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Lightning and convective rain study in different parts of India

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ABSTRACT

The effect of solar variability parameters (solar flux ($F_{10.7}$ cm), cosmic ray flux, sunspot numbers) and meteorological parameters on convective rainfall and lightning flashes in four different Indian regions of equal area is studied. Regions are selected having different topological, vegetation, proximity with ocean and habitat features. Solar variability shows statistically insignificant effect on lightning flash and convective rainfall. The seasonal variation of lightning flashes and convective rainfall in each region could be explained considering the variation of CAPE and surface temperature in that region. The dependence of lightning flashes and convective rainfall on meteorological parameters varies from region to region, as is evident from correlation studies. Lightning flashes is well correlated ($R = 0.81$) with CAPE in region R_1 and barely correlated ($R = 0.23, 0.24$) in region R_3 and R_4 whereas rainfall is well correlated ($R > 0.68$) in all the regions. Lightning flashes are better correlated ($R > 0.57$) with temperature in R_1, R_2 and R_4 and moderately correlated in R_3 ($R = 0.44$). Rainfall in R_3 is very well correlated ($R = 0.91$) with surface temperature and there is insignificant correlation in R_1 ($R = 0.09$). There is very good positive correlation ($R > 0.59$) between cloud cover and convective rainfall in the entire region and well negative correlation ($-0.83 < R < -0.61$) between OLR and convective rainfall. OLR and cloud cover show little impact on lightning flashes. Lightning flashes and convective rainfall show average positive correlation ($0.48 < R < 0.53$). Aerosol concentration is the largest in region R_4 and showed an increasing trend between 2007 and 2011. Lightning flashes and convective rainfall are positively correlated ($0.10 < R < 0.58$) with aerosol concentration.

1. Introduction

The incident solar radiation through scattering, reflection and absorption affect the surface and atmospheric temperature, which affect convective process leading to thunderstorm activity/lightning flashes and rainfall. The solar radiation reaching the Earth's surface can be indicated by the $F_{10.7}$ flux, cosmic rays and sunspot numbers. The $F_{10.7}$ flux is well correlated with the sunspot numbers whereas sunspot number showed opposite variation with cosmic rays because solar magnetic fields scatter cosmic ray flux in the interplanetary space. The incident solar irradiance differentially heats land and sea surfaces and helps in the development of convective systems responsible for the large scale thunderstorm/lightning and precipitation activity (Williams et al., 1989, 2004, 2005). The regional activity differs in the two cases. The activity ranking from the most active to the least active based on thunderstorm activity is Africa, South America and South Asia, whereas that based on rainfall is Southeast Asia, South America and Africa (Price, 2006, 2009; Christian et al., 2003; Singh et al., 2004; Siingh et al., 2007, 2011, 2013, accepted for publication). Studies showed that weak to moderate updrafts are required for rainfall whereas stronger and deeper uplift is necessary for lightning (Williams et al., 2004; Mach et al., 2010, 2011).

Early studies showed correlation between thunderstorm frequencies and sunspot numbers and the correlation coefficient varied from station to station (Fritz, 1878; Brooks, 1934).

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Brooks (1934) found a low correlation at mid-latitude and enhanced correlation towards the pole and the equator. Even at the same location thunderstorm frequency is differently correlated with sunspot numbers. For example, Aniol (1952) analyzed data from South Germany between 1851 and 1950 and found no correlation, whereas for the period 1889–1913, a negative correlation (correlation coefficient ~ −0.55) and for the period 1923–1944, a positive correlation (correlation coefficient ~ 0.74) was reported. Girish and Eapen (2008) reported maximum lightning activity during the declining and minimum periods of sunspot activity and minimum during the maximum sunspot periods.

Cosmic ray flux incident on the Earth's atmosphere is partly scattered by the Earth's magnetic field and hence its intensity and energy spectra are dependent on latitude, longitude and azimuth angle (Nehar, 1967; Smart and Shea, 2005; Siingh and Singh, 2010; Kirkby, 2007). During the disturbed condition magnetic field is modified leading to changes in cosmic ray flux (Desorgher et al., 2009). Cosmic rays affect the formation and characteristic features of different types of clouds (Harrison, 2004; Tripathi et al., 2008) through the production of ionization in the lower atmosphere affecting the electric field and current flowing through the cloud layers. Cosmic ray induced cloud nucleation hypothesis is being tested in CLOUD (Cosmics Leaving OUtdoor Droplets) experiment at CERN, Switzerland (Kirkby, 2007) and initial measurements yield encouraging results (Duplissy et al., 2010). On the basis of synchronous measurement of cosmic ray flux and atmospheric electric field, Wang et al. (2012) reported simultaneous changes in cosmic ray flux percentage change and electric field amplitude in ~80% cases. The change in counting rate did not occur when thunderstorm is just over electric field mill. The changes occur when electric field mill is not exactly below thunderclouds but in the control of bottom positive charge layer. Clouds affect radiation transfer mechanism of the atmosphere leading to changes in local/global mean temperature which controls lightning flash rates and precipitations. As the considered regions vary in longitudes and latitudes, it is interesting to study the effect of cosmic ray flux on lightning flash and convective rain.

The solar radiation heats the Earth's surface and adjacent boundary layer leading to rise in surface air temperature and thermodynamic instability of boundary layer, which help the formation of thunderstorm. The energy that feeds this process is the convective available potential energy (CAPE) (Williams, 1992). The complex interaction among CAPE, vertical air motion, vertical distribution of ice particles and microphysics controls electrical activity in thunderstorms (Williams, 1995). Studies showed that CAPE and surface temperature are highly positively correlated with lightning flashes and convective rain (Qie et al., 2003; Williams et al., 2005; Price and Asfur, 2006; Sekiguchi et al., 2006; Penki and Kamra, 2012a,b, 2013; Siingh et al., 2013). Yuan and Qie (2008) analyzed LIS, PR, and TMI data and tried to express the lightning flash rate of precipitation system as function of maximum snow depth, maximum storm top height and minimum polarization corrected temperatures, respectively. The most stable relationship was between flash rate and maximum snow depth. The spatial distribution of deep convective systems (DCSs) and CAPE shows that the DCSs occur mainly over land and is closely related with CAPE (Wu et al., 2013). They also reported that DCSs over the Tibetan Plateau and Northeast India during monsoon season are more frequent than in the Central and South India. DCSs have significant diurnal variation closely related to that of solar heating and dominantly occur from afternoon through mid-night, with peaks from 1500 to 1700 LT.

Studies showed that the cloud-to-ground lightning flash activities of a thunderstorm could be used in local short term forecasting of heavy rain or in precipitation estimation (Williams et al., 1989; Petersen and Rutledge, 1998; Soula et al., 1998) and flash flood or hailstone (Zhou et al., 1999). Thus high precipitation corresponds to strong atmospheric activity in convective systems. Zhou et al. (2002) showed that the average precipitation and lightning flashes in the main precipitation period are positively correlated with the coefficient = 0.86. Total lightning flashes and convective rain during 1998–2010 over the South and Southeast Asia exhibited positive correlation with coefficient 0.68 and 0.81 respectively (Siingh et al., 2013).

Aerosols present in the atmosphere affect the solar radiation through scattering, reflection and absorption of incident radiation and hence affect the solar radiation budget and the surface temperature. The aerosols indirectly affect cloud droplets size (Twomey et al., 1984), cloud life time and cloud extent (Hansen et al., 1997; Ackerman et al., 2000), precipitation process (Albrecht, 1989) and electrical properties of cloud and hence lightning discharges (Westcott, 1995; Stallins and Rose, 2008; Kar et al., 2009; Siingh et al., 2008, 2011, 2013). Enhanced aerosol concentrations cause a narrow droplet spectrum that inhibits collision and coalescence processes leading to reduced particle sizes and suppression of warm-rain processes (Rosenfeld, 1999) and enhancement of the growth of large hail and cold rain processes (Rosenfeld and Woodley, 2000). The enhanced aerosols derived from pollution, desert dust and biomass burning invigorate convective clouds (Koren et al., 2005) and leads to rise in cloud top heights, large anvils and more rainfall (Liu et al., 2007). The aerosol effects on cloud properties may vary with convective available potential energy (CAPE) and wind shear (Lee et al., 2008; Fan et al., 2009); relative humidity (Fan et al., 2007) and cloud morphology (Lee et al., 2010).

Aerosols may cause a decrease in the percentage of positive cloud-to-ground (+CG) lightning flashes and an increase in the total number of flashes (Orville et al., 2001; Steiger et al., 2002; Naccarato et al., 2003; Koren et al., 2005; Stallins and Rose, 2008; Kar et al., 2009; Wang et al., 2011; Tao et al., 2012). Aerosols act as cloud condensation nuclei (CCN) and also affect the charge separation mechanism (Jayaratne et al., 1983) in thunderstorms and may enhance −CG lightning activity (Steiger et al., 2002; Kar et al., 2009). High concentrations of pollutants in super cooled cloud droplets lead to negative charging of graupel at higher cloud temperatures, extending towards the cloud base and covering the positive charge center region (Pruppacher and Klett, 1997). This newly created stretched negative charge region makes tri-polar charge distribution in thunderstorms (MacGorman and Rust, 1998) and produces more −CG flashes. Enhanced −CG flashes decrease the relative frequency of +CG flashes. Williams et al. (1999) proposed that under continental and polluted boundary layer conditions, the available liquid water in the storm updraft shared by an innumerable number of small droplets, as a result mean droplet size is decreased and the coalescence process is thwarted. The available cloud water reaches the mixed phase region and participates in cloud buoyancy, precipitation formation, electric charge separation