Study of ionospheric irregularities during intense magnetic storms

L. F. C. de Rezende, E. R. de Paula, Inez S. Batista, I. J. Kantor, M. T. H. Muella, INPE, São José dos Campos,SP, Brazil

Abstract

The effects of intense magnetic storms over ionospheric irregularities were analyzed using GPS data from the stations of São Luís (2.57^0 S, 44.21^0 W, dip latitude 1.73^0 S) in the equatorial region, São José dos Campos (23.07^0 S, 45.86^0 W, dip latitude 18.01^0 S) and Cachoeira Paulista (22.57^0 S, 45.07^0 W, dip latitude 18.12^0 S) both under the Equatorial Ionospheric Anomaly (EIA), and São Martinho da Serra (29.28^0 S, 53.82^0 W, dip latitude 18.57^0 S), located in the South of Brazil. Total Electron Content (TEC) data were also analyzed. The two storms analyzed occurred in October 28-31, 2003 and in November, 7-11, 2004. The Dst (Disturbance Storm-Time) index reached –401 nT around 23 UT in October 30 and –373 nT around 7 UT in November 8. In the night of 29/30 October, during the storm main phase, it was observed that TEC in São José dos Campos reached high values in comparison to a quiet magnetic day. Scintillation was strongest for Cachoeira Paulista (under EIA) and São Martinho da Serra, South of Brazil, compared to the quiet day (Oct 10). During the November 8 storm, TEC keeps the behavior of a quiet day except during days 10 and 11, when a large TEC decrease was observed. The scintillation was inhibited for the São Luís and São José dos Campos stations.

Introduction

The magnetosphere:

The interaction of the solar wind with the Earth's magnetic field produces a cavity with a tail that extends in the opposite direction to the Sun (Davies, 1990). This cavity is called magnetosphere (see Figure 1). During magnetic storms solar plasma supersonic emissions distort the Earth's magnetic field and magnetosphere. A magnetic storm consists of sporadic and polar disturbances, the lifetimes being usually one or more hours (Gonzalez et al, 1994). The magnetosphere can extend like a long tail by hundreds Earth's radii. Energy from the solar wind is transferred to the ionosphere-thermosphere-magnetosphere system, producing an enhancement of particles precipitation, intensifying convection electric fields in the magnetosphere and currents in the high latitude ionosphere. The structure and dynamic of the thermosphere and ionosphere is globally affected due to the increase of ionospheric conductivity, the Joule heating and the ion drag in the upper atmosphere of high latitudes. The disturbed thermospheric circulation changes the neutral composition distribution and moves the plasma along magnetic field lines, modifying the rates of production and recombination of ionized species (Fedrizzi, 2004).

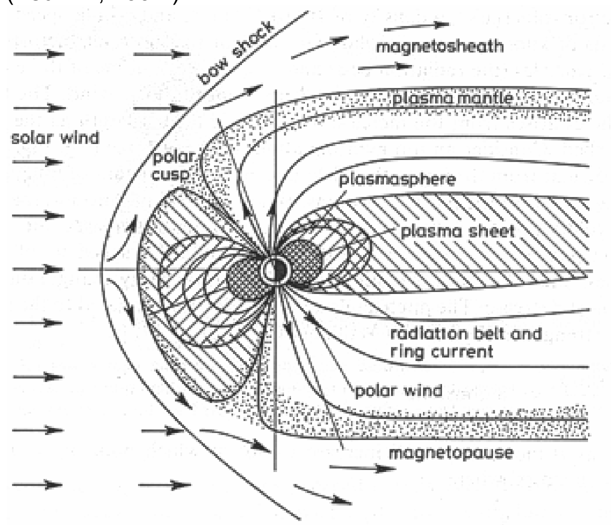

Figure 1 – Earth magnetic field
Source: Davies, K. (1990)

Prereversal peak:

In the equatorial F region, soon after the sunset, the plasma moves up forming a peak that is called prereversal peak, around 21 to 24 UT (18 to 21 LT). The prereversal peak is explained through the action of uniform neutral wind in the F region (see Figure 2). Close to the night-day terminator, an electric field E_z generated by the F region dynamo ($-\mathbf{U}\times\mathbf{B}$) is mapped to the conjugated E region along magnetic field lines giving origin to a electric field E_θ directed to the equator. This electric field generates a Hall current, $J_{\theta\phi}$, directed to west.

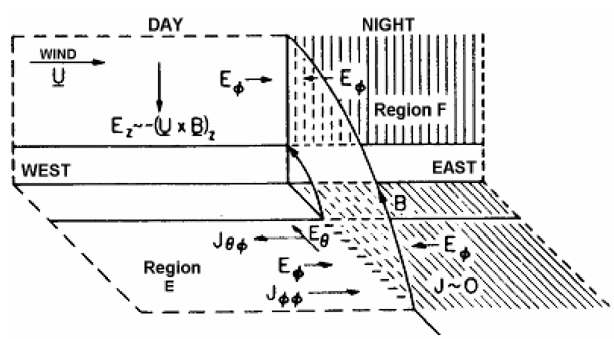

Figure 2 – Simple model to explain of the prereversal peak caused by a uniform wind U.

SOURCE: changed from Farley *et al.* (1986).

No current flows in the nocturnal E region and consequently negative charge accumulates in the terminator and gives origin to an E_ϕ field and to a current $J_{\phi\phi}$ that tries to cancel $J_{\theta\phi}$ (shown in Figure 2). E_ϕ is then mapped back to the F region and it causes, firstly, an upward **E×B** drift of the plasma to higher altitudes and soon after, a downward drift around 21 LT.

Equatorial Ionospheric Anomaly (EIA):

Equatorial Ionospheric Anomaly or Appleton Anomaly consists of an ionospheric region with high electronic density, observed around 15 degrees North and South of the magnetic equator. This electronic density increase in low latitudes has its origin in the vertical E×B plasma drift of the equatorial F layer. As previously shown, the zonal electric field that exists in the equatorial ionosphere is directed to the east during day, creating an upward $E\times B/B^2$ vertical drift. Soon after the sunset, this eastward electric field is increased (prereversal peak) and the plasma from F region drifts to high altitudes. Meanwhile, the plasma from low altitudes quickly decline due decreasing of the intensity of incident solar radiation (Kelley, 1989). After lifting to high altitudes in the equatorial region, the plasma starts a descent movement along magnetic field lines. This movement happens due to the action of gravity **(**g**)** and pressure gradient (∇p) forces. This phenomenon (the plasma elevation and the subsequent descent along magnetic field lines to low latitudes) is known as the Source Effect (see the scheme in Figure 3).

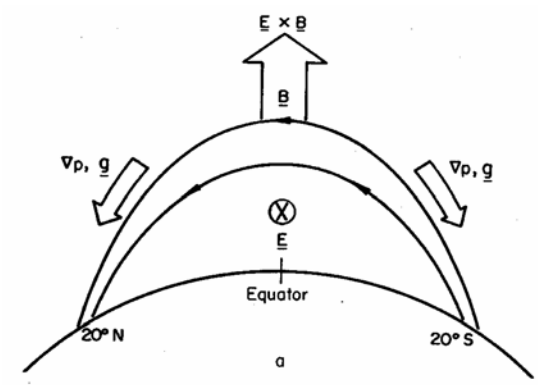

Figure 3 – Appleton Annomaly scheme

Ionospheric scintillation:

The ionospheric scintillation can be defined as fluctuations in the amplitude or phase of a radio wave, as the result of its propagation through a region where irregularities in the electronic density are present. The irregularities produce a scintillation or amplitude intensity pattern on the ground which also drifts from west to east during magnetically quiet periods and is elongated to north-south direction (Kintner et al., 2001). The ionospheric scintillations are highly dependent of the upward vertical plasma drift in the equator (Fejer et al., 1999), so penetration of electric field from magnetospheric origin during storms can trigger or can inhibit then. The scintillation amplitude is dependent also from the background ionization (TEC).

Method

A few magnetic índices like Dst, Kp (planetarische Kennziffer) e AE (Auroral Electrojet) were used to analyze the intensity of the storms. Other parameters were used to study the behavior of the plasma and of the ionospheric irregularities like TEC and S_4 index. TEC corresponds to the number of electrons contained in the column of unitary base that extend from Earth surface to a determined height in the atmosphere. This parameter is measured in the TEC units (1 TECU = 1 x 10^{16} electrons/m^2). The S_4 index is the normalized standard deviation of the signal intensity for each minute. We used the double frequency TurboRoque ICS-4000Z, Allen-Osborne Associates receivers TEC measurements and SCINTMON receivers for scintillation monitoring. Turbo Rogue is a optimized receiver for ionospheric TEC measures and it is able to track 8 satellites simultaneously. The SCINTMON receiver was implemented through a ISA (GEC Plessey GPS Builder-2[TM]). It is able to sample simultaneously signals from up to 11 satellites. The data are only collected from satellites with elevation angle higher than 10 degrees. GPS Wide Band Power (WBP) of L1 (1,57542 GHz) that is transmitted by GPS satellites is sampled at 50 Hz rate.The SCINTMON receivers data analyzed were for São Luís, São José dos Campos, Cachoeira Paulista and São Martinho da Serra stations. TEC data (from Allen-Osborne receivers) were analyzed for the São Luís and São José dos Campos stations (see Figure 4).

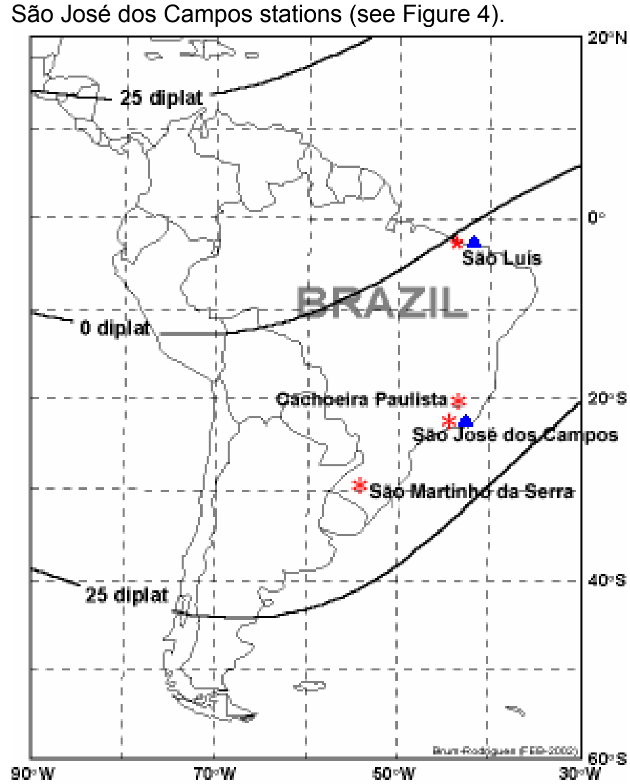

Figure 4 - Location of the receivers: SCINTMON * and Allen-Osborne ▲

The disturbed days were compared to quiet days. Prior and post-storm periods were analyzed.

Results

We observed than TEC had different behaviors in the periods of analyzed storms. For the October 2003 storm, the strongest main phase occurred in 30 October around 0100 UT (see Figure 5). The main phase was around the prereversal peak period. In São José dos Campos, during the October 29/30 night, under the EIA, TEC reached highest values than a quiet day (October, 10, 2003) simultaneously with a TEC decrease at equatorial station of São Luís. This is an evidence of magnetospheric eastward electric field penetration to low latitudes during this storm that increases the EIA. In São José dos Campos and São Martinho da Serra larger scintillation occurred (compared to quiet time); it lasted after midnight which is frequently observed during storm time. During November 8 storm, the main phase of the first storm occurred around 6 UT, when the ionospheric ionization is still low, TEC had a behavior of a quiet day for both stations and the scintillation was inhibited for São Luís and São José dos Campos stations (see Figure 6).

Conclusions

There is a complex dependence of the ionospheric irregularities with the magnetic activity. One magnetic storm can inhibit the irregularities during their period of occurrence or it can trigger irregularities at any month of the year, even during a period when irregularities are not expected (de Paula et al., 2004). This behavior during storm is very complex because it depends of the hour of the storm commencement, of the season, and if the storm occurred before the end of another storm. During a magnetic storm an electric field of magnetospheric origin can penetrate to equator reinforcing the normal E layer electric field (direct penetration) triggering irregularities or can contributing to its inhibition (disturbance dynamo). During one of analyzed periods (October 2003), the storm induced eastward magnetospheric electric field that penetrated to the magnetic equator and intensified the vertical plasma drift, creating favorable conditions for the irregularities to grow. The large scintillation period in the Brazilian territory occurs in the months from September to March in the time period from 21 to 03 UT (18 to 24 LT). The scintillation occurred even after 03 UT and this behavior is typical of storm time. In the November period, the storm main phase occurred during dawn, about 6 UT (day 8) and no scintillation was observed in the subsequent days. This was due to the action of the westward magnetospheric electric field generated by the disturbance dynamo (Fejer and Scherliess, 1995; Scherliess and Fejer, 1997) that penetrated to the magnetic equator and inhibited the prereversal plasma drift after sunset and consequently inhibited the GPS scintillations. Also, the TEC was completely washed out during November, 10 and 11 up to 9 UT that contributed substantially for scintillation inhibition.

References

Davies, K., Ionospheric Radio, Short Run Press Ltda, England, 1990.

de Paula, E. R., K. N. Iyer, D. I. Hysell, F. S. Rodrigues, E. A. Kherani. A. C. Jardim, L. F. Rezende, S. G. Dutra, N. B. Trivedi, Multi-technique investigations of storm-time ionospheric irregularities over the São Luís equatorial station in Brasil, Ann. Geophysicae, in press, 2004.

Fedrizzi, M., Estudo do Efeito de Tempestades Magnéticas na Ionosfera Utilizando Dados do GPS, Phd Dissertation, INPE, Brazil, 2003.

Fejer, B.G., L. Scherliess, Time dependent response of equatorial electric fields to magnetospheric disturbances, Geophys. Res. Lett., 22, 851-854, 1995.

Fejer, B.G., L. Scherliess, E.R. de Paula, Effects of the vertical plasma drift velocity on the generation and evolution of equatorial spread F, *J. Geophys. Res.*, 104, 19859, 1999.

Gonzalez, W. D., Joselyn,J.A., Kamide,Y., Kroehl,H.W., Rostoker, G., Tsurutani,B.T., Vasyliunas, V.M., What is a geomagnetic storm?, Journal Of Geophysical Research, Vol. 99, No. A4, Pages 5771-5792, April,1, 1994.

Kelley, M. C. The earth’s ionosphere: plasma physics and electrodynamics, San Diego: Academic Press, USA, 1989..

Kintner, P. M., Kil, H., Fading timescales associated with GPS signals and potential consequences, Radio Science, Vol. 36, Number 4, Pages 731-743, July/August 2001.

Scherliess, L., Fejer, B. G. Storm time dependence of equatorial disturbance dynamo zonal electric fields. Journal of Geophysical Research, v. 101, n. A11, p. 2437-24046, 1997.

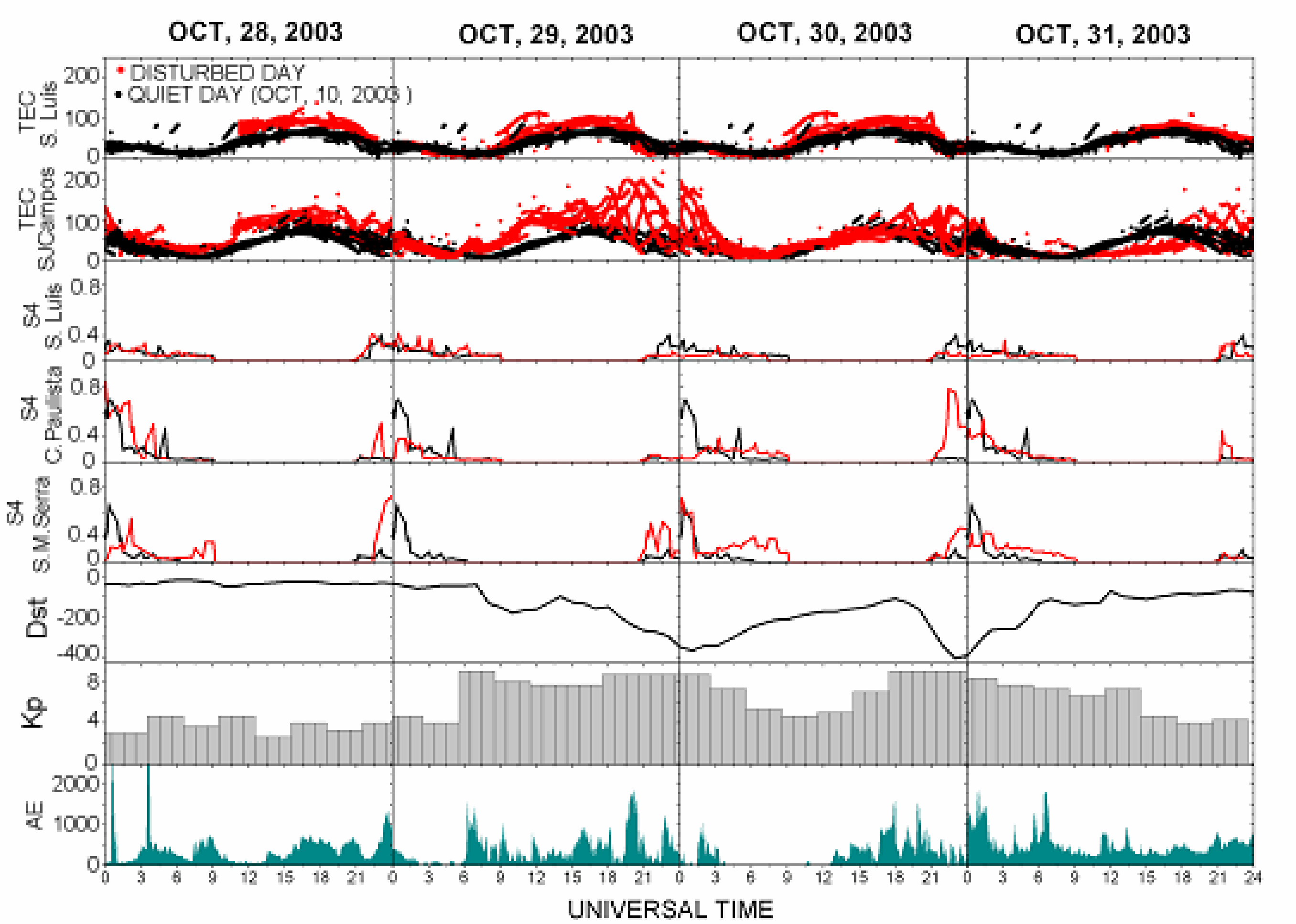

Figure 5 – Magnetic indices: TEC, S4, Dst, Kp, and AE to period of October, 28-31, 2003.

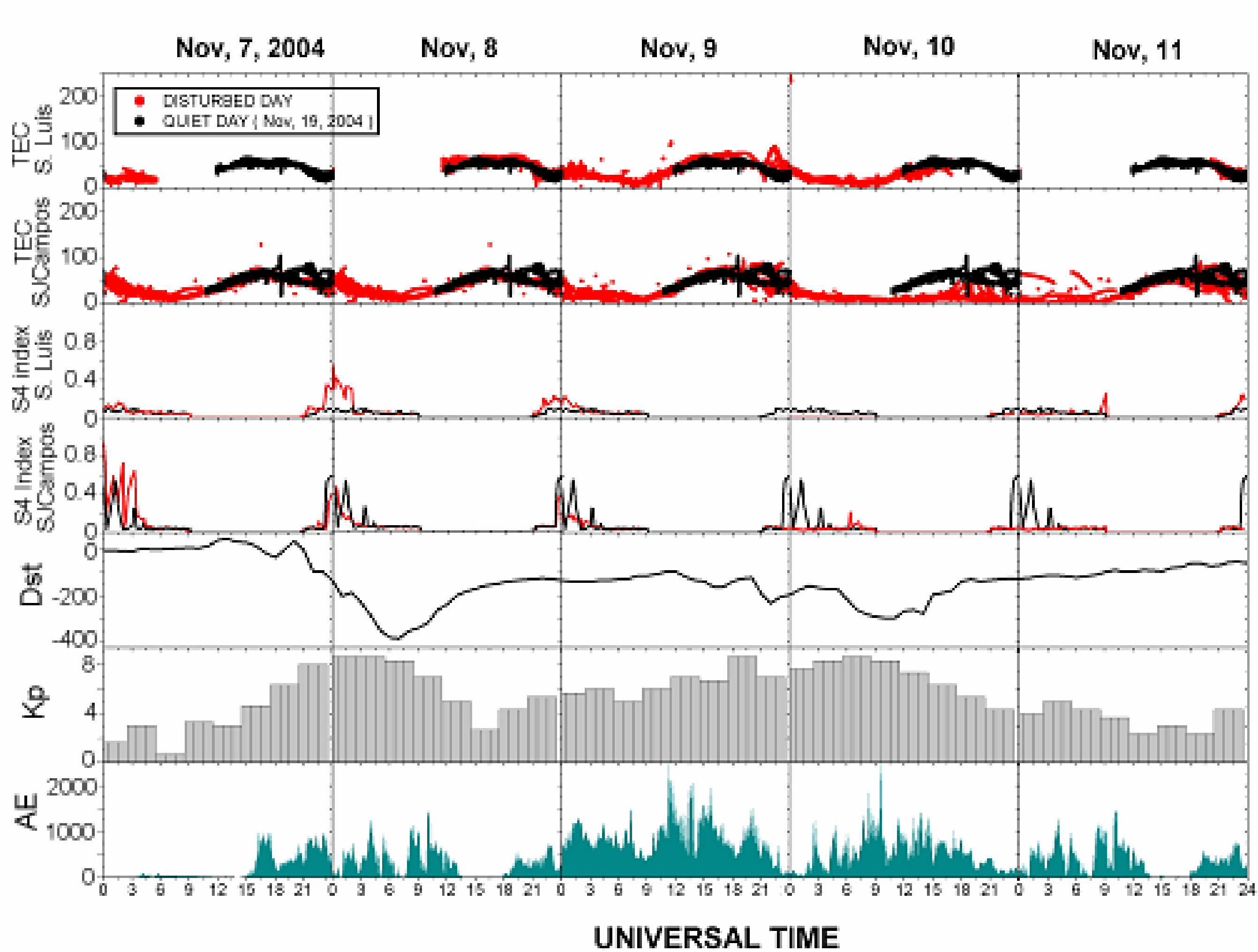

Figure 6 – Magnetic indices: TEC, S4, Dst, Kp, AE to period of November, 7-11, 2004.