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Investigation on mid-latitude stations to storm-time variations of GPS-TEC

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Abstract

The ionospheric response to some selected storm events, occurring at different seasons, was studied using the Global Positioning System (GPS) measurements obtained from the International GNSS Service (IGS) receivers located at four mid-latitude stations comprising the northern and southern hemispheres. The inter-hemispheric comparison of the total electron content (TEC) variation during these solar events reveals clear hemispheric and seasonal asymmetries. Generally, the TEC deviation, relative to the reference quiet time averaged values, reveals strong latitudinal dependence within the mid-latitude region. The trend in the variation of TEC over the two stations in the northern hemisphere is similar, whereas some similarities/differences are generally observed over the two southern stations. We suggested that in evaluating the storm-time TEC variation over the mid-latitude, it is essential to differentiate precisely between the global, regional and local characteristics. Mechanisms considered to be responsible for the ionospheric behaviours during these storm events are also discussed.

Keywords: TEC; Mid-latitude; Hemisphere; Storm; Season

1. Introduction

The effect of solar disturbance on the ionosphere is a complex physical process that has attracted a large number of studies in both past and present (Adeniyi, 1986; Joshua et al., 2011; Adebesin, 2012; Adebiyi et al., 2012, 2014b). The earth's ionospheric parameters such as the electron density, total electron content (TEC) and many more respond in an unpredictable manner to the input of solar flux, electric fields and even the electrodynamic drifts caused by the disturbances, thus making it difficult to understand the temporal and spatial perturbation produced during this solar event. A precise knowledge of its impact on the earth's atmosphere is important for accurate prediction of some ionospheric parameters which may affect high frequency radio wave propagating through the ionosphere or trans-ionospheric signals such as the Global Positioning System (GPS) signals. Many researchers have studied the ionosphere using different observing techniques such as the Ionosonde, the incoherent radar system, and the GPS. The GPS has been widely used over the last decade for the study of the Ionosphere (e.g. Jakowski et al. (1999), D'ujanga et al. (2013), Olwendo et al. (2012), Malini et al. (2012)) and has provided a means of estimating the TEC over a station. The ionospheric response to the ever present geomagnetic activity has been reported to vary with latitude, season and local time by large numbers of studies and excellent reviews (Adebiyi et al., 2014a; Danilov, 2013; Buonsanto, 1999; D'ujanga et al., 2013; Chakraborty and Hajra, 2010; Gao et al., 2008; Jakowski

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et al., 1999). Apart from the high latitude, which constitutes a large portion of the overall storm time ionospheric variability (Forbes et al., 2000), the mid-latitude ionosphere is susceptible to the effect of the high latitudes and low latitude disturbances (Matuura, 1972; Fuller-Rowell et al., 1996; Prölss and Očho, 2000; Tsagouri et al., 2000; Huang et al., 2005; Zhao et al., 2009; Balan et al., 2011). The mid-latitude is strongly influenced by the global thermospheric disturbance caused by the high latitude heat and momentum sources during geomagnetic disturbances with a consequent deviation from their quiet time values on a time scale of hours.

The morphology of the mid-latitude region to ionospheric storms has been extensively studied by many researchers (Prölss, 1987; Zhao et al., 2009; Mansilla and Zossi, 2013; Vasiljevic and Cander, 1996; Mansilla, 2011; Leonovich et al., 2012; Stankov et al., 2009; Yuan et al., 2009). In spite of these large number of studies on ionospheric storm over this region, some features of the storm-time seasonal ionospheric variations are still valuable in providing detailed information of ionospheric disturbances under different seasons in the two hemispheres. Report of the investigation by Stankov et al. (2010) into the seasonal variations of TEC during geomagnetic storms over the European middle latitudes revealed that positive storm effect was more pronounced in winter while the strongest and shortest negative phase was detected during the equinox. The storm-time action of the high latitude ionosphere to the heat input from the magnetosphere during the storm sets up molecular-rich environment that affect the global wind system. This has been revealed as the main mechanism driving the storm-time ionospheric behaviour over the mid-latitude station and has also been reported to show seasonal features across the latitudes (Fuller-Rowell et al., 1996). Consequently, the mechanisms and the simultaneous alternation of enhancement/depletion of ionospheric electron content during geomagnetic storms occurring at different seasons is less studied over the mid-latitude stations in both hemispheres.

Thus, this study aims at investigating the ionospheric morphological differences between the mid-latitude stations in both hemispheres to four moderate storm events which occurred at different seasons of the year. In order to study the storm time seasonal variations of TEC over the selected mid-latitude stations, hourly values of TEC derived from the GPS observations obtained from the database of the International GNSS Service (IGS) were analysed and presented in this paper. The GPS measurements are from the network of IGS receiver located at two northern and southern mid-latitude stations as presented in Table 1. The selected storms are all moderate storms and they occurred at different seasons of the year. Table 2 shows the detail of the selected storm events.

Table 2
The selected storm events used for the study.

Storm events	Season of storm occurrence	Dst minimum value (nT)	Classification of storm event
9 Apr., 2006	March Equinox	−82	Moderate
29 May, 2010	June Solstice	−85	Moderate
11 Oct., 2010	September Equinox	−80	Moderate
30 Nov., 2006	December Solstice	−74	Moderate

2. Data and method of analysis

The southward component of the Interplanetary Magnetic Field (IMF Bz) and the geomagnetic indices used for the description of the storm events were obtained from the National Space Science Data Center website (http://nssdcgsfc.nasa.gov/omniweb). In order to study the TEC response during this storm period, we have processed TEC data from stations located at mid-latitude in both hemispheres. Raw GPS measurements from the IGS database were collected and analysed. The receivers are located in Hailsham (HERS) and Penc (PENC) in the northern hemisphere; Port aux Francais (KERG) and Sutherland (SUTH) in the southern hemisphere. The GPS data, which are available to the public domain via the internet were obtained from the Scripps Orbits and Permanent Array Center (SOPAC) data archive (ftp://garner.ucsd.edu). The GPS-TEC retrieval algorithm developed by Gopi Krishna Seemala of the Institute of Scientific Research, Boston College, Boston, USA, was used to derive the vertical TEC (VTEC). The differential satellite bias values, published by the Center for Orbit Determination in Europe (CODE) and made available to the public through the blog (ftp://ftp.unibe.ch/aiub/CODE/), are included in the GPS-TEC analysis software to calculate the TEC over the stations. The percentage deviation of storm time TEC (% Δ

Table 1
List of the stations used with their geographical and geomagnetic coordinates.

Location	Country	Station ID	Geographic		Geomagnetic		Diff. between LT and UT
			Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)	
Northern hemisphere							
Hailsham	United Kingdom	HERS	50.87	0.34	52.74	84.93	+0 h
Penc	Hungary	PENC	47.79	19.28	46.40	102.17	+1 h
			Lat. (°S)	Long. (°E)	Lat. (°S)	Long. (°E)	
Southern Hemisphere							
Port aux Francais	Kerguelen Islands	KERG	49.35	70.26	56.85	132.33	+4.5 h
Sutherland	South Africa	SUTH	32.38	20.81	32.19	86.72	+1 h