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Zero drift and solid Earth tide extracted from relative gravimetric data with principal component analysis☆

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ABSTRACT

Zero drift and solid Earth tide corrections to static relative gravimetric data cannot be ignored. In this paper, a new principal component analysis (PCA) algorithm is presented to extract the zero drift and the solid Earth tide, as signals, from static relative gravimetric data assuming that the components contained in the relative gravimetric data are uncorrelated. Static relative gravity observations from Aug. 15 to Aug. 23, 2014 are used as statistical variables to separate the signal and noise with PCA to obtain desired signals. The results of the linear drift extracted by PCA are consistent with those calculated by the least squares linear fitting, and the differences only reach to 10^{-2} μGal/day order of magnitude. Furthermore, PCA is used to estimate the solid Earth tide from the relative gravimetric data corrected by the zero drift. The statistical results are consistent with the results derived from the solid Earth tide correction provided by the internal software of the CG-5 gravimeter (SCINTREX Limited Ontario Canada). The statistical results of the differences between the two methods are both less than 8 μGal, and the RMSs for 9 days are all less than 5 μGal.

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1. Introduction

The relative gravimetric data include effects of Earth tide, atmospheric pressures, hydrology, instrument height, zero drift, and scale value correction [1,2]. The tidal correction for gravity measurements is the most important correction, which can be as much as $\pm 300 \times 10^{-8}$ m/s^2 [3,4]. The ocean tide loading has a greater influence on the high precision relative gravimetric measurement on coastal areas and between islands, which can be up to $\pm 10 \times 10^{-8}$ ms^{-2}-level. With the increase of distance away from the coast to land, the ocean loading effect is gradually reduced [5,6]. The ocean tide loading effect, which is only 1×10^{-8} ms^{-2}-level, is smaller on the mainland. Generally, this small effect can be negligible in the relative gravimetry [7,8]. The solid Earth tide is the solid Earth's response to the tidal forces generated by the Sun and the Moon. The Earth's external and internal shape is always periodically changing. The study on Earth tide is important [9–15] because it can provide an effective way to detect the Earth's internal dynamics and implement the inversion of Earth's internal structure. It is an effective constraint on the oscillation in the interior of the Earth, the Earth's liquid core resonance parameters, and the Earth's rotation. It can also provide an important method for explaining the surface mass migration (such as air, sea, and land water) and various kinds of regional environmental effects. The standard method generally adopted to calculate gravity tidal parameters is ETERNA [16,17]. With a lot of functions, such as filtering, spectral analysis, and regression analysis, the tidal data preprocessing software Tsoft [18,19] can directly modify various kinds of interference that makes the observational data preprocessing convenient and intuitive. In addition, the gravity measurement accuracy of the elastic gravimeter is mainly restricted by the instability of metal or quartz spring, that is, zero drift. CG-5 gravimeter's fused quartz elastic system with a good linear drift can accurately determine its static zero drift. Consequently, the zero drift influence can be effectively corrected [2,20]. Therefore, obtaining linear drift and the solid Earth tide from CG-5 gravimeter static observation becomes particularly important.

CG-5 relative gravimeter is a new type of digital gravimeter produced by Canada Scintrex Company. This gravimeter adopts a microprocessor device, which can realize automatic measurement. As the sensor is designed with no static fused quartz spring, the gravimeter's design accuracy is 5×10^{-8} m/s^2, and reading resolution is 1×10^{-8} m/s^2 [21].

In this paper, principal component analysis (PCA) will be used in an experimental study to estimate the zero drift and the solid Earth tide from static gravimetric data. Observations by CG-5 gravimeter are used as statistical variables. Assuming that the components in the static relative gravimetric data are uncorrelated, the zero drift and the solid Earth tide extracted by PCA are within the signals. Then we estimated the zero drift and the solid Earth tide with PCA by separating the signal and noise. Two groups of experimental data will be used in the experiment. The original observations obtained by CG-5 gravimeter have been implemented the solid Earth tide correction but not the drift correction. After smoothing, the original observations are the first data series. The method of PCA will be applied to the first data series to extract the linear drift. The linear drift derived from PCA will be used for comparative analysis with the results calculated by the least squares linear fitting (LSLF). The solid Earth tide provided by CG-5 gravimeter internal tidal model will be added to the first data series after the daily zero drift correction obtained from PCA, and then the second data series are obtained. The method of PCA will be applied to the second data series to estimate the solid Earth tide. The reliability of PCA will be verified through comparative analysis of the estimated results from PCA and the results derived from the solid Earth tide correction (SETC) provided by CG-5 gravimeter internal software.

2. Analysis method

Principal component analysis [22–26] of gravity observations is based on the covariance matrix. The observations by CG-5 gravimeter are used as originals values so that new statistical variables can be obtained by a linear transformation. The new variables are statistically uncorrelated. The main purpose of PCA is to extract information by separating unrelated components and data reduction. In this paper, according to the PCA principle, the solid Earth tide and the linear drift are considered signals. Assuming that original gravimetric variables are $\mathbf{G} = (\mathbf{G}_1, \ \mathbf{G}_2, \ \cdots, \ \mathbf{G}_n)^{\mathrm{T}}$ and the new variables $\mathbf{PCA_G} = (\mathbf{PCA}_1, \ \mathbf{PCA}_2, \cdots, \ \mathbf{PCA}_n)^{\mathrm{T}}$ are obtained by $\mathbf{G}$ after a linear transformation; we can get the linear model:

$$\mathbf{PCA_G} = \mathbf{GE} \tag{1}$$

where $\mathbf{E}$ is the linear transformation matrix calculated by the covariance matrix of statistical variables from the relative gravimetric data. Assuming that the covariance matrix, $\sum_G$, is an n-order symmetric matrix and solving eigenvalue and eigenvector of the matrix, $\sum_G$, it can be decomposed into

$$\sum\nolimits_G = \boldsymbol{EDE}^{\mathrm{T}} \tag{2}$$

where $\boldsymbol{D}$ is a diagonal matrix, whose elements are λ_1, λ_2 ... λ_n, which are eigenvalues of the matrix $\sum_G$, and equal to the variances of the corresponding principal components. Their relationship is $\lambda_1 \geq \lambda_2$ ... $\geq \lambda_n$. $\boldsymbol{E}$ is an orthogonal matrix composed of eigenvectors [24,25]. Therefore, by equation (1), the original observations $\mathbf{G}$ can be expressed as

$$\mathbf{G} = \mathbf{PCA_G E}^{\mathrm{T}} \tag{3}$$

The first k principal components and the reconstructed variables contain some information. The amount of information can be measured by the cumulative contribution percent, α, which is the proportion of the variance of the first k principal components that accounts for a portion of the total variance. It can be expressed as

$$\alpha = \sum_{i=1}^{k} \lambda_i \Bigg/ \sum_{i=1}^{p} \lambda_i \times 100\% \tag{4}$$

where λ_i is the ith eigenvalue, p is the total number of the eigenvalues, and k is the number of the selected eigenvalues.

We select the new variable $\mathbf{PCA}_K^G = (\mathbf{PCA}_1^G, \ \mathbf{PCA}_2^G, \cdots, \ \mathbf{PCA}_K^G)$ whose elements correspond to relatively large eigenvalues to