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Seasonal variability of GPS-VTEC and model during low solar activity period (2006–2007) near the equatorial ionization anomaly crest location in Chinese zone

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Abstract

Variability of vertical TEC recorded at Fuzhou (26.1°N, 119.3°E, geomagnetic latitude 14.4°N), Xiamen (24.5°N, 118.1°E, geomagnetic latitude 13.2°N), Nanning (22.8°N, 108.3°E, geomagnetic latitude 11.4°N), China, during the low solar activity in 2006–2007 have been analyzed and discussed. Remarkable seasonal anomaly was found over three stations with the highest value during spring and the lowest value during summer. The relative standard deviation of VTEC is over 20% all the time, with steady and smooth variation during daytime while it has a large fluctuation during nighttime. The biggest correlation coefficient was found in the VTEC-sunspot pair with a value of over 0.5. It seems that solar activity has a better correlation ship than geomagnetic activity with the variation of VTEC and better correlations are found with more long-term data when comparing our previous study. The results of comparing observation with model prediction in three sites reveal again that the SPIM model overestimates the measured VTEC in the low latitude area.

Keywords: Vertical TEC; Low solar activity; Equatorial ionospheric anomaly; Seasonal variation; SPIM

1. Introduction

Acting as a dispersive medium, the ionosphere has great influence on the satellite navigation and communication, and the effect is directly proportional to the free electron density, which could change the phase and strength of electromagnetic radio frequency wave. When the satellite signal propagates through the ionosphere, the carrier experiences a phase advance and the code experiences a group delay due to the total number of free electrons along the path of the signals from the satellite to the receiver. Therefore, the carrier phase pseudo ranges are measured too short and the code pseudo ranges are measured too long compared to the geometric range between the satellite and the receiver, which induces range error in the positioning and navigation (Bagiya et al., 2009). These range errors are relatively obvious in the ionosphere above the EIA regions due to the high background electron density and its rapid, complex variation. The EIA, i.e., “equatorial ionization anomaly” or “Appleton anomaly” was reported in 1946. This interesting phenomenon of EIA is like as: The distribution of ionization density at the F layer in the vicinity of magnetic dip equator is characterized by a trough at the equator and two crests on either side of the equator (at about ±15° magnetic latitude) during the day. The electrodynamics drift and diffusion theories have been used to explain this interesting phenomenon. During the daytime, the mutual perpendicular eastward electric field and northward geomagnetic field give rise to an upward E × B drift. After the plasma is lifted to greater heights, it diffuses along magnetic field lines due to the combined influence of pressure gradient forces and gravity, which forms a trough

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at the equator and two crests at higher latitudes on F_2 layer (Appleton, 1946; Martyn, 1955; Duncan, 1960; Hanson and Moffett, 1966). In order to reduce the detrimental effects on the GPS based navigation, it is very necessary to have a prior and precise knowledge of the variation and distribution of ionosphere parameters in different region, especially low latitude regions.

The Total Electron Content (TEC) is one of the most important parameters to characterize the ionosphere property, which is calculated as an integral of electron number density along the line of sight from satellite to receiver and could vary intensely from day to day (Huang et al., 1989; Rastogi and Klobuchar, 1990). Since the F region density has a great weight for total electron content and the main contribution to TEC would occur around the height of the maximum ionization in the F layer, the development and variation of EIA is as seen in TEC. Now it is accepted that the magnitude and variation of TEC relate to local time, solar activity, geomagnetic conditions, region of the earth and sudden space weather events. In the low latitude of East Asia, some studies of TEC have been reported using the data recorded round 120°E. Huang and Cheng (1996) studied the solar cycle variation of EIA in TEC using observed data from a single ground station at Lunping (25.00°N, 121.17°E), and found no significant solar cycle effect in the occurrence time of the most developed equatorial ionospheric anomaly and the winter crest appears larger and earlier than the summer crest. Wu et al. (2004) found there is a weak correlation between EIA and F10.7, and the seasonal variation of EIA is likely influenced by the seasonal variations of geomagnetic activity (Dst) during the solar minimum by analyzing a short-term data set (September 1996 to August 1997). Wu et al. (2008) studied ten years GPS data and suggested that the geomagnetic effects (Kp) on the crest are short-term and solar effects (F10.7) are long-term. Many studies also have been carried out by other researchers in different country using the observational data recorded in different locations. Various variation properties, the effects of solar and geomagnetic activities, and model comparative analysis were reported by those works (Tsai et al., 2001; Rao, 2006; Bhuyan and Borah, 2007; Bagiya et al., 2009; Kumar and Singh, 2009; Mukherjee et al., 2010).

In our previous study (Liu et al., 2012) we were the first time to analyze the temporal characteristic of VTEC using one-year data observed in Xiamen. We found the remarkable seasonal anomaly of VTEC, and poor correlation with geomagnetic and solar activity. In this work, we extend the data-set for two years and use three observational stations, including Xiamen site. We think the results in this paper are necessary because there are a few observations and study of the TEC along the tropic of cancer in the Chinese zone. On the other hand, as the advent of GPS, which has served as a valid instrument to study ionosphere, many researchers use the observation data to set up a new TEC model or verify the classical ionospheric model. But the results are not very good, which overestimate or underestimate the GPS-derived value (Bhuyan et al., 2006; Bhuyan and Borah, 2007; Obrou et al., 2009; Galav et al., 2010; Aggarwal, 2011; Liu et al., 2012; Adewale et al., 2012). One reason is lack of consecutive long-term observation in low latitude, another is the established ionosphere model is based on the data more from high and middle latitude (Bilitza, 2001). Therefore, as the part of the global ionosphere characteristic, these results of our work will be good complements and be propitious to study and establish a more accurate model of ionosphere.

In this work, Observation data recorded in Fuzhou (26.1°N, 119.3°E, geomagnetic latitude 14.4°N), Xiamen (24.5°N, 118.1°E, geomagnetic latitude 13.2°N), and Nanning (22.8°N, 108.3°E, geomagnetic latitude 11.4°N) were used to investigate the characteristics of VTEC. We will give an overall description of temporal variation characteristics of VTEC in low solar activity period from year 2006 to 2007; we also examine the effect of solar and geomagnetic activity on the VTEC in those three sites. As the extension of our previous study, The results will make one too well understand the variation of TEC around 110–120°E near the Tropic of Cancer, and the difference between observation and output of Standard Plasmasphere–Ionosphere Model (SPIM, Gulyaeva and Bilitza, 2012).

2. Observation data

To study the characteristic of TEC near the Tropic of Cancer in Chinese zone, a few dual frequency GPS receivers were established since 2005. There are 28 GPS satellites orbiting the Earth at an inclination of 55°and at a height of 20,200 km. They broadcast information on two frequency carrier signals, which are f_1 (1575.42 MHz) and f_2 (1227.60 MHz), respectively. Ground-based GPS receiver could record constantly the pseudo-ranges (P_1 and P_2) and the phases (L_1 and L_2) corresponding to the two signals. In this work, we used these data to estimate the slant total electron content ($\mathrm{TEC_{sl}}$) in 30 s interval using the technique of calculating the VTEC developed by Ma and Maruyama (2003). Since the slant TEC is the total number of electrons in a column of the unit cross section along the ray path, it is desirable to calculate an equivalent vertical value of TEC, which is independent of the elevation of the ray path. To convert the slant $\mathrm{TEC_{sl}}$ to vertical TEC, we assumed the ionosphere to be a thin screen shell model and its center is assumed to be the same as that of the Earth. It is because the main contribution to TEC variations would occur around the height of the maximum ionization and this allows us to consider the ionosphere as a thin layer located at the height of ionosphere F_2 layer. According to Davies (1990), the height of the mean layer of the ionosphere could lie between 300 and 450 km. It is assumed to be 400 km in this paper and got the calculation technique of VTEC as shown:

$$\mathrm{VTEC} = (\mathrm{TEC_{sl}} - b_s - b_r)\cos\left[\arcsin\left(\frac{R_E\cos\alpha}{R_E + h}\right)\right] \quad (1)$$

where b_s and b_r are the satellite and receiver biases, respectively, $R_E = 6378$ km, and the h is the height of the ionospheric layer, α is the elevation angle of satellite. Because the pseudo-range with low elevation is apt to be affected by multipath effect and the reliability decrease, thus, in order to minimize the time shift and neglect unwanted errors due to multipath and insure the number of data, we chose 30° as the cut off elevation angle.

In this paper, we choose the VTEC in an hour interval (in the whole point of UT) and then make average for season to investigate the temporal characteristic over three stations. To analyze the correlation between VTEC and geomagnetic and solar activity, Kp and Dst data were downloaded from the website (<http://wdc.kugi.kyoto-u.ac.jp>), and F10.7 data from a website (<http://www.swpc.noaa.gov>), sunspot number SSN from the website (<http://ftp.ngdc.noaa.gov>), respectively. The model SPIM also was used to compare with the observed in three sites during 2006–2007.

3. Results and discussion

3.1. Seasonal variations of vertical TEC

Due to the combined effect of various physical mechanisms and dynamic progress, TEC in the low latitude has complex variation, including short-term (such as diurnal or daily variation) and long-term (such as seasonal or annual variation). Fig. 1 gives a map of VTEC distribution in low latitude region and the locations of three stations used in the work. Fig. 2 shows an example of the day-to-day variation of VTEC using 30 s data recorded in three sites during 18–27 May, 2006. It could be seen from the figure that the values of VTEC vary day to day without remarkable variation law in respective stations, which denotes that it is difficult to predict the defining performance of VTEC in the next day. Another fact revealed by those three curves in the figure is that there are some differences (including the magnitude and variation trend) caused by different location, of the stations. Therefore, it is necessary to make a study of statistic analysis to understand the basic characteristic of TEC variation in this region. To investigate the mean diurnal variation and seasonal property in three sites, the observational data were sorted into four seasons, spring (March, April and May), summer (June, July, and August), autumn (September, October, and November), winter (December, January, and February). Fig. 3 exhibits the seasonal variation of hourly average VTEC during 2006 (left panels) and 2007 (right panels) observed in Nanning (top panels), Xiamen (middle panels) and Fuzhou (bottom panels), respectively. We could see that the maximum value of VTEC in Nanning occurs at 07 UT (14.22 LST) during spring, autumn and winter, while it occurs at 08 UT (15.22 LST) during summer of 2006. On the other hand, the middle and bottom panels show that the occurrence time of maximum For Xiamen and Fuzhou station both are 06 UT (13.87–13.95 LST) in spring, autumn and winter while they delay 2 h to 08 UT (15.87–15.95 LST) during the summer, like as Nanning. The right panels of Fig. 3 exhibit that the maximum of VTEC occurs at 08 UT during spring of the year 2007 recorded in Nanning may be due to the lack of data in March and April, while the tendency of VTEC during other seasons is the same as that in 2006, meanwhile, the variation characteristic for Xiamen and Fuzhou during 2007 similar to that during 2006. Comparing the left panels and right panels of Fig. 3 we could also find that the magnitude of VTEC between 2006 and 2007 depicts an annual variation. The peak values of VTEC in year 2006 are higher than that in 2007 over all sites, especially during spring with ~35 TECU in 2006 while they are less than 30 TECU in 2007. There are some variation characteristics in common shown in this figure. The scale of time for relative high (0–12 UT) and relative low (13–23 UT) levels is almost equal. The minimum of VTEC occurs at 21 UT for all seasons and all sites, when it is the time of pre-sunrise in the local area. For the similarities and differences between four seasons, the magnitude and variation in winter are very close to that in autumn, and the max values of peak VTEC are found in spring while the minimum occurs during summer. In addition, peak VTEC in summer is slightly lower than that in winter, accompanying the delay of two hours from the occurrence time of maximum. These seasonal differences found over three stations reveal the weak winter anomaly future in this region.

As a more systematic statistic work, we group 2-year data-set into four seasons to study the basic pattern of average variation and spatial difference between three observational stations. The manner of group is the same as above part and the results are shown in left panel of Fig. 4. As a whole, it could be seen that VTEC has almost the same trend of variation regardless of the seasons and

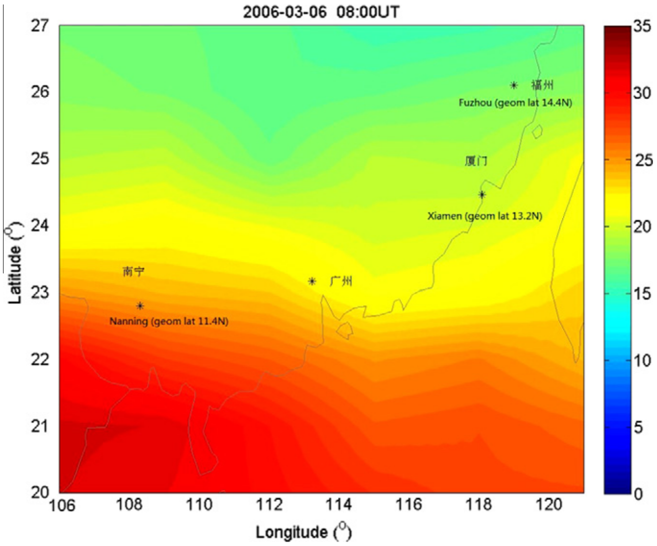

Fig. 1. Sample of spatial distribution of TEC in the low latitude in China zone and the location of observational sites (Nanning, Xiamen and Fuzhou) used in this paper.

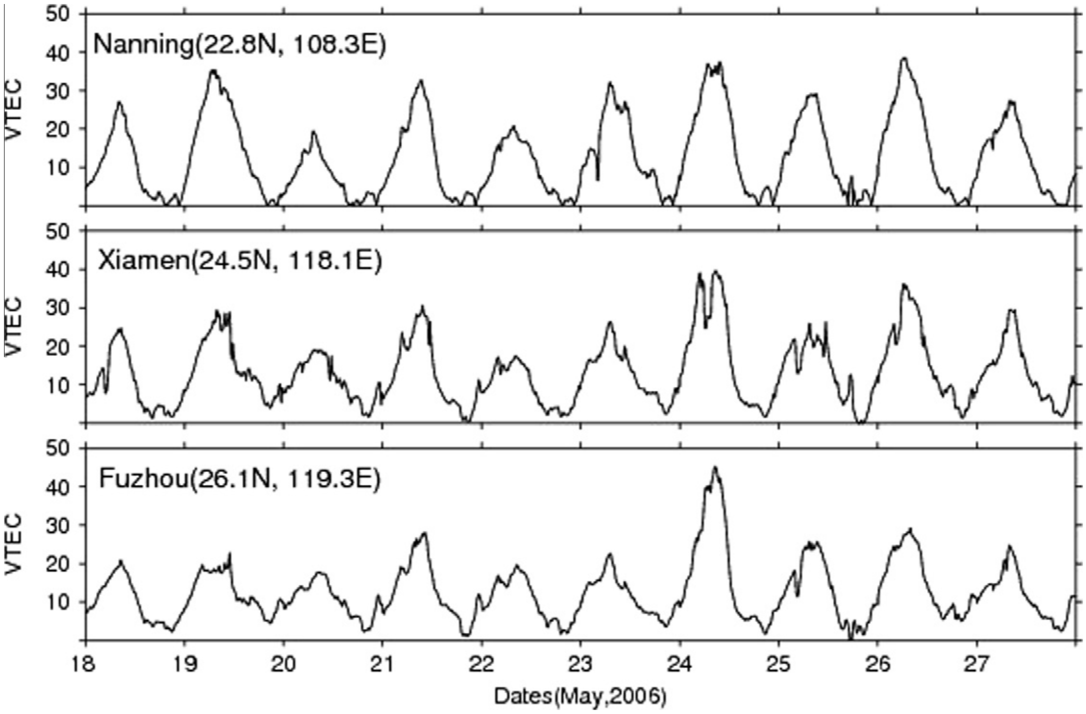

Fig. 2. Day-to-day variation for VTEC from 18 to 27 May, 2006 recorded in Nanning, Xiamen and Fuzhou.

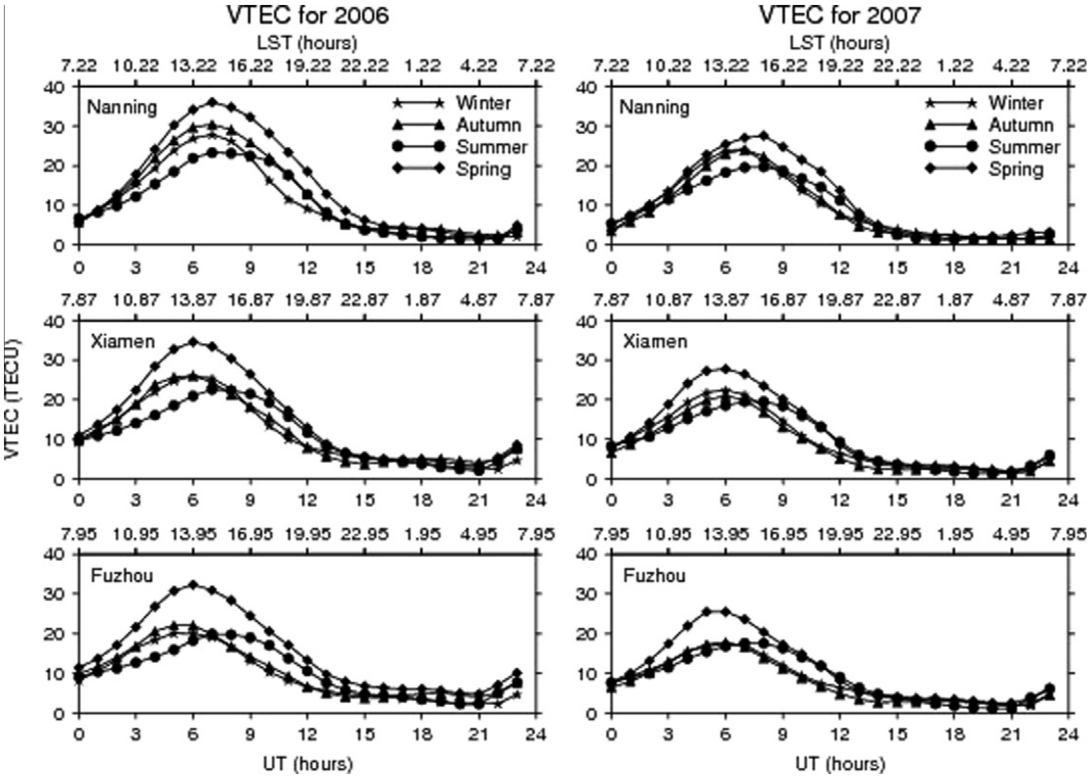

Fig. 3. The seasonal variations of VTEC during year 2006 (left) and 2007 (right) recorded in Nanning (22.8°N, 108.3°E, geomagnetic latitude 11.4°N), Xiamen (24.5°N, 118.1°E, geomagnetic lat 13.2°N), Fuzhou (26.1°N, 119.3°E, geomagnetic lat 14.4°N), respectively. (LST = UT + LON/15.)

stations. It is increasing from 00 UT until reaching the maximum in the afternoon (06–07 UT), and then decreasing gradually to attain the minimum value around 21 UT. Some researchers (Bagiya et al., 2009; Perevalova et al., 2010; Chauhan and Singh, 2010) reported the similar results. They also found the maximum of TEC occurs in

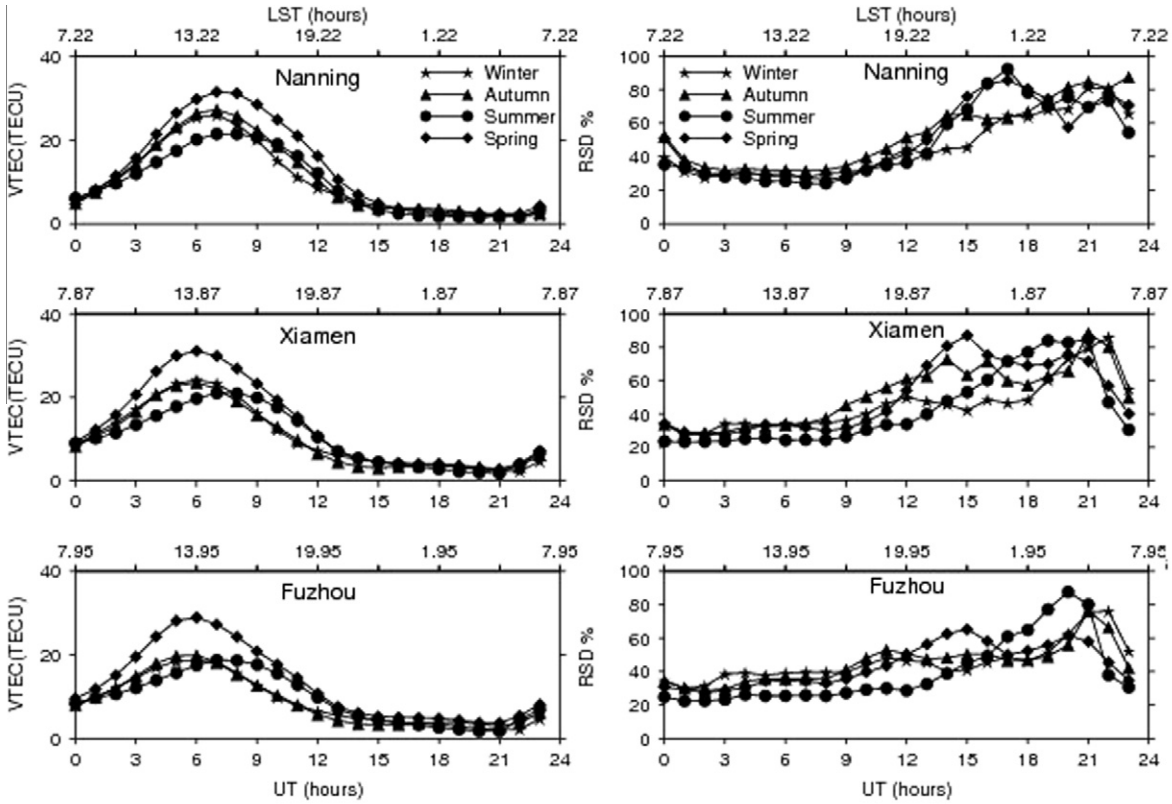

Fig. 4. Variation of VTEC (left) and relative standard deviation (right) during different seasons for two-year data over Nanning, Xiamen and Fuzhou. (LST = UT + LON/15.)

the afternoon and minimum occurs in the pre-dawn. On the other hand, the highest value of peak VTEC is found in Nanning, which is followed by Xiamen and the lowest VTEC occurs in Fuzhou. For the occurrence time of peak value, again, one could find that it is 07 UT in Nanning (14.22 LST) while other two stations are still at 06 UT (13.87 and 13.95 LST). Considering the similar latitude of three sites (26.1°N, 24.5°N and 22.8°N, respectively), the result that the seasonal mean peak value of VTEC in Fuzhou is manifest lower compared to that in Xiamen and Nanning is interesting, which also reveal that the complex local variation in this region. The main reason of lower value may not be the latitude, but the especial location of Fuzhou, which lies on the fringe of the northern equatorial ionization anomaly. During high solar activity, the EIA crest could move higher latitude which makes the corresponding high peak TEC. But in low solar activity the EIA crest may occur in lower latitude, therefore, the TEC recorded in Fuzhou, where the geomagnetic latitude is 14.4°N, could be lower than Xiamen and Nanning.

The phenomenon of seasonal or semiannual variation (anomaly or winter anomaly) for VTEC over three stations presented in this work is anticipated and reasonably. It has been discussed and explained by many researchers and scientists during past years. The behavior of seasonal (winter) variation could be interpreted using the change of composition of the atmosphere. Due to the asymmetric heating of the two hemispheres, neutral constituents are transported from the summer (hot) to the winter (cold) hemisphere. As a result, an increase of the O/N_2 ratio caused by the convection of atomic oxygen is formed in the winter hemisphere. Therefore, the recombination in winter hemisphere is weaker than that in the summer hemisphere, which results in the relatively higher electron concentration in winter (Rishbeth, 1961; Johnson, 1963; Torr and Torr, 1973). Another possible mechanism for this seasonal anomaly is the change of direction of neutral wind. A meridional component of neutral wind blows from the summer to the winter hemisphere which can reduce the crest value during summer solstice as it blows in an opposite direction to the plasma diffusion process originating from the magnetic equator; at the equinoxes (or spring), meridional winds from equator blows pole-wards should result in a high ionization crest value. Based on this scenario, a seasonal effect on the crest should be expected with the crest maximum at the equinoxes and minimum in the summer (Bramley and Young, 1968; Stening, 1992; Wu et al., 2004, 2008; Bhuyan and Borah, 2007).

3.2. The relative standard deviation of VTEC

In order to further understand the variations of VTEC, we calculate the relative standard deviation (RSD) of hourly VTEC for four seasons. The RSD = (VTEC standard deviation) × 100/(VTEC average value). RSD can reveal more information of temporal variation of VTEC, which is propitious to help people to better understand the characteristic in detail. The diurnal distributions of RSD for three stations during different seasons are shown in right panels of Fig. 4. It could be seen that RSD in all observation stations has the similar and smooth increasing tendency from 00 UT to 14 UT during all seasons, while variations have a few differences after 15 UT. In the detail, RSD in Fuzhou resembles that in Xiamen, with the max value at 15 UT and reaches a second peak value in 20 UT during spring. The difference of them in spring is that the values of RSD in Xiamen are higher than in Fuzhou after 12 UT, while RSD in Nanning has other trend with the highest value occurring at 17 UT and second high value at 22 UT. During summer, RSD in Fuzhou reaches the highest value in 20 UT while 21 UT in Xiamen, 17 UT in Nanning. RSD in Xiamen and Fuzhou display same trends during autumn with maximum at 21 UT, but value in Nanning is increasing after 02 UT. During winter, the variation of RSD in three sites is almost the same with high levels at 21–22 UT. The behaviors of RSD for all seasons in all sites indicate that the distribution of VTEC has a large fluctuation, especially after 12 UT. This is night to the breakdown of local solar time, which is corresponding to the low value period of VTEC. From Fig. 4 one also could find that the minimum of the RSD is larger than 20%, which reveals that the periods of low solar activity may lead to higher levels of relative standard variation of VTEC. Another similar variation characteristic is that RSD during spring is higher than the other three seasons during 12–16 UT. Our result is slightly similar to Lazo et al. (2004). They found that the relative variability (relative standard deviation) of TEC is higher during dawn and sunset period, mainly in equinoctial months. Adewale et al. (2012) also found that the variability of VTEC has large value during nighttime, especially post-midnight hours and post-sunset. The steep electron density gradients caused by the turn-off of solar ionization and onset could explain this variation. However, Mukherjee et al. (2010) analyzed VTEC data during the period 2005–2006 at Bhopal (23.2°N, 77.6°E, geog. 14.29°N, 151.12°E) and found that the standard deviation of VTEC is relatively smooth during nighttime hours and increases after predawn with a maximum values in the afternoon hours, while the relative variability index for summer is higher than that compared to other seasons. Aggarwal (2011) found the different result using data from Rajkot (geog. 22.29°N, 70.74°E), i.e., the standard deviation of TEC from the median values is relatively smaller during nighttime than daytime. These reports further demonstrate that the variation of TEC relates with the local latitudes and longitudes.

3.3. Correlation with solar and geomagnetic activity

To reveal the seasonal variation of peak VTEC in month details, we calculate the monthly value of the data and the results are presented in bottom panels of Fig. 5. Again, a remarkable semiannual variation of monthly average peak VTEC is found in the figure. The monthly trend shows that the first maximum occurs in April of 2006 at all observational stations while it is found in March during 2007 in Xiamen and Fuzhou (no data in March and April of 2007 for Nanning station due to technical reason). The second maximum of mean peak VTEC is found in the October regardless of year. Except for the basic pattern of variation, to a certain extent, the magnitude and temporal fluctuation characteristic of TEC is influenced by solar and geomagnetic activity. In order to examine the effect of these two factors on the variation of peak VTEC during the low solar period from year 2006 to 2007, solar activity index sunspot SSN, F10.7, geomagnetic activity index Kp and Dst are analyzed in this work. The monthly variations of their values in these 2 years are shown in top four panels of Fig. 5. It is clearly found from the figure that the monthly mean value of the SSN and F10.7 are both at their high value in April, while the maximum of $\sum$Kp and the minimum of Dst occurs in December during 2006, but four indices did not show large fluctuation during 2007. The solar activity index shows a declining trend while $\sum$Kp and Dst did not exhibit remarkable annual variation during the chosen period. Fig. 6 shows the correlation of monthly peak VTEC with geomagnetic activity indices over three stations. Correlation coefficients (represented by C.C) are determined and the corresponding fitting is shown by the straight line. We could find that the correlations of monthly peak VTEC with monthly $\sum$Kp, Dst, sunspot SSN and F10.7 are 0.14, −0.15, 0.33 and 0.25, respectively and the values of coefficients are 0.23, −0.26, 0.34 and 0.34 in Xiamen, while they are 0.23, −0.35, 0.53 and 0.52 in Nanning.

Kp index represents planetary magnetic activity on a global scale, while Dst records the equatorial ring current variation (Mayaud, 1980). Wu et al. (2004) found a general good relationship between Kp as well as Dst index. They suggested that the Dst index is a more suitable parameter for studying long-term ionospheric dynamics around the EIA regions. Kumar and Singh (2009) also found a good relationship between Kp index while there is a bad relationship between the monthly values of the EIA crest in TEC and the monthly Dst-index ($R = -0.03$). The value of correlation coefficient for $\sum$Kp in our finding is relative small compared these two reports, but value for Dst index lies on between them. On the other hand, The sunspot number SSN indicates the degree of sunspot activity on the sun, and the solar radio flux F10.7 cm, which is the proxy for solar EUV radiation responsible for photo-ionization in the ionosphere, is reckoned as one of the factors to affect the magnitude and variation of TEC. The analysis in our work indicates that the best correlation is found between monthly VTEC and SSN among four indices, wherein the largest value of correlation coefficient occurs in Nanning with a little over 0.5, while the minimum correlation is shown in Fuzhou.

For the coefficients in Xiamen station in this paper, we notice that the value of correlation coefficient is bigger than

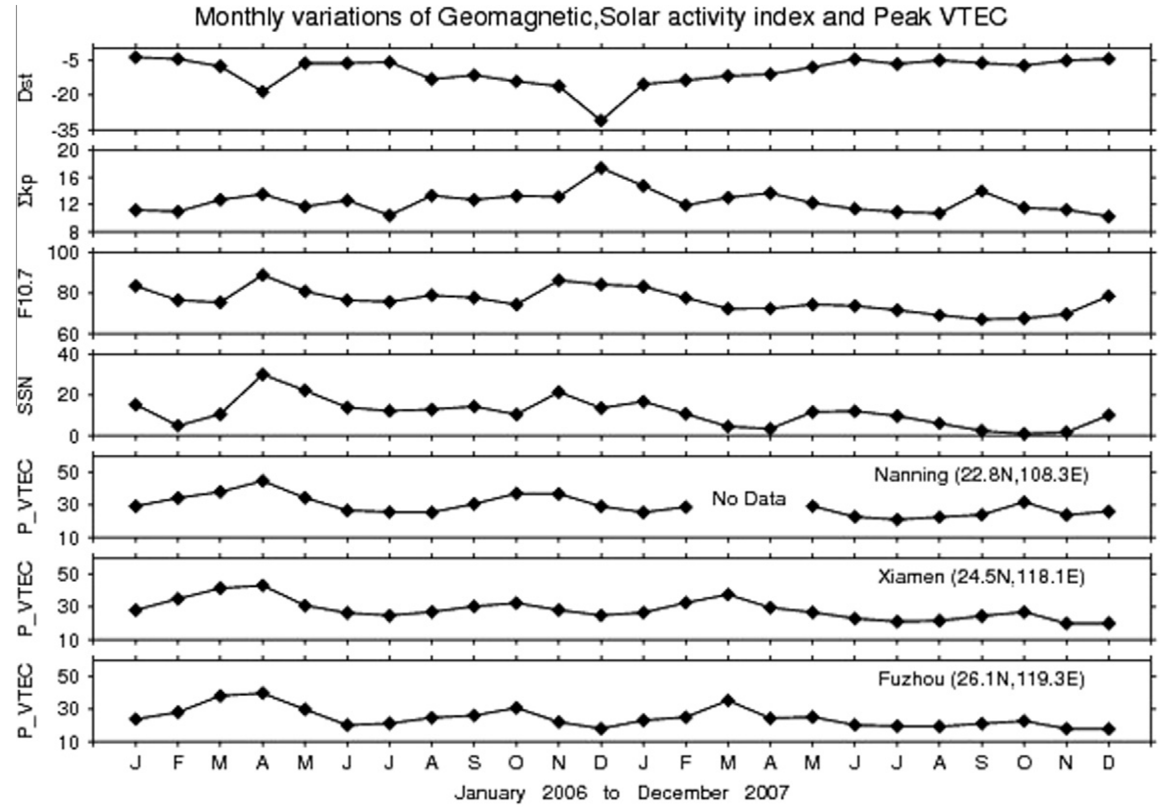

Fig. 5. Monthly variations of Dst, $\sum$Kp, F10.7, sunspot number SSN and averaged peak VTEC in three observational stations.

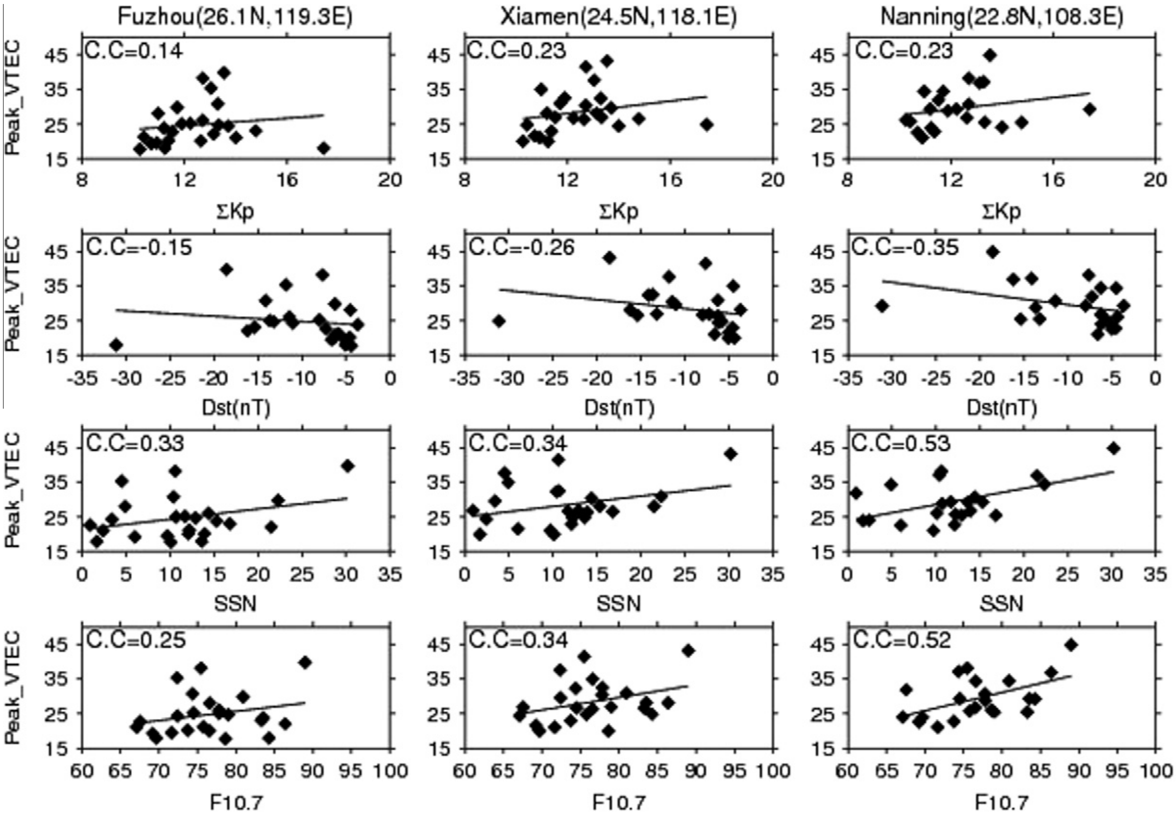

Fig. 6. Correlation coefficients comparing monthly averaged peak VTEC with monthly averaged $\sum$Kp, Dst, SSN and F10.7 over three sites.

that in our previous study (Liu et al., 2012), which was gotten by analyzing one-year observed data. It was found in that paper the coefficient is 0.26 between peak VTEC and sunspot SSN, while it was 0.14 for F10.7 and −0.11 for Dst. This difference may be due to the longer term data used in this paper. The meaning of this increase of effect similar to some results reported by other researchers though the value of correlation coefficient may be unlike. Wu et al. (2008) found a good correlation of EIA and F10.7 (correlation coefficient = 0.87) through analyzing a long-term data set (1994–2003). Bagiya et al. (2009) reported that there is a positive correlation between peak TEC and solar radio flux. Galav et al. (2010) showed a good correlation with the F10.7 during the declining phase of the solar activity. A positive linear relationship between the value of EIA and the sunspot number also has been found by Huang and Cheng (1996). On the other hand, some researchers found the different result in their works. For example, Kumar and Singh (2009) found that the SSN has very little effect ($r = -0.03$) on the variation of EIA crest in TEC and suggested that this may be due to the solar minimum period of May 2007 to April 2008.

As a whole, the values of correlation coefficients showed in Fig. 6 revealed a relatively good correlation between solar activity and monthly Peak VTEC, while low correlations were found between geomagnetic activity and it during 2006–2007. One also could see that there is a litter difference between three observation sites, which is the relative high value of coefficients in Nanning (22.8°N, 108.3°E) and lowest values in Fuzhou (26.1°N, 119.3°E) regardless indices.

In general, electron populations in the ionosphere are mainly controlled by solar photo-ionization and recombination processes. The photo-ionization caused by solar EUV radiation can produce more electrons and therefore enhances the background electron density. During the equinoxes, the subsolar point is around the equator, where the eastward electrojet-associated electric field is often larger. Because of the collocation of the peak photoelectron abundance and the most intense eastward electric field region, the fountain effect should be developed the most; during the solstices, photoelectrons at the equator decrease because the subsolar point moves to higher latitudes and the fountain effect is expected to wane (Wu et al., 2004). This EUV effect could be well demonstrated in our results.

3.4. Difference between observed and model

The model outputs of the International Standard Plasma-sphere Ionosphere Model, SPIM, are used to compare with the observational result of those three sites. The detailed characteristic of SPIM will not to be described in this part, but the comparative results are displayed directly. Fig. 7 shows the predicted VTEC by SPIM and GPS measured results for eight seasons during 2006–2007 at three sites. It is easy to see that.

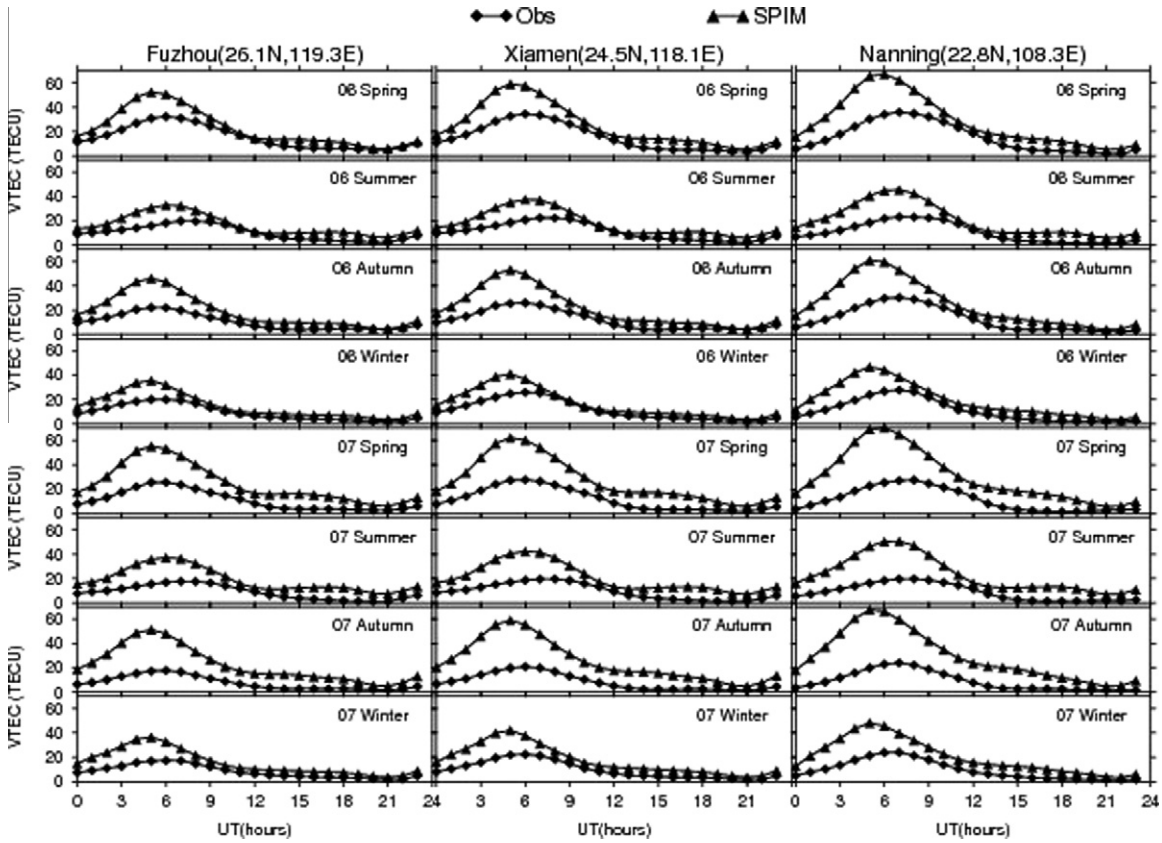

Fig. 7. Comparison of seasonal average of observed VTEC with predicted values from SPIM in three sites during 2006–2007.

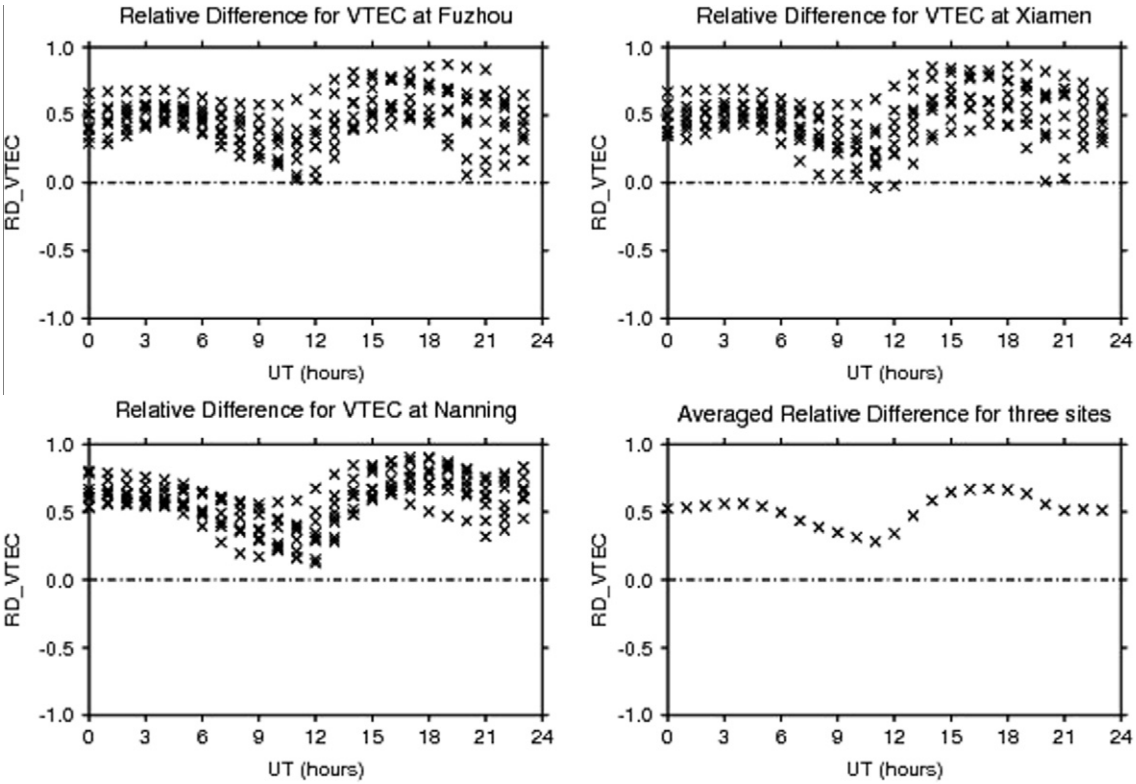

Fig. 8. Diurnal distribution of the relative difference RD_VTEC and average values vary in three sites regardless seasons.

The model overestimates the magnitude of VTEC during all season. Although SPIM predict a good variable tendency, the absolute value of the difference between measured result and model output is unsatisfactory. Fig. 8 gives the diurnal distribution of relative difference parameter regardless the seasons, which is calculated as follows:

$$RD_{VTEC} = 1 - \frac{VTEC(Obs)}{VTEC(SPIM)}$$

Where VTEC (Obs) represents the GPS-derived VTEC and VTEC (SPIM) is the output of SPIM. It is noted that RD_VTEC are almost plus, which means the predicted results of SPIM overestimate the VTEC at all seasons and almost all the time. We found that the diurnal distribution of RD_VTEC is similar in three sites, so the average values of RD_VTEC for all seasons in three sites were calculated and the variation vs. UT was shown in the right bottom of Fig. 8. The average values of relative difference could reveal the general precision and availability of SPIM to some extent. In brief, the existential difference between practical observation and model results of SPIM, which is recommended by the International Standardization Organization (ISO), should be consider while it was used to study the ionosphere.

Although the height (20,000 km) that SPIM could model seems more reasonable for model the TEC, the morphological characteristics of VTEC as shown in this paper indicate again that the shortcoming of SPIM can easily be seen when it is applied at these three sites, in the low latitude region. One reason of difference could be related with the second part of SPIM, Russian Standard Model of Ionosphere (SMI), which based on the data more from high latitude, so when the model is used to predict the TEC or other ionospheric parameters, it may not show great agreement with the measurements from the low latitude. Another is could be partly caused the shape of profile assumed by the model. Bhuyan and Borah (2007) found the outputs of IRI may overestimate the GPS TEC at most time during low solar activity both in the Indian and East Asian longitude sectors, thus, the SPIM, which based IRI and merged the Russian Standard Model of Ionosphere overestimates the TEC is to be expected.

4. Conclusion

In the present paper we investigated the diurnal and seasonal variations, solar (F10.7 and SSN) and magnetic (Kp and Dst) activity effects on the characteristics of the northern equatorial ionospheric anomaly by using the GPS-derived VTEC at three ground observational stations, Fuzhou (26.1°N, 119.3°E, geomagnetic latitude 14.4°N), Xiamen (24.5°N, 118.1°E, geomagnetic latitude 13.2°N), Nanning (22.8°N, 108.3°E, geomagnetic latitude 11.4°N) near the Equatorial Ionization Anomaly crest location in Chinese zone, from 2006 to 2007 during the low solar activity. Some results confirm our previous study (Liu et al., 2012) using the data recorded single station. More data from different stations during the period of low solar activity are analyzed in this work, which are more convincing to represent the law of variation of TEC in the low latitude of China. The results will help people get more understanding about the temporal characteristics of vertical total electron content in this region, and main results from this study are as follows:

1. Manifest seasonal anomaly of VTEC was found in three stations, with the maximum in spring and minimum in summer. Meanwhile, a weak winter anomaly existed with the magnitude of peak VTEC in the winter slightly higher than that in summer, and 2 h delay of occurrence time of maximum.
2. The basic pattern of variation of VTEC shows that the max value of the diurnal curve occurs at 06 UT in Fuzhou (LST = 13.95 h) and Xiamen (LST = 13.87 h), while it is 07 UT in Nanning (LST = 14.22 h); the minimum value occurs at 21 UT over three stations.
3. VTEC recorded in Fuzhou station is remarkable lower than other two stations. It may be due to the especial location (geomagnetic latitude 14.4°N), on the fringe of the crest of northern EIA.
4. The distribution of the relative standard deviation (RSD) for VTEC reveals that it is relatively smooth and steady during 00–12 UT, while it has complex variation after 12 UT which corresponding the period of low value VTEC.
5. The results of correlation analyses between monthly peak VTEC and magnetic and solar index indicate that a solar index has a better relationship with VTEC compared to the geomagnetic index, wherein the sunspot number SSN shows the best correlation among the chosen indices. Compared our previous study, the better correlation between VTEC and solar-geomagnetic activity is prone to long-term, but not short-term.
6. The predicted vertical TEC by SPIM is greater than the GPS-derived TEC during all seasons in three sites, and the average relative difference for all data is about 0.5, which illustrates again that this ionosphere model recommended by the International Standardization Organization need to improve its prediction accuracy, especially used in the area of low latitude.

Now the solar activity is coming to high period gradually, accompanying more intense space events. In order to improve the predicting ability of ionosphere model and avoiding the bad influence of space accident in the application of GPS based navigation and positioning, the variation in different location and the effect of Disturbance and the storm on TEC and other ionosphere parameters need more observational data in different longitudes and latitudes, as well as specific works to study the characteristic.

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