Night-time total electron content enhancements at equatorial anomaly region in China

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Abstract

This paper presents small scale (duration $\lesssim 1$ h, $\Delta TEC \geq 1$ TECU) night-time total electron content (TEC) enhancements observed at the equatorial anomaly region in China, for the first time. The data is from a GPS receiver chain established in 2005 by Institute of Center for Space Science and Applied Research, Chinese Academy of Sciences and a GPS receiver of International GPS Service (IGS), located between Fuzhou (26.1°N, 119.3°E) and Nanning (22.8°N, 108.3°E). Two other GPS observations of IGS taken at higher latitude were also used to investigate the localization of such phenomenon. The characteristics of the night-time TEC enhancement are examined with two case studies. The TEC increases about 1–3 TECU, intermittently. While the night-time TEC enhancement mainly occurs at the equatorial anomaly region, it can be observed at middle latitude as well. The spatial size of the enhancement region is less than 5° in longitude.

The primary statistical study shows that the TEC enhancement is more often observed in spring and autumn, but rarely in summer. It has no dependence on geomagnetic activity. The enhancement can occur both before and after midnight.

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Keywords: GPS; Total electron content; Night-time TEC enhancement

1. Introduction

Equatorial spread F (ESF) is a very important phenomenon in the night-side equatorial ionosphere. It is caused by the ionospheric irregularities. The irregularities can result in the scattering of radio waves with a wide frequency range and affect the satellite communication and precision navigation. Of which the equatorial plasma bubbles (also known as plasma depletion) have been investigated since last 1970s.

On the other hand, another type of plasma irregularity, plasma blob, was firstly observed as the localized plasma density enhancement by Hinotori satellite (Oya et al., 1986; Watanabe and Oya, 1986). It is found that the plasma blob has a complementary occurrence with plasma bubble. Such plasma density enhancement was re-studied with ROCSAT-1 and DMSP spacecraft by Le et al. (2003). Park et al. (2003) also studied the plasma blobs in association with large-scale plasma depletions using the data from KOMPSAT-1 and DMSP satellites. Pimenta et al. (2004), with all-sky images of the OI 630 nm night-glow emission, reported first ground-based optical observation of equatorial plasma blob. These studies suggested that the plasma density enhancement is associated with the plasma depletion. And Le et al. (2003) proposed that the eastward polarized electric field within the plasma bubble is responsible for the density enhancement.

Dashora and Pandey (2005) reported the correlation between the TEC and scintillation at Udaipur (24.6°N, 73.7°E, geomagnetic latitude:15.6°N) in India, with a case study of the localized TEC enhancement which was thought to be the manifestation of above mentioned plasma blobs. And the TEC enhancement was not always accompanied by scintillation.

In this paper, the characteristic of this kind of TEC enhancement is analyzed in detail, for the first time. The TEC data is mainly from several GPS stations at equatorial
anomaly region in China, and a few receivers at middle latitude are also included. Section 2 describes the observation data analysis method and the definition of the night-time TEC enhancement studied in this paper. Section 3 gives two case studies of the TEC enhancements and the primary statistical analysis for its occurrence. Section 4 discusses the characteristic of the TEC enhancement and the possible mechanism. Section 5 gives a brief summary for the observation results.

2. Observations

A GPS receiver chain consists of 4 dual-frequency GPS receivers established at Fuzhou, Xiamen, Guangzhou and Nanning in 2005 by the Center for Space Science and Applied Research, Chinese Academy of Sciences. The data resolution of the four stations is 1 s. Three other GPS observations at Beijing, Wuhan, and Taoyuan from international GPS service (IGS) are also used in our study, with data interval of 30 s. Table 1 gives the geographic and geomagnetic coordinates of the GPS receivers.

The ionospheric total electron content (TEC) can be obtained from the different delays at two frequencies of a dual-frequency GPS receiver. The line-of-sight TEC calculated from the differential carrier phase observations is as follows

$$TEC = \frac{(N_1 + \phi_1 - N_2 + \phi_2)}{f_1} \cdot \frac{c^2 f_1^2 f_2^2}{40.28 (f_1^2 - f_2^2)}$$  \hspace{1cm} (1)

Here, $N_1$ and $N_2$ are the integer ambiguities of the GPS L1 and L2 carrier phases. $\phi_1$ and $\phi_2$ are the carrier phase measurements of the frequency $f_1$ (1.57542 GHz) and $f_2$ (1.2276 GHz). And $c$ is the light speed. Since it is the TEC enhancement we studied, there is no need consider the integer ambiguities. The Eq. (1) can be simplified,

$$TEC = 2.853 \left(\frac{\phi_1}{f_1} - \frac{\phi_2}{f_2}\right)$$  \hspace{1cm} (2)

The unit of TEC is TECU (1TECU = 10^{16} electron/m²).

3. Results

3.1. February 26, 2006

Fig. 2 shows the relative slant TEC observed with 7 GPS receivers for the period of 12–22 UT on February 26, 2006 when the geomagnetic condition is quiet with Dst index about −10 nT at night. The relative slant TEC is calculated from Eq. (2) plus a constant in order to show them in one panel. The corresponding satellite PRN number is also shown in the figure. The small TEC enhancements, less than 2TECU, are observed in all the seven stations intermittently. The start time of the TEC enhancements are

![Fig. 1. Variation of TEC on November 28, 2005 for PRN 5 at Fuzhou. The top panel gives the satellite elevation. The second panel gives the variation of geographical longitude of the IPP. The third panel gives the variation of geographical latitude of the IPP. The fourth panel gives the variation of slant TEC, the dot line is the estimated background TEC. Number 5 at the top of the figure means PRN 5. The two vertical lines point out the TEC enhancement’s range.](image-url)
listed in Table 2. The blanks mean that there are no TEC enhancement observed for the pair of GPS receiver and satellite. Sometimes the enhancements are not considered because the TEC increment smaller than 1TECU, such as PRN 3 at about 20:20 UT, PRN 14 at about 15:00 UT, PRN 16 at 17:00 UT, and PRN 25 at 17:00 UT at Wuhan. It can be seen that the TEC enhancements mainly occur at Wuhan, Taoyuan, Fuzhou, Xiamen and Guangzhou. Surprisingly, the TEC enhancement is also observed at middle latitude (Beijing). The start time has some difference for the same satellite in different sites. Fig. 3 shows satellites ionospheric pierce points (IPP) positions for the seven sites. To calculate the IPP, the ionosphere is assumed to be a thin shell at about 400 km altitude. The gray dash lines in Fig. 3 show the distribution of the IPP of all satellites that can be observed during 10:00–22:00 UT (Beijing standard time is from 18:00 to 06:00). It is shown that the latitude observation range is from 15° to 45°. The thick black lines are the satellites position for the TEC enhancement as listed in Table 2. It is obvious that the TEC enhancement occurs at a limited area, with latitude from 20° to 38°. But most TEC enhancements occur between 20° and 32° in latitude. The TEC enhancements can be observed in different region at about the same period. But for each satellite, its longitude range is less than 5°.

3.2. September 12, 2005

The other case about the night-time TEC enhancement is on September 12, 2005 during the recovery time of a geomagnetic storm with DST index about −50 nT at night. Fig. 4 shows the variations of the relative slant TEC at Beijing, Wuhan, Taoyuan, Fuzhou, Xiamen, and Guangzhou. The corresponding start time of the TEC enhancements for different satellite are listed in Table 3. It is evident that the TEC enhancements mainly occur at Taoyuan, Fuzhou, Xiamen, and Guangzhou, in several discontinuous periods. In Wuhan, only PRN 2 observed the TEC enhancement. TEC for PRN 2 in Beijing also has a disturbance like enhancement, but it is out of the criteria in Section 2 because of the duration larger than one hour. The same is for PRN 2 in Taoyuan, PRN 24 and PRN 7 in

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Table 2

<table>
<thead>
<tr>
<th>PRN</th>
<th>Beijing (UT)</th>
<th>Wuhan (UT)</th>
<th>Taoyuan (UT)</th>
<th>Fuzhou (UT)</th>
<th>Xiamen (UT)</th>
<th>Guangzhou (UT)</th>
<th>Nanning (UT)</th>
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<td></td>
<td>16:11</td>
<td>16:11</td>
<td>16:53</td>
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</tr>
</tbody>
</table>

Those satellites without TEC enhancement observed were not listed in the table.
Xiamen. Also PRN 7 in Taoyuan station, PRN 10 between 17:00 and 18:00 UT in Xiamen are not considered because the enhancement is smaller than 1TECU. From Fig. 4 and Table 3, we can see that the TEC enhancement is about 1–3TECU, with duration mostly about 30 min for each satellite. The start time of the enhancement was divided into four periods according to Table 3, labeled (a)–(d). The period (a) is from 14:00 to 15:30 UT. The period (b) is from 16:00 to 17:00 UT. The period (c) is from 17:00 to 18:00 UT. The period (d) is from 18:00 to 19:30 UT. Fig. 5 shows the IPP position during these four periods. It can be seen that the TEC enhancement region distributed

Fig. 3. The satellite's IPP position on February 26, 2006. The gray dash lines are the satellites' position with elevation higher than 30° in seven stations. The dense lines are the satellite positions with TEC enhancement observed. The station name and satellite PRN are shown, as B for Beijing, W for Wuhan, T for Taoyuan, F for Fuzhou, X for Xiamen, G for Guanzhou, and N for nanning. The start universal time is also shown when the enhancement begins, noted as the small circle.

Fig. 4. The variations of the relative slant TEC on September 12, 2005.
differently for the four periods. Moreover, the enhancement still limits in the geographical latitude between 20° and 32°, the same as the case shown in Fig. 3. The longitude range of the enhancement for each satellite is also about 5°.

3.3. Statistical result

We survey the data gathered in Taoyuan station from January 1, 2005 to August 31, 2006 to study the occurrence of the night-time TEC enhancement. Fig. 6 is the occurrence distribution in different month during this period. If there are several enhancements observed in one night, like discussed above, we only consider them as one case in the month. In Fig. 6, the upper panel is the total occurrence. The second panel shows the occurrence for the distributed geomagnetic condition in the day or before the day (Dst index < -30 nT). The third panel shows the occurrence when the geomagnetic condition is quiet. It is apparent that the enhancement is observed more often in spring and autumn than in summer. In winter, the occurrence rate is large in January. The enhancement occurs rarely in summer. The enhancement can be observed both in geomagnetic disturbed time and in quiet time. Fig. 7 shows the time distribution when the enhancement is observed. The TEC enhancement can be observed pre-midnight and post-midnight. And the occurrence in post-midnight is larger than in pre-midnight.

4. Discussion

The localized plasma density enhancement was mainly studied with satellites observations (Oya et al., 1986;
The ground optical observation of the plasma density enhancement was also studied by Pimenta et al. (2004). Since the TEC is a measurement of the integral plasma density, the enhancements in the plasma density can be observed as TEC enhancements. Dashora and Pandey (2005) reported one case of the TEC enhancement with a GPS receiver at low latitude for the first time. These studies show that the TEC enhancement is a low latitude phenomenon. In this paper, the GPS data from low to middle latitude are used to analyze the TEC enhancement in more detail.

The purpose of using data from Beijing is to confirm the distribution region of this kind of TEC enhancement. However, it observes the TEC enhancement, which suggests the TEC enhancement is not limited at low latitude. As expected, most of the TEC enhancements mainly occur at equatorial anomaly region, which is consistent with the observation results as described in Oya et al. (1986) and Le et al. (2003). The small enhancement range in longitude and latitude suggests that it is caused by small-scale irregularity.

The TEC enhancement can occur both before and after midnight, as shown in Tables 2 and 3 and Fig. 7. Satellite observation indicates the plasma density enhancements mainly occur about 21:00 LT. No density enhancement observed after midnight may be due to the observation time limitation of the DMSP satellite at low latitude region at night (Burke et al., 2004). In addition, Le et al. (2003) have proposed the mapping of the polarized electric fields associated with the depletions at the equator to be responsible for the generation of the localized regions of plasma enhancements. The eastward polarization field can map to higher latitudes along the field lines and attain the equatorial anomaly region when the plasma bubbles rise to the topside F region at the equator. The mapped eastward electric field lifts the high-density plasma upward and results in the density increments occurrence. In this paper, we are not able to analyze the relationship between the TEC enhancements and depletions. But the statistical analysis indicates that the seasonal occurrence of the TEC enhancements is similar to plasma bubbles (Huang et al., 2001, Fig. 3). Actually, in one case as shown in Fig. 2, a bubble like structure is observed by PRN 14 in Xiamen at about 18:00 UT on February 26, 2006. Case studies and statistical analysis should be done to clarify the correlation between plasma bubbles and blobs and hence the mechanism of the TEC enhancement generation.

5. Conclusion

The small scale night-time TEC enhancement with its duration less than 1 h and maximum $A_{TEC}$ larger than 1 TECU was investigated with two case studies and statistical analysis, with data from GPS receivers at equatorial anomaly region in China, for the first time. One case was for the night-time TEC enhancement at the geomagnetic quiet time, and the other was at the recovery phase of a moderate storm. It is found that the TEC enhancement mainly occurs at the equatorial anomaly region with latitude from 20° to 30°. However, the TEC enhancement is not limited at low latitude region. It can be observed at middle latitude as well. Most of the TEC enhancements last about 30 min. It can be observed intermittently, with the longitude range less than 5°. The increment of the TEC is about 1–3 TECU. For the statistical analysis, the primary results indicate that the night-time TEC enhancement can occur both before and after midnight. It occurs more often in spring and autumn, but rarely in summer. The occurrence of the TEC enhancement has no significant dependence on the geomagnetic condition.

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References

