OBSERVATIONAL EVIDENCE OF SUDDEN STRATOSPHERIC WARMING EFFECTS ON GPS_TEC

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ABSTRACT: We present some evidence of five Sudden Stratospheric Warming (SSW) events which occurred during low solar activity of 2008 and 2009 (1 major warming in 2009 and 3 minor and 1 major warming in 2008). Our ionospheric GPS TEC data exhibit an obvious and distinctive daytime anomaly pattern. Kp $\leq$ 3 was observed to ensure quiet conditions. Our results show a suppression of EIA in the afternoon while enhancement of EIA was observed during the morning hours. TEC was characterized by a semidiurnal and a large amplitude which lasted for several days. A secondary TEC perturbation, represented by an increase relative to periods without SSW occurrence, during nighttime was also observed in some cases. TEC estimations were obtained using the Nagoya model. TEC data used were collected from a wide range of geomagnetic latitudes ($\pm 20^o$) and from geographic longitude traced between 52^oW - 60^oW corresponding to the geomagnetic meridian of 60^oW.

1 INTRODUCTION

It is well known that the ionosphere varies readily with solar radiation and geomagnetic activity. The portion of ionospheric variability not yet accounted for by these drivers is up to ~20% of the F region ionospheric electron density at daytime and ~33% at nighttime [1]. A number of studies have shown that meteorological processes such as planetary wave, gravity wave, tides etc. can directly or indirectly cause an impact on the ionosphere electron density.

Large scale electrodynamics and plasma density variation of the ionized layer have been recently associated with SSW event which has been a subject of intensive study [2]. A SSW event is characterized by a sudden breakdown of the stratospheric polar vortex caused by dynamical forcing of upward propagating planetary waves from lower atmospheric layers. The interaction between the zonal mean flow and the growth of vertically propagating planetary waves is known to be the major driver of winter stratospheric dynamics. The SSW was first observed in 1950s [3], and since then many literatures have reveal the coupling between stratosphere and ionosphere (e.g.[4,5]). Although the physics behind atmospheric tides and planetary waves influences over the ionosphere are generally well understood, it is not still certain about the processes responsible for generating ionospheric variability in connection with SSWs. Evidence from [6] shows a primarily semidiurnal modulation of the ionosphere during the 2008 SSW and they suggested that enhanced planetary wave activity associated with SSWs play an important role in producing the ionospheric perturbations. It is clear from the conclusion of [2] that SSW event is an amplification of lunar tide that modulates the low-latitude and mid-latitude ionosphere. Liu et al.(2010), proposed that the observed semidiurnal perturbations in the ionosphere during SSW events are due to the nonlinear interaction between migrating tides and planetary waves. However, significant changes in the tidal winds were found to occur in the low latitude E region where electric fields are generated by the dynamo effects, resulting in modulation and enhancement of the electron densities and a decrease of the vertical drift velocity in the ionosphere.

Using GPS-TEC from many receivers in South America sector along geomagnetic field line, we intend to provide observational evidence that clearly demonstrates how the ionization phenomena at the EIA and generally over the South American continent is affected by five uniquely strong and long lasting SSW events.

DATA DESCRIPTION AND BRIEF ANALYSIS

2009 SSW

Figure 1 represents the summary of stratospheric, solar and geomagnetic conditions for the winter solstice in the northern hemisphere of 2009. Data were collected from the National Centre for Environmental Prediction (NCEP). The first and second upper panels are the stratospheric temperature at 10hPa (~32 km) and 90-90^{o}N and 90-60^{o}N respectively. There is a sharp increase in both cases by more than 70K. From the top the third panel shows the zonal mean wind at 60^{o}N which reversed from eastward (winter hemisphere) to westward (summer hemisphere) indicating a major warming. The fourth panel indicate the planetary wave number 1 activity at 60^{o}N which is relatively low compared to the planetary wave number 2 shown in the fifth panel from top which exceeds the long-term mean level by a factor of ~3. The lower 2 panels indicate the extremely low solar and geomagnetic activity, showing the F10.7 cm flux and daily ΣKp index respectively. The red lines, common to the first to fifth panels represents the average of the respectively data from 1979 to 2008.

2009 Parameters

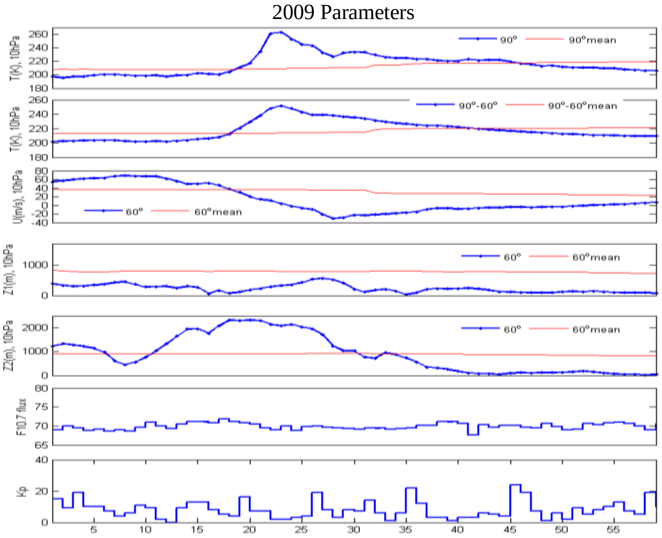

Figure 1- Summary of stratospheric and geomagnetic conditions for the winter solstice of 2009.

2008 Parameters

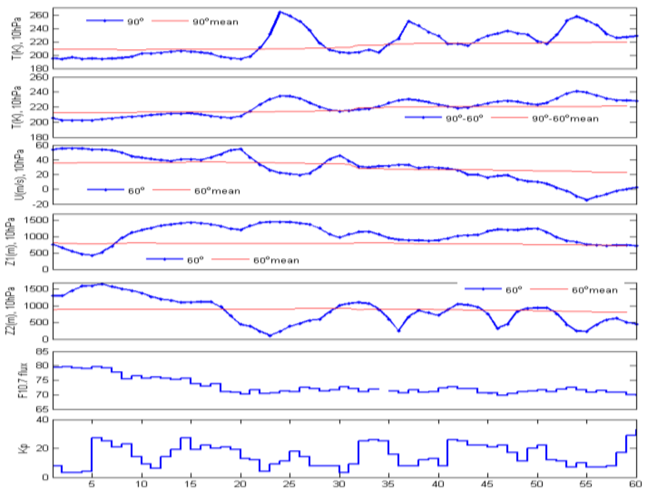

Figure 2 - Summary of stratospheric and geomagnetic conditions for the winter solstice of 2008.

2008 SSW

The event of Sudden Stratospheric Warming events of January - February 2008 was characterized by minor and major warmings. The strong decrease in the zonal wind at 60^{o}N (Figure 2) but having no change in the direction for 3 consecutive peaks for stratospheric temperature at 90^{o}N and 10hPa observed on 24 January, 6 February and 16 February respectively signified a minor warming event. On the other hand, the last warming of 24 February fulfilled the condition for a major stratospheric warming when the zonal wind at 60^{o}N turned westward (negative) and the temperature at 90^{o}N increased by ~40K within 3 days. In contrast to 2009 SSW event, the warmings were dominated by the planetary wave number 1 activity which lead to the displacement of the polar vortex off the pole and a two-cell pattern of warming and cooling at stratosphere altitude while the activity of the planetary wave number 2 remained relatively low as show in Figure 2.

Unlike 2009 winter period when it was observed an absolutely low solar flux, in 2008 winter there was some little enhancements in the solar flux activity up till 20 January 2008 and return to very low level after this day. The geomagnetic activity also showed some enhancements. Although there were increases in the daily ΣKp index of days 5-6, 14 January and days 2,10 and 28 February 2008, other periods were predominantly quiet and the solar flux (F10.7 cm flux) varied between 70-80 units.

RESULTS

To carry out our observation, 10 days mean of TEC (from 3 - 12 January of 2009) representing quiet time was calculated and plotted (Figure 3) and the TEC of each day is estimated by subtracting the ten days mean without SSW effects from each day under SSW effects. The 10 days mean represented in of Figure 3 shows that the EIA was well developed as expected and at the right time with maximum TEC value (20TECU) during the day and minimum at night (around 1 - 2TECU). Before the SSW peak, the average TEC difference shows normal daytime variation behavior as showed in the example of January 19, 2009 (Figure 4) on the top upper panel. But around the SSW peak on 24th, (shown in second upper panel of Figure 4) a clear semidiurnal signature appears during the daytime hours, with TEC enhancement coming earlier in the morning around 8 LT to 12 LT, TEC decreases occurs during afternoon around 12 LT to 18 LT and a secondary TEC increases appearing at 19 to 22 LT. This semidiurnal signature reduces several days after the SSW peak, as indicated in the third panel from the top while EIA starts to return to its normal behavior as shown in the fourth and last panel. Similar perturbations were observed in the remaining four other SSW events.

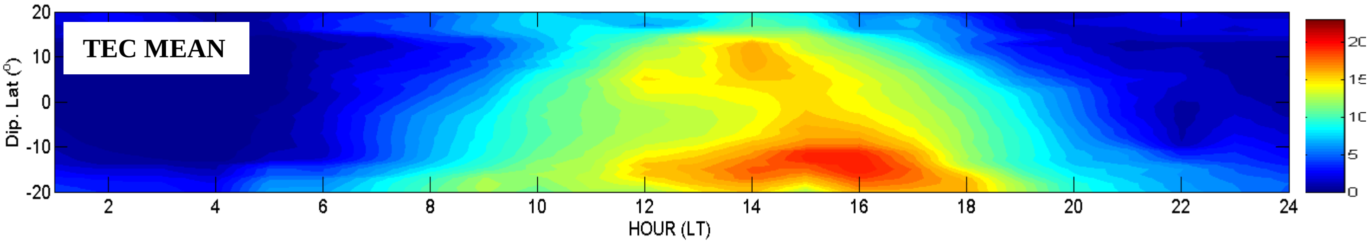

Figure 3: 10 days mean of TEC (TECU) from 3 - 12 Jan 2009 along the geomagnetic meridian of 60^{o}W

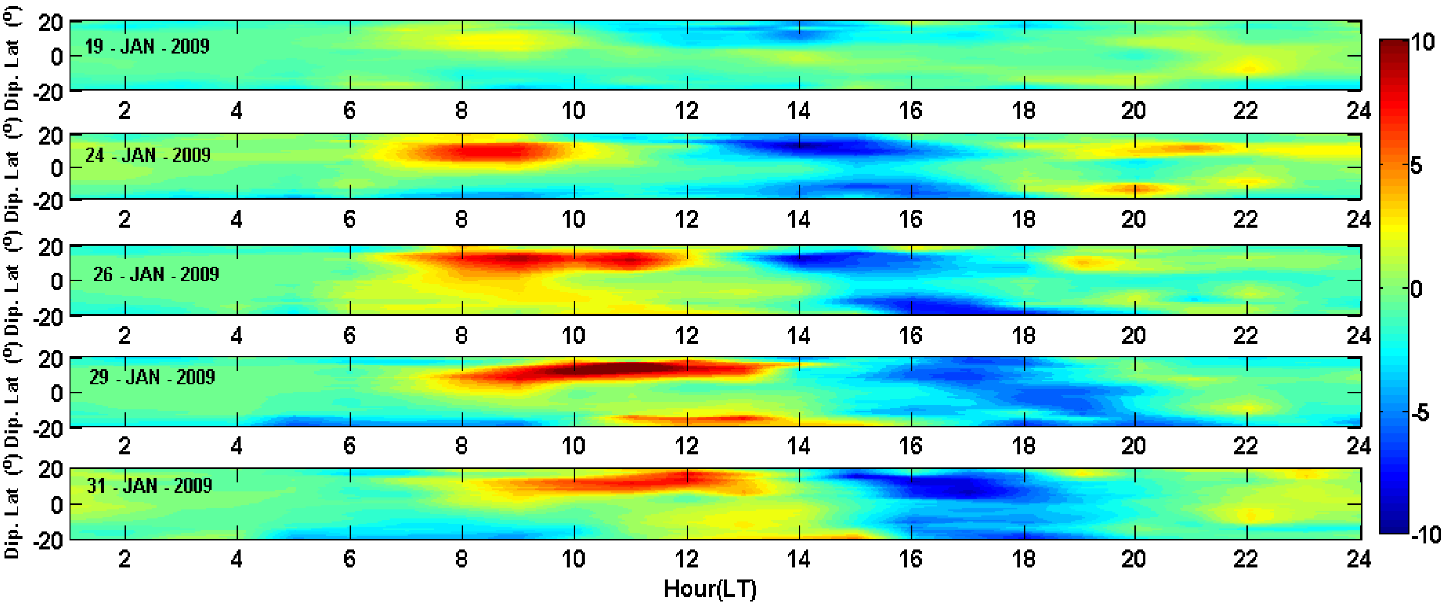

Figure 4: Change in TEC (TECU) during the SSW event of 2009 along the geomagnetic meridian of 60°W

CONCLUSIONS

1) SSW events could lead to increase and decrease in TEC as shown in the semidiurnal behavior of Figure 4 above.
2) There is a clear inter-hemisphere difference in TEC perturbations during the SSW events particularly in the morning hours.
3) Generally, besides the fact that the upward propagating wave (e.g. quasi-stationary planetary waves) enhanced by lunar tides during SSW event could cause a semidiurnal TEC ionospheric perturbation, It is also evident that the correlation of TEC with SSW event in a long term range could serve as a mechanism for predicting ionospheric variations or behavior several days in advance from the peak of the SSW event.

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