Variation of single-frequency GPS Positioning Errors at Taiwan based on Klobuchar ionosphere model

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Abstract

In this paper, 11 year's single-frequency pseudorange observations from one IGS GPS receiver set up at Taoyuan, Taiwan, were used to analyze the relation of the positioning error to the changes of the solar activities. The receiver's position at each epoch is obtained by positioning solution. Positioning error is defined as the difference between the position from the positioning solution and the position published by IGS. The Klobuchar model is used the correct the ionospheric range delay during the positioning solution. The results showed that during the high solar activity years the positioning error is larger than that during the low solar activity years. For the single-frequency GPS receiver, the ionospheric range delay is the main error source, and the error of the Klobuchar during the high solar activity years is larger than the error during the low activity years.

1. Introduction

Ionosphere is formed in the atmosphere partly by the cosmic rays but mostly by solar radiation. Sufficient free ions exist in the ionosphere to affect the propagation of the radio waves. Ionosphere lies between 60 km and 1000 km above the earth. When radio signals passed through the ionosphere, group delay and phase advance will happen. The delay induced by the ionosphere is related to the total electron content (TEC) along the light of sight path and the frequency of radio signal.

For dual-frequency Global Positioning System (GPS) receiver, the ionospheric delay can be eliminated by dual-frequency measurements. But for most of the single-frequency GPS users, the ionospheric delay is corrected by Klobuchar model. The model parameters are broadcasted from the GPS satellite. Klobuchar model is verified to be a simple, practical and effective model. It was reported that the Klobuchar model can correct about 50%~60% RMS ionospheric range error worldwide [1-2]. But the model does not properly represent the behavior of the ionosphere in the near-equatorial region and high latitude areas of the world, where the ionospheric delay are large and the ionospheric variability is high [3]. When severe ionosphere activity happens, the model correction will become very poor [4].

With the development of GPS theory and measurement method, higher and higher positioning accuracy is required. More and more countries researched on ionosphere and ionospheric model to get higher accuracy correction model or predict ionosphere in high precision. Most of south of China is located near the north crest of the equatorial anomaly. The variation of the ionospheric TEC is large in this area. Many researchers focused on studying the ionospheric model of this area, and established a regional ionospheric model of China [5-7]. But few people evaluated or researched the improvement of the ionopsheric model to the positioning accuracy of the single-frequency GPS receiver. In this paper, 10 years GPS data from one International GNSS service (IGS) station is used to research the positioning error of the single frequency GPS receiver in Taoyuan Taiwan, China. The Klobuchar model is used during the solving the positioning equation set. The long-term variation of positioning precision is analysed.

2. Analysis Method

The GPS station used in this paper is named as TWTF, located at Taoyuan, Taiwan, (25°N, 121°E). The coordinates of the receiver is listed in table 1 as the standard position. The coordinates are published by IGS in log file in December 2004.

This station is chosen because the receiver is near the equatorial anomaly region. In this region, Klobuchar model correction may be limit and affect the positioning accuracy of the single-frequency GPS receiver. Ten years' data from 2003 to 2012 are collected and used to analyze the positioning accuracy based on C/A code measurement and Klobuchar model. This receiver records ephemeris, dual-frequency pseudoranges and phases in RINEX (Receiver Independent Exchange Format) files. Ephemeris and the pseudorange of C/A code are used in positioning solution. Dual-frequency pseudoranges and phases are used to obtain the TEC on line of sight.

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Table 1 Coordinates of the receiver

Station		TWTF
Location of the		Taoyuan, Taiwan, China
Type of the		ASHTECH Z-XII3T
Coordinates in ECEF	X	-2994428.3682
	Y	4951309.1805
	Z	2674496.7722
Coordinates in WGS-84	Longit	121°09’52” E
	Latitud	+24°57’13” N
	Height	203.122m

At least, psudorange measurements from 4 GPS satellites are needed to get the position of the receiver [*8-9*]. Linearization is used to simplify the positioning equations set, and the pseudoranges from all the visible satellites take part in positioning solution by least-square method [9]. Satellite clock offset is compensated using the parameters broadcasted in ephemeris by a second-order polynomial. The troposphere delay is corrected by a troposphere model, and the ionosphere delay is corrected by the Klobuchar model [1].

The coordinates of the receiver in EFEC is obtained at each epoch by solving the positioning equation set. And then, the eastward, northward and upward error $(\delta_e, \delta_n, \delta_u)$ is calculated in local East, North, Up (ENU) coordinates with its origin defined as (x_0, y_0, z_0). (x_0, y_0, z_0) is the coordinates in table 1. The horizontal error and vertical error are separately defined as:

$$\delta_{horizontal} = \sqrt{\delta_e^2 + \delta_n^2}$$

$$\delta_{vertical} = \delta_u$$

The receiver used in this paper began to record the Klobuchar ionospheric correction parameters on the 141^{st} day in 2003, and therefore, the data from the 141^{st} day 2003 are used to analyze the positioning accuracy of the single frequency GPS receiver. In view of the daily variation of the ionosphere, two time segments are chosen. 1000BJT-1600BJT is considered as day time, and 2200BJT-0400BJT as night time. The positioning errors during the day time and the night time are analyzed in statistic respectively.

The 1σ and 3σ positioning accuracy are defined as the positioning error which is larger than 68.3% and 99.7% positioning errors. After the horizontal error and vertical error are obtained at each epoch, the 1σ, 2σ and 3σ positioning accuracy are simply calculated statistically in every month respectively.

3. Positioning Results

Figure 1 shows the monthly 1σ (left) and 3σ (right) positioning accuracy of the receiver based on C/A code pseudorange measurements. The horizontal axis is the time (in year), and the vertical axis is the positioning accuracy in meters. Black line with dot shows the positioning accuracy during the day time (1000BJT-1600BJT), and blue line with star mark represents the accuracy in night (2200BJT-0400BJT). The horizontal accuracy and vertical accuracy are in up panel and bottom panel separately.

As can be seen from this figure, the 1σ and 3σ horizontal accuracy at the daytime is larger than that at night. Both of them vary in a similar way, except the different values. The horizontal accuracy on the day time varies with the solar activity. Obvious seasonal variation can be observed. The minimum of the horizontal accuracy on the daytime appeared in summer or winter, and the minimum in summer is less than that in winter. The maximum of the horizontal error at the daytime appeared in equinox. Generally in the high solar activity years, the maximum is larger than the maximum value of spring, in the low solar activity, this phenomenon is not obvious.

In the high solar activity years, the horizontal accuracy at night also varied with the seasons, but in the low solar activity years (2007-2009), the horizontal accuracy at night did not change with the seasons obviously. In addition to the variation with the seasons, the positioning accuracy changes with the 11-years solar activity years. In the high solar activity years, the horizontal positioning accuracy is larger than that in the low solar activity years.

Compared with the horizontal accuracy, the difference is not obvious between the vertical accuracy in the daytime and that in night. In the high solar activity years (2003, 2004, 2011, 2012), the vertical accuracy in the daytime is slightly larger than that at night. And in the low solar activity, the height errors in the daytime were not larger than that at night.

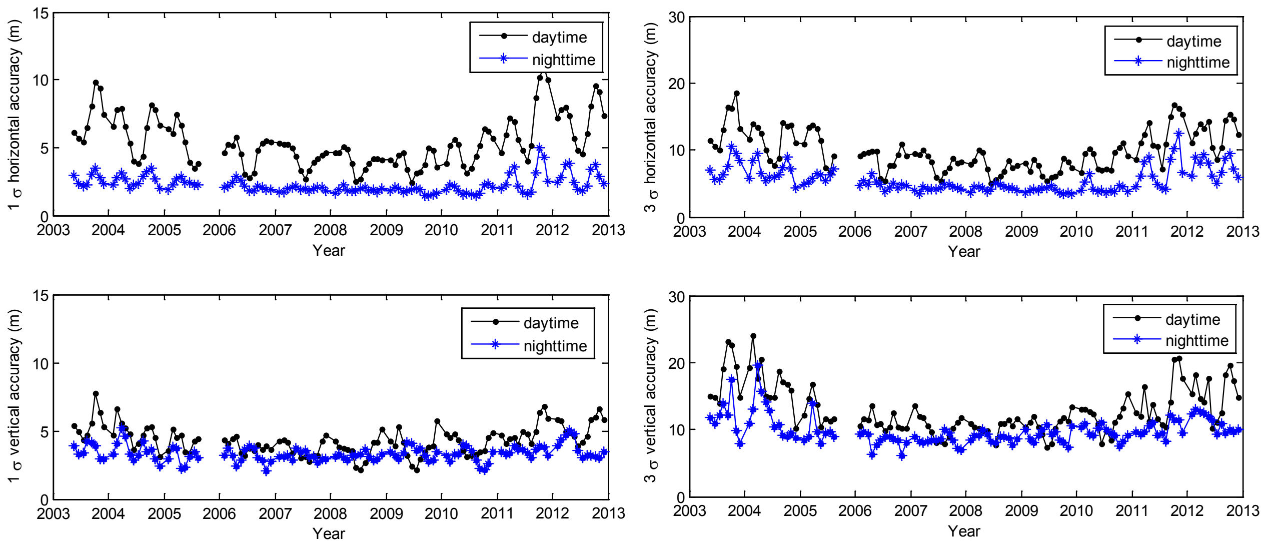

Figure 1. 1σ (left) and 3σ (right) positioning accuracy of the Single-frequency GPS

Seasonal variation of vertical accuracy is not as obvious as that of horizontal ones either. The summer minimum still appeared for the vertical accuracy, but the winter minimum only appeared in the high solar activity years. The maximum appeared in spring or autumn during the high solar activity years, such as in 2003, 2004, 2011 and 2012. However during the low solar activity years (2008-2010), the maximum appeared in winter. In the night, the vertical accuracy did not show seasonal variation.

3σ positioning accuracy in the night is more obvious than the 1σ accuracy in high solar activity years. It manifests that the effect of the solar activity on 3σ positioning accuracy is more significant in high solar activity years.

4. Discussion and summary

In this paper, 10 years (2003-2012) data from the GPS receiver located at Taoyuan, Taiwan are used to analyze the long-term changes of positioning precision of the single- frequency GPS receiver. Ionospheric delay estimation from Klobuchar model is used to correct the ionospheric delay. The results showed that, the horizontal positioning errors in the daytime are larger than that at night. The horizontal positioning accuracy changes with solar activity. At high solar activity years, the horizontal errors are large, and in the low solar activity years, the positioning horizontal are small. In the daytime, the positioning errors change with the seasons. The maximum appeared in the spring or autumn, and the minimum appeared in winter or summer. At night, the horizontal errors did not appear obvious seasonal variation in the low solar activity years. But in the high solar activity years, the horizontal positioning errors at night appeared seasonal variation. At night, the horizontal errors did not appear obvious seasonal variation in the low solar activity years. But in the high solar activity years, the horizontal positioning errors at night appeared seasonal variation. Vertical positioning error appeared seasonal variation in the daytime. Minimum was summer, but in winter the minimum did not always appear.

The TEC of the ionosphere varies with the seasonal, the maximum appeared in equinox, and the minimum is in the winter or winter. The annual variation and seasonal variation of the horizontal positioning errors is consistence with the variation of TEC. TEC is proportional to the ionospheric time delay. For the single-frequency GPS receiver, ionosphere delay error is one mainly error source. Although the ionospheric delay is corrected using the Klobuchar model, the remained error is still large enough to affect the positioning accuracy of single frequency GPS receiver, especially in the high solar activity years.

In the low solar activity years, the night error did not obvious seasonal variation. This is because the TEC at night is low. Lower TEC errors made smaller positioning error. But in the high solar activity years, the horizontal positioning errors at night appeared seasonal variation. In high solar activity years, the high TEC in the daytime may play a role on remain of TEC at night, so that the horizontal positioning errors appeared seasonal variation. The long term variation of TEC at night needs further research.

The TEC variation well explained the variation of horizontal accuracy. But for the vertical error, the minimum error only appeared in summer, which is not same with the TEC minimum in summer and winter. TEC minimum in winter did not caused minimum of the height positioning error. To better understand the error variation of the positioning error of the single GPS receiver, the following four points needed to be studied further: (1) the variation of the error of the Klobuchar model, (2) the effect of the Klobuchar error on GPS positioning error, especially on the vertical error, (3) the relationship between the Klobuchar model error and positioning error, (4) the effect of the model error at different areas.

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