



Lightning activity over Telangana and Andhra Pradesh states situated in the east coast of India

P. Ramesh Kumar¹ · S. S. V. S. Ramakrishna¹ · Alok Sagar Gautam² · Tomomi Narita³

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Abstract

Lightning activity over Telangana (17° N–19° N and 78° E–82° E), and the 13 districts of Andhra Pradesh (A.P) are studied using the data from the lightning imaging sensor aboard the Tropical Rainfall Measuring Mission (TRMM) satellite data during the period 1998–2013. It is observed that the flash rate density, flash count, and flash days over the study regions (Telangana, Rayalaseema, and coastal A.P) exhibit semi-annual variation with primary maximum in the pre-monsoon season (May–June) and secondary maximum in the post-monsoon season (September). The annual mean flash count is maximum (87.645) over Vishakhapatnam district, and flash rate density is maximum (0.058 fl km⁻² day⁻¹) over Srikakulam district compared to all other regions. The Inter-annual variation of lightning flash count shows that the lightning over Srikakulam district is increasing significantly. In Telangana, Rayalaseema (except Chittoor district), and coastal A.P (except Guntur, Krishna and Nellore) regions the flash count is highly correlated with surface temperature and convective available potential energy. The correlation of flash count with Aerosol Optical Depth and convective precipitation is very poor over these regions. This shows that the lightning over Telangana, Rayalaseema and in coastal A.P districts during pre-monsoon season is mainly due to buoyancy force developed because of the heating of land during daytime. The lightning flash Radiance values over Telangana, Rayalaseema, and coastal Andhra Pradesh regions are maximum during post-monsoon season (October–November). This study helps in understanding the spatio-temporal variation and the intensity of lightning activity over Telangana and A.P, which is first of its kind, over these regions.

Keywords Lightning · Convective rain · Lightning strength

✉ P. Ramesh Kumar
penki35@gmail.com

¹ Department of Meteorology and Oceanography, Andhra University, Visakhapatnam, India

² Department of Physics, HNB Garhwal University, Srinagar, Garhwal, Uttarakhand, India

³ Shanon Institute of Technology, Tokyo, Japan

1 Introduction

Lightning, because of its hazardous nature is one of the topics of vigorous research in the recent decade. The study of spatio-temporal variability of lightning activity and its correlation with different meteorological parameters is very much important because of the dependence of lightning activity on the environmental conditions and the topography of the region over which it develops (Saha et al. 2017; Mustaq et al. 2018; Yadava et al. 2020; Kamra and Ramesh Kumar 2021). The meteorological conditions and their interaction with topography are mainly responsible for the development of clouds with greater variability in their dynamical features. The intense incoming solar radiation heats the surface of the earth and the atmosphere present above the surface. The air parcel above the surface becomes less dense than the surrounding atmosphere. This results in the uplift of the lower surface air parcel to move vertically upwards. The lower surface air parcel continues to grow upwards as long as it is warmer than the surrounding atmosphere. The upward moving air parcel starts condensing when the temperature reaches the dew point temperature. Formation of cloud takes place once the air parcel reaches the lifting condensation level. If the air parcel reaches the altitude where the temperatures are above the freezing level (level of 0 °C isotherm) Ice nuclei and super cooled liquid water coexist (Dolezalek and Reiter 1977; Kessler 1982). The needed energy for this process to occur is supplied by the convective available potential energy (CAPE). CAPE is the measure of buoyancy force that performs on a parcel of air (Murugavel et al. 2014). The simultaneous presence of super cooled liquid droplets and the ice particles in the mixed phase region is considered as the necessary ingredient for the development of lightning activity (Williams et al. 1989; Saunders et al. 1995). The study on spatio-temporal variation of deep convective systems (DCS) (Wu et al. 2013) show that DCS, characterized by 20dbz Tropical Rainfall Measuring Mission (TRMM) satellite Precipitation Radar (PR) echo top height extending 14 km, are mainly associated with CAPE.

Different studies revealed the dependence of lightning activity on different meteorological parameters. Some studies such as (Williams et al. 1992; Petersen et al. 1996) found the dependence of lightning on the updraft development, and studies by (Petersen and Rutledge 1998; Tapia et al. 1998) established the relationship between rain rate and lightning. A wide range of studies (Price 1993; Markson and Price 1999; Willaims et al. 2000) shows the dependence of lightning on surface temperature. The aerosols affect the radiation budget of the atmosphere directly or indirectly by the process of absorption and scattering of incoming solar radiation. Aerosols are mainly responsible for cloud droplet size (Twomey et al. 1984), precipitation process (Albrecht 1989), and electrical properties of cloud and in turn lightning discharges (Westcott 1995; Stallins and Rose 2008; Kar et al. 2009; Siingh et al. 2013, 2014) by the process of an indirect affect.

Various studies on lightning activity over the Indian region deal with the spatio-temporal distribution of lightning activity and its association with different meteorological parameters of the region. Most of the studies on spatio-temporal variability of lightning activity over the Indian region are by (Kandalgaonkar et al. 2003, 2005; Chaudhari et al. 2008; Nath et al. 2009; Ranalkar and Choudhary 2009; Tinmaker and Chate 2013; Unnikrishnan et al. 2021; Chakraborty et al. 2021; Kamra and Ramesh Kumar 2021), while studies on lightning activity association with global electric circuit are by (Siingh et al. 2008), lightning activity and projected change in climate and its association with Indian subcontinent by Saha et al. 2017, and studies on lightning activity variation with different teleconnections such as El–Nino Southern Oscillation (ENSO), Indian Ocean Dipole

(IOD), and monsoon trough are by (Penki and Kamra 2012a, 2012b, 2013). Critical review of the results of these studies show that these studies mainly focused on the dependence of lightning activity over different meteorological parameters of the region.

The present study region is situated on the east coast of Southern peninsular India. The east coast of India is much prone to severe thunder storms and progress of the synoptic systems, developed over the Bay of Bengal, through this region. The main aim of the present study is to understand the spatio-temporal variability of lightning over Andhra Pradesh and Telangana, comprising of 13 districts of Andhra Pradesh. These are divided into two regions in which the 4 districts Anantapur, Chittoor, Kadapa, and Kurnool are referred to as Rayalaseema and the remaining 9 districts (East Godavari, West Godavari, Guntur, Krishna, Nellore, Prakasam, Srikakulam, Visakhapatnam, and Vizianagaram) are referred to as coastal A.P. The study also includes the spatio-temporal variation of flash radiance which enables us to understand the strong physical processes of the storm and the energy of the lightning flash (Qie et al. 2003; Michael Peterson and Scott Rudlosky 2019). Optical radiance is affected by the scattering of cloud medium (Boccippio et al. 2000; Peterson et al. 2016, 2017) which helps in the understanding the structure of the cloud. The lightning flash radiance data from TRMM LIS sensor are used for the study of spatio-temporal variation of lightning intensity in the study regions.

2 Datasets

The lightning data used for this study are obtained from the Lightning Imaging Sensor (LIS) onboard TRMM satellite. The LIS onboard TRMM satellite was launched on November 28, 1997, at an altitude of 350 km with 35° inclination. The lightning imaging sensor is capable of taking images with storm-scale resolution of 3–6 km with swath width of 550 km. The temporal resolution of the sensor is 90 s with a spatial extent of 38°N and 38° S. The lightning data for the study region are obtained from the space time domain search of the website https://ghrc.nsstc.nasa.gov/lightning/data/data_lis_trmm.html during the period 1998–2013 and also TRMM LIS Very High Resolution data with 0.1°X0.1° resolution monthly mean data product was used.

The meteorological parameters such as surface temperature, convective rainfall data were obtained from MERRA-2 (Modern-Era Retrospective analysis for Research and Applications version 2) model with a resolution of 0.5° × 0.625° for the period 1998–2013. Aerosol optical depth (AOD) is obtained from MODIS version 3 (Moderate Imaging Spectroradiometer) with a resolution of 1° × 1° for the period 2001–2013 from the Giovanni website <https://giovanni.gsfc.nasa.gov/giovanni/>.

The convective available potential energy (CAPE) data are obtained from ERA5 ECMWF (European Centre for Medium Range Weather Forecasting) website with a resolution of 0.25° X 0.25° for the period 1998–2013.

3 Climate of the study regions

Spatio-temporal variation of lightning is studied over Telangana and Andhra Pradesh states. Figure 1 represents the location of the study region. Telangana is situated on the Deccan plateau with an average elevation of the plateau is 500 m. The region is located in the semi-arid area with hot and dry climate. Most of the rainfall occurs over this region

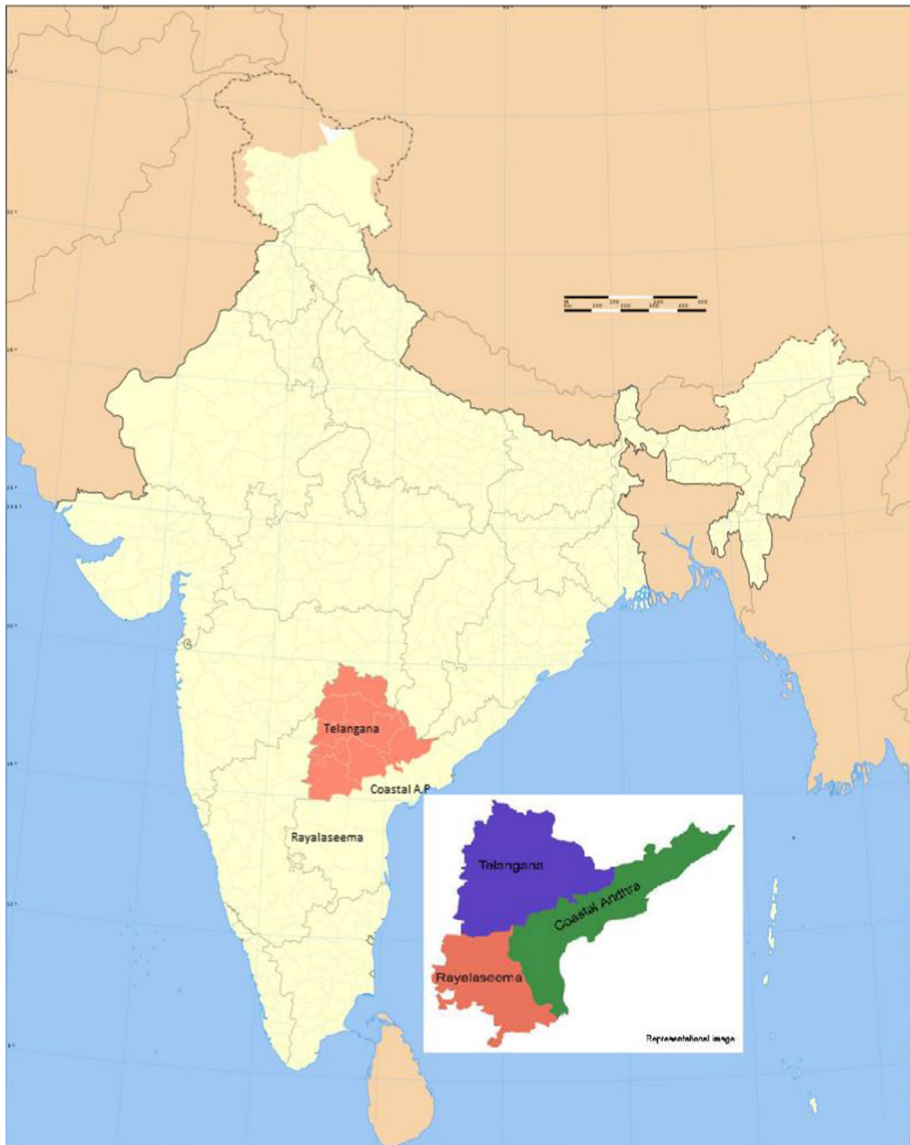


Fig. 1 Location map of the study region (source: https://en.wikipedia.org/wiki/Telangana_movement#/media/File:India_Telangana_locator_map.svg, <https://www.clearias.com/teelangana-andhra-pradesh/>)

during south–west monsoon season (June–September) and North–East monsoon (https://www.tsdps.telangana.gov.in/Weather&Climatology_of_telangana.pdf). The central Telangana region is chosen to study the spatio-temporal variation of lightning. Southwest monsoon hit the Telangana state in the second week of June.

The spatio-temporal variation of lightning is also examined over Andhra Pradesh. Generally, the climate of coastal Andhra Pradesh is hot and humid, while Rayalaseema is comparatively drier region. South–west monsoon plays a major role in determining the climate

of Andhra Pradesh. Summer season with associated high level of moisture content extends from March–June in this state. The summer season is followed by the monsoon season which extends from June to September. About one third of rainfall occurs over this region during North–East monsoon which occurs during the month of October (https://imdpune.gov.in/hydrology/rainfall%20variability%20page/andhra_final.pdf).

4 Results and discussion

4.1 Monthly variation of flash rate density, flash count, flash days, and radiance

Figure 2 shows the area average monthly mean values of flash rate densities of the study regions Telangana and Andhra Pradesh. In the study regions flash rate densities exhibits semi-annual variation with primary maximum during the month of May and secondary maximum during the month of September. Similarly, semi-annual variation of flash count is observed over Telangana with primary maximum in the month of May and the secondary maximum in the month of September (Fig. 3a). Similarly monthly variation of flash count over the districts of Rayalaseema region shows primary maximum in the month of May and secondary maximum in the month of September (Fig. 3b). Flash count over the districts of coastal Andhra Pradesh also exhibit semi-annual variation with primary maximum during April–May and secondary maximum during the month of September (Fig. 3c). The increase in flash frequency during the September month can be explained on the basis of thermodynamic instability developed during withdrawal phase of the monsoon and onset of northeast monsoon in this region during

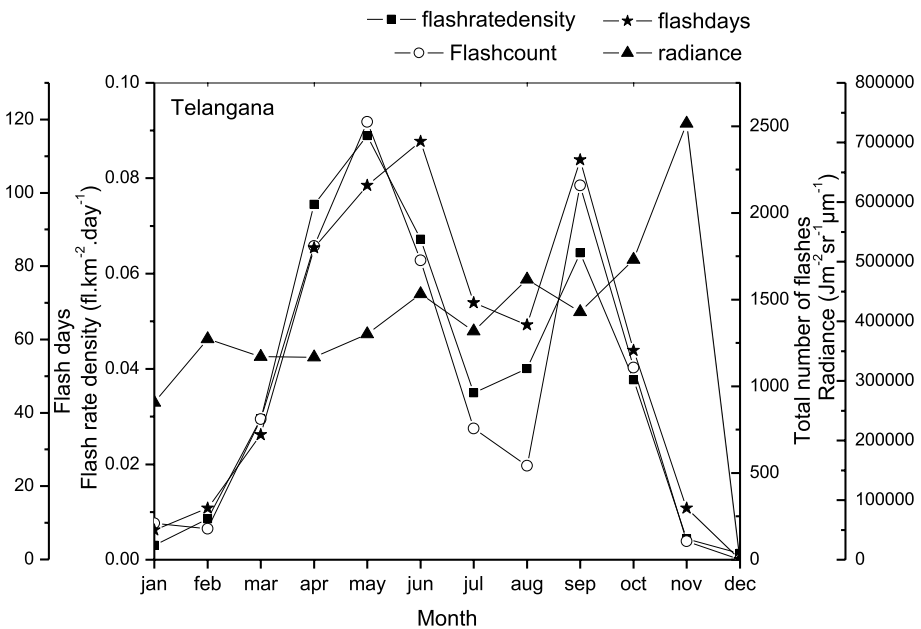


Fig. 2 Monthly variation of lightning flash characteristics (Flash rate density, Flash count, Flash day, and Flash radiance) over Telangana

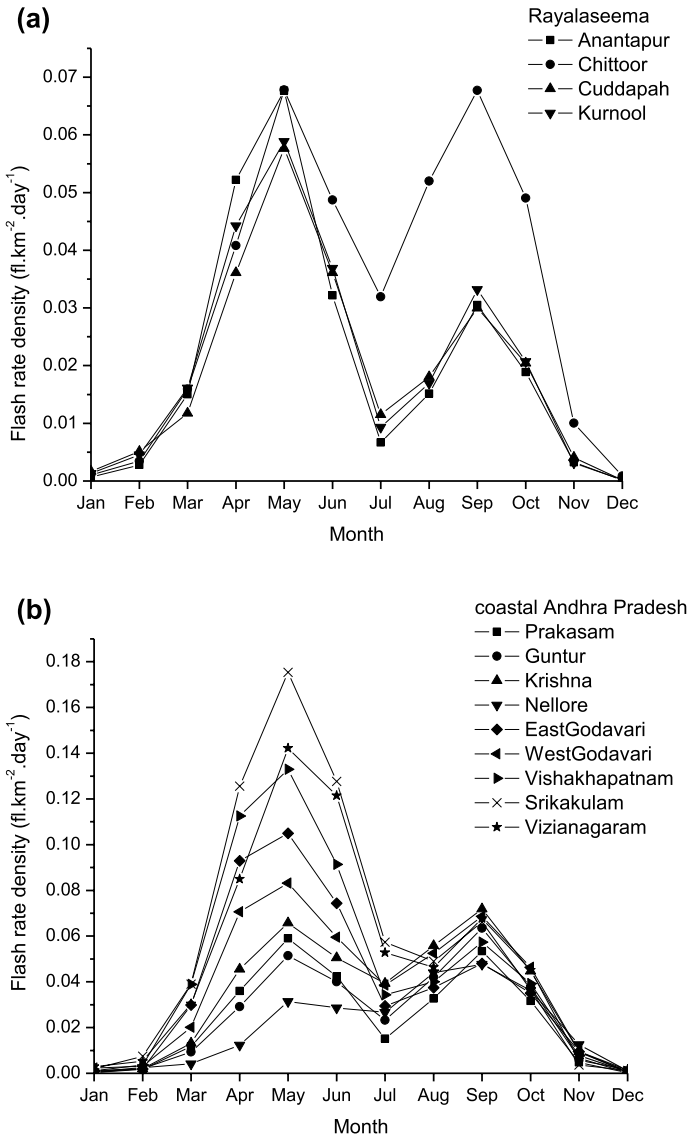


Fig. 3 Monthly variation of Flash rate density over **a** Rayalaseema and **b** coastal Andhra Pradesh

this month. While considering the monthly variation of meteorological parameters over Telangana, surface temperature (Fig. 4a) is found to increase during pre-monsoon season (March–May) reaching maximum value in the month of May. Thereafter the surface temperature is found to decrease during the monsoon season (June–September) and post-monsoon season (Oct–Nov) reaching minimum value in winter season (Dec–Jan). Similar trend is observed in the districts of Rayalaseema and coastal Andhra Pradesh. The high frequency of lightning and maximum values of surface temperature during the pre-monsoon season suggests association of lightning with surface temperature

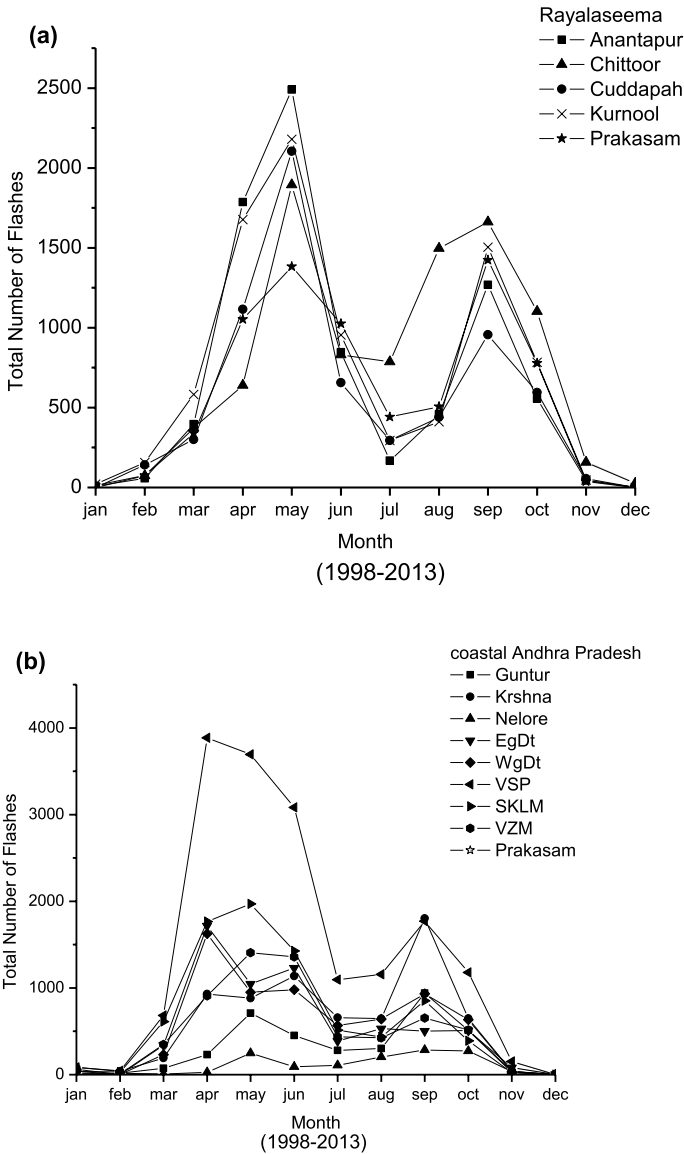


Fig. 4 Monthly variation of Flash radiance over **a** Rayalaseema and **b** coastal Andhra Pradesh

(Williams et al. 1994). The latitude and longitude of all the districts of Andhra Pradesh state were collected from Andhra Pradesh state portal (ap.gov.in).

The frequency of flash days over Telangana (Fig. 5a) shows semi-annual variation with primary maximum during the month of June and secondary maximum during the month of September. Rayalaseema and coastal Andhra Pradesh also exhibit semi-annual variation of flash days (Fig. 5b and c) with primary peak during the month of May and secondary peak during the month of September.

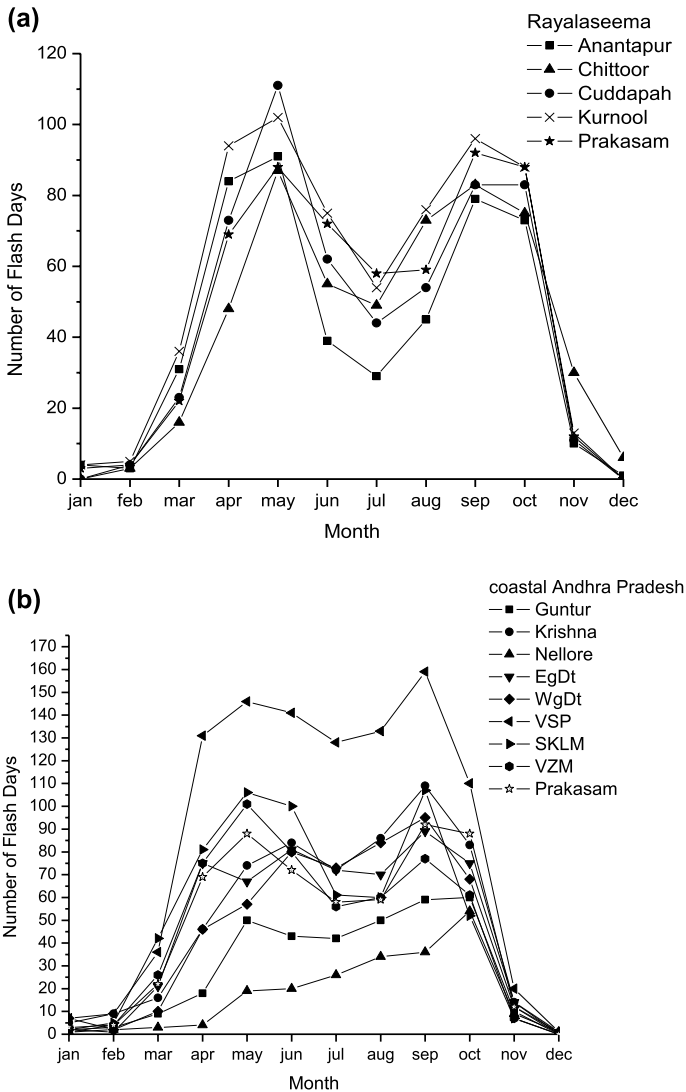


Fig. 5 Monthly variation of Flash count over **a** Rayalaseema and **b** coastal Andhra Pradesh

Lightning flash radiance over Telangana, Rayalaseema, and coastal Andhra Pradesh region is found maximum during the post-monsoon season (October–November) (Fig. 6a) and minimum during the winter season (Dec–Jan). TRMM LIS lightning flash radiance represents the strong physical processes of thunderstorm, its dependence on depth of the cloud and energy of lightning over different regions (Qie et al. 2003). The study by (Petersen et al. 2017a) shows that superbolt is associated with high radiance values. This suggests lightning over Telangana and Rayalaseema regions during monsoon season are more energetic compared to other season lightning.

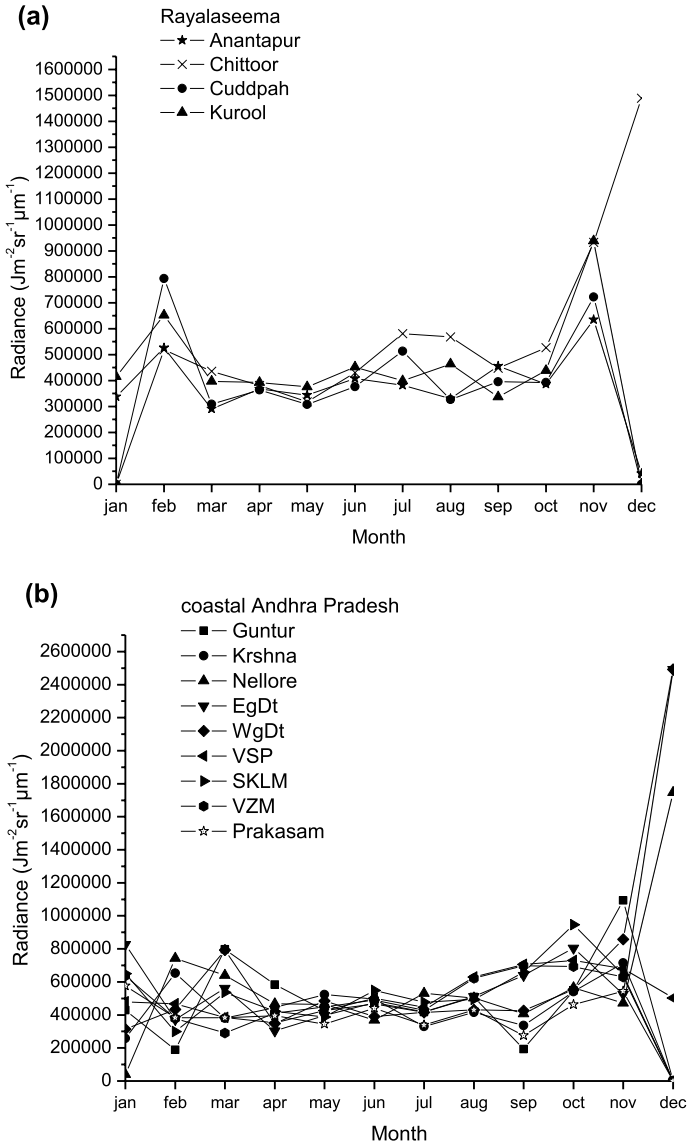


Fig. 6 Monthly variation of number of Flash days over a Rayalaseema and b coastal Andhra Pradesh

4.2 Inter-annual variation and correlation of flash count with meteorological parameters

Simple linear regression is performed to find out the correlation between flash count and meteorological parameters (surface temperature, CAPE, convective precipitation, and AOD). Table 2 represents the values of correlations between flash counts, surface temperature, CAPE, convective precipitation, and AOD with the corresponding *p* values with a significance level of 0.05. High correlations ($0.76 < CC < 0.82$) were observed

between lightning flash count and surface temperature over Telangana, in all the districts of Rayalaseema except Chittoor where moderate CC (0.67) is observed. High correlation ($0.70 < CC < 0.89$) is found in all the districts of coastal Andhra Pradesh except in the districts of Guntur, Krishna, and Nellore where moderate correlation ($0.51 < CC < 0.58$) is observed. High correlation between flash count and surface temperature indicates that the development of lightning is due to the convection developed because of excessive heating of land by the incoming solar radiation. Previous studies (Price and Asfur 2006; Sekuguchi et al. 2006) also emphasizes the strong association of lightning with surface temperature.

Similarly, significant correlation ($0.90 < CC < 0.96$) is observed between lightning flash count and CAPE in the districts of Telangana, Rayalaseema (except Chittoor where $CC=61$) and in the districts of coastal Andhra Pradesh ($0.87 < CC < 0.96$) except in Guntur, Krishna, and Nellore where moderate correlation ($0.34 < CC < 0.53$) is observed.

Very poor correlation of flash count with convective precipitation is observed over Telangana and Rayalaseema regions, whereas moderate correlation ($CC < 0.50$) (Table 2) is observed in the districts of coastal Andhra Pradesh except Guntur, Krishna, and Nellore districts where significant correlation (CC) (varies from 0.72 to 0.76) is observed (Table 2). This confirms the earlier studies (Piepgrass et al. 1982; Williams et al. 1989; Tapia et al. 1998; Lang and Rutledge 2002; Lal and Pawar 2009) that the lightning is regionally dependent on rainfall. Observations in the previous studies (Rutledge and MacGorman 1985; Sun et al. 2019) show that –CG flashes are mainly concentrated on convective precipitation regions. Hence lightning flash count during post-monsoon season over Guntur, Krishna, and Nellore is mainly due to convective precipitation. Very poor correlation is observed between lightning flash count and AOD in the study regions except in Chittoor where significant correlation (0.74) is observed.

Inter-annual variation of lightning characteristics is studied to understand the variation of lightning activity over longer time period. Figure 7 represents the inter-annual variation of lightning characteristics during the period 1998–2013. Lightning flash count in the study regions Telangana, Rayalaseema, and in the districts of coastal Andhra Pradesh shows increasing trend. Lightning flash count over Srikakulam district shows significant increasing trend during the period 1998–2013 compared to other regions. The lightning flash count is highly correlated with surface temperature ($CC=0.89$), CAPE (0.95) and moderately correlated ($CC=0.65$) (Table 2) with AOD in the Srikakulam district. The increasing trend of lightning flash count in this region is attributed to the change in the surface temperature during the period 1998–2013 because of global warming. Annual mean flash count (Table 1) over Vishakhapatnam district is maximum (87.645) compared to all other regions. Annual mean flash rate density is maximum over Srikakulam district compared to all other regions.

5 Discussion

Maximum flash count, flash rate density, and high correlation of lightning flash count with surface temperature and CAPE are observed (Table 2) during pre-monsoon season (March to May) over Telangana, Rayalaseema (Except Chittoor), and in coastal Andhra Pradesh (except Guntur, Krishna, and Nellore). This confirms several earlier studies (Price 2003; Kandalgaonkar et al. 2005; Penki and Kamra 2012a, 2013) which establishes the sensitivity of lightning activity with surface temperature and CAPE. It is observed that a change in the wet-bulb temperature of 1° K would result in the increase

Fig. 7 Monthly variation of aerosol optical depth (AOD) over **a** Telangana, **b** Rayalaseema, and **c** coastal Andhra Pradesh

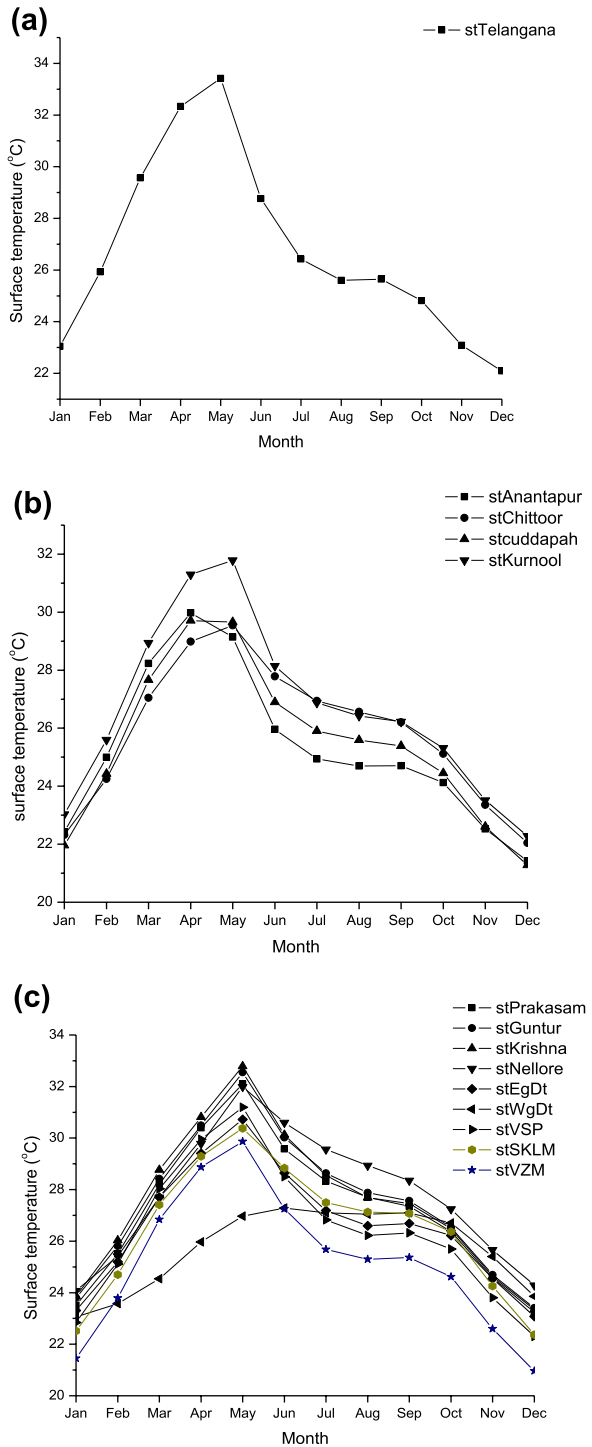


Table 1 Annual mean value of lightning flash characteristics and the meteorological parameters over the study regions

Region	Annual mean flash rate density Fl km ⁻² day ⁻¹	Annual mean Flash count	Annual mean Surface temperature °C	Annual mean CAPE, j kg ⁻¹	Annual mean Convective precipitation kg m ⁻² s ⁻¹	Annual mean AOD 550 nm
Telangana	0.038	62,266	26.7	744,089	1.11E-05	0.371
17° N–19° N 78° E–82° E						
<i>Rayalaseema</i>						
Anantapur	0.02	48,781	25.3	145,279	1.06E-05	0.233
13.41° N–15.14° N 76.47° E–78.26° E						
Chittoor	0.032	47,078	25.9	310,201	1.27E-05	0.264
12.37°N–14°N 78.30° E–79.55° E						
Kadapa	0.019	34,671	25.5	183,528	1.03E-05	0.237
13.43° N–15.14° N 77.51° E–79.29° E						
Kurnool	0.02	44,833	26.6	217,521	9.20E-06	0.294
14.54° N–16.18° N 77.24° N–79.40° N						
<i>Coastal Andhra Pradesh</i>						
Prakasam	0.024	39,083	27.2	217,521	1.29E-05	0.348
15.30° N–16.0° N 79° E–80° E						
Guntur	0.025	36,828	27.5	483,426	1.32E-05	0.396
15.18° N–16.50°N 79.10° E–80.55° E						
Krishna	0.033	36.75	27.5	614,257	1.43E-05	0.422

Table 1 (continued)

Region	Annual mean flash rate density Fl km ⁻² day ⁻¹	Annual mean flash count	Annual mean surface temperature °C	Annual mean CAPE, j kg ⁻¹	Annual mean convective precipitation kg m ⁻² s ⁻¹	Annual mean AOD 550 nm
Latitude/longitude						
15.45° N–7.10° N						
80.01° E–81.33° E	0.02	6.755	27.8	904.094	1.35E-05	0.289
Nellore						
13.25° N–15.55° N						
79.9° E–80.14° E	0.039	33.125	26.6	840.058	2.30E-05	0.496
East Godavari						
16.30° N–18° N						
81.29° E–82.37° E	0.038	34.693	25.7	698.916	1.85E-05	0.424
West Godavari						
16.15° N–17.30° N						
80.50° E–81.55° E	0.047	87.646	26.4	756.032	2.09E-05	0.404
Vishakhapatnam						
17.15° N–8.32° N						
81.06° E–83.31° E	0.058	64.89	26.5	698.916	2.61E-05	0.426
Srikakulam						
18.20° N–19.10° N						
83.25° E–84.50° E	0.051	31.969	25.2	805.254	2.25E-05	0.333
Vizianagaram						
17.15° N–19.15° N						
83° E–83.45° E						

Table 2 Correlation of flash count with surface temperature ($^{\circ}\text{C}$), CAPE (J kg^{-1}) aerosol optical depth (550 nm), and convective precipitation ($\text{kg m}^{-2}\cdot\text{s}^{-1}$) in Telangana, Rayalaseema, and coastal Andhra Pradesh

Region	St ($^{\circ}\text{C}$)		CAPE Jkg^{-1}		Convective precipitation $\text{kg m}^{-2}\text{s}^{-1}$		AOD 550 nm	
	CC	<i>p</i> value	CC	<i>p</i> value	CC	<i>p</i> value	CC	<i>p</i> value
1. Telangana	0.76	0.00393	0.90	<0.0001	0.29	0.34393	0.33	0.29303
<i>Rayalaseema</i>								
1. Anantapur	0.76	0.00355	0.96	<0.0001	0.23	0.47137	0.34	0.2847
2. Chittoor	0.67	0.01599	0.61	0.03397	0.59	0.04055	0.74	0.0059
3. Kadapa	0.78	0.00256	0.91	<0.0001	0.29	0.35885	0.46	0.12579
4. Kurnool	0.82	9.69928E-4	0.94	<0.0001	0.24	0.43762	0.34	0.2713
<i>Coastal Andhra Pradesh</i>								
5. Prakasam	0.79	0.00203	0.85	3.52675E-4	0.52	0.07877	0.49	0.1055
6. Guntur	0.57	0.04921	0.53	0.07017	0.76	0.00345	0.50	0.09308
7. Krishna	0.58	0.04374	0.62	0.03122	0.72	0.0079	0.49	0.10109
8. Nellore	0.51	0.08394	0.34	0.27864	0.81	0.00135	0.46	0.12501
9. EgDt	0.84	5.30258E-4	0.87	1.59991E-4	0.26	0.39759	0.32	0.30851
10. WgDt	0.70	0.01066	0.88	1.51544E-4	0.45	0.1394	0.49	0.1053
11. Vishakhapatnam	0.88	1.25565E-4	0.96	<0.0001	0.28	0.36187	0.51	0.08802
12. Srikakulam	0.89	<0.0001	0.95	<0.0001	0.27	0.38071	0.65	0.0218
13. Vizianagaram	0.86	2.93301E-4	0.93	<0.0001	0.42	0.16878	0.60	0.03616

in lightning activity by 40% (Reeve and Toumi 1999). This emphasizes that a small increase in surface temperature would result in a marked increase in lightning activity. This indicates that the rise in surface temperature due to global warming is responsible for the increasing trend in lightning activity over the study regions. CAPE is found to influence nonlinearly the growth and accumulation of ice particles in the upper part of the cloud and also helps in the charge separation by the differential motions of the particles (Williams 1992). Hence, buoyancy force developed due to heating of land, because of incoming solar radiation, is mainly responsible for the electrical activity of the thunderstorm during pre-monsoon season in Telangana, Rayalaseema (except Chittoor), and in coastal Andhra Pradesh (except Guntur, Krishna, and Nellore). The secondary maximum is attributed to the instability developed due to the withdrawal phase of the monsoon and onset of the northeast monsoon over this region. Maximum lightning over these regions during pre-monsoon and post-monsoon seasons is not only due to the sensitivity of lightning with surface temperature and CAPE but also because of the thunderstorms developed due to the passage of the tropical cyclones emerged over Bay of Bengal (Penki and Kamra 2012b).

Monthly variation of convective precipitation (Fig. 8a and b) over Telangana and Rayalaseema shows maximum value during post-monsoon season. The monthly variation of convective precipitation (Fig. 8c) over coastal Andhra Pradesh shows maximum value during monsoon and post-monsoon season. Aerosol optical depth does not show any definite trend over coastal Andhra Pradesh and Rayalaseema regions (Fig. 9b and c), while maximum values of AOD are observed during monsoon season over

Fig. 8 Monthly variation of surface temperature over **a** Telangana, **b** Rayalaseema, and **c** coastal Andhra Pradesh

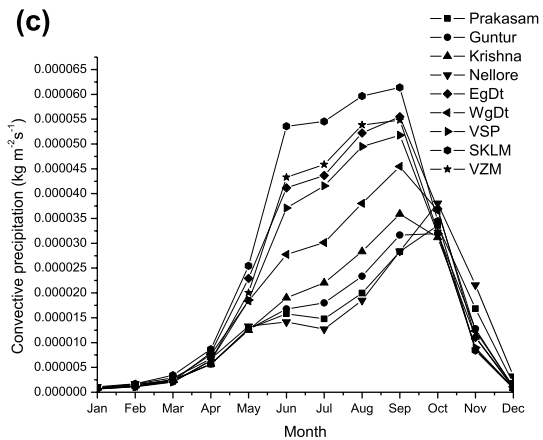
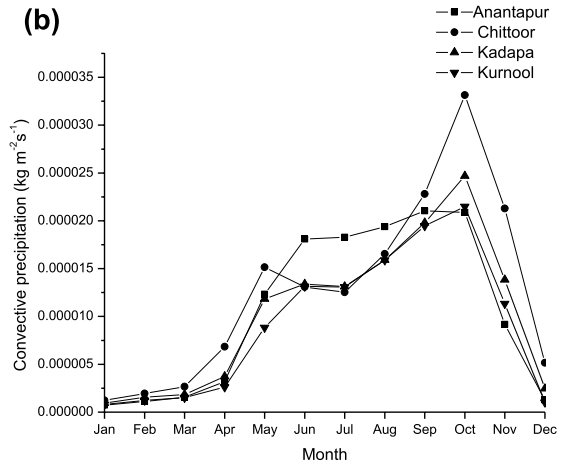
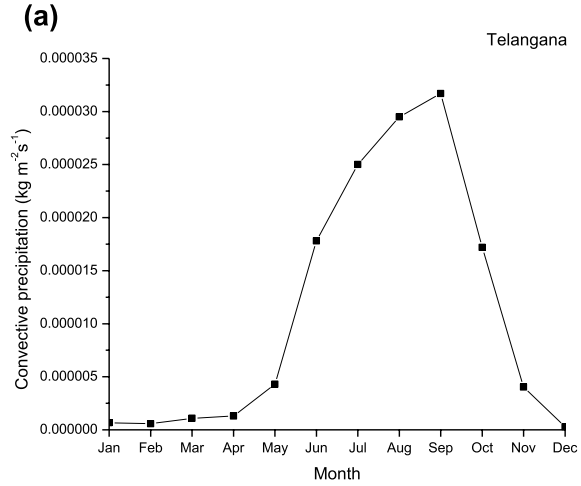
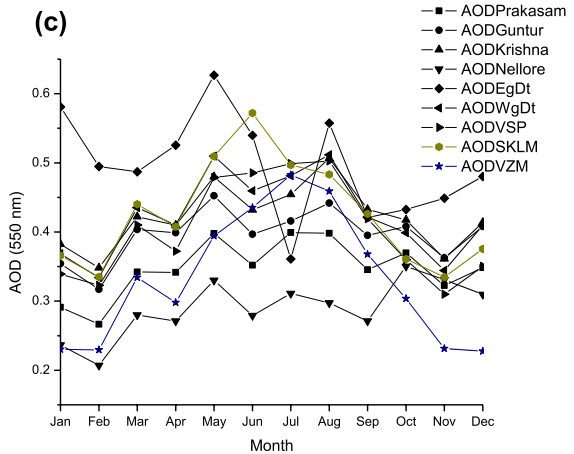
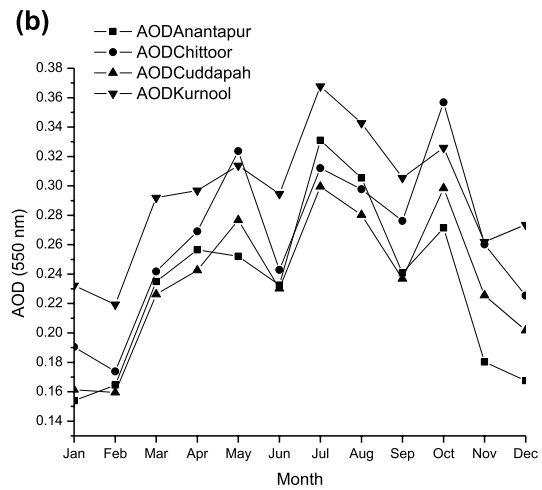
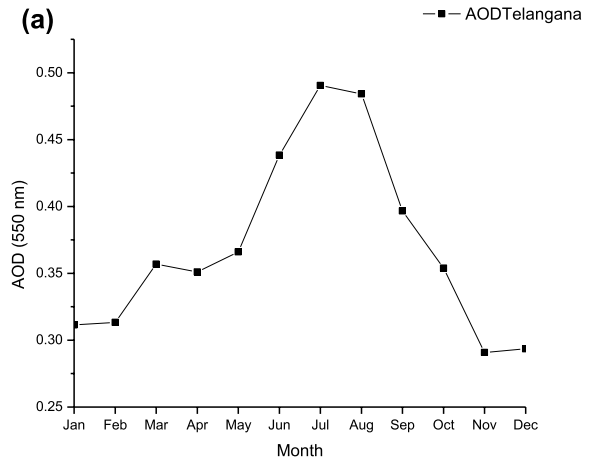


Fig. 9 Monthly variation of convective precipitation over **a** Telangana, **b** Rayalaseema, and **c** coastal Andhra Pradesh



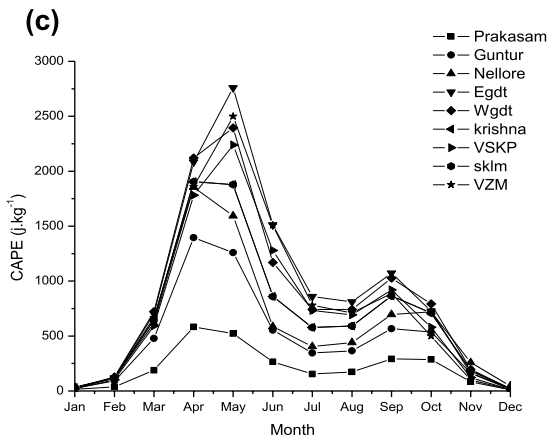
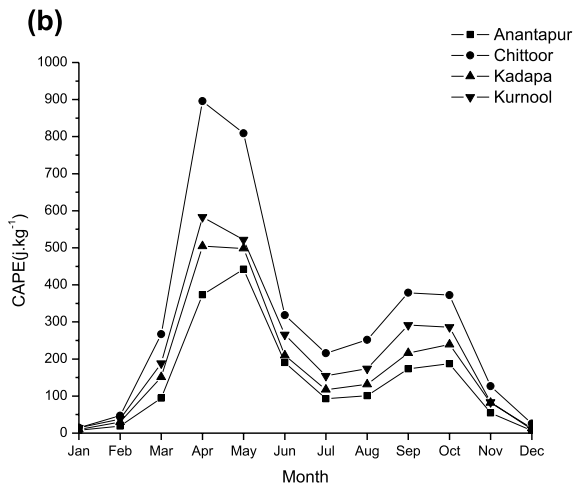
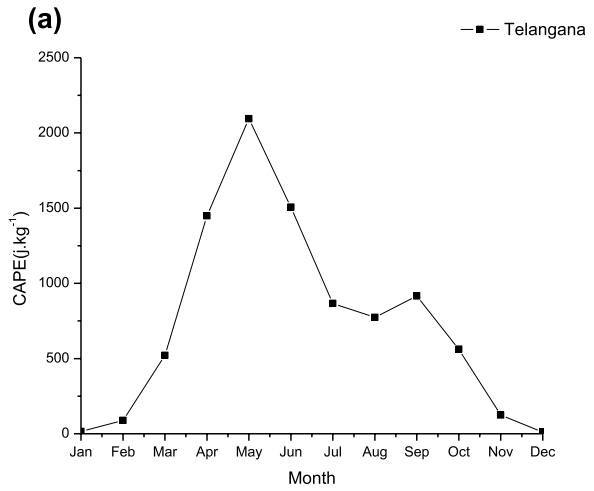
Telangana (Fig. 9a). Very poor correlation of lightning with convective precipitation (except Guntur, Krishna, and Nellore) and AOD (except Chittoor) is observed (Table 2) in the study regions. In Chittoor high correlation is observed between lightning flash count and AOD. Hence the lightning activity over Chittoor is due to high AOD values during the pre-monsoon season. High concentration of aerosols inhibits collision and coalescence process results reduced droplet size and suppression of warm rain process (Rosenfeld 1999). High aerosol concentration is responsible for the formation of large hail (Rosenfeld and Woodley 2000) and increase in the total number of lightning flashes (Orville et al. 2001; Stallins and Rose 2008; Wang et al. 2011; Tao et al. 2012). This clearly establishes the earlier studies finding that the sensitivity of lightning with precipitation and aerosols varies from region to region (Rosenfeld 2003; Kamra and Ramesh Kumar 2021). The monthly variation of lightning flash radiance over Telangana shows maximum during the month of June (Fig. 6a). The radiance values of lightning flash characterize the convective intensity of thunderstorm (Jin You et al. 2019). This shows that in spite of decreasing trend of lightning flash count during monsoon season the lightning flashes are highly energetic because of the presence of deep convective systems over Telangana. Similar pattern of lightning flash radiance is observed in the districts of Rayalaseema (Fig. 6b). The lightning flashes due to low radiance values in the pre-monsoon season (Fig. 6b), are less energetic compared to monsoon season lightning over Rayalaseema, whereas over coastal Andhra Pradesh lightning flash radiance is maximum during pre-monsoon season.

Very poor correlation of flash count and convective precipitation is observed over coastal Andhra Pradesh except Guntur, Krishna, and Nellore districts where high correlation is observed. This clearly shows that lightning over Guntur, Krishna, and Nellore districts is mainly due to the deep convective systems because of the passage of the synoptic systems developed over Bay of Bengal through these regions during pre-monsoon and post-monsoon seasons. The maximum annual mean value of flash count shows that lightning frequency is high over Vishakhapatnam district and maximum flash rate density shows that frequency of intense thunderstorms and lightning frequency over Srikakulam district are high compared to other regions. The inter-annual variation of flash count shows increasing trend over Telangana and Andhra Pradesh regions with a significant increasing trend over Srikakulam district during the period 1998–2013. The significant increasing trend over Srikakulam is due to the change in surface temperature over this region. Earlier studies by (Kandalgaonkar et al. 2005) show that a small change in surface temperature leads to a greater increase in lightning activity (Fig. 10).

6 Conclusions

The monthly variation of flash count and flash rate density exhibits semi-annual variation in the study regions. Primary maximum of both the parameters flash count and flash rate density over Telangana is observed during May and secondary maximum is observed during September. Similar trend is observed in flash rate density over coastal Andhra Pradesh and Rayalaseema, whereas the lightning flash count exhibits primary maximum during April–May and Secondary maximum during September. High correlations between flash count with surface temperature and CAPE over Telangana, Rayalaseema regions (Except Chittoor), and coastal Andhra Pradesh (except Guntur, Krishna, and Nellore) shows that lightning discharge in the pre-monsoon season occurs because of excessive heating of land

Fig. 10 Monthly variation of convective available potential energy (CAPE) over **a** Telangana, **b** Rayalaseema, and **c** coastal Andhra Pradesh



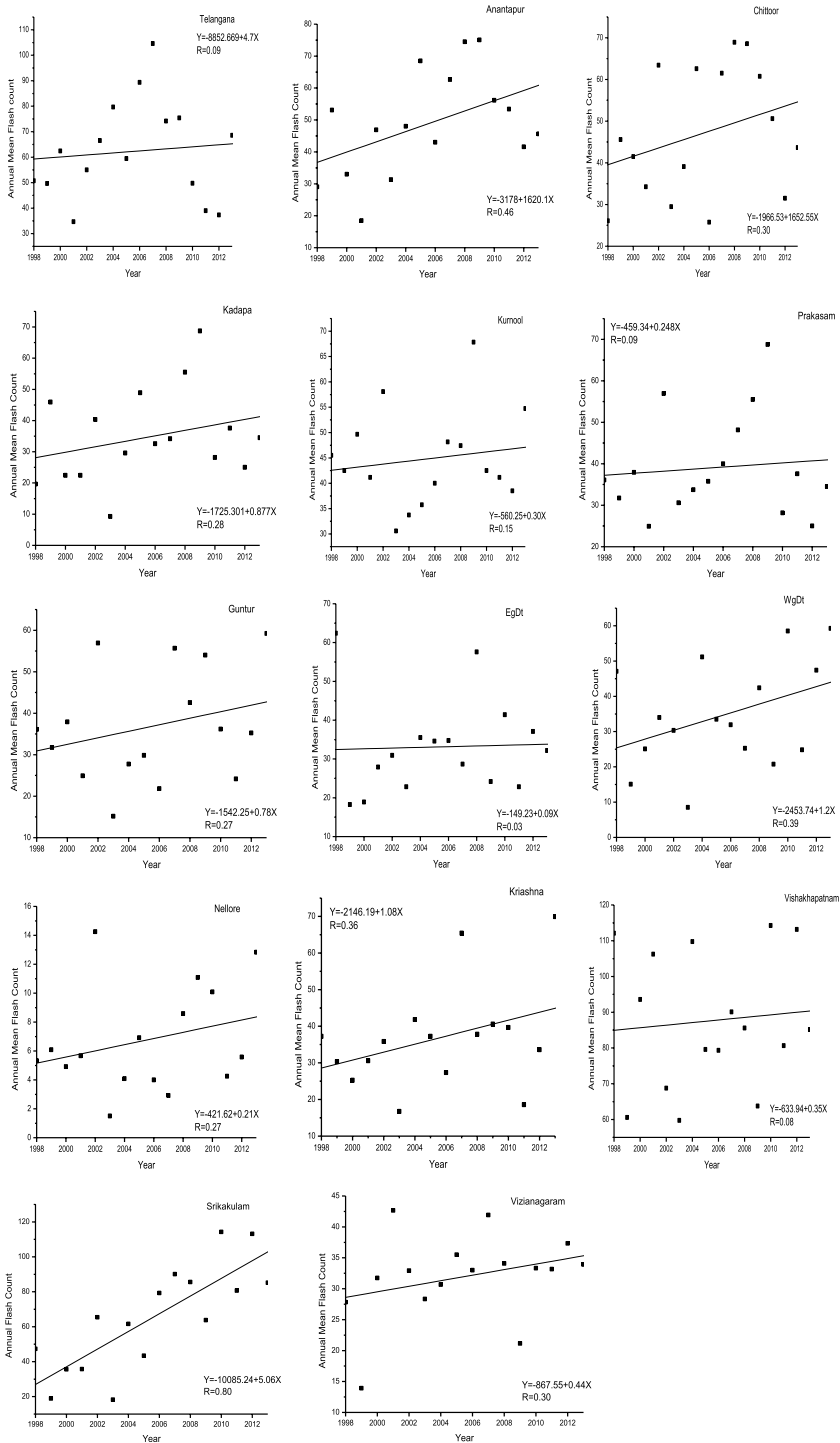


Fig. 11 Inter-annual variation of Flash count over Telangana, Rayalaseema, and coastal Andhra Pradesh

supported by buoyancy force, while the maximum lightning flash count during September is attributed to the convective instability developed due to withdrawal of the monsoon and onset of northeast monsoon. Monthly variation of radiance, characteristics of lightning energy, shows maximum values during post-monsoon season over Telangana, Rayalaseema, and coastal Andhra Pradesh regions. This shows that lightning flash count during post-monsoon season is highly energetic than that in the pre-monsoon and winter season lightning over these regions. Lightning flash count is maximum over Vishakhapatnam. Inter-annual variation of lightning over the study regions shows increasing trend during the period 1998–2013. Flash rate density is found maximum over Srikakulam and lightning flash count over Srikakulam, district of coastal Andhra Pradesh exhibits significant increasing trend. The increasing trend of lightning flash count over Telangana, Rayalaseema, and coastal A.P is attributed to the change in surface temperature which is due to global warming (Fig. 11).

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Declarations

Conflict of interest The authors have not disclosed any competing interests.

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