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Lightning and middle atmospheric discharges in the atmosphere

Devendraa Siingh [a,*,1], R.P. Singh [b,1], Sarvan Kumar [b], T. Dharmaraj [a], Abhay K. Singh [b], Ashok K. Singh [c], M.N. Patil [a], Shubha Singh [d]

[a] *Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pashan, Pune 411008, India*
[b] *Department of Physics, Banaras Hindu University, Varanasi 221105, India*
[c] *Department of Physics, Lucknow University, Lucknow 226007, India*
[d] *Department of Physics, University of Petroleum and Energy Studies, Dehradun 248007, India*

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ABSTRACT

Recent development in lightning discharges including transient luminous events (TLEs) and global electric circuit are discussed. Role of solar activity, convective available potential energy, surface temperature and difference of land–ocean surfaces on convection process are discussed. Different processes of discharge initiation are discussed. Events like sprites and halos are caused by the upward quasi-electrostatic fields associated with intense cloud-to-ground discharges while jets (blue starter, blue jet, gigantic jet) are caused by charge imbalance in thunderstorm during lightning discharges but they are not associated with a particular discharge flash. Elves are generated by the electromagnetic pulse radiated during lightning discharges. The present understanding of global electric circuit is also reviewed. Relation between lightning activity/global electric circuit and climate is discussed.

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[*] Corresponding author. Fax: +91 20 25865142.
E-mail addresses: devendraasiingh@tropmet.res.in, devendraasiingh@gmail.com (D. Siingh).
[1] Authors have equal contributions.

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1. Introduction

The discharges in thunderstorms could be cloud-to-ground (CG), inter cloud, intra-cloud and from cloud top upwards and the activity is related to the stage of convective cloud development (Vonnegut et al., 1963), cloud top height (Price and Rind, 1992), the updraft intensity (Williams, 1992), convective available potential energy (CAPE) (Williams et al., 1992; Siingh et al., 2013a, 2014, 2015), rainfall rate (Tapia et al., 1998; Soula et al., 2009; Singh et al., 2015; Siingh et al., 2014, 2015) and surface air temperature (Price, 1993; Singh et al., 2015; Siingh et al., 2013a, 2014, 2015). The spatial and temporal distributions of lightning flashes around the globe have been studied using ground and satellite based measurements (Christian et al., 2003; Bailey et al., 2007; Mach et al., 2011; Cecil et al., 2014). Based on early observations, Brooks (1925) proposed global mean flash rate $\sim$100 flashes s^{-1}, whereas from a combination of observations and model studies, Mackerras et al. (1998) proposed 65 flashes s^{-1}. Recently Cecil et al. (2014) analyzed Lightning Imaging Sensors (LIS) and Optical Transient Detector (OTD) data from Tropical Rainfall Measuring Mission (TRMM) satellite and reported global mean flash rate as 46 flashes s^{-1}. The diurnal variation showed the average peak flash rate maximum between 1600 UT and 1800 UT and the minimum between 0200 UT and 0400 UT. The global monthly average flash rate was the maximum in August (60 flashes s^{-1}) and the minimum in February (35 flashes s^{-1}).

The latitudinal distribution of lightning flashes showed the largest occurrence in the tropical region during summer months (Christian et al., 2003, Cecil et al., 2014; Blakeslee et al., 2014) and is highly dependent on surface temperature (Williams et al., 2005; Markson, 2007; Siingh et al., 2013a, 2014, 2015). Global measurements of surface temperature suggested warming of tropical land regions during the El Niño phase and the cooling during the La Niña phase (Williams, 1992; Wang et al., 2012); as a result global lightning was found to be enhanced in the warm El Niño phase and slightly suppressed in the cold La Niña phase (Satori and Zieger, 1999; Yoshida et al., 2007; Harrison et al., 2011; Kulkarni and Siingh, 2014).

Lightning discharges are major source of maintenance of global electrical circuit (GEC) as is evident from the comparison of the diurnal variation of global lightning flash rate distribution and measured electric fields from the Carnegie and Maud research ships (Whipple, 1929; Blakeslee et al., 1999; Bailey et al., 2007; Harrison, 2013; Siingh et al., 2013b). The diurnal variation of percentage of mean global flash rate agrees with that of fair-weather electric field (Carnegie curve) and thunderstorm days in phase but not in amplitude (Fig. 1), with a maxima in the afternoon time sector and a minima around the morning hours (Mach et al., 2011). They also reported 10–20% mean-to-peak variations in Carnegie curve and about 35–40% in the thunderstorm days and lightning flash rates.

Discharges between the cloud top and the middle atmosphere (stratosphere and mesosphere) are referred to as transient luminous events (TLEs), which are short lived discharges either caused by the transient electrostatic fields associated with the charge imbalance in thunderstorm during cloud-to-ground and inter/intra cloud discharges or by the electromagnetic fields associated with the return stroke current during lightning process. The morphological features of some form of TLEs above mesoscale convective cloud system along with altitude profile of day/night time electron density and temperature are shown in Fig. 2. Blue starters (not shown in the figure), blue jets, gigantic jets are upward electrical discharges from top of thunderstorms with their tops reaching different altitudes: 20–30 km for blue starters, 40–50 km for blue jets, and 70–90 km for gigantic jets (Wescott et al., 1995, 1996; Pasko, 2003, 2008; Lyons et al., 2003a; Krehbiel et al., 2008; Siingh et al., 2012; Liu et al., 2015). Blue starters and jets are cone of light shooting upward from thunderstorm and their intensity decreases near their tops (Wescott et al., 1995; Edens, 2011; Chou et al., 2011; Liu et al., 2015). Gigantic jets having a tree-like structure display complex dynamics (Su et al., 2003; Hsu et al., 2005; Chou et al., 2010; Soula et al., 2011; Liu et al., 2015). The top of gigantic jet may reach the Earth's lower ionosphere and can transfer charge between thunderstorm and ionosphere (Pasko, 2008). The amount of charge transfer will depend on the intensity and duration of gigantic jet. In typical cases it can be as high as (100–200 °C) the charge transfer between thunderstorm and ground during intense lightning discharges (Cummer et al., 2009).

Sprites are large luminous electrical discharges in the upper atmosphere caused by intense cloud-to-ground discharges and their dynamics is governed by streamer discharges (Sentman et al., 1995; Lyons et al., 2003b; Pasko, 2007; Siingh et al., 2012; Pasko et al., 2013; Liu, 2014). They are typically initiated at 70–85 km altitude with downward propagating streamers, which may terminate at about 40–50 km altitude (Stenbaek-Nielsen et al., 2007, 2010, 2013). Later upward propagating streamer may appear, which can reach up to about 90 km altitude (Stenbaek-Nielsen et al., 2007, 2010, 2013).

Inan et al. (1999) theoretically showed that electromagnetic field pulses radiated by cloud-to-ground discharges can heat electrons in the lower ionosphere (about 90–95 km altitude) to sufficiently high energy which can excite and ionize neutral molecules leading to brief flash of light, which is now called as elves (an achronym for emission of light and VLF perturbations due to EMP sources) (Fukunishi et al., 1996). Elves are short duration (<1 ms) outward fast expending ring of optical emissions in the lower ionosphere. When viewed upward (from the top of thunderstorm) elves may appear as a doughnut shape ring with

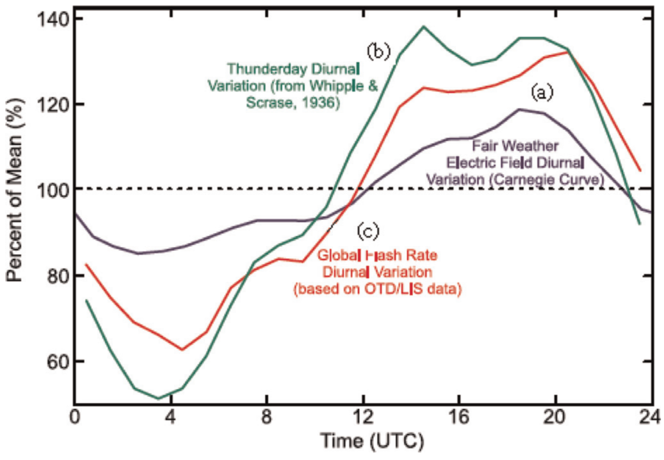

Fig. 1. Diurnal variation of the fair-weather field; (a) Carnegie curve, (b) diurnal variation of flash rates (Whipple and Scrase, 1936), (c) derived from Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD) data (after: Mach et al., 2011).