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Influence of meteorological data and horizontal gradient of tropospheric model on precise point positioning

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Abstract

Using GPT2 derived meteorological data and actual meteorological observations can achieve the same positioning precision in the most areas worldwide except for the Antarctic region. However, the improvement of the actual meteorological observations on the positioning result is significant comparing to using GPT2 derived meteorological data in Antarctic. In the case of 5° elevation cut-off angle, the height precision can be improved by 25%. Furthermore, when the elevation cut-off angle is lower, the effect of the actual meteorological observations on the positioning precision is more significant in Antarctic due to the retention of low elevation angle observations. This study also shows that the influence of tropospheric horizontal gradient correction can improve the PPP precision. Under the lower elevation cut-off angle and higher humidity conditions, especially in summer time and low-latitudes area, the usefulness of the horizontal gradient correction is remarkable. The average improvement of N, E and U directions can reach up to 51%, 15% and 30%, respectively.

Keywords: Tropospheric delay; Meteorological data; Precise point positioning; Horizontal gradient; Elevation angle

1. Introduction

The tropospheric delay in satellite navigation positioning usually refers to the signal delay generated when the electromagnetic waves get through the non-ionized neutral atmosphere below 80 km. The tropospheric delay could be about 2 m in the zenith direction and a few tens of meters in the case of a lower satellite elevation (Xu, 2007). Tropospheric delay is one of the key factors which affect the precision of GPS positioning (Dai et al., 2011). There are two methods for dealing with the tropospheric delay in single point positioning. One is using a tropospheric model to calculate and correct the delay immediately. The other one is to treat the delay as an unknown parameter which will be estimated in the adjustment (Ge and Liu, 1996). However, in high-precision GPS positioning it is difficult to obtain optimal positioning results by only using the first method. That is because of the existence of model errors and measurement errors of the meteorological parameters. It is better to regard the computed value of the tropospheric model as an approximation, and then to estimate the exact tropospheric delay by a stricter adjustment procedure.

The effects of tropospheric model on GPS precise point positioning was researched by Kouba (2009). In the study the global pressure and temperature model GPT (Boehm et al., 2007) was used to compute a priori zenith hydrostatic delay and demonstrated to perform well for low

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and mid latitude stations. However, in polar region or with low elevation cut-off angles, the GPS height solution errors can sometimes achieve more than 10 mm. Nevertheless, it should be noted that the station height time series based on simple GPT model have a better repeatability than those based on more realistic tropospheric a priori delay derived from surface pressure if atmosphere loading correction is not included, since the a priori zenith hydrostatic delay derived from the empirical pressure can partially compensate for the atmospheric loading displacement (Kouba, 2009; Steigenberger et al., 2009). According to Xu et al. (2014), there are more visible satellites with lower elevation angles in the Antarctic region comparing with the low-latitude observatories. And researches show that the observations with lower elevation angles are more significantly influenced by the tropospheric delay (Ren et al., 2011; She et al., 2011). Thus the residual errors of the tropospheric model can greatly affect the precision of the positioning there. Both zenith delay model and mapping function play an important role. In recent years, there are some most commonly used models. An improved global pressure and temperature empirical model GPT2 (Lagler et al., 2013) was proposed in 2013. In this paper, the impact of the tropospheric delay on the Antarctic positioning, especially the effect of the meteorological data derived from GPT2 model and actual meteorological data on global positioning were analyzed and compared. The existing tropospheric models were proposed usually based on the assumption that the atmosphere is homogeneous in all directions (Xu and Wu, 2009). However, the tropospheric delay is anisotropic in the horizontal direction (Miyazaki et al., 2003; Cao et al., 2014). Thus the influence of horizontal gradient correction on the precise point positioning was studied in this article.

In Section 2 the commonly used tropospheric model and mapping functions were introduced and are outlined. A comparison of tropospheric delays based on GPT2 and actual meteorological observations are also analyzed. In Section 3 the effect of the meteorological data on precise point positioning are displayed. The impact of adding horizontal gradient estimation on the precise point positioning is described in Section 4. A summary of the analysis conclusions is given in Section 5.

2. Tropospheric delay model

The tropospheric delay can be represented as the product of the tropospheric refraction in zenith direction and a mapping function related to the elevation angle. It is separated into hydrostatic (about 90%, caused by dry gas in the atmosphere) and wet (about 10%, caused by water vapor) parts, which can be defined according to Hoffmann-Wellenhof et al. (2001) and Leick (2004) as

$$\delta = \delta_h + \delta_w = Z_h \times MF_h + Z_w \times MF_w \tag{1}$$

where δ denotes the tropospheric delay, the subscript h and w denote hydrostatic and wet, Z_h and Z_w denote the tropospheric zenith hydrostatic delay and zenith wet delay, MF_h and MF_w are mapping functions related to the hydrostatic and wet components.

2.1. Zenith tropospheric delay

The hydrostatic zenith delay Z_h can be accurately modeled based on the surface pressure as (Saastamoinen, 1972)

$$Z_h = \frac{0.0022768P}{1 - 0.00266\cos(2B) - 0.00028 \times 10^{-3}H} \tag{2}$$

where Z_h is the zenith hydrostatic delay (in units of meters), P is the atmospheric pressure (in units of millibars), B is geodetic latitude at the station (in units of radians) and H is the geodetic height at the station (in units of meters).

On the other hand, the zenith wet delay component is more difficult to model accurately due to its temporally unpredictable changes and is therefore estimated as an unknown along with other unknowns in the adjustment in precise point positioning. The zenith wet delay could also be computed by Saastamoinen formula with a loss of precision:

$$Z_w = \frac{0.0022768 \times \left(\frac{1255}{T} + 0.05\right) \times e}{1 - 0.00266\cos(2B) - 0.00028 \times 10^{-3}H} \tag{3}$$

where Z_w is the zenith wet delay (in units of meters), T is the temperature at the station (in units of Kelvin), e is the partial pressure of water vapor (in units of millibars).

With the approximate position and the meteorological data, the hydrostatic and wet zenith delay could be easily computed by Eqs. (2) and (3). According to Eq. (2), 1 mbar pressure change at sea level can cause a change of about 2.3 mm in a priori zenith hydrostatic delay, it is essential to use as accurate meteorological data as possible (Tregoning and Herring, 2006).

Generally, the meteorological data needed by Eqs. (2) and (3) can be obtained from actual observations, or derived from using a standard atmospheric value at sea level and the height of the station (Berg, 1948). Meteorological data can also be determined by empirical models called GPT (Boehm et al., 2007) or the later GPT2 model (Lagler et al., 2013). In this paper, the meteorological data derived from GPT2 models and the actual meteorological observations were used.

2.2. Mapping functions

To obtain the slant tropospheric delay, a mapping function which describes the variation of the slant tropospheric delay with respect to satellite elevation angle is needed. Many mapping functions were proposed in the past, such as NMF (Niell Mapping Function, (Niell, 1996)), VMF1 (Vienna Mapping Function 1, (Boehm et al., 2006b)), GMF (Global Mapping Function, (Boehm et al., 2006a)), which were commonly researched in the recent years. By