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# Observed effects in the equatorial and low-latitude ionosphere in the South American and African sectors during the 2012 minor sudden stratospheric warming

R. de Jesus[a,*], I.S. Batista[a], A.J. de Abreu[b], P.R. Fagundes[c], K. Venkatesh[c], C.M. Denardini[a]

[a] Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, SP, Brazil
[b] Instituto Tecnológico de Aeronáutica (ITA), Divisão de Ciências Fundamentais, São José dos Campos, SP, Brazil
[c] Universidade do Vale do Paraíba /IP & D, São José dos Campos, SP, Brazil

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ABSTRACT

In this paper, the effects of a minor sudden stratospheric warming (SSW) event of 2012 in the ionosphere over South American and African sectors have been studied using C/NOFS satellite data and GPS observations. Also, the magnetometer measurements obtained at two stations in the equatorial and low-latitude regions in the South American sector are presented. There were significant Vertical Total Electron Content (VTEC) depletions in the afternoon in both South American and African sectors during the 2012 minor SSW event. A novel feature of the present study is the reduction of the quasi 16-day oscillation (periods ranging from 11 to 20 days) in the daily averaged VTEC in the Brazilian and African sector during an SSW event. Also, the results for the Brazilian sector show an amplification of the ~2–6 day period in the daily averaged VTEC at equatorial and low-latitude regions, after the SSW temperature peak. This investigation shows that a minor SSW can affect the irregularities at ionospheric heights in the Brazilian and African sectors. Ground-based magnetometer measurements in the American sector shows strongly enhanced equatorial electrojet (EEJ) after the SSW temperature peak.

## 1. Introduction

SSW event is a process in the winter polar stratosphere generated by the interaction between the quasi stationary planetary waves and zonal mean flow in the stratosphere (Fuller-Rowell et al., 2011; Sumod et al., 2012). Goncharenko and Zhang (2008) have reported a link between the lower atmosphere and the ionosphere during a large-scale meteorological event known as sudden stratospheric warming (SSW). During an SSW event, the polar stratospheric temperature increases at least 25 K in a period of a week or less (McInturff, 1978).

Yiğit et al., (2009, 2012) have reported that gravity waves of lower atmospheric origin propagate strongly into the upper thermosphere. An important review of vertical coupling in the atmosphere-ionosphere system induced by internal waves generated in lower atmosphere has been provided by Yiğit and Medvedev (2015). Yiğit and Medvedev (2012) and Yiğit et al. (2014) have investigated the propagation of gravity waves originating in the lower atmosphere to the thermosphere during a SSW event, using a general circulation model that incorporates the spectral gravity waves parameterization of Yiğit et al. (2008). Another review paper by Yiğit et al. (2016) focuses, among others, on vertical coupling in the atmosphere and ionosphere system during the SSW events and connection to internal atmospheric waves. According to Yiğit and Medvedev (2012) and Yiğit et al., (2014, 2016), during the SSW events the thermosphere, coupled to the ionosphere, are influenced by small-scale gravity waves generated in the lower atmosphere.

Since 2009, numerous works have demonstrated significant ionospheric variability related with SSW events (Goncharenko et al., 2010a, 2010b, 2013; Liu et al., 2011; Korenkov et al., 2012; Chau et al., 2012; Jonah et al., 2014; Fagundes et al., 2015; Klimenko et al., 2015). Liu et al. (2011) have reported semidiurnal perturbation in both total electron content (TEC) and equatorial electrojet (EEJ) in the Asian sector during the 2009 SSW event. Goncharenko et al. (2010b) observed an enhancement and a suppression of the equatorial ionization anomaly (EIA) in the morning and afternoon sector, respectively, in the American sector during the SSW events which occurred in 2008 and 2009. Sumod et al. (2012) have observed ionospheric perturbation in the Indian sector during the January 2008 SSW event. Park and Lühr (2012) have reported that the E region dynamo changed significantly during the December 2001 SSW event. Goncharenko et al. (2010a) have reported a connection between changes in the high latitude stratosphere and the equatorial ionosphere. However, according to Goncharenko et al. (2010a), it is still very difficult to explain how

* Correspondence to: Av. dos Astronautas, 1758, Jardim da Granja, 12201-970 São Jose dos Campos, SP, Brazil.
*E-mail address:* jesus.rodolfo@hotmail.com (R. de Jesus).

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**Table 1**
Details of the magnetometers and GPS receivers sites considered in the present study.

| Station Name | Code | Geog. Lat. | Geog. Long. | Dip. Lat. | Local Time (LT)[a] |
|---|---|---|---|---|---|
| **GPS Receivers in the Brazilian Sector** | | | | | |
| Imperatriz | IMPZ | 05.5°S | 47.5°W or 312.5°E | 03.69°S | LT=UT – 3 h |
| Palmas | PAL | 10.2°S | 48.2°W or 311.8°E | 07.44°S | LT=UT – 3 h |
| Brasília | BRAZ | 15.9°S | 47.9°W or 312.1°E | 12.46°S | LT=UT – 3 h |
| Rio Paranaíba | MGRP | 19.2°S | 46.1°W or 313.9°E | 16.15°S | LT=UT – 3 h |
| Ourinhos | OURI | 23.0°S | 49.9°W or 310.1°E | 17.07°S | LT=UT – 3 h |
| Imbituba | IMBT | 28.2°S | 48.7°W or 311.3°E | 21.45°S | LT=UT – 3 h |
| Porto Alegre | POAL | 30.1°S | 51.1°W or 308.9°E | 21.61°S | LT=UT – 3 h |
| **GPS Receivers in the African Sector** | | | | | |
| Cotonou, Benin | BJCO | 06.4°N | 357.5°W or 02.5°E | 06.1°S | LT=UT |
| Libreville, Gabon | NKLG | 00.4°N | 350.3°W or 09.7°E | 13.7°S | LT=UT+1 h |
| **Magnetometers in the Brazilian Sector** | | | | | |
| São Luís | SL | 02.3°S | 44.6°W or 315.4°E | 02.43°S | LT=UT – 3 h |
| Eusébio | EUS | 03.9°S | 38.4°W or 321.6°E | 07.43°S | LT=UT – 3 h |

[a] UT – Universal Time.

such geographically separated regions are connected with each other in altitude and latitude. Vineeth et al. (2009) have investigated the equatorial counter electrojet (CEJ) occurrences over Trivandrum (8.5°N, 76.5°E, 0.5°N diplat.) related with SSW events. According to Vineeth et al. (2009), the interaction of the lower atmospheric waves with the tidal components at the upper mesosphere, due to the enhanced planetary wave activity as a result of the lower atmospheric circulation changes during the SSW event, and subsequent modification in the tidal components are suggested to be the mechanisms for the occurrence of CEJs having planetary wave periods. Chau et al. (2012) provided an important review about the ionospheric perturbations during the SSW events. Chau et al. (2012) suggested that more work is needed for accurate identification and specification of ionospheric disturbances related to SSW events.

During the post-sunset period, equatorial ionospheric irregularities are generated in the equatorial F layer due to the growths of Rayleigh-Taylor instability and the presence of seed perturbations (Hysell et al., 1990; Sultan, 1996; Paznukhov et al., 2012; Ngwira et al., 2013a; Deng et al., 2013). De Paula et al. (2015) have reported that the scintillation intensity (represented by the S4 index) in a low-latitude station in the Brazilian sector weakened significantly during SSW events.

The present paper discusses the ionospheric response in the equatorial and low-latitudes in the South American and African sectors during a minor SSW event which occurred on January-February 2012. The observations from C/NOFS satellite data and a chain of nine Global Positioning System (GPS) stations are used in this study. Ground magnetometer measurements from two stations in the South American sector were used to understand the variability of the equatorial electrojet (EEJ) during the SSW event. Wavelet power spectra analysis was employed to find the significant periodicities of the daily average of VTEC (vertical total electron content) data during the 2012 SSW event. The main objectives of this investigation are to study the generation or suppression of the ionospheric irregularities and electrodynamics of the ionosphere in the South American and African sectors during the 2012 SSW event. To the authors' knowledge, this is the first simultaneous study of the response of the ionospheric F layer in the South American and African sectors during a minor SSW event, using C/NOFS (ion density) and GPS (VTEC and phase fluctuations) data.

## 2. Observations

In this work, the stratospheric temperature at 10 hPa and 90°N, and zonal mean wind at 10 hPa and 60°N were obtained from the Goddard Space Flight Center (GSFC) National Aeronautics and Space Administration (NASA) online data service http://acdb-ext.gsfc.nasa.gov/Data_services/met/ann_data.html. The solar index F10.7 was obtained from http://omniweb.gsfc.nasa.gov/form/dx1.html website. The Kp index was collected from http://ftp.gwdg.de./pub/geophys/kp-ap/tab/ website, and the Dst index was collected from http://wdc.kugi.kyoto-u.ac.jp/dstdir/ website. All these data were obtained during the minor SSW event that occurred from 10 January to 3 February 2012 (DOY 10 – 34). For comparison with the disturbed time stratospheric temperature, the thirty-four-year median values of the stratospheric temperature are also presented. Generally, to generate the historical mean of the stratospheric temperature, all data available from 1979 until the year of occurrence of the SSW event are used. Consequently, the 34 years of data (used to generate the historical mean of the stratospheric temperature) correspond to all available data by NOAA satellite from 1979 to 2012 (year of occurrence of the SSW event).

The Global Positioning System (GPS) observations were obtained from 9 GPS receiving stations in the Brazilian and African sectors during the period from 10 December 2011 to 17 February 2012 (DOY 344–48). The GPS data have been used to calculate the vertical total electron content (VTEC) in units of TECU (1 TECU=$10^{16}$ electrons/$m^2$) (Wanninger, 1993) and phase fluctuations (rate of change of TEC) in TECU/min (Aarons et al., 1996). The stations named, Imperatriz (IMPZ), Palmas (PAL), Brasília (BRAZ), Rio Paranaíba (MGRP), Ourinhos (OURI), Imbituba (IMBT), and Porto Alegre (POAL) belong to the "Rede Brasileira de Monitoramento Contínuo de GPS (RBMC; Brazilian Network for Continuous GPS Monitoring)". The Cotonou (BJCO) and Libreville (NKLG) stations belong to the International GNSS Service (IGS) for Geodynamics. All the GPS stations are located in the South American and African sectors and cover equatorial to low-latitude regions. Table 1 and Fig. 1 present the details of all the magnetometers and GPS stations from which data have been utilized in the present investigation.

The slant TEC (STEC) measurements derived from GPS data recorded at our nine stations were converted into VTEC according to the relation defined by Mannucci et al. (1993), Langley et al. (2002) and Rao et al. (2006):

$$VTEC = \{STEC - (B_R + B_S)\}/OF(E) \quad (1)$$

$$OF(E) = \frac{1}{\cos(y)} = \left[\frac{1}{\sqrt{1 - (R_E \times \cos(E)/(R_E + H_S))^2}}\right] \quad (2)$$

where $B_R$ and $B_S$ are the GPS satellite differential delay and the receiver differential delay, respectively, $OF(E)$ is the obliquity factor with the zenith angle ($y$) at an ionosphere pierce point, $E$ is the elevation angle of the satellites, $R_E$ is the mean Earth's radius, and $H_S = 350\ km$ is the

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