Astrophysics from Antarctica
Proceedings IAU Symposium No. 288, 2012
M. G. Burton, X. Cui & N. F. H. Tothill, eds.

doi:10.1017/S1743921312017139

Secular variation and fluctuation of GPS Total Electron Content over Antarctica

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Abstract. The total electron content (TEC) is an important parameters in the Earth's ionosphere, related to various space weather and solar activities. However, understanding of the complex ionospheric environments is still a challenge due to the lack of direct observations, particularly in the polar areas, e.g., Antarctica. Now the Global Positioning System (GPS) can be used to retrieve total electron content (TEC) from dual-frequency observations. The continuous GPS observations in Antarctica provide a good opportunity to investigate ionospheric climatology. In this paper, the long-term variations and fluctuations of TEC over Antarctica are investigated from CODE global ionospheric maps (GIM) with a resolution of $2.5^\circ \times 5^\circ$ every two hours since 1998. The analysis shows significant seasonal and secular variations in the GPS TEC. Furthermore, the effects of TEC fluctuations are discussed.

Keywords. GNSS, TEC, Ionosphere, Antarctica.

1. Introduction

The Earth's ionosphere is one of main parts in the Earth's upper atmosphere and plays a significant role in the space environment. Although the ionosphere represents less than 0.1% of the total mass of the Earth's atmosphere, it has a great effect on the global electric circuit, the Earth's magnetic field and on electromagnetic wave propagation through the Earth's ionosphere due to its partially ionized gas. However, understanding of the complex ionospheric environments is still a challenge due to the lack of direct observations, particularly in the polar areas, e.g., Antarctica. Antarctica is the southernmost and coldest continent on the Earth. It is well-known that Antarctica has special daily and seasonal variations due to the Earth's rotation and revolution, which also affect the Earth's ionospheric variation. Since the Earth's ionosphere is a dispersive medium, when electromagnetic wave signal propagates through the ionosphere, the signal will be delayed. The ionospheric TEC can be calculated from dual-frequency GPS measurements. As more and more continuous operational GPS stations are set up, GPS has become a powerful tool to monitor global and region TEC. The international GNSS services (IGS) has routinely produced global vertical TEC maps every two hours for more than 10 years. Secular variations of vertical TEC over Antarctica can be investigated using these data. Here TEC maps provided by CODE are used to extract vertical TEC time series over the Antarctica. In section 2, the basic method on VTEC computation and data processing from CODE is described. Secular variations and fluctuations of GPS TEC over Antarctica are discussed and analyzed in section 3. Finally, the conclusions are given in Section 4.

2. Method and Data

As is well known, slant TEC can be derived from GPS geometry-free combination measurements. Usually, the high-order effects of the ionospheric refractivity are ignored

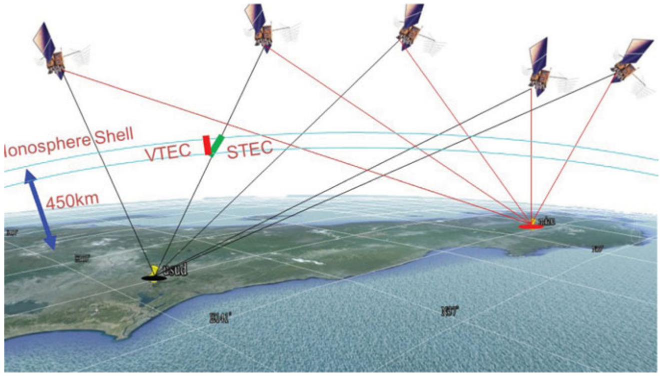

Figure 1. Geometry of GPS-TEC estimation.

as their effects are very small. Here we assumed all electrons are concentrated in an infinite thin shell in order to simplify expression of the slant TEC from GPS dual-frequency data. As shown in Figure 1 (here we just use two GPS stations (usud and mizu) to show the Geometry of GPS TEC estimate), the altitude of the ionosphere shell is adopted as 450 km, because the electron density peak of the Earths ionosphere is about 300–500 km. The vertical TEC is transformed from slant TEC using a cosine function of elevation.

$$\frac{vTEC}{cos(z)} = -\frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}(P_1 - P_2 + B) = \frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}(L_1 - L_2 - (N_1\lambda_1 - N_2\lambda_2) + b) \tag{2.1}$$

where, f_1 and f_2 are the GPS carrier wave frequencies, P_1 and P_2 are the GPS pseudorange measurements and carrier phase measurements, respectively, N_1 and N_2 are the ambiguity, λ_1 and λ_2 and are the wavelength of GPS signals. B and b are the differential codes biases and inter-frequencies differences, respectively.

In this paper, the GPS TEC time series over Antarctica are obtained from CODE. In order to avoid an error caused by the TEC computation algorithm, the recent data are used after March 16, 2002. These are results for the middle day of a 72-hour combination from the next day rather than 24-hour analysis. In this way, discontinuities at day boundaries can be minimized. Furthermore, a time-invariant quality level is achieved.

3. Result and Discussion

Although the GPS satellites orbit inclination angle is 55° and GPS satellites cannot fly over the South Pole, many GPS TEC measurements are provided by ground GPS stations located in Antarctica, such as vesl, syog, maw1, dav1, cas1. CODE provides global vertical TEC maps every two hours with a spatial resolution of 2.5°×5° in longitude and latitude. Vertical TEC values over Antarctica are extracted from ionox files released by CODE from day 076, 2002 to day 252, 2012. In order to check the characteristics of secular GPS TEC variations over the Antarctica, mean values of vertical TEC along the parallel of latitude are computed. As shown in Figure 2, obviously annual variation appears in long GPS TEC time series over Antarctica at latitudinal circles from S87.5° to S72.5°, and the mean values of the vertical TEC over Antarctica have a slight decreasing trend. The 2880 MHz solar flux variations during 2002 to 2012 are also shown in Figure 2. The vertical TEC variation shows agreement with the solar activities. Higher amplitudes

https://doi.org/10.1017/S1743921312017139 Published online by Cambridge University Press

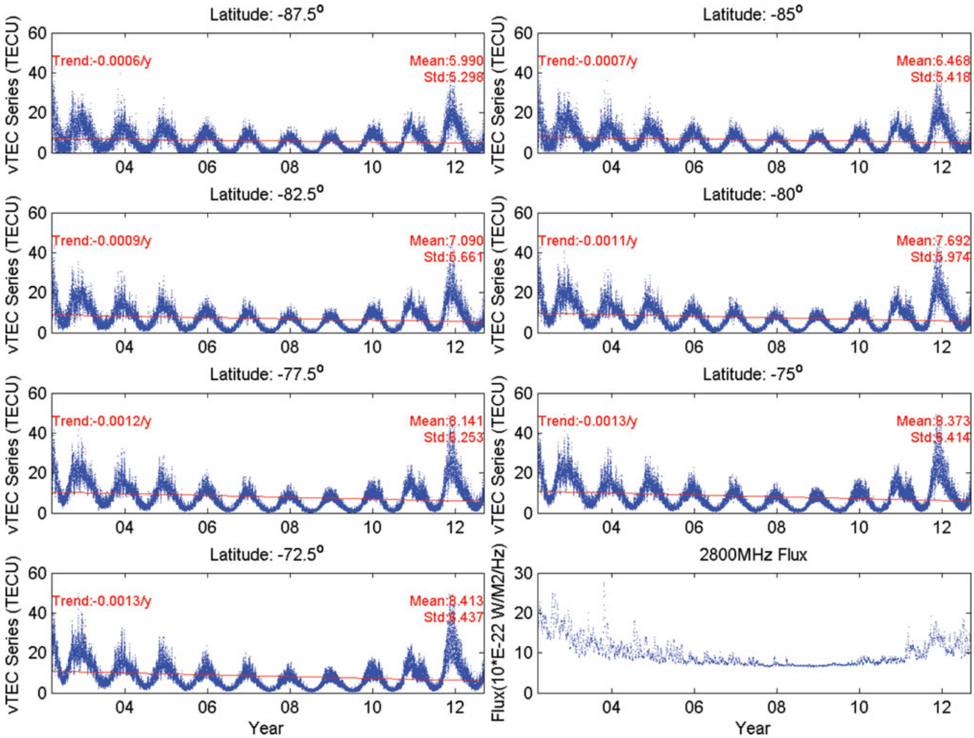

Figure 2. Long term variation and fluctuation of TEC from 2002 to 2012 over Antarctica.

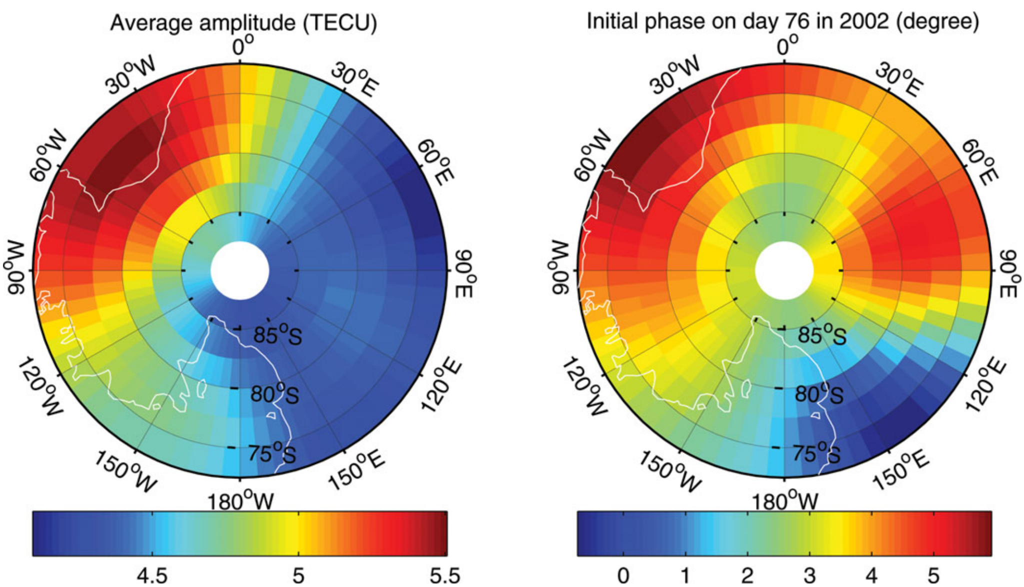

Figure 3. Average annual amplitudes and initial phases of GPS TEC over Antarctica.

of vertical TEC time series are found in around 2003 and 2011, which are higher solar activities years. Although, for the most time, the Sun is not visible in areas near the South Pole in Antarctica, the variation of amplitudes is obvious. In addition, the mean values and the standard deviations of about 10 years GPS TEC series over Antarctica

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increase as the latitude decreases. Probably, this phenomenon can be explained due to differences in solar radiation with latitude. Solar fluxes become smaller and smaller as the location gets closer to the South Pole. The Earth's ionosphere receives less energy for ionization near the South Pole. Lower vertical TEC and fewer fluctuations are shown in long-term vertical TEC in higher latitude area over Antarctica, which agrees with our inference. Higher amplitudes of vertical TEC time series are found around 2002 and 2012. Earth's ionosphere is affected by solar activity. Although, for the most time, the Sun is not visible in areas near the South Pole in Antarctica, the variation of amplitude is obvious. Figure 3 shows the distribution of the annual amplitudes and phases of GPS TEC times series from day 076, 2002 to day 252, 2012. The amplitudes and phases are both related to the longitude and latitude. The average amplitudes range from 4 to 6 TECU, and increase as the decrease of latitudes. And for W0° to W120°, the average amplitudes are relatively large. Initial phases also changes with the latitude variations exclude from E120° to E170°.

4. Conclusion

In this paper, the long-term variations and fluctuations of TEC over Antarctica are investigated from CODE global ionospheric maps (GIM) with a resolution of 2.5°*5° every two hours since 1998. The analysis results show significant seasonal and secular variations in GPS TEC. The long-term vertical TEC variations have good agreement with the solar activities. The annual amplitudes and phases are both related to the longitude and latitude. The average amplitudes range from 4 to 6 TECU over most Antarctic and phases are almost closer. The different patterns in West and East Antarctic are existed, which needs to be further investigated in the future.

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