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# Traveling ionospheric disturbances observed at South African midlatitudes during the 29–31 October 2003 geomagnetically disturbed period

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**Abstract**

This paper presents traveling ionospheric disturbances (TIDs) observations from GPS measurements over the South African region during the geomagnetically disturbed period of 29–31 October 2003. Two receiver arrays, which were along two distinct longitudinal sectors of about 18°-20° and 27°-28° were used in order to investigate the amplitude, periods and virtual propagation characteristics of the storm induced ionospheric disturbances. The study revealed a large sudden TEC increase on 28 October 2003, the day before the first of the two major storms studied here, that was recorded simultaneously by all the receivers used. This pre-storm enhancement was linked to an X-class solar flare, auroral/magnetospheric activities and vertical plasma drift, based on the behaviour of the geomagnetic storm and auroral indices as well as strong equatorial electrojet. Diurnal trends of the TEC and foF2 measurements revealed that the geomagnetic storm caused a negative ionospheric storm; these parameters were depleted between 29 and 31 October 2003. Large scale traveling ionospheric disturbances were observed on the days of the geomagnetic storms (29 and 31 October 2003), using line-of-sight vertical TEC (vTEC) measurements from individual satellites. Amplitude and dominant periods of these structures varied between 0.08–2.16 TECU, and 1.07–2.13 h respectively. The wave structures were observed to propagate towards the equator with velocities between 587.04 and 1635.09 m/s.

*Keywords:* Total electron content (TEC); Geomagnetic storm; Substorm; Traveling ionospheric disturbances (TIDs)

## 1. Introduction

The ionosphere is a highly dynamic plasma of the Earth's upper atmosphere which strongly depends on the electromagnetic radiation from the Sun. The ionosphere is a very important component of space weather studies. Of importance is the ionosphere's influence on trans-ionospheric radio signals, which modern society heavily rely on for many real-time or near real-time Global Navigation Satellite System (GNSS) applications, e.g. communication and navigation, and which the military and aviation still sometimes rely on for high frequency (HF) communication. In addition, the ionosphere introduces additional calibration problems for new radio astronomy interferometers, especially those operating on low frequencies, as discussed by Intema et al. (2009). Therefore the more the ionosphere is understood, the better the errors associated with it are predicted, modelled and mitigated. The ionosphere can be characterised by the total number of columnar electron density between a transmitter and a receiver, i.e. the total electron content (TEC). TEC measurements from ground based GPS network provide a powerful tool to study the time evolution of the ionosphere over a large region or on a global scale, see for example Chartier et al. (2012), Hernandez-Pajares et al. (2012), Tsugawa et al. (2007), and Tsai et al. (2001).

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It has been well documented that geomagnetic storms have adverse effects on the ionosphere, causing changes to geophysical features of the ionosphere. The response of the ionosphere to a geomagnetic storm depends on the local time of the storm onset, intensity of the storm, geomagnetic/geographic location of the observer, season, phase of solar cycle, etc. Because of the dynamic response of the ionosphere to a storm, many studies have been devoted to understanding the relationship between the nature of the storm and the response of the local, regional and global ionosphere to a particular storm. For example, Lopez-Montes et al. (2012) have looked at the impact that geomagnetic storms associated with large solar events between 2000 and 2006 have on the ionosphere at mid latitudes by using GPS stations in Mexico and found that these events may indeed affect the mid latitude ionosphere as they observed appreciable increases in TEC caused by storm induced ionospheric disturbances.

One of the effects of geomagnetic storms is the generation of large scale traveling ionospheric disturbances (LS TIDs) launched by high latitude sources such as Joule heating, Lorentz forces or particle precipitations (Valladares et al., 2009; Ding et al., 2007). It is commonly accepted that the LS TIDs are ionospheric manifestation of atmospheric gravity waves generated in the northern and southern auroral zones (Afraimovich et al., 2001). LS TIDs are not exclusively observed at high latitudes, e.g. Perevalova et al. (2008), but also at mid latitudes, e.g. Ngwira et al. (2012), Katamzi et al. (2012) and Ding et al. (2008). Mid latitudes LS TIDs are usually associated with meridional winds propagating equatorward (Ngwira et al., 2012; Shiokawa et al., 2002).

Although the study of storm induced LS TIDs has received wide interest world wide, relatively few studies of such structures have conducted in the South African region. Habarulema et al. (2013) did a comparison study of TEC response to the geomagnetic storms of 7–12 November 2004 at African equatorial and mid latitudes regions. Using South African ground based GPS and ionosonde measurements for mid latitudes, they observed that a traveling atmospheric disturbance could be responsible for short duration electron density enhancements and the upwelling of the ionospheric F region. Amabayo and Cilliers (2012) studied the response of South African mid latitude ionosphere to the strong geomagnetic storms of 31 March – 2 April 2001 and 7–9 September 2002 using ground based GPS, ionosonde, solar wind from ACE and ground based magnetometer measurements. They found that the storms had both negative and positive ionospheric effects over South Africa and observed TEC perturbations and spread F phenomenon which they associated with storm induced TIDs. Ngwira et al. (2012) using South African ground based GPS TEC and ionosonde foF2 measurements observed TID structures during the 15 May 2005 geomagnetic storm with velocities between 438 and 515 m/s. They associated these structures with equatorward meridional winds. Habarulema et al. (2013), Ngwira et al. (2012) and Amabayo and Cilliers (2012) highlighted that there are still unresolved issues in the understanding of the response of ionosphere to geomagnetic storms over the South African region. More studies of this nature are important for South Africa to meet its mandate as the Regional Space Weather Warning Center for Africa, especially in its frequency prediction *duties*.

This paper reports on the study of traveling ionospheric disturbances over the South African region during the geomagnetic disturbed period of 29–31 October 2003. The geomagnetic storms of 29 and 30 October 2003 belong to some of the most powerful storms studied in the recent years and thus many studies have been conducted to explore the response of the ionosphere to these storms in different latitudes, see for example Horvath and Lovell (2010), Valladares et al. (2009), Ding et al. (2007), Wang et al. (2007). Results presented in this paper will include amplitudes, periods and virtual horizontal velocities of TIDs estimated from TEC measurements from several GPS receivers along similar longitudes in South Africa.

Table 1
Geographic latitude (GLAT) and longitudes (GLON), and geomagnetic latitude (MLAT) and longitude (MLON) of the ionosphere measuring instruments used in this study. Geomagnetic coordinates obtained from wdc.kugi.kyoto-u.ac.jp/igrf/gggm/

| Station Code | Station Name | GLAT (° S) | GLON (° E) | MLAT (° S) | MLON (° E) |
|---|---|---|---|---|---|
| *GPS stations* | | | | | |
| SBOK | Springbok | 29.67 | 17.88 | 29.03 | 84.49 |
| CALV | Calvinia | 31.48 | 19.76 | 31.13 | 85.91 |
| HERM | Hermanus | 34.42 | 19.22 | 33.90 | 84.67 |
| ERAS | Ellisras | 23.69 | 27.70 | 24.89 | 95.45 |
| GEOS | Pretoria | 25.73 | 28.28 | 26.99 | 95.61 |
| ANTH | Aliwal North | 30.68 | 26.72 | 31.55 | 92.94 |
| ELDN | East London | 33.04 | 27.83 | 34.04 | 93.48 |
| *Ionosonde stations* | | | | | |
| LV12P | Louisvale | 28.50 | 21.20 | 28.46 | 88.00 |
| GR13L | Grahamstown | 33.32 | 26.51 | 34.09 | 92.10 |
| *Magnetometer stations* | | | | | |
| HER | Hermanus | 34.42 | 19.22 | 33.90 | 84.67 |
| HBK | Hartebeesthoek | 25.88 | 27.70 | 27.03 | 94.99 |