Anti-correlation between magnetic storms and ionospheric scintillation observed at stations in the equatorial anomaly.

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Abstract

Ionospheric scintillations are due to the presence of plasma irregularities in the ionosphere, which show seasonal dependence (occur in September-March) and with greater intensity during periods of high solar activity. It was studied the effect of magnetic storms on the ionospheric scintillations during the maximum (1999-2001) and minimum (2006-2007) of solar activity. To represent the intensity of the scintillations, it was used hourly averages scintillation index S4 of São José dos Campos and Cachoeira Paulista stations (under the peak of the Equatorial Ionization Anomaly - EIA), São Luís and Natal (near the valley of the EIA) and Cuiabá (between valley and peak of the EIA). Using the geomagnetic indices Kp and Dst to represent the magnetic activity, it was found an anti-correlation in the GPS amplitude during the storm main phase. This represents an improvement of the GPS signal reception during magnetic storms. This inhibition of scintillations is associated with penetration of electric fields from the disturbed dynamo, which inhibit the formation of the prereversal peak plasma vertical drift, which is one of the main factors in the generation of plasma irregularities in the ionospheric F region. The prereversal peak inhibition and consequently a decrease in the S4 scintillation index occurs predominantly when the storm main phase happens in the range of 1000 to 1600 LT. In this study it is analyzed the relation between S4 and Dst indices during this local time interval.

Introduction

Large quantity of energy is deposited in the high latitude ionosphere during periods of strong geomagnetic activity (magnetic storms), enhancing the electric field and electrical conductivity, causes intense currents to flow there and giving rise to increased Joule heating during these events. The neutrals thus get heated and a disturbance dynamo is set up by the changed neutral wind at high latitudes (Blanc and Richmond, 1980). Disturbance dynamo and prompt penetration of electric fields are the major sources, for modulating the ionospheric electric field and hence the dynamics of equatorial ionosphere, due to increased magnetic activity. The perturbation electric field associated with Rayleigh-Taylor (R-T) plasma instability, which produces the ESF irregularities, that give rise to the observed scintillations causes rapid changes in the plasma vertical drift in the initial phase of development of irregularities (Bhattacharyya et al., 2001).

The phenomenon, known as ionospheric scintillation, is the rapid fluctuation of the amplitude of the RF signal, which arise when an RF signal passes through the ionospheric region that contains plasma density irregularities (Kintner et al, 2007). In the presence of magnetic storm an ionospheric global perturbation is observed in the GPS L1 band signal fluctuation, and consequently the scintillation index S4 is enhanced (de Paula et al., 2004). But there are storm nights during the principal phase (Max. Dst) when the scintillation index is very low comparing with prior and subsequent days.

In this paper will be used a multitechnique measurements using GPS L1 band (1.575 GHz) amplitude scintillation of stations in the Brazilian territory, and using h´F digisonde observations from the São Luís station, to study the day-to-day variability of ESF and their dynamics in the presence of magnetic storms.

Data Analysis

The main objective of this work is to analyze the effects of the storm initial, main and recovery phases for over the ionospheric scintillation using GPS data from the Brazilian stations at different latitudes and longitudes.

The stations are located near the valley of EIA (São Luís and Natal), between the valley and peak of EIA (Cuiabá) and under the peak of the EIA (São José dos Campos and Cachoeira Paulista).

The Table 1 lists the geographic latitudes and longitudes coordinates and the dip latitude of the five stations, located under the south side of the EIA -Equatorial Ionization Anomaly-, considered in this paper.

Stations	Lat.	Long.	dipLat.
São Luís:	2.33ºS	44.2ºO	**1.5ºS**
Natal:	5.84ºS	35.2ºO	**10ºS**
Cuiabá:	15.5ºS	56.1ºO	**6.1ºS**
São José dos Campos:	23.1ºS	45.8ºO	**17.1ºS**
Cachoeira Paulista:	22.4ºS	45.0ºO	**16.8ºS**

Table 1. Geographic coordinates of the ground-based stations.

It was compared scintillations for the last solar cycle, in maximum (1999-2001) and minimum (2006 - 2007) solar activity in these stations, in the months September to March (a period of high scintillation activity), when the data are present. It was selected the storms in these periods with Dst <-100 nT. Only data of January 2000 presented Dst = -97 nT. The data during descendent and ascendent phases are not analysed. When there are no São José dos Campos data the Cachoeira Paulista data were used. It was used the h'F digissonda data from São Luís station for the same periods. A similar study was conducted for the years 2003 to 2005 (Bonelli, 2008) and there are several studies examining the years 2002-2003 in the Brazilian region (Muella et al., 2008, Rezende et al., 2008, Abdu et al., 2008).

Figure 1 shows the scintillation index S4 versus local time in presence of the main phase (minimum Dst) for seven magnetic storms with S4 data collected at diferent stations, for three local time intervals (00 – 08, 08 – 16, and 16 – 24 hours), for high solar activity. It can be observed S4 index inhibition during the main phase of such storms was observed only when the main phase occurred during the 08 – 16 LT interval, in the equinoxes and summer solstice seasons. When the main phase occurred in the range of 2 to 8 LT no effect in the S4 index was observed. Some storms with main phase occurring in the range of 18 to 24 LT were observed however there were no GPS data and it was presented only the S4 index behavior for October 2001 and no conclusive result could be inferred. For low solar activity it was observed just one strong stom (Dst<-100 nT).

It were studied 11 magnetic storms of which 6 strong magnetic storm (with Dst<-100nT, according Gonzales et al. (1994)), that occurred during the solar maximum and just the December 15, 2006 storm during the solar minimum, and four moderate magnetic storms that happened in solar minimum.

The drift velocity **ExB** during solar maximum is more intense than during the solar minimum activity, lifting upward the ionospheric plasma to higher altitudes. So during solar maximum the crests of the EIA reach higher latitudes compared to solar minimum. In this work it is presented the digisonde h'F parameter to represent the layer upward movement. It is shown in Figure 2 the h'F data of São Luís for maximum and minimum solar activity.

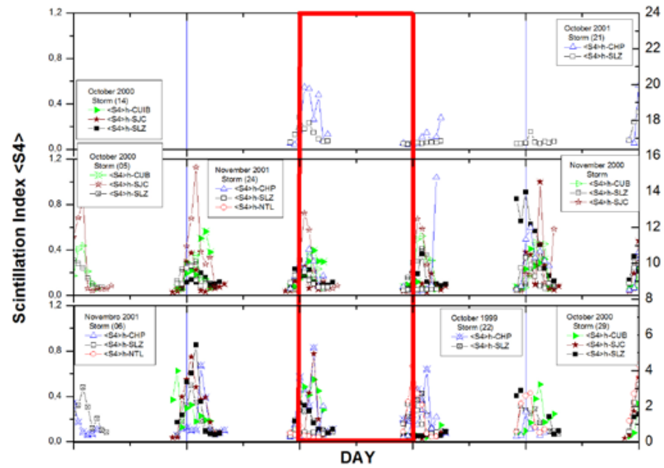

Figure 1. Scintillation index S4 versus local time. Hourly <S4> data are being used during the storm initial phase (left), main phase (within the square in red) and recovery phase (right) with the local time occurrence showed in the right vertical axis. The symbols represent the data collected in each Brazilian station.

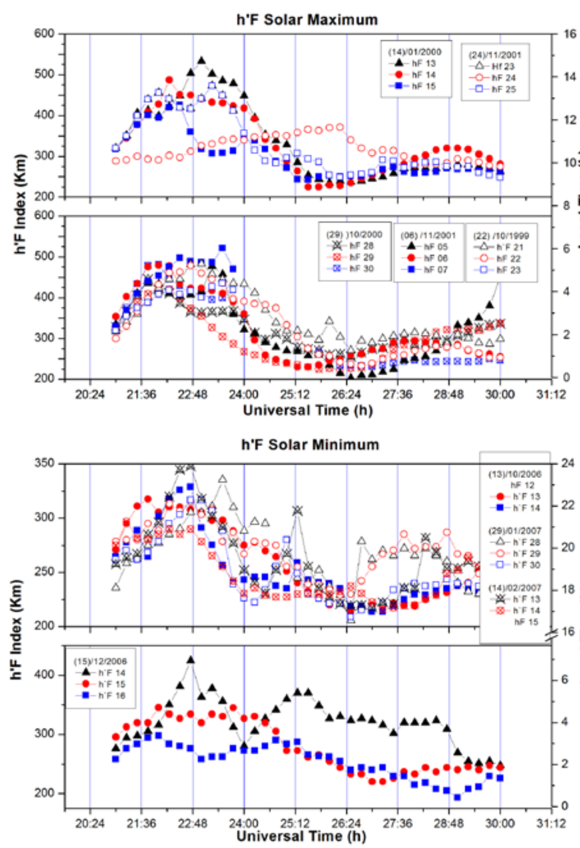

Figure 2. h'F parameter versus universal time for solar maximum (upper panels) and solar minimum (lower panels). The symbols represent the day when each magnetic storm phase happened, and in different formats to differentiate each storm.

In Figure 2 the 1600 to 2400 LT and 0800 to 1600 LT data are not presented in the upper panels and lower panels respectively due to absence of digisonde data from the magnetic storms. It is shown the h'F data of prior, during and consequent days of the magnetic storms.

For the period in which the 09 magnetic storms showing in the Figure 2 it can be seen that around 1945 LT there is peak in the h'F parameter. It was observed that the h'F for the day in the storm main phase (maximum Dst) is less than the initial phase, and in many cases higher than the recovery phase, during the maximum and minimum solar.

There were 03 magnetic storms that occurred in the solar maximum, and about 04 in the solar minimum with high Kp when there is a decrease in the S4 index during the main phase (max. Dst), as can be seen in Figure 3.

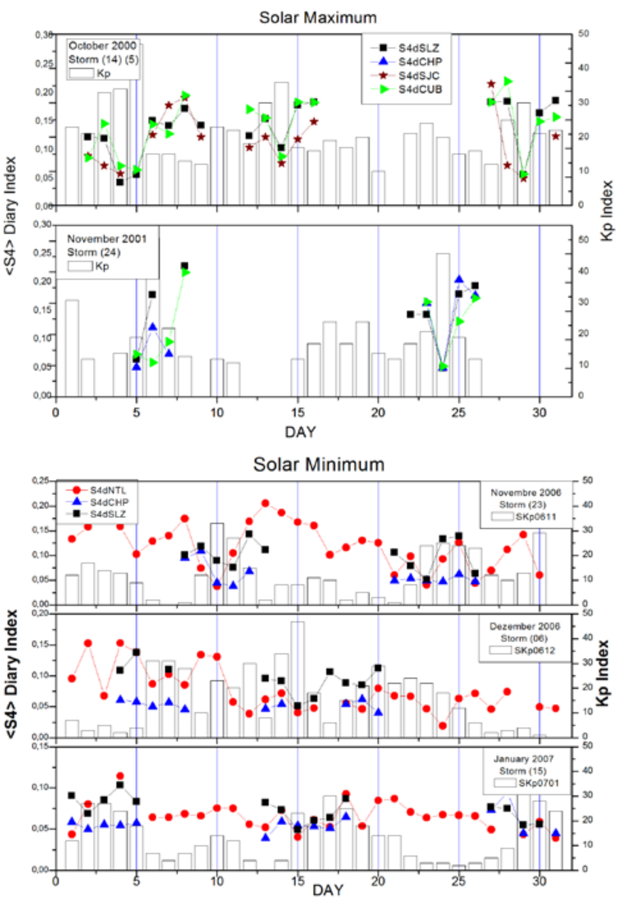

Figure 3. Average S4 and Σ(Kp) versus day for maximum (upper panels) and minimum (lower panels) solar activity. Each symbol represents one station where the data was available.

In Figure 3 it was used the Kp sum for each day (ΣKp), and the numbers between parentheses is the day when there is maximum Dst in the 08-16 LT interval. The Figure represents the day-to-day behavior of the magnetic storm phases, magnetic activity (Kp index) and S4 average index.

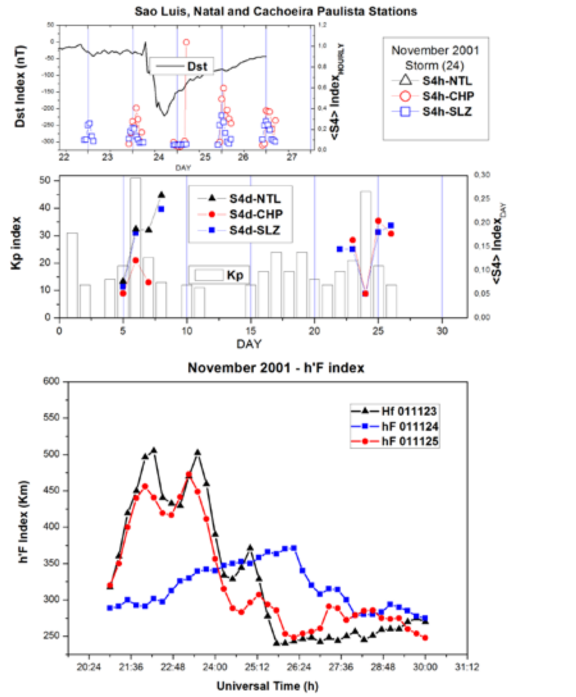

Figure 4. November 2001 storm. The upper two panels shows <S4> data from São Luís and Cachoeira Paulista stations and the Kp and Dst indices in function of the day. The lower panel shows h'F parameter for the days 23, 24 and 25 of November 2001. The magnetic storm main phase occurred on day 24.

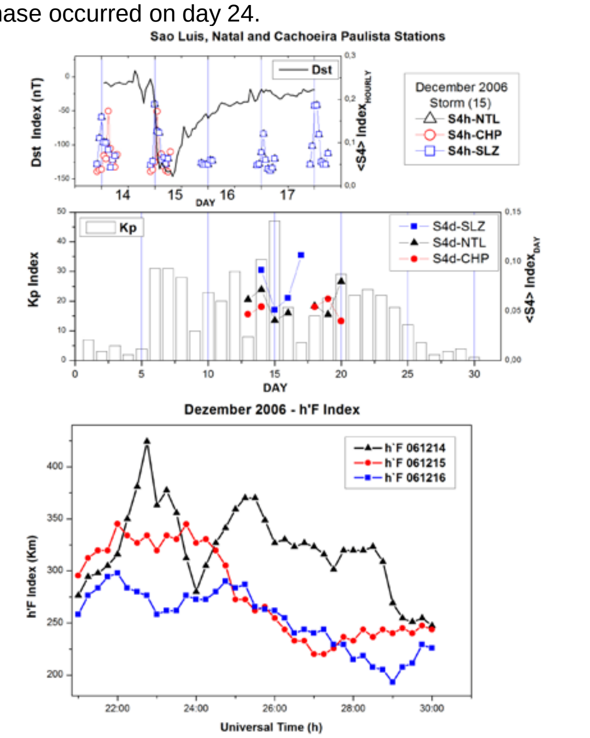

Figure 5. December 2000 storm. The upper two panels shows <S4> data from Natal, São Luís and Cachoeira Paulista stations and the Kp and Dst indices in function of the day. The lower panel shows h'F parameter for the days 14, 15 and 16 of December 2006. The magnetic storm main phase occurred on day 15.

Following it will be presented the data analysis of two magnetic storms, one for each solar activity period. In the solar maximum it was selected the November 2001 (day 24) and December 2006 (day 15) in the solar minimum. Only these two magnetic storms are presented in details to explain the scintillation attenuation observed during the storm main phase.

The strong storm of November 2001, shown in Figure 4, presents very strong attenuation in the <S4> scintillation index for the stations of São Luís and Cachoeira Paulista on day 25 (below 0.2 in S4 index), when Dst reached a maximum value of -221nT at 14 UT.

The strong storm of December 2006, shown in Figure 5, minimum solar activity, presents very strong attenuation in the <S4> scintillation index (below 0.1 in S4 index) in the night of the day 15 (it can be seen in the upper panels) for the stations of Natal and São Luís, when the Dst reached -146 nT at 08 UT.

This effect in the <S4> index scintillation observed during the storm main phase is due to the disturbance dynamo electric fields penetration into low latitudes in the opposite direction of the quiet time electric field, inhibiting the prereversal peak and consequently the irregularities generation. The São Luís h'F parameter decrease during the storm phase (18-21 LT) of the November 2001 and December 2006, compared to the other storm phase supports the prereversal peak inhibition.

Conclusions

It was compared <S4> scintillation data from ionospheric stations in the Brazilian territory under the EIA during strong magnetic storms (daily Kp index more than 30) in maximum and minimum solar activity of the last solar cycle. It can be observed S4 index inhibition during the main phase of such storms occurring during the 08 – 16 LT interval, in the equinoxes and summer solstice seasons.

The h'F parameter peak around 1945 LT during the storm main phase day (maximum Dst) was lower than the initial phase as it can be observed at Figure 2, during solar maximum and solar minimum activity. The h'F peak is many times during the main phase larger than the h'F during the recovery phase.

This effect in the <S4> index scintillation observed during the storm main phase is due to westward electric fields from the disturbance dynamo. These westward electric fields are in the opposite direction of the quiet time electric field and these inhibit the prereversal peak and consequently the irregularities generation.

Acknowledgments

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