Effect of removing the common mode errors on linear regression analysis of noise amplitudes in position time series of a regional GPS network & a case study of GPS stations in Southern California

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Received 26 March 2017; received in revised form 22 February 2018; accepted 25 February 2018
Available online 2 March 2018

Abstract

The analysis of the correlations between the noise in different components of GPS stations has positive significance to those trying to obtain more accurate uncertainty of velocity with respect to station motion. Previous research into noise in GPS position time series focused mainly on single component evaluation, which affects the acquisition of precise station positions, the velocity field, and its uncertainty. In this study, before and after removing the common-mode error (CME), we performed one-dimensional linear regression analysis of the noise amplitude vectors in different components of 126 GPS stations with a combination of white noise, flicker noise, and random walking noise in Southern California. The results show that, on the one hand, there are above-moderate degrees of correlation between the white noise amplitude vectors in all components of the stations before and after removal of the CME, while the correlations between flicker noise amplitude vectors in horizontal and vertical components are enhanced from un-correlated to moderately correlated by removing the CME. On the other hand, the significance tests show that, all of the obtained linear regression equations, which represent a unique function of the noise amplitude in any two components, are of practical value after removing the CME. According to the noise amplitude estimates in two components and the linear regression equations, more accurate noise amplitudes can be acquired in the two components.

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Keywords: Regional GPS network; GPS time series; Noise; Correlation; Linear regression analysis

1. Introduction

GPS position time series are widely used in geodesy and geodynamic research. The precise noise amplitudes in the GPS position time series are crucial for obtaining high-accuracy uncertainties of the velocity and cyclically-varying amplitude of the station (Deng et al., 2017). Numerous studies showed that a GPS position time series not only contains white noise (WN) but also other types of time-dependent coloured noise. A combination of white noise and flicker noise (FN) is considered the best noise model for a global GPS station time series (Zhang et al., 1997; Mao et al., 1999; Williams, 2003; Langbein, 2008; Amiri-Simkooei, 2016). Apart from these, a spatial correlation error, whose physical source remains to be determined,
is verified to be present in the time series of the same components of different GPS stations. This error substantially influences the accuracy and reliability of station location (Wdowinski et al., 1997). Since then, studies focused on calculating and removing the CME (Jackson and Chen, 2004; Dong et al., 2006; Teferle et al., 2006; Wang et al., 2012; Tian and Shen, 2016); however, a non-deterministic relationship exists between the noise signals in the time series of different components of GPS stations in the same area. Spatial correlation was previously investigated by fitting the residuals of the time series in the same component of different stations (Williams, 2003; Wang et al., 2012) or by estimating the variance–covariance of noise in different time series from a single station (Amiri-Simkooei, 2009). Amiri-Simkooei (2009) found that the noise correlation between different components of a single station is insignificant when only white noise is present in the GPS position time series. Bock et al. (1997) revealed the weak correlation between noise signals in different components of a station.

Although several advances have been made in the research into noise in GPS position time series, the estimation of noise variance and the removal of the CME, the analysis of the spatial correlation between stations is generally based on a single component, and the studies of the correlations of different component noise signals are also based on single station analysis. These achievements have neglected the correlations between the noise signals in different components of a regional GPS network. Since the noise amplitude estimates in the three components are obtained from observed values, they are also subject to deviation or error. As a result, the velocity and uncertainty of station movement cannot be obtained accurately, and the tectonic signals of the area where the stations are located cannot be completely explained. Thus, the noise amplitude vectors in different components in a regional GPS network were analysed by using one-dimensional linear regression, which can be used to study the linear relationship between two variables and establish a linear mathematical model for evaluation and prediction. In this study, we investigate the correlations between noise amplitude vectors in different components of 126 GPS stations in Southern California with white noise + flicker noise + random walk noise, and establish a linear regression equation between the noise amplitudes in any two components. Based on the estimates of the noise amplitude and the linear regression equations, more accurate noise amplitudes in the three components of the stations can be obtained. This method could not only facilitate the acquisition of more accurate uncertainties of velocities in station movement, but also be of significance in studying the non-linear movement of the reference station.

The remainder of this paper is structured as follows: Section 2 describes the GPS data sources, pre-processing, and processing methods. Section 3 presents the estimation of the noise amplitudes in the three components of the 126 stations in Southern California, and the linear regression analysis of the correlations of the amplitudes in this region. In Section 3, the linear regression equations are also established. Section 4 discusses the experimental results, and key conclusions are drawn in Section 5.

2. Data and methods

2.1. GPS data

The daily time series from stations (Fig. 1) of the PBO (plate boundary observatory) GPS network in Southern California, which are generated by GAGE (Geodesy Advancing Geosciences and EarthScope) project were selected. The correction models used in the production of a daily solution are shown in Table 1 (Herring et al., 2016). Before selecting the experimental data, we looked at the seismic records of the area and found that earthquakes in June 2010 and October 2016 produced a larger offset in the time series at some stations in the region. Liao et al. (2013) shows that the seismic events lead to significant changes in white noise, flicker noise, random walk noise, and so on, in the GPS noise component. So, we used GPS position time series from August 2010 to August 2016. In addition, we ruled out the stations for which the data were missing for more than one month during this period. As a result, 162 stations were initially chosen. In order to avoid anomalous noise amplitude estimates which affect the regression equation, we estimated the noise amplitude in each component based on the WN + FN + RWN model. And about 8% of the largest amplitudes were removed in every component. The remaining 126 stations were eventually selected. Before the noise was estimated, the position time series of many stations were corrected by the coseismic offset estimates provided by GAGE.

2.2. Removal of the CME

Common mode error (CME) is one of the major, spatially-correlated, error sources in GPS solutions. Dong et al. (2006) proposed that the CME are likely caused by unmodelled or mismodelled motions of satellite orbits, reference frame, or Earth Orientation Parameter (EOP) (Wdowinski et al., 1997). Large-scale atmosphere effects, receiver and satellite antenna phase centre mismodelling are also potential candidates for the CME. Extracting the CME from GPS time series can remove the correlation between the time series in the same component of the stations and improve the signal-to-noise ratio. The distances between the GPS stations considered in this study are less than 500 km; thus, the regional stack filtering method is adopted. On the assumption that the CME are evenly distributed over a region, this algorithm takes the error of the single-day solution as the weighting factor and then calculates the CME by a simple arithmetic average:

\[
\varepsilon_i = \frac{\sum_{i=1}^{S} \frac{y_i}{\sigma_i^2}}{\sum_{i=1}^{S} \frac{1}{\sigma_i^2}}
\]
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