Chapter 38
Comparison of Methods on Computing Ionospheric Delays in GNSS System Time Offset Determination

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Abstract Ionospheric delay error is one of the main factors that have significant impact on GNSS system time offset determination. Two methods are adopted to calculate the ionospheric delays in the monitoring of the GNSS system time offset. The first one is Total Electron Content (TEC) map provided by International GNSS Service (IGS) and the other one is the dual-frequency measure correction. The different effects of these two calculating methods are compared and analyzed in this paper. The results show that the ionospheric delays are corrected using dual-frequency observation is better than using the IGS TEC MAP. The monitoring results of the GPS/GLONASS system time offset compared with GPS/GLONASS system time offset published by Circular T, the accuracy of the former one is increased by 15 % than the latter one.

Keywords Ionospheric delays · TEC map · Dual-frequency measure · System time offset

38.1 Introduction

With the development of multiple Global Navigation Satellite Systems, the navigation based on the combination of more than one satellite navigation system will be the important development direction in the future. By choosing the

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combination of different navigation system based on their actual needs, the users can avoid excessive reliance on the only one system. However, since every GNSS system has their own time reference system, the time differences between two GNSS system will cause the deviation of positioning. The positioning precision can be highly improved in the multi-GNSS applications if we take the GNSS system time offset into consideration [1]. Therefore, the GNSS system time offset determination is a very important issue in the multi-GNSS application.

Nevertheless, the ionospheric delay error is one of the main factors that influence the result in the monitoring of the GNSS system time offset. When the electromagnetic signals go through the ionosphere, the path of the signal will be bend and the propagation velocity will be change because ionospheric is a diffuse medium for propagation of electromagnetic waves. As can be seen based on the actual data analysis, the distance difference of the electromagnetic wave propagation path along the zenith direction up to 50 m, in the horizontal direction up to 150 m due to ionospheric refraction for GNSS system. Such a large deviation must be considered for the calculation of the GNSS system time offset [2].

Two methods are mainly used to determine the ionospheric delay in the monitoring of the GNSS system time offset, the first one is Total Electron Content (TEC) map provided by International GNSS Service (IGS) and the other one is the dual-frequency measurement. This paper will evaluate these two methods in term of analyzing the accuracy and precision of the GNSS system time offset.

38.2 GPS/GLONASS System Time Offset Detection Principles

Because Standard Time in China is produced in National Time Service Center (NTSC), we can take the advantage of GNSS timing receiver to measure the difference between GPST with UTC (NTSC), and the difference between GLONASST with UTC (NTSC). We can obtain the system time offset by that indirectly.

Figure 38.1 shows the schematic diagram of GNSS system time offset monitoring system. The precision time interval counter measures the time difference of UTC (NTSC) 1pps signal and 1pps signal of the GNSS timing receiver output. Timing receiver receives GNSS satellite signal. After processing pseudorange data and Ephemeris data, the timing receiver can obtain the time offset between the navigation system and receiver. And then, by doing a simple arithmetic calculation, we can get the time deviation of UTC (NTSC) and GPST as well as the time deviation of UTC (NTSC) and GLONASST [3].

We need to consider variety of factors in this monitoring approach, such as the pseudorange measurement error, ephemeris error, tropospheric delay error, ionospheric delay error, receiver delay, and local clock delay. Among these factors, the

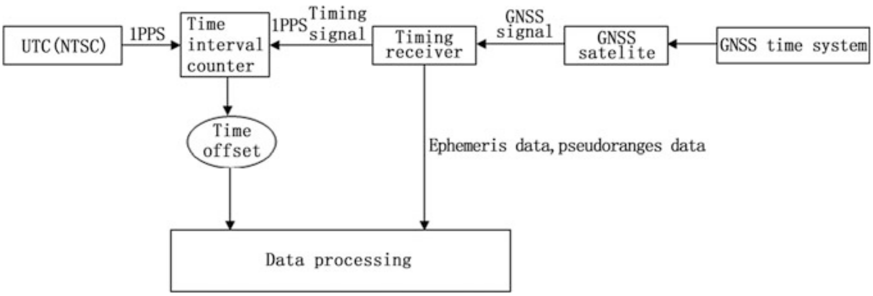


Fig. 38.1 Schematic diagram of monitoring GNSS system time offset

ionospheric delay error is one of the most important factors, which will influence GNSS system time offset monitoring results.

38.3 Ionospheric Delays Algorithm

38.3.1 Ionospheric Delays Determination by IGS TEC Map

IGS provides a global range of ionospheric TEC figure every 2 h. This figure is given in each 5° of longitude direction and each 2.5° of latitude direction in grid form. The total electron content of some region at t moment is interpolated by TEC map at T_i and T_{i+1} moment ($T_i < t < T_{i+1}$) [4]. The four points grid interpolation as shown in Fig. 38.2:

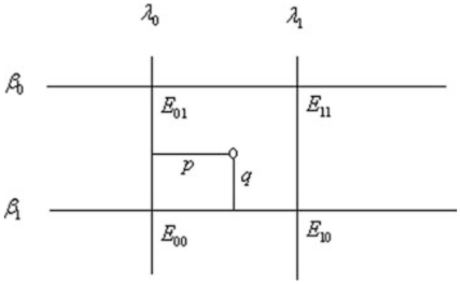
The detailed steps are as follows:

Firstly, we calculate the tec of T_i moment and T_{i+1} moment by spatial interpolation through the surrounding four points. E_i and E_{i+1} can be calculated by:

$$E(\lambda, \beta) = (1-p)(1-q)E_{00} + p(1-q)E_{10} + q(1-p)E_{01} + pqE_{11} \tag{38.1}$$

where (λ, β) is the latitude and longitude of the puncture point. $E_{00}, E_{01}, E_{10}, E_{11}$ is the TEC of surrounding four points (λ_0, β_1), (λ_0, β_0), (λ_1, β_1), (λ_1, β_0) provided by IGS TEC map. ($\Delta\lambda$, $\Delta\beta$) is the latitude and longitude intervals of ionosphere

Fig. 38.2 Diagram of the four points grid interpolation



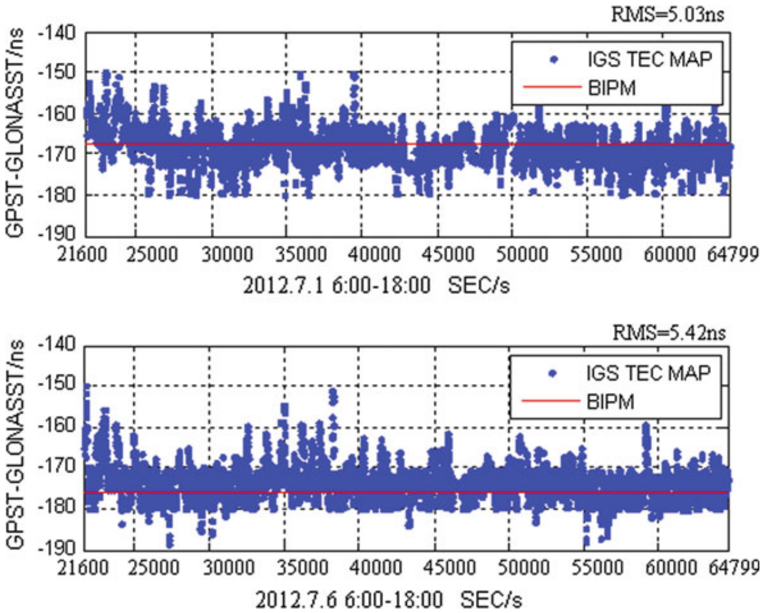


Fig. 38.3 Result of GPS/GLONASS system time offset (TEC map)

map grid point. $p = (\lambda - \lambda_0)/\Delta\lambda$, $q = (\beta - \beta_0)/\Delta\beta$, E_i and E_{i+1} are the tec at T_i, T_{i+1} moment.

Secondly, bilinear interpolation is calculated in two epochs, which t as a variable. The TEC along zenith direction at t moment is expressed as $E(\lambda, \beta, t)$, it can be calculated by:

$$\frac{T_{i+1} - t}{T_{i+1} - T_i} E_i + \frac{t - T_i}{T_{i+1} - T_i} E_{i+1} \tag{38.2}$$

Lastly, we select the appropriate mapping function to obtain each direction of the ionospheric delay.

Using the IGS TEC map for ionospheric delay determination in calculating the GPS/GLONASS system time offset. Figure 38.3 shows a part of the experimental results, and the RMS of about 5 ns.

38.3.2 Ionospheric Delays Determination by Dual-Frequency Observation

The difference of L1 and L2 pseudorange measurement is reflecting the changes in ionospheric delays because they are related to frequency. Do observe with dual-frequency receivers will be able to basically eliminate the ionospheric delays (the

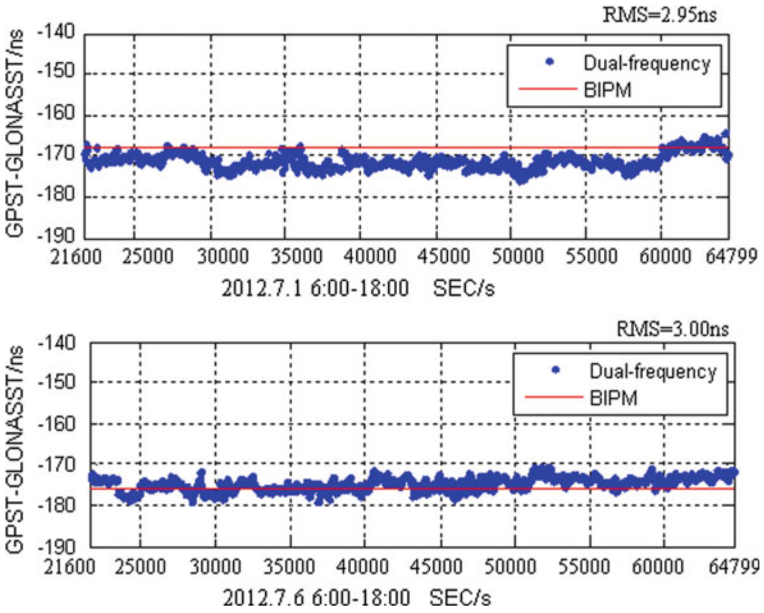


Fig. 38.4 Result of GPS/GLONASS system time offset (dual-frequency)

accuracy of the ionospheric delay measurement up to 1.2 m (about 4 ns)). Pseudoranges have no ionospheric influence can be expressed as:

$$\rho = \frac{\rho_{L2} - \rho_{L1}}{1 - \gamma} \tag{38.3}$$

where $\gamma = (f_{L1}/f_{L2})^2$. ρ is the ionospheric-free pseudarange. f_{L1} is the Carrier frequency of L1 as well as f_{L2} is the Carrier frequency of L2. ρ_{L1} is the measured value of pseudorange in L1 and ρ_{L2} is the measured value of pseudorange in L2. The disadvantage of this method is that the measurement error is enlarged although ionospheric delay error is erased. Based on a better method produced, the ionospheric delay error on L1 estimated in accordance with the following formula 38.4 [5]:

$$\Delta s_{iono,L1} = \left(\frac{f_{L2}^2}{f_{L2}^2 - f_{L1}^2}\right)(\rho_{L1} - \rho_{L2}) \tag{38.4}$$

Owing to ionospheric delays usually change slowly and a correction value Estimated should be subtracted from the pseudorange values, these corrected values must be smoothed [6].

Using the dual-frequency observation for ionospheric delay determination in calculating the GPS/GLONASS system time offset. Figure 38.4 shows a part of the experimental results, and the RMS of about 3 ns.

38.4 Analysis of the Results of GPS/GLONASS System Time Offset that Using the Different Methods to Calculate the Ionospheric Delays

Analyzing the results of GPS/GLONASS system time offset that using the different methods to calculate the ionospheric delays (shown in Fig. 38.5), it can be seen that dual-frequency correction works better than correction by IGS TEC map, the accuracy [7] of the former (the RMS about 3 ns) is higher than the latter one (the RMS about 5 ns). Figure 38.6 shows the results are compared with GPS/GLONASS system time offset published by circular T.

Determining GPS/GLONASS system offset by taking these two ionospheric delay corrections from July 2012 to September 2012, the RMS is shown in Table 38.1.

From Table 38.1, it can be concluded: After a dual-frequency measure correction, the RMS of GPS/GLONASS system time offset results is smaller about 2 ns and its accuracy improved by about 15 % compared with correction by IGS TEC map.

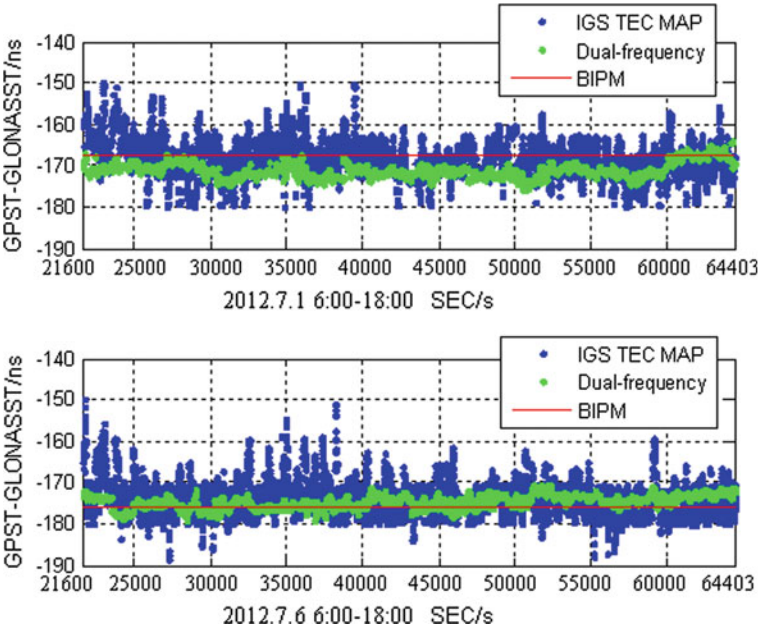


Fig. 38.5 Result of GPS/GLONASS system time offset in July 1 2012, July 6 2012 compared with the BIPM circular T

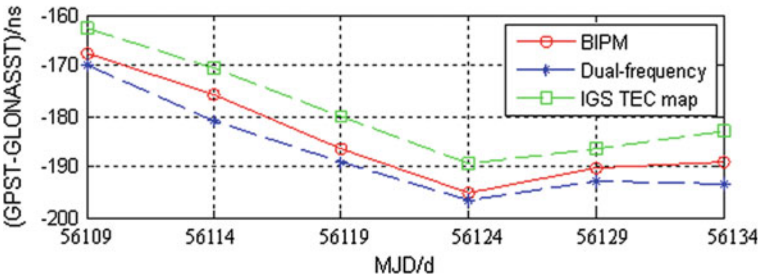


Fig. 38.6 Result of GPS/GLONASS system time offset in July 2012 compared with the BIPM circular T

Table 38.1 The RMS data compared by the two methods correction of GPS/GLONASS system time offset

	TEC map (RMS/ns)	Dual-frequency (RMS/ns)
2012.7	5.49	3.34
2012.8	5.23	3.12
2012.9	5.02	2.95

38.5 Conclusions

Ionospheric delay error has significant impact on GNSS system time offset determination. The Main objective of this article is to analyze two methods to measure the ionospheric delays in the monitoring of the GNSS system time offset, the one is TEC map provided by IGS and the other one is the dual-frequency measurement. From the experiment result, we can see that the ionospheric delays are corrected using dual-frequency observation is better than using the IGS TEC MAP. The accuracy of the former one is increased by 15 % than the latter one in monitoring results of the GPS/GLONASS system time offset.

Although the TEC map estimated ionospheric delays are not as good as dual-frequency measured ionospheric delays, the TEC map method is much simpler and cheaper. However, the reliability of IGS TEC map is not high due to there are no enough IGS sites. Besides, that will result in the estimated ionospheric delays drop in accuracy. In addition, the TEC map ionospheric delays are estimated by lag calculation, it is not recommended in real-time calculation. The ionospheric delay correction calculated by the dual-frequency measure is higher, but the L2 carrier signal of dual-frequency receivers is relatively weak and the cost is high. From this point of view, both of these two methods have their advantages and disadvantages. Therefore, when we determine the receiver delay [8] and the inter system hardware delay in monitoring the GNSS system time offset, it may be a better way to have these two methods combined.

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