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The Atmospheric Global Electric Circuit: A Review

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ABSTRACT

In recent years, the studies in Global Electric Circuit (GEC) have received additional interest because of its potential to monitor climate and its use in representing the planets electrical subsystem in Earth system models. The new tools and climate models developed recently have improved our insight not only into various atmospheric processes involved in GEC, but also in their mutual interactions on the local and global scales. The processes occurring within the atmosphere and outside it in space have been observed to influence the Earth's electrical environment and act as internal and external drivers of the GEC. In this article, we summarize the work done in these directions in order to focus our attention on the gaps in our understanding of GEC.

Keywords: Thunderstorms/ Lightning discharges, Global Electric Circuit and climate, GEC generators, Electrified shower cloud, Transient luminous events, Electric field, Carnegie curve

INTRODUCTION

Global electric circuit (GEC) defines the Earth's electrical environment in the lower atmosphere with nearly a constant potential difference (~240 kV) between the Earth's surface and lower boundary of the ionosphere all over the Earth at all the time. As a result, a current flow down from the ionosphere to the Earth's surface in all fair-weather regions. Wilson (1921, 1924) originally proposed the sources of this quasi-stationary electric current to all types of electrified clouds (thunderstorms, and electrified shower clouds or ESC). All the charge separation processes operating inside all such clouds deposit positive charges in the upper portions and negative charges in the lower portions of these clouds (Krehbiel, 1986; Saunder, 2008). The charge generation and separation processes in clouds have also been reviewed earlier (e.g., Yair, 2008; Saunder, 2008; Stolzenburg and Marshall, 2008). The upward and downward directed currents, also referred as 'Wilson current' (after C.T.R. Wilson), depend on the charge structure of the storm, variation in conductivity between the lower and upper atmosphere and other factors imposed by geosphere (solar wind, solar wind-magnetosphere-ionosphere coupling etc).

Recently GEC has received considerable importance because of its potential in monitoring climate (Williams, 2005), and its use in representing the planets electrical subsystem in Earth system models (Lucas et al., 2015). Recent advances in observations make it possible to quantify the contribution of thunderstorms and ESCs and their distributions over the globe (Markson, 2007; Mach et al., 2010, 2011; Liu et al., 2010; Burns et al., 2017; Siingh et al., 2023). During the last few years there has been considerable progress in studies of different aspects of GEC using measurements and theoretical studies (Rycroft et al., 2012; Baumgaertner et al., 2013; Singh et al., 2004; Siingh et al ., 2008, 2013a, 2015, 2023; Mareev and Volodin, 2014; Williams and Mareev, 2014; Lucas et al., 2015; Bayona et al., 2015; Jeeva et al., 2016; Kalb et al., 2016; Victor et al., 2016, 2017, 2019; Peterson et al., 2017; Burns et al., 2017; Kumar et al., 2018; Slyunyaev et al., 2019; Denisenko et al., 2019 and references there in). In view of these developments, it became imperative to summarize the recent results.

GLOBAL CIRCUIT PARAMETERS

The concept of GEC became more evident in late 1950s with the integration of vertical potential gradient profile measurements using electric field sensors mounted on balloons and aircrafts (Markson, 2007). The simultaneous variation of ionospheric potential (Vi) at two locations (balloon sounding over Wissenau (Germany) and the Meteor research ship in the equatorial Atlantic (6000 km separated), coupled with the synchronous changes in potential gradient (PG) supported the GEC concept and diurnal variation in Vi, closely resembled with the Carnegie curve (Nicoll, 2012). The measurements using more reliable and modern equipments for atmospheric electrical parameters during the last seventy years were more systematic and closer to modern concepts. During this period, it is well established that a vertical positive potential gradient exists during fair-weather days, Ions in the atmosphere are formed naturally and air has a finite electrical conductivity. The fair-weather small current flowing between the ionosphere and the Earth's surface (Figure 1) (Markson, 1978), remains constant with altitude, although atmospheric electric conductivity increases with height from ~ 10^{-14} Sm^{-1} to 10^{-7} Sm^{-1} at 80 km altitude (bottom of ionosphere) (Ampferer et al., 2010). The upper atmosphere and the Earth are considered to be good conductor of electricity and the enclosed atmosphere between the two is assumed to be a leaky dielectric (Rycroft et al., 2000, 2024; Harrison, 2004, Siingh et al., 2005, 2012; Markson, 2007; Williams, 2009). Therefore, considering the ionosphere and the Earth's surface as two conducting plates of a giant spherical condensers, following these parameters are taken as the three parameters of Ohm's law, (i) ionospheric potential, (ii) air-earth conduction current, (iii) columnar resistance of the atmosphere.