Journal of Atmospheric and Solar-Terrestrial Physics 125-126 (2015) 50–58

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

On the coupled interactions between ring current intensity and high-latitude ionospheric electron density variations

Sneha Yadav*, Duggirala Pallamraju

Space and Atmospheric Sciences Division, Physical Research Laboratory, Ahmedabad 380009, India

ARTICLE INFO

Article history:
Received 5 September 2014
Received in revised form
17 February 2015
Accepted 21 February 2015
Available online 24 February 2015

Keywords:
High-latitude ionosphere
Ring current
Solar wind–magnetosphere–ionosphere coupling
High- to low-latitude coupling
Space weather

ABSTRACT

Investigations on the magnetospheric–ionospheric processes form an important element of research in the understanding of the solar–terrestrial interactions. In this work, we have investigated the linkage between the ring current intensity and the high-latitude ionospheric plasma density variations during different geomagnetic conditions. The Global Positioning System (GPS) derived Vertical Total Electron Content (VTEC) during 2011–2013 over high- and low-latitude stations in both the hemispheres and the symmetric ring current index (SYM-H) have been used in this study. A cross-correlation analysis performed between the variations of these two parameters during a wide range of geomagnetic conditions reveal that there is a seasonal, latitudinal and hemispherical dependence in the interrelationship between SYM-H and VTEC. The best cross-correlation between SYM-H and VTEC over both the hemispheres is obtained during equinoctial months which can be attributed to the semiannual variation of the solar wind–magnetospheric–ionospheric coupling. Summer time VTEC over southern hemisphere exhibits a better correlation with SYM-H index in comparison to that of the northern hemisphere. These results have been explained in the light of relative contributions from seasonal and hemispherical variation that exists in the ionospheric plasma. The results are striking as the correlation is found between the variation in two independent processes occurring at widely separated regions in space, namely, the ring current intensity and the behavior of ionospheric densities at high-latitudes. Season-dependent high- and low-latitude coupling of the ionospheric VTEC is observed during the disturbed geomagnetic conditions.

1. Introduction

One of the important science issues in the field of solar–terrestrial physics is to understand the multifaceted phenomena of magnetosphere–ionosphere coupling. The broad forms of magnetospheric–ionospheric coupling are in the form of energy deposition to form the ring current, Joules heating of the ionosphere, and particle precipitation (e.g. Akasofu, 1981c; Gonzalez and Gonzalez, 1984). Hence, in order to understand the different processes occurring in the magnetosphere and ionosphere, it is a prerequisite to understand as to how these systems work together, and in this regard a detailed qualitative and quantitative study is required.

Ring current dynamics is a fundamental element in understanding the onset and development of geomagnetic storms. The intensification of the ring current is the main feature of magnetic storms which manifests as a world-wide depression in the horizontal (H) component of the geomagnetic field that is induced due to the ring current. The H-component of magnetic field is recorded at several observatories and is used to calculate the disturbed storm time index (Dst). This index and its high-time resolution SYM-H (symmetric horizontal component of ring current) index are used to estimate the intensity of the ring current and to understand the progression and intensity of a geomagnetic storm. Several studies have been conducted in the past to study the coupling between the cause (magnetospheric variation) and effect (ionospheric variation) at high- to low-latitudes. However, it is noted that these studies are primarily based on the variations in the current system as inferred from the induced magnetic field, e.g., Dst, SYM-H, ASYM-H, AE, AU, AL, etc. Akasofu (1981a) modeled Auroral Electrojet (AE) and Dst by using $\mathcal{E}$ parameter to show that both are directly driven by the solar wind. Akasofu (1981b) showed that there is a linear relationship between AE and Dst only for weakly disturbed conditions ($\text{Dst} > -50$ nT) because storm-time AE index shows rapid fluctuations. Cade III et al. (1995) performed a correlative study to establish a relationship between Dst and AE index, while the studies of Grafe and Feldstein (2000) suggested that storm-time ring current and AE index develop more or less independently of each other although they are caused by the same source. Feldstein and Starkov (1968) showed that the

---

* Corresponding author.
E-mail address: snehay@prl.res.in (S. Yadav).

http://dx.doi.org/10.1016/j.jastp.2015.02.006
1364-6826/

position of the auroral oval may be related to the strength of the ring current. Using IMAGE spacecraft data, Milan (2009) showed that both the solar wind–magnetosphere coupling and the ring current intensity control the size of the auroral oval and suggested that magnetic perturbations linked with the ring current adversely affect the nightside reconnection rate thereby preventing the polar cap from contracting. The polar cap can contract only when the ring current dissipates. By studying the positive and negative ionospheric disturbances at 13 middle latitude stations, Tsagouri et al. (2000) showed that the maximum negative deviation in the hourly foF2 values of all the stations during geomagnetic storm and shape of the ring current is visually correlated. However, there have been very few, if any, quantitative studies on the coupling between ring current and ionospheric electron density over high-latitudes.

The purpose of this work is to understand as to how the plasma injected into ring current due to geomagnetic forcing is coupled to the changes in the electron density of the ionosphere during different space weather conditions. In that regard, we have carried out cross-correlation analysis to study the coupling between the ring current intensity and high-latitude ionosphere in terms of plasma density variations. It is well-known that high-latitude ionosphere gets directly affected by the magnetospheric processes. The low-latitude ionosphere, although not directly coupled to the magnetospheric processes, is nevertheless affected by the processes that take place at high-latitude regions. Further, an attempt has been made to examine the latitudinal, seasonal and hemispherical dependence of the coupling phenomenon.

2. Database and methodology

The GPS measured TEC data during the period 2011–2013 has been utilized for the present study. The data from five International GNSS Service (IGS) stations are used in addition to that from the Indian Antarctic research station, Maitri. The geomagnetic and geographic coordinates of stations from which data has been used in this study are listed in Table 1. Fig. 1 shows the geographic location of the GPS stations. Three high-latitude stations from the southern hemisphere (Davis (DAV1), Syowa (SYOG) and Maitri) have been chosen for this study. Davis is located in the polar cap region, Syowa lies in the auroral region, and Maitri is a sub-auroral station under quiet geophysical conditions. Apart from the high-latitude stations, a low-latitude station, Krugersdorp (HRAO), is also chosen to examine the ionospheric activity over low-latitudes. The high-latitude stations, Ny-Alesund (NYAL) and Iqaluit (IQAL), from the northern hemisphere are also considered in the present study to investigate the conjugacy of this coupling. NYAL is approximately conjugate to Davis. IQAL, a longitudinally separated location, has been chosen to substantiate the findings from NYAL.

Table 1
The geographic and geomagnetic coordinates of the stations from which GPS data has been used for this study.

Stations	Geographic coordinates		Geomagnetic coordinates		Corrected geomagnetic coordinates	
	Lat.	Long.	Lat.	Long.	Lat.	Long.
Maitri	70.4°S	11.4°E	62.4°S	53.1°E	62.5°S	52.9°E
Syowa (SYOG)	69.0°S	39.9°E	70.5°S	85.4°E	66.4°S	72.1°E
Davis (DAV1)	68.5°S	77.9°E	76.2°S	130.1°E	74.9°S	101.9°E
Ny-Alesund (NYAL)	78.9°N	11.8°E	75.8°N	127.9°E	76.4°N	109.6°E
Iqaluit (IQAL)	63.7°N	291.4°E	73.5°N	5.9°E	71.8°N	14.8°E
Krugersdorp (HRAO)	25.8°S	27.6°E	27.0°S	95.0°E	35.8°S	95.0°E

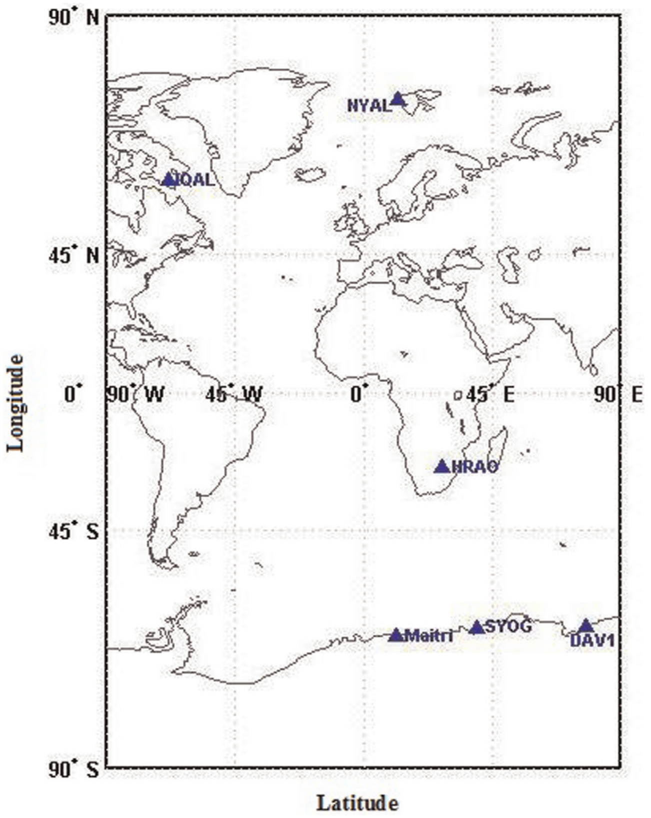

Fig. 1. Location of GPS stations from which data has been used in the present study.

The IGS data obtained from the website consist of a standard RINEX file. Daily Differential Code Biases (DCB) for satellites and receivers are obtained from the CODE IGS Analysis Centre. The VTEC values have been estimated from the RINEX files by using the GPS-TEC application (http://seemala.blogspot.com/). The output of this application provides the VTEC calculated by using the mapping function that assumes ionospheric pierce point (IPP) of 350 km:

$$\text{VTEC}=\text{STEC}X\cos(\chi) \tag{1}$$

where χ is the zenith angle at IPP which is estimated from the elevation angle of the satellite, and STEC is the slant TEC. The VTEC values with a data cadence of 1-min and elevation cut-off greater than 35° are used for the present study. The SYM-H index at 1-min time resolution, and three hourly Kp index are obtained from the website of World Data Center for Geomagnetism, Kyoto, Japan.

It is well-known that ionospheric electron densities are mainly produced by photoionization of the earth's upper atmospheric constituents by the solar EUV radiation. Thus, at any location, the production of ionospheric electron densities is a function of solar zenith angle (diurnal variation), solar declination angle (seasonal variation), and solar flux. Transportation of plasma from other locations and compositional variations during geomagnetic storms contribute to both decrease and increase in densities. In order to remove the diurnal component in the VTEC variation, 24-h (one day) smoothing of VTEC values has been performed. This method removes the small-scale fluctuations (of periods < 24 h) in VTEC and the detrended data represents the variation of electron content over a large time scale. The 24-h smoothing is also performed over SYM-H index to remove the small-scale variations and enable comparison with smoothed VTEC data. These 24-h smoothed time series have been used to study the relationship between VTEC and SYM-H index. In order to estimate the degree to which these two series are related, cross-correlation analysis has been carried out