Analysis on the performances of the GNSS tropospheric delay correction models

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Abstract. Tropospheric delay is one of the important factors affecting GNSS positioning accuracy, and there are different ways to deal with the multiple measurement situations. In short baseline measurements, the difference method is commonly used to eliminate tropospheric errors. However, it cannot be used in long baseline measurements or complex weather since it still has great influences on precision measurement after difference calculation. Therefore, modelling method is usually used to reduce tropospheric delay. As it is well known, there are three types of commonly used tropospheric delay correction models, which are suitable for different situations. When any model is used to solve the tropospheric delay in a large scale, there is always an error between the model value and the actual one. In order to investigate the applicability of the three models in different atmospheric conditions, we actually used the measured meteorological data provided by IGS (International GNSS Service) stations as a reference, and then calculated the ZTD (Zenith Tropospheric Delay) with the different models, including Hopfield model, Saastamoinen model and Black model. The calculation results indicate that Saastamoinen model is the most robust and practical model.

1 Introduction

The error caused by the delay of GNSS satellite signal passing through troposphere is called tropospheric delay error, which belongs to the error caused by signal transmission process. Tropospheric delay correction is commonly used in the world by model correction. Because of the complexity of tropospheric atmosphere, tropospheric model can be divided into two ways: One is based on the troposphere as an ideal gas state, aiming at the modeling of meteorological parameters, that is, temperature, pressure, relative humidity, etc. They are used as the basis for calculation, and then the zenith delay is calculated by using atmospheric physics equations.

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2 Method of tropospheric delay correction for delayed modification

2.1 Hopfield model

Hopfield model divides troposphere into dry and wet components along the direction of signal propagation. Let i = dry and wet, we can calculate the tropospheric delay by:

$$\Delta D_{drop} = \Delta D_{dry} + \Delta D_{wet} = 10^{-6} N_i \left[\sum_{i=1}^{9} \frac{\delta_{k,i}}{k} r_i^k\right] \tag{1}$$

where the N_{dry} and N_{wet} are refraction indexes, and it is calculated with the following formulae

$$\begin{cases} N_{dry} = \frac{0.776\times10^{-4}P}{T} \\ N_{wet} = \frac{0.373e}{T^2} \end{cases} \tag{2}$$

where T is atmospheric temperature (K), P is atmospheric pressure (mbar), e means vapor pressure (mbar), r_{dry} , r_{wet} respectively represent the distance (m) from the ground station to the intersection of the boundary plane where the dry and wet refraction indices tend to zero in the propagation path. The calculation formula is as follows:

$$r_i = [(r_0 + h_i)^2 - (r_0 cosE)^2]^{\frac{1}{2}} - r_0 sinE \tag{3}$$

where the E represents the height Angle of the satellite, R_0 represents the geocentric diameter of the station (m), h represents the height of the outer edge of the dry and wet components of the troposphere (m), and it could be calculated by:

$$\begin{cases} h_{dry} = 40136 + 148.72(T - 273.16) \\ h_{wet} = 11000 \end{cases} \tag{4}$$

2.2 Saastamoinen model

Saastamoinen model is an internationally recognized tropospheric delay correction model with high accuracy. We can calculate the tropospheric delay with the model by:

$$\Delta D = \frac{0.002277}{sinE_0}\left[P_S + \left(\frac{1255}{T_s} + 0.05\right) e_s - \frac{\alpha}{tan^2 E_0}\right] \tag{5}$$

where the coefficient can be calculated by:

$$\begin{cases} E_0 = E + \frac{16}{T_S}\left(P_s + \frac{4810}{T_s} e_s\right) cotE \\ \alpha = 1.16 - 0.15 \times 10^{-3} H_s + 0.716 \times 10^{-8} H_S^2 \end{cases} \tag{6}$$

where T_s is the temperature, P_S is the pressure, e_s is the vapor pressure, E is the height Angle of the station, and H is the elevation of the station

2.3 Black model

H.D.Black added path bending corrections to the Hopfield model in 1978, resulting in the Black model. It is calculation formula is as follows:

$$\Delta D = \sum_{i=dry,wet} \Delta D_i = \sum_{i=dry,wet} K_i \left\{ \left\{ 1 - \left[\frac{cosE}{1+\frac{(1-l_0)h_i}{r_s}} \right]^2 \right\}^{\frac{1}{2}} - b(E) \right\} \tag{7}$$

where

$$\begin{cases} K_{dry} = 0.002312 \times (T_s - 273.16) - 0.3E \\ K_{dry} = \frac{0.0746542 e_s h_{wet}}{T_s^2} \end{cases} \tag{8}$$

where, RS is the geocentric radius of the station; $h_{wet} = 1300$, $h_{wet} == 148.98 \times Ts - 3.96$; l_0 and path bending correction factors can be calculate by:

$$\begin{cases} l_0 = 0.833 + \left[0.076 + \frac{0.00015(T_s - 3.96)P_s}{T_s} \right] \\ b(E) = \frac{1.92}{(E^2+0.6)} \end{cases} \tag{9}$$

3 Analysis on the performances of the GNSS tropospheric delay correction models

In order to analyze the model, there are two observation stations of IGS stations in China will be selected, namely BJFS station in Fangshan, Beijing and LHAZ station in Lasa, as shown in the table.

Table 1. Station information.

Information	Station·	
	BJFS	LHAZ
Latitude (φ)	39.51	29.66
Elevation (m)	87.5	3656.6

The delay values corresponding to the three models of meteorological parameter belt of BJFS station were calculated respectively, and they were expressed in a broken line chart together with the standard ZTD provided by IGS station. The results are shown in the figure.

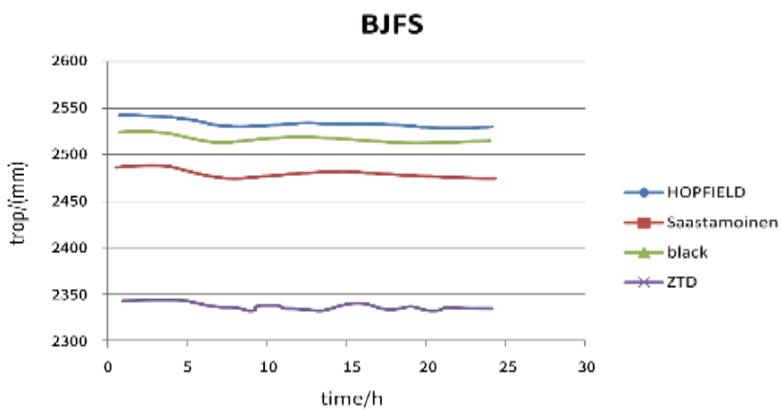

Fig. 1. The tropospheric delay of BJFS.

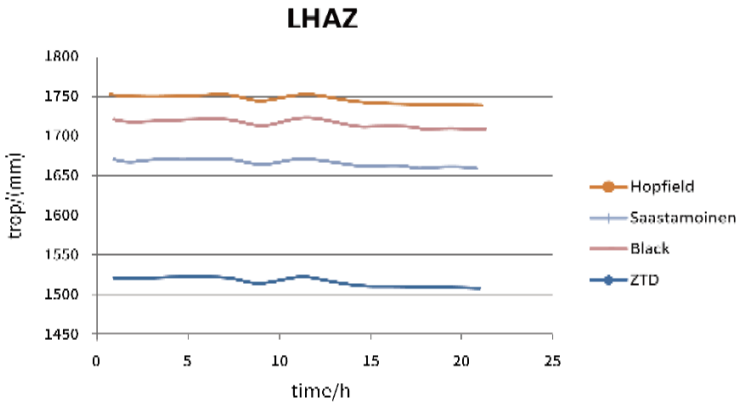

Fig. 2. The tropospheric delay of LHAZ.

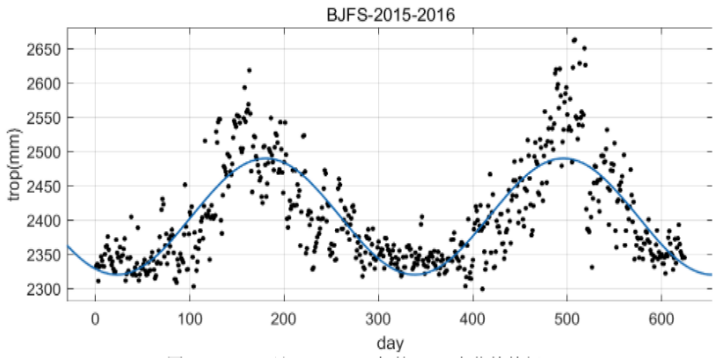

Fig. 3. The characteristic of ZTD variation of BJFS during2015-2016.

4 Conclusion

In summary from the calculation results of the two stations in China selected this time, the ZTD calculated by the three models is basically consistent with the standard reference value provided by IGS, and the floating trend is basically consistent, indicating that the three models have effectively carried out tropospheric correction and have strong applicability in China.For high altitude areas, Saastamoinen model has stronger applicability and higher accuracy, which basically coincides with the reference value. However, Hopfield model and Black model have relatively large errors, and the calculated tropospheric delay needs further adjustment before it can be used.

Finally, Through the analysis of ZTD of 2016, it can be concluded that tropospheric delay reaches the maximum value in summer and the minimum value in winter, and the largest gap between the calculated value and the reference value is also in summer.

References

1. Yan Zhao D Modeling and analysis of regional tropospheric delay (Central south university,2013)
2. Zhao Tiecheng, Han Yaoxu J Discussion on several tropospheric models in GPS positioning system (Global positioning system), **p036(1)**:46-52(2013)

3. Ma Kai, Li Ming. J Application of GMF model to atmospheric refraction (Mine surveying) p27-29(2009).
4. Huang Liangke. D Study on tropospheric zenith delay correction model and method of ground-based GNSS (Guilin University of Technology, 2014).
5. Li KeZhao, Yang Li, Chai Lin, Ding Anmin, Guo Chang-sheng M GNSS positioning principle (Beijing: China Coal Industry Press)