RESEARCH ON ZENITH TROPOSPHERIC DELAY MODELING OF REGIONAL CORS NETWORK

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ABSTRACT:

By calculating the zenith troposphere information from 11 reference stations of the CORS network in Guilin City, Guangxi Province in 2018 by GAMIT10.6 as the reference values, analyzing the relationship between the zenith troposphere and the elevation, as well as the latitude in the Guilin Region, building a model for the zenith tropospheric delay (ZTD) suitable for the Guilin Region, uniformly selecting 8 CORS reference stations in the Guilin Region to build a new model, comparing with the ZTD estimated by GAMIT10.6 and studying the applicability of the new model in the Guilin Region, the results showed that: 1) In the Guilin Region, the ZTD presented linear negative correlation with the station elevation; 2) the ZTD estimated by the new model was well consistent with the reference value, with high precision, and increased with the elevation.

1. INTRODUCTION

ZTD is an important factor affecting the satellite navigation and positioning precision. The main methods for eliminating the tropospheric delay include parameter estimation method, model correction method and difference method, but these methods are adopted in a limited scope due to expensive price, high cost or high requirements for tropospheric correlation [1, 2, 3]. In recent years, with the establishment of the CORS network, many scholars have established a precise tropospheric delay model based on the data measured by the CORS reference stations, without a need to measure the meteorological parameters [4, 5]. In the literature [6], a precise tropospheric delay correction model suitable for the Hong Kong Region was built only based on the time and position parameters, depending on the ZTD of the CORS network in Hong Kong obtained for several years, which had a significant correction effect on the tropospheres with a high height difference. In the literature [7], through zenith troposphere analysis by the IGS station, it was concluded that, in large regions, the ZTD presented a negative exponential relation with the station elevation, and the ZTD models for relevant regions were built, with a precision of 12mm. However, these models were built based on data obtained for 5 days. In the literature [8], a new regional model was built based on the ZTD data from several IGS stations in California, and the increase in the model precision with the elevation was verified. In local regions or smaller regions, certain meteorological differences existed in different locations, so the troposphere varied greatly with different regions and seasons [9,10]. In this pa-per, taking Guilin City, Guangxi Province as a research object, GAMIT10.6 software was used to estimate the ZTD of 11 CORS reference stations in this region in 2018. By analyzing the variation of the ZTD with the elevation and latitude, a precise tropospheric delay model which was only related to the station location and DOY and suitable for the Guilin Region was built. 8 reference stations were selected in the Guilin Region to build a new model, and the remaining 3 were used as check stations to check the precision of the model.

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2. MODELING

2.1 Data source

Guilin City is located in China (109° - 12°E, 24° - 27°N). The reference stations of the CORS network were built with an average spacing of 50km, and data were sampled with an interval of 15s. Besides, one copy of observation file was kept for each reference station every day, and the station distribution map was shown in Figure 1. In this paper, based on the data measured by 11 reference stations in Guilin City, Guangxi Province in 2018, by selecting 4 IGS stations in total (BJFS (Beijing Fangshan), CHAN (Changchun), SHAO (Shanghai) and TWTF (Taiwan), jointly solving the ZTD in 2018 by GAMIT10.6 and comparing the ZTD of BJFS (Beijing Fangshan), CHAN (Changchun), SHAO (Shanghai) and TWTF (Taiwan) estimated by GAMIT10.6 to those of the IGS station, the ZTD deviations between the two were shown in Figure 2.

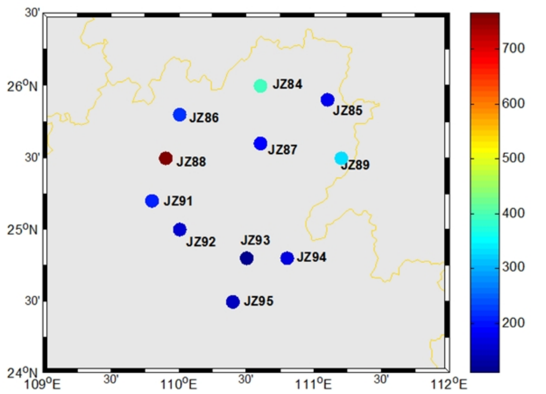

Figure 1 Distribution Map of CORS Stations in Guilin City, Guangxi Province

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In Figure 2, the data from the SHAO Station were missing during the DOY of 066-110. As can be seen from Figure 2, the deviations between the ZTD estimated by GAMIT and the IGS ZTD were mostly within ±5 mm (discrete in the middle but concentrated at both ends), namely the ZTD deviations in summer increased. Relevant research and experiment results showed that, the precision of the ZTD estimated by GAMIT was larger than 1cm, as a true value of the ZTD.

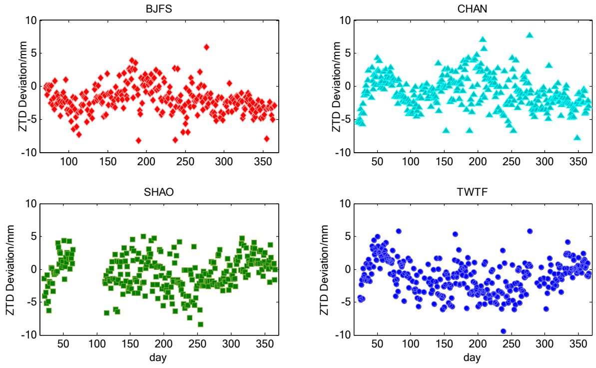

Figure 2 Deviations between ZTD estimated by GAMIT10.5 and IGS ZTD

2.2 Analysis of the relationship between ZTD and station elevation

In order to analyse the relationship between ZTD in the Guilin Region and the station elevation, this paper gave statistics over the relationship between ZTD and the station elevation for the daily average ZTD of the 11 CORS reference stations in 2018 solved by GAMIT10.6 by month, and its results were shown in Figure 3.

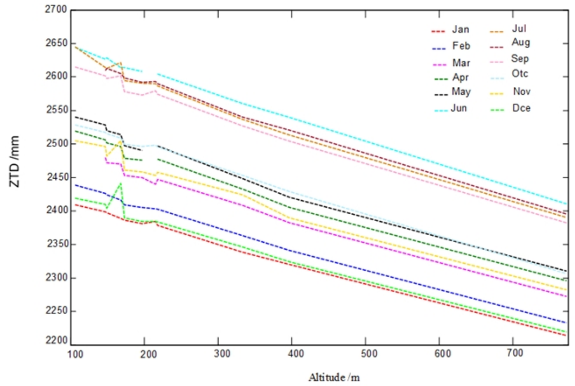

Figure 3 Variations of Monthly Average ZTD with Station Elevation

As can be seen from Figure 3, in 12 months, the ZTD of each month presented the same variation trends with the station elevation, and the ZTD decreased with the station elevation, namely, the ZTD presented a linear negative correlation with the station elevation. Therefore, in the Guilin Region, the relationship between the ZTD and the station elevation can be expressed as:

$$\mathrm{ZTD}(H_i, \varphi_i, \mathrm{t}) = -A_0(t)H_i + A_1(t) \quad (1)$$

In which, H and φ correspond to the elevation and latitude of the i station, and $\mathrm{ZTD}(H_i, \varphi_i, \mathrm{t})$ corresponds to the zenith troposphere of the i station at t. $A_i(t)$ is a parameter related to time, and can be solved by iteration. The above formula is expanded according to the multiple-term formula:

$$A_1(t) = a_0^i + a_1^i t + a_2^i t^2 + \cdots\cdots + a_n^i t^n \quad (2)$$

In which, $a_n^i(n = 0,1,2 \cdots \mathrm{n})$ is a coefficient of $A_1(t)$ at t, and the coefficients can be solved based on $A_1(t)$ at several intervals [8].

2.3 Analysis of the relationship between ZTD and station longitude

In order to further analyze the relationship between the ZTD and the station longitude, this paper gave statistics over the variations of the ZTD with the longitude by month by selecting the ZTD of JZ85 (25.9 E, 111.1 N, 176 m) and JZ86 (25.8 E, 110.1 N, 220 m) with close latitudes and elevations in 2018, as shown in Table 1.

Table 1. The relationship between average ZTD in January and longitude of the station

mark	Jan	Feb	Mar	Apr	May	Jun
Jz85	2.3975	2.4241	2.4716	2.5012	2.5195	2.6285
Jz86	2.3987	2.4261	2.4795	2.5060	2.5285	2.6261
Deviation	0.0012	0.0020	0.0079	0.0049	0.0090	-0.0025
mark	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Jz85	2.6125	2.6126	2.5975	2.5154	2.4819	2.4035
Jz86	2.6140	2.6097	2.6015	2.5173	2.4962	2.4095
Deviation	0.0015	-0.0029	0.0040	0.0019	0.0143	0.0059

As can be seen from Table 1, the monthly average ZTD of two stations presented small differences, (1.4cm in November, but less than 1cm in other months), so the station longitude had less influence on the ZTD. Related researches showed that the ZTD variations in the horizontal direction were mainly affected by latitude, and the ZTD linearly changed with the latitude.

2.4 New modeling

Through the above analysis, a precise zenith troposphere model for the Guilin Region can be obtained, and its expression is as follows:

$$\mathrm{ZTD}(H_i, \varphi_i, \mathrm{t}) = -A_0(t)H_i + A_1(t)\varphi_i + A_2(t) \quad (3)$$

$A_1(t)$ can be solved by the least square method.

3. MODEL PRECISION TEST

3.1 Relative tropospheric delay test

In order to verify the precision of the new model, a total of 8 stations (JZ84, JZ85, JZ86, JZ87, JZ91, JZ93, JZ94 and JZ95) were uniformly selected in the Guilin Region as known reference stations, and JZ88, JZ89 and JZ92 were used as the check stations. The ZTD solved by GAMIT10.6 in 2018 was a true value, and the model parameters were obtained by the least square method to establish a ZTD model suitable for the Guilin Region. The ZTD of 8 fitting stations was estimated using the new model, and the deviations from the true value were shown in Figures 4 and 5.

As can be seen from Figures 4 and 5, the deviations between the ZTD of the fitting stations and the true value were controlled within 20 mm, among which the data from jz86 during the DOY of 087-183, and the data from JZ93 were missing during the DOY of 60-90 and 184-243. The deviations of JZ84, JZ85, JZ87 and JZ91 were relatively concentrated (within 0-10 mm), but the deviations of JZ93 and JZ95 were relatively discrete. It can be seen from the distribution map of the CORS reference station (Figure 1) that JZ93 and JZ95 had the minimum elevations (110m and 151m respectively), and JZ84, JZ85, JZ87 and JZ91 had relatively large elevations (between 180m and 400m). Thus, the new model presented higher precision in the regions with higher elevations.

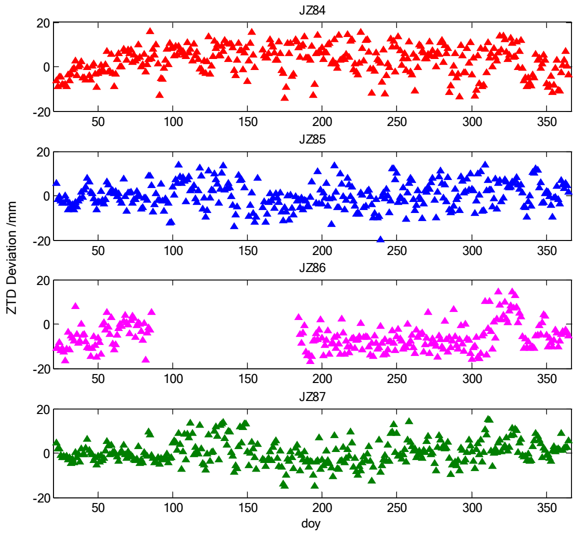

Figure 4 Deviations between ZTD of Fitting Stations Estimated by New Model and True Value

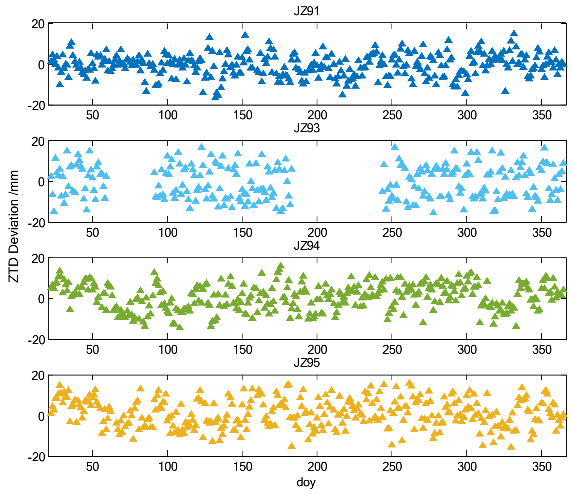

Figure 5 Deviations between ZTD of Fitting Stations Estimated by New Model and True Value

3.2 Absolute tropospheric delay test

The stations JZ88, JZ89 and JZ92 were not involved in modeling and used as the check stations. The ZTD of the check stations in 2018 was estimated by the new model and were compared with the true value, as shown in Figure 6.

It can be seen from Figure 6 that the deviations between the ZTD of the check stations and the true value were controlled within 20 mm, in which the jz88 had the maximum elevation of 779 m. The deviations between the ZTD calculated by the new model and the true value were concentrated, mainly in [0,10]m, while the JZ92 had the minimum elevation of 224 mm, and the deviations between the ZTD and the true value were relatively discrete.

In order to further analyze the relationship between the precision of the ZTD calculated by the new model and the station elevation, statistics were given on the number of deviations between the ZTD of the fitting stations and check stations calculated by the new model in 2018 and the true value at different scopes, and the RMS of the stations was calculated, as shown in Figure 7 and Table 2. The stations were arranged from high to low according to the station elevation in Figure 7 and Table 2.

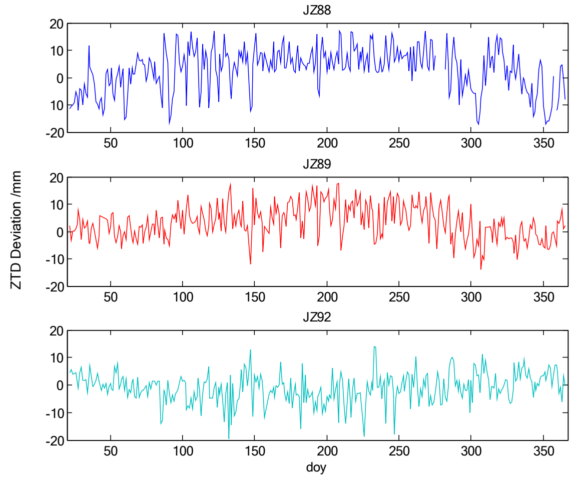

Figure 6 Deviations between ZTD of Check Stations Estimated by New Model and True Value

Among 8 fitting stations, the maximum deviation of the ZTD occurred at the jz85 station, namely 18.80mm. Except for JZ86, the proportion of the deviations within [1,5]mm at each fitting station increased in turn with the elevation, and the RMS also decreased with the elevation; among 3 check stations, the deviations between the estimated value and the true value within [1,5]mm accounted for 71.1% at the jz88 station with the maximum elevation, and the RMS was 5.44. Besides, its precision was significantly increased with the elevation.

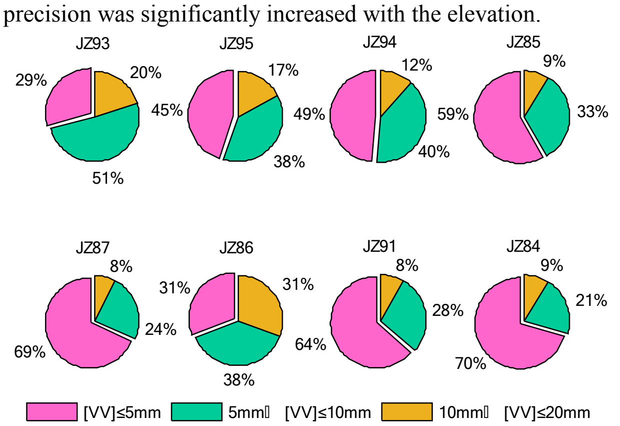

Figure 7 Comparison of Proportion of Different Deviations

4. CONCLUSION

Based on the measured data of the CORS network in the Guilin Region, the precise ZTD model suitable for the Guilin Region was built by analyzing the ZTD in the Guilin Region in 2018. The model was easily built only based on the position and time of the station, without a need to measure any meteorological parameter. The following conclusions were drawn after test:

1) The ZTD had a linear negative correlation with the station elevation in the Guilin Region;

2) The maximum deviation between the ZTD calculated by the new model and the true value was 18.80m, mostly within [0,5]mm, and its RMS fell within 5.10 mm - 8.54 mm, with average precision of 6.70mm and good applicability.

3) The precision of the new model increased with the elevation, and this model had certain advantages in the regions with high elevation.

Table 2 zenith tropospheric residual statistics of each station (unit /mm)

	Station	Elevation	Maximum	RMS	Station	Station	Maximum	RMS
Fitting station	JZ93	110	16.69	8.54	JZ87	201	14.18	5.60
	JZ95	151	15.88	7.08	JZ86	220	16.85	8.39
	Jz94	172	15.74	6.55	JZ91	226	13.57	5.59
	JZ85	176	18.80	5.83	JZ84	403	16.01	5.10
Check station	Station	Elevation	Maximum	RMS	[VV]≤5	5＜[VV]≤10	10＜[VV]≤20	
	JZ92	224	18.71	8.56	36.7%	37.3%	26.0%	
	JZ89	337	17.52	7.01	54.1%	28.1%	17.8%	
	JZ88	779	17.20	5.44	71.1%	22.2%	6.7%	

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