Study area, data, and methods

Fig. 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 $0.25^\circ \times 0.25^\circ$ are taken for JJAS months for 1980 to 2019 from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis (ERA5), UK (Hoffmann et al. 2018; Hersbach et al. 2020) (https://cds.climate.copernicus.eu/). The regime of the southwesterly wind during the summer monsoon lies in between 1000 hPa and 700 hPa (with the core at 850 hPa). From 600 hPa, the winds change the direction; therefore, the wind and $rh$ profile from 1000 to 700 hPa is considered for analysis. 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 $1^\circ \times 1^\circ$ for the same periods are obtained from the National Centre for Environmental Information (NOAA). The observed rainfall data of the India Meteorological Department (IMD) is taken at a resolution of $0.25^\circ \times 0.25^\circ$ 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). However, the data from ECMWF and IMD are available at a similar spatial resolution, and OLR data are available at the surface spatial resolution of $1^\circ \times 1^\circ$. Furthermore, neither interpolated nor extrapolated to achieve the similar grid resolution, as analysis considers the large domain.

The daily climatology for CP, LSP, and OLR is calculated over the region of interest in the months of June, July, August, September, and June to September on average (JJAS). Furthermore, the daily climatology for CP and LSP in different ranges is analyzed over each region. The association of OLR with the CP and LSP is also analyzed.

3 Results and discussion

3.1 Convective and large-scale precipitation

The spatial distributions of mean monthly values of CP and LSP in JJAS, and mean JJAS from 1980 to 2019 in...
ERA5(0.25° × 0.25°) data over the study area are 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 respectively. The percentage of occurrence of 0–2 mm/day (minimum range) and 8.1–10 mm/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 8.1–10 mm/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 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 et al. 2007).

### 3.2 Outgoing longwave radiation

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 behavior of CP and LSP. Thus, the spatial distribution of mean monthly OLR in June, July, August, September, and the mean JJAS OLR is shown in Fig. 6a, 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, are 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 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 originating from the stratiform cloud may have less turbulence, while CP from convective clouds would have strong updrafts of air mass and more turbulence. Furthermore, 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, 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 stronger (large value of $R^2$) in the case of CP and OLR.

Over the Gangetic West Bengal (Fig. 8), the values of CP are more concerning LSP in the individual months, especially in July and August, as well as in JJAS when OLR lies in between 190 watts/m² and 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 $R^2$). These
results suggest that the occurrence of convective activity
supports a large value of CP over the Gangetic West Ben-
gal 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 consist-
ency and dependency on OLR; the relation is relatively bet-
ter 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

\[
y = ax + b \quad \text{(a)} \\
y = cx + d \\nR^2 = 0.192 \\
y = 0.1503x + 38.957 \\nR^2 = 0.4978 \\
y = 0.1294x + 33.733 \\nR^2 = 0.4595 \\
y = -0.0697x + 21.247 \\nR^2 = 0.3495 \\
y = 0.0348x + 9.8102 \\nR^2 = 0.0649 \\
y = -0.0615x + 19.285 \\nR^2 = 0.2397 \\
y = 0.0385x + 10.362 \\nR^2 = 0.1329 \\
y = -0.0506x + 13.287 \\nR^2 = 0.1038 \\
y = 0.0952x + 26.758 \\nR^2 = 0.3392 \\\n(\text{e})
\]
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 show a relatively poor relation (low values of $R^2$), 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
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 types of rainfall are 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. Furthermore, the larger values of OLR reduce the convective activity, and the 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 comparison to that over the other 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)
is essential for the occurrence of LSP and CP. During monsoon season, the mean \( rh \) value (74.7\%) is relatively lower than that over the coastal regions (\( rh > 80\% \)) (Jaswal and Koppar 2011). In general, the moisture and the evaporative flux from the Indian ocean are carried by the zonal flow across peninsular India (Wilson et al. 2018); therefore, zonal and meridional winds have great importance in the Indian summer monsoon.

In Fig. 13, the zonal wind and \( rh \) at the vertical pressure levels of 1000 hPa, 850 hPa, and 700 hPa 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, \( rh \) attains the maximum value at 850 hPa over all meteorological subdivisions, but it is 80 to 90\% over the Gangetic West Bengal, Jharkhand,
and Bihar and is in between 75% and 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 hPa, 850 hPa, and 700 hPa. 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 1000 to 700 hPa 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 (1000 to 700 hPa) 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 700 hPa and initiate vertical wind shear, but low values of $rh$ do 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 $rh$ exist 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 (1000 to 700hPa) and increased value of $rh$ could be favorable 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 be considered to explain the extreme precipitation variability linked with LSP and CP owing to its importance (Yang et al. 2021). The long-lived and well-organized mesoscale convective systems may explain the dynamics of extreme precipitation over the tropics (O’Gorman 2015; Roca and Fiolleau 2020). The large-scale extreme precipitations contribute approximately half of the summer monsoon rainfall and are associated with low-pressure systems crossing the Indian subcontinent (Nikumbh et al. 2020).


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. The LSP precipitated from the stratus or nimbostratus clouds, while CP occurs from the cumulus and cumulonimbus clouds, and both of them coexist. 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 precipitation are suppressed over the East and West Uttar Pradesh. During the period 1980–2019, the relative frequency of daily climatological values of CP (LSP) is relatively higher (lower). The frequency 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 2.1–4 mm/day is 63% (42%) over the Gangetic West Bengal (West UP). The lower values of OLR (180–220 watt/m²) are found over the Gangetic West Bengal, Jharkhand, and Bihar; higher values of OLR (240–290 watt/m²) 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 the zonal wind, i.e., easterly to westerly and vice versa, from the 1000 to 700 hPa levels and a large amount of \( rh \) (80–95%) 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. The relatively stronger zonal wind of easterly and the larger value of \( rh \), i.e., 80–95% over the Bihar, are 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 hydrology, agriculture, and tourism sectors over the Gangetic plain.

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Author contribution Pradhan Parth Sarth (PPS) did conceptualize the idea for this research. Praveen Kumar (PK) performed the analysis and produced the results. PPS and PK combinely drafted the manuscript.

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 the corresponding author.

Declarations

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

Consent to participate None

Consent for publication The authors have consented to publish this research.

Conflict of interest The authors declare no competing interests.

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