Sudden Stratospheric Warming Event Influence on the Equatorial Ionization Anomaly

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Abstract

The present study investigates the ionospherics effects and influences on the equatorial ionization anomaly (EIA) over the Brazilian region caused possibly by a sudden stratospheric warming (SSW) event that occurred in Northern Hemisphere during January – February 2009.

We use digisondes installed in Fortaleza (3.8° S; 38° W) and Cachoeira Paulista (22.5° S; 45° W) and total electron content (TEC) from GPS receivers installed in São Luís (2.6° S; 44.2° W) and São José dos Campos (23.2° S; 45.8° W) to obtain the parameters ΔfoF2 (F2 layer critical frequency variation) and ΔVTEC (vertical TEC variation) respectively, which can be used to quantify the intensification or suppression of the EIA.

Introduction

The presence of an eastward electric field at the magnetic equator, in the presence of the northward geomagnetic field, causes an upward $\vec{E} \times \vec{B}$ plasma drift that moves the ionization to altitudes where the diffusion along magnetic field lines becomes the most important process. This plasma diffusion along magnetic field lines brings the plasma back to lower altitudes but at latitudes away from the geomagnetic equator. This process, known as fountain effect, is the responsible for the formation of two peaks in density located at approximately 15^{o} north and south and for the trough at the equator (Figure 1).

The EIA variability is strongly linked with geomagnetic field disturbances, but during geomagnetically quiet periods, the main agent of the equatorial region plasma drift is the interaction between the ionosphere and thermospheric winds (Richmond, 1995), which are highly variable as a result of changes in the global tidal forcing, and effects of irregular winds, planetary and gravity waves (Chau et al., 2010).

A SSW event is a sudden breakdown of the stratospheric polar vortex caused by dynamical forcing of upward propagation planetary waves from the troposphere and their non-linear interaction with the zonal mean flow (Matsuno, 1971), where the polar vortex of westerly winds in the Northern winter hemisphere abruptly (in a few days' time) slows down (minor event) or even reverses direction (major event), accompanied by a rise of stratospheric temperature by several tens degrees (Chau et al., 2009).
A SSW event can generate waves and disturb the winds in the upper atmosphere. The winds are responsible for the dynamo mechanism that generates the ionospheric electric fields. The electric fields, in their turn, are the main responsible for the EIA generation. In this way, it should be expect some effect of the SSW on the EIA development.

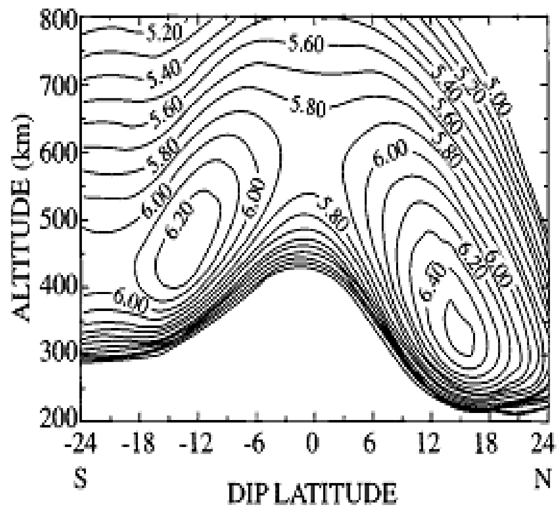

Fig. 1 – Calculated electron density contours ($\log_{10} n_e$) as a function of altitude and dip latitude at 2000 LT for December solstice conditions
Schunk and Nagy, 2000

Method

First we identified the period of occurrence of the SSW event from the point where the temperature begins to rise up, reaching a maximum until returning to a stable temperature condition (Figure 2), slightly different from methodology adopted by Goncharenko et al. (2010), which considered only the temperature increase. Then we analyzed digisondes data from Fortaleza and Cachoeira Paulista and TEC data from GPS receiver installed in São Luís and São José dos Campos from January 14th to February 12th 2009.

Fortaleza and São Luís are located close to magnetic equator, while Cachoeira Paulista and São José dos Campos are located on the equatorial ionization anomaly crest. Thus, we can observe the daily equatorial anomaly intensity using de parameters ΔfoF2 and ΔVTEC, which can be calculated by the following expressions, as described in Nogueira (2009):

$$\Delta foF2 = foF2_{low} - foF2_{eq}$$
$$\Delta VTEC = VTEC_{low} - VTEC_{eq}$$

where $foF2_{low}$ and $VTEC_{low}$ are measured at the EIA crest (Cachoeira Paulista and São José dos Campos, respectively), while $foF2_{eq}$ and $VTEC_{eq}$ are measured close to magnetic equator (Fortaleza and São Luís, respectively).

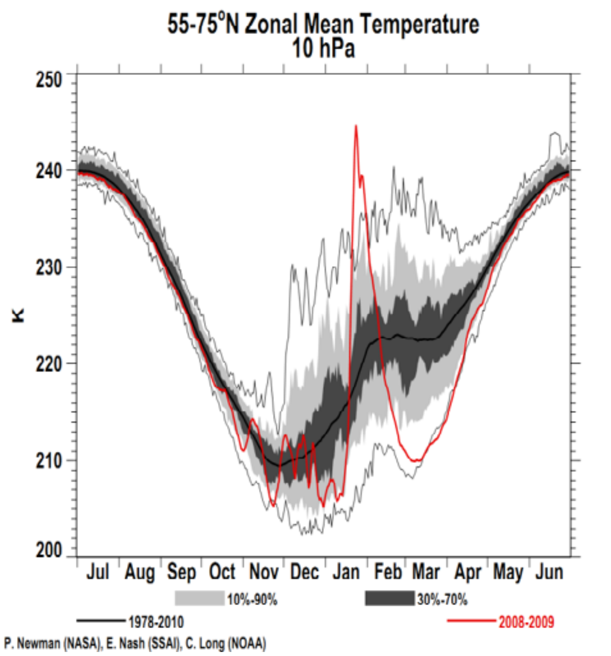

Fig. 2 – Stratospheric temperature – where the red and black curves represent the zonal mean stratospheric temperature over 2008-2009 and 1978-2010, respectively.

For the ΔVTEC calculation, we used only data from satellites with elevation angle higher than 45°, in order to minimize the errors that could be introduced in the process of transforming oblique TEC in vertical TEC.

Results

We have analyzed ΔfoF2 and ΔVTEC for the whole period following the SSW event. The following figures are representative of the ionospheric behavior over the Brazilian region. All the periods are representative of low geomagnetic activity, as can be seen by the low values of the daily sum of the geomagnetic index Kp.

In Figure 3 we show, for comparison, the EIA parameter ΔfoF2 for January 13, just before the SSW event, and for January 14, when the event started. In all the figures, the red curve represents the quiet day mean and the black curve represents the value for the day. For January 13 the EIA daily variation was similar to the quiet day curve, but with higher values. For January 14, the day of the strong temperature increase, we observe increases in the EIA parameter from 12 to 17 UT (EIA intensification), and decreases (EIA suppression) from 17 to 24 UT. This pattern suggests a semi-diurnal variation in the EIA parameter.

According to Goncharenko et al. (2010) for all SSW events, we can observe increased variations in TEC in low-latitude to mid-latitude, thus the same behavior can be expected for foF2.

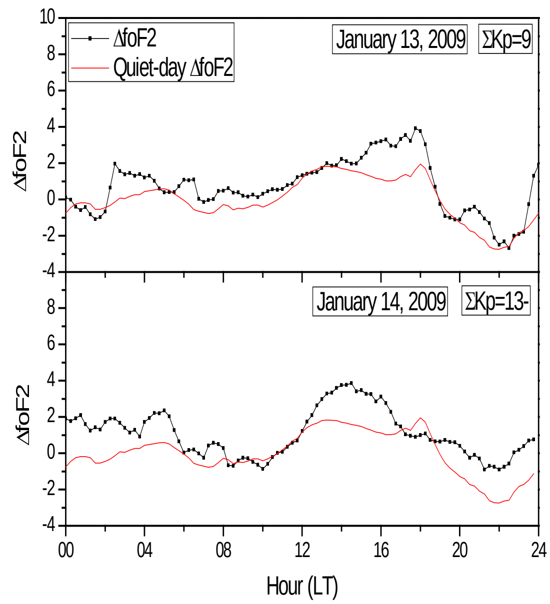

Fig. 3 – ΔfoF2 on January 13, before the SSW and on January 14, when SSW event started

Figure 4 shows the EIA parameters ΔfoF2 and ΔVTEC for January 22, when the temperature reached its maximum value. We can observe that ΔfoF2 and ΔVTEC are following the average quiet day's curves without EIA intensification or suppression on this day. On January 29, following a secondary increase in temperature, the same semi diurnal pattern of disturbance in the EIA parameters was observed, with intensification from 12 to 17 and suppression from 17 to 22 (Figure 5).

In all figures presented in this section we can observe that ΔfoF2 and ΔVTEC are most pronounced in daytime hours and have a clear semidiurnal character and according Goncharenko et al. (2010) this behavior can persist for days.

Conclusions

The results shown in Figure 3 are representative of low geomagnetic activity, thus the EIA variations could not be attributed to disturbed $\vec{E} \times \vec{B}$ drift. One possible explanation for the semi-diurnal variation in ΔfoF2 in the lower panel of Figure 3 is the modulation of the atmospheric tides by planetary waves generated at the beginning of the SSW event. The atmospheric tides are the responsible for the electric fields that produce the fountain effect and the EIA. The tides, modulated by the planetary waves, could generate a modified electric field pattern that disturbs the EIA from its quiet day configuration.

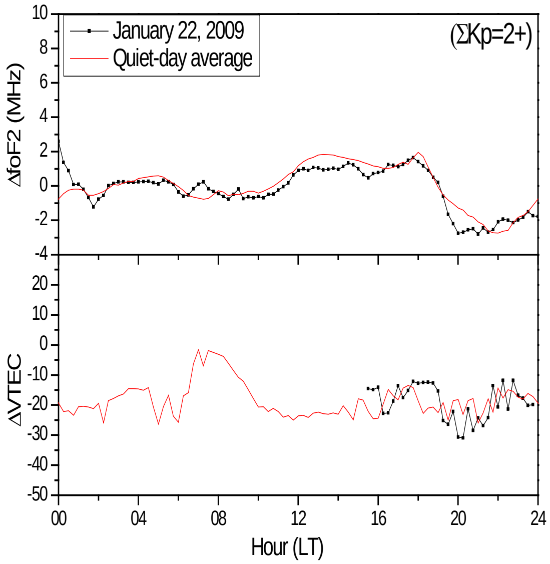

Fig. 4 – ΔfoF2 and ΔVTEC during the temperature peak SSW event

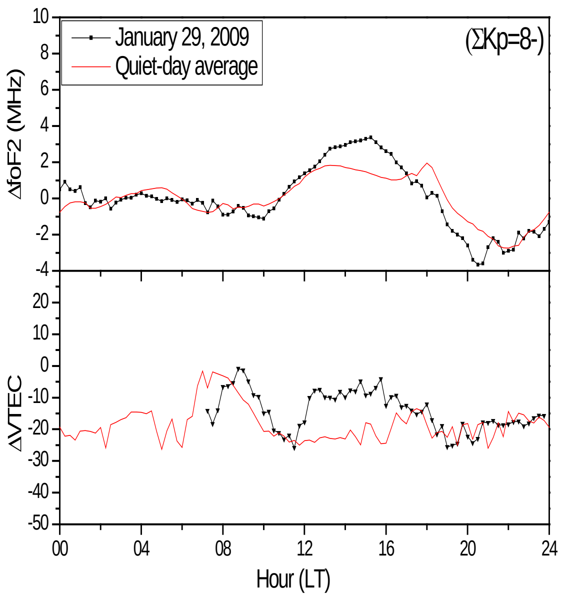

Fig. 5 – ΔfoF2 and ΔVTEC after the temperature sub peak SSW event

Our results show that the effect in EIA subsides at the temperature peak and ΔfoF2 and ΔVTEC behave as the quiet day average (Figure 4).

After a secondary and small stratospheric temperature increase we can observe a small effect on the EIA very similar to the one observed before, probably caused by weaker planetary waves (Figure 5).

With the results presented in this study it is possible to associate some ionospheric behavior with the planetary wave activity that occurres in the lower atmosphere, but we cannot rule out the possibility that much of this connection might be caused indirectly through the E region dynamo according to suggestions from other authors. The main feature of the ΔfoF2 and ΔVTEC is a semi diurnal variation with amplitude larger than the observed during geomagnetic quiet periods. This semi diurnal variation is produced by a semidiurnal change in the vertical ion drift, which is caused by the enhanced semidiurnal tide in the lower thermosphere. The EIA is enhanced when the eastward electric field increases and the crests move to higher latitudes, increasing foF2 and TEC.

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