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Estimation of nighttime dip-equatorial E-region current density using measurements and models

Kuldeep Pandey [a,b], R. Sekar [a,*], B.G. Anandarao [a], S.P. Gupta [a], D. Chakrabarty [a]

[a] Physical Research Laboratory, Navrangpura, Ahmedabad 380009, India
[b] Indian Institute of Technology-Gandhinagar, Ahmedabad 382424, India

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ABSTRACT

The existence of the possible ionospheric current during nighttime over low-equatorial latitudes is one of the unresolved issues in ionospheric physics and geomagnetism. A detailed investigation is carried out to estimate the same over Indian longitudes using in situ measurements from Thumba (8.5°N, 76.9°E), empirical plasma drift model (Fejer et al., 2008) and equatorial electrojet model developed by Anandarao (1976). This investigation reveals that the nighttime E-region current densities vary from ~0.3 to ~0.7 A/km^2 during pre-midnight to early morning hours on geomagnetically quiet conditions. The nighttime current densities over the dip equator are estimated using three different methods (discussed in methodology section) and are found to be consistent with one another within the uncertainty limits. Altitude structures in the E-region current densities are also noticed which are shown to be associated with altitudinal structures in the electron densities. The horizontal component of the magnetic field induced by these nighttime ionospheric currents is estimated to vary between ~2 and ~6 nT during geomagnetically quiet periods. This investigation confirms the existence of nighttime ionospheric current and opens up a possibility of estimating base line value for geomagnetic field fluctuations as observed by ground-based magnetometer.

1. Introduction

It is well known that an intense current, commonly referred to as equatorial electrojet, flows in a narrow altitudinal band (peak around 105 km) over the dip equatorial regions. The strengths and variations of these currents during daytime had been derived in detail using rocket borne magnetometer measurements over Indian (e.g. Sastry, 1970; Sampath and Sastry, 1979 and references cited therein), Peruvian (e.g. Davis et al., 1967; Shuman, 1970) and Brazilian (e.g. Pfaff et al., 1997 and references cited therein) longitudes. Systematic observations of the electrojet current strengths during daytime were obtained by ground-based magnetometers (e.g. Rastogi and Iyer, 1976). Satellite borne measurements of these current densities during daytime (Jadhav et al., 2002; Lühr et al., 2004, etc.) are also available. However, the existence (or the lack of it) of the possible ionospheric current during nighttime and its characteristics over low-equatorial latitudes are not well understood. This is because of the fact that during nighttime, the ionospheric E-region plasma density goes down drastically. As a consequence, the midnight values of Sq current are generally taken as the base line for the overhead equivalent ionospheric current system. However, based on theoretical calculations, Takeda and Araki (1985) concluded that the ionospheric Sq currents flow westward in the nighttime during high solar activity period and their contribution to the geomagnetic Sq field is about 1/10 of the maximum Sq variation. On the other hand, the nocturnal currents are shown to be weak during low solar activity period and below the detection limit. In addition, Campbell (1973) and Mayaud (1976) found that the geomagnetic variations during nighttime are not negligible on many occasions. Campbell (1979) suggested that the ground geomagnetic variations during nighttime may be present even during apparently quiet conditions. Matsushita and Maeda (1965) used the daily mean as the base level to be representative of the zero Sq current and showed the presence of significant nighttime ionospheric current. On the other hand, if the nighttime Sq level is taken as the base value, as in Matsushita (1968), it would imply zero ionospheric current during nighttime. Therefore, determination of the base geomagnetic level is important to determine the nighttime E-region current over low-equatorial latitudes. Based on only a single rocket flight Davis et al. (1967) inferred small westward current in E-region (corresponding to magnetic variation of about 6 nT on the rocket borne magnetometer) during midnight hours around 100 km altitude over the Peruvian dip equatorial sector. This inference was derived

* Corresponding author.
E-mail address: rsekar@prl.res.in (R. Sekar).

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using the data obtained from the ascent and descent phases of the rocket flight. After a few days, under similar geomagnetic conditions, Shuman (1970) did not detect any significant current over the same place and around the same local time during the descent phase of the rocket, although the resolution of the magnetic measurements was slightly higher (5 nT). It is to be noted here that the magnetometer measurements are not expected to alter significantly depending on the ascent and descent phases of the rocket as current integrated over large area is measured. Thus, considering that rocket wake does not modify the magnetometer measurements, the results of Shuman (1970) are in contradiction with the results of Davis et al. (1967). Over the Indian dip equatorial sector (Thumba), Sastry (1970) measured about 9.4 A/km^2 peak current density during daytime but concluded the absence of such current (with uncertainty of 4 nT of magnetic measurements) during pre-midnight hours on the same day. Onwumechili (1992a) compiled the available in situ measurements of ionospheric current density over the globe and the nighttime current over the dip equatorial region was suggested to be absent.

The above observations pose an uncertainty on the magnitude of the current that can be expected to flow through the equatorial E-region during nighttime. Further, as suggested by Haerendel and Eccles (1992) and Eccles (2015), the generation of pre-reversal enhancement (PRE) of the equatorial F-region zonal electric field will depend crucially on the closure of the F-region dynamo current through the E-region in the low and equatorial latitudes. Therefore, determination of nighttime E-region current is essential to understand the underlying processes that couples E and F regions over low-equatorial latitudes during nighttime. There was an attempt by Stening and Winch (1987) to estimate the nighttime ionospheric current using the in situ measurements of electron density, obtained over Thumba (Prakash et al., 1970), and with a fixed zonal Sq electric field of -0.3 mV/m. They concluded that a finite ionospheric current flows during nighttime. Further, Rastogi et al. (1996) reported that the nocturnal variation of horizontal geomagnetic field over Huancayo showed remarkable similarity with corresponding variation of ionospheric electric field determined by Doppler radar. This indicates a finite nighttime ionospheric current which can be inferred by ground-based magnetometer. However, it is difficult to separate ionospheric and magnetospheric components from these magnetometer measurements in spite of the resolution being 0.1 nT in the present digital magnetometer systems as their effects are comparable on ground during nighttime. It is not clear whether the ground-based magnetometer measurements during nighttime, even during magnetically quiet times, are free from the contributions from magnetosphere. During geomagnetically disturbed period, many authors (e.g. Matsushita, 1971; Onwumechili and Ezema, 1977; Chakrabarty et al., 2005) had indicated the non-ionospheric (magnetospheric) origin of the currents responsible for the magnetic fluctuations observed at the ground. Therefore, a comprehensive understanding on the magnitude of the nighttime E-region current and its variation with time is missing till date although the nighttime horizontal component of the magnetic field measured by the magnetometers is being used as base or reference value for determining the daytime electric fields (Rastogi and Patil, 1986). These variations in the reference value during magnetically disturbed period make matter worse as far as the determination of the daytime electric fields is concerned. Given the above background, it is imperative that knowledge about the changes in nocturnal ionospheric current during geomagnetically quiet time is essential to comprehensively understand the equatorial electrodynamics. In this context, the present investigation is important as it provides estimation of the equatorial E-region current at a few local nighttimes by different methods using experimental data and modeling investigations.

2. Details of observations and other inputs

In the present investigation, electron densities and plasma wave information obtained from six rocket flights containing Langmuir probe system with high frequency response (Prakash and Subbaraya, 1967; Subbaraya et al., 1983, 1985) conducted over Thumba, during 1967–1975, are utilized as inputs. In addition, in situ measurements of zonal current density (Sastry, 1970; Sampath and Sastry, 1979) using magnetometer on board two rocket flights over Thumba are used. Throughout this work, time corresponds to local time (*LT*) which for Thumba (76.9°E) is about 22 min behind the Indian Standard Time, *IST* (time corresponding to 82.5°E). It is important to note here that simultaneous measurements of electron and current densities obtained on 29 *August*, 1968 at 1354 *LT* (Subbaraya et al., 1972) and 3 *March*, 1973 at 1159 *LT* (Sampath and Sastry, 1979) are used to calculate the *R* values ($R = \sigma_H/\sigma_P$, ratio of Hall (σ_H) to Pedersen (σ_P) conductivities). These flights correspond to high (yearly averaged sunspot number in 1968 was 150) and low (yearly averaged sunspot number in 1973 was 54) solar activity periods. This *R* value is used to deduce the altitude profile of nighttime current densities over the dip equator. The validity of the extrapolation of *R* value to the nighttime is discussed in Section 3.1. Further, the observed presence of streaming waves (plasma waves generated due to the streaming of electrons in the dip equatorial E-region with velocity exceeding ion-acoustic speed) in the electron density measurements (e.g. Farley, 2009) is also used to give the physical estimate of minimum strength of nighttime current density that must be present over the altitude range wherein streaming waves were detected. The generation of streaming wave is shown (Sekar et al., 2013) to be possible over Thumba only when the dip angle $(I) < 1.5°$. The present investigation makes use of the electron density observations from Thumba during 1967–1975 wherein the dip angle was between $-1.0°$ and $-1.1°$ and thus consistent with the conclusion of Sekar et al. (2013). Further, as the objective of the present investigation is to find out the nighttime E-region current density that is a realistic representative of the nighttime base value during quiet time, the electron density profiles before 2100 *LT* are avoided to minimize the contributions from PRE. The other important input parameters are as follows:

(i) The altitude profiles of neutral density and temperature are taken from Jacchia-71 (Jacchia, 1971) model which is built-in electrojet model used in this investigation.
(ii) The geomagnetic field in altitude-latitude plane is adopted from International Geomagnetic Reference Field (IGRF)-11 model (Finlay et al., 2010).
(iii) The vertical drifts corresponding to quiet time Sq electric fields over the dip equator are taken from F-region vertical plasma drift model of Fejer et al. (2008).

It is to be noted here that the accuracy of the electron density measurements is 5% (Subbaraya et al., 1983), the resolution of drift measurements is 10% (Fejer et al., 2008) and the standard deviation of neutral parameters is 8% (Marcos, 1990). These numbers determine the maximum uncertainty in the estimated nighttime current values.

3. Methods to estimate nighttime current density

Three different approaches have been adopted to estimate the nighttime current density in the equatorial E-region. These are described and compared in the subsequent sections.