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Seasonal gravity changes estimated from GRACE data

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Abstract: Since 2002, the GRACE program has provided a large amount of high-precision data, which can be used to detect temporal gravity variations related to global mass re-distribution inside the fluid envelop of the surface of the Earth. In order to make use of the GRACE data to investigate earthquake-related gravity changes in China, we first studied the degree variances of the monthly GRACE gravity field models, and then applied decorrelation and Gaussian smoothing method to obtain seasonal gravity changes in China. By deducting the multi-year mean seasonal variations from the seasonal maps, we found some earthquake-related gravity anomalies.

Key wards: GRACE; earthquake; gravity variations; decorrelation; Gaussian smoothing.

1 Introduction

Earthquake occurrence results in crustal stress, strain and material-density changes. Thus gravity changes observed at and over the surface of the Earth contain earthquake-related information, which can be used to investigate the mechanism of earthquakes[1].

Since the successful launching of Gravity Recovery and Climate Experiment (GRACE) on March 17, 2002, studies on static gravity fields and their temporal variations by using gravity-observing satellites have been fully developed. Gravity changes associated with the 2004 Sumatra-Andaman earthquake were detected by GRACE in many recent studies[2-4], illustrating that satellite observation of gravity can be a most effective method of monitoring strong earthquakes. How to effectively use the internationally gathered GRACE data for earthquake monitoring and prediction in China will hence become the focus of our research.

In this paper, we report a study on how to use the GRACE products to detect gravity changes in China and its vicinity. We first studied how to use the monthly gravity field; then used the GRACE level 2 products, together with decorrelation and Gaussian smoothing method, to calculate the gravity changes. We then present, and give an analysis of, the observed seasonal variations, and point out their correlation with several large earthquakes.

2 Data reprocessing and filtering methods

2.1 Data

The main GRACE data are divided into four levels: 0, 1A, 1B and 2; in addition, some other products have been released. The level 0 products (raw data) are collected on-board the GRACE spacecraft and are sent to the ground. The level 1A products are the results of a non-destructive processing applied to the Level 0 data. The level 1B products are data correctly time-tagged and re-sampled from the high-rate data of the previous

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levels; they can be used to determine the gravity field and the precise orbit of the GRACE satellite. The level 2 data refer to monthly estimates of spherical harmonic coefficients of the earth's gravity field.

In this study we used the level 2 products released by university of Texas at Austin (UTCSR). This product has two versions: Release 01 (truncated to 120, from April 2002 to December 2006) and Release 04 (truncated to 60, from April 2002 to June 2010), which is an improved version of Release 01[5].

Because commission error becomes larger when the degree is higher, especially when over 90, UTCSR remind users not to use the coefficients when the degree is larger than 90, but to use a suitable truncation or smoothing technique.

2.2 Degree-variance analysis and maximum – degree truncation

The Root Mean Square (RMS) error of gravity field models consists of omission and commission errors. In theory, such models can represent the whole-wavelength information of gravity fields only when sphere harmonic (SH) coefficients contain all degrees, from 0 to infinite[6-8]. Since it is practically impossible to get all frequencies of the Earth's gravitational field, we must truncate the gravity field models to a certain degree and order, if we want to get required precision, and this causes additional omission error. Commission errors are generated in the process of calculating spherical harmonic coefficients.

Degree variances are one of the most important errors of gravity field model. Degree variance spectrum of gravity anomalies σ_l^2[6] is computed by,

$$\sigma_l^2 = \left(\frac{GM}{R^2}(l-1)\right)^2 \sigma_{l0}^2(\bar{C}) + \left(\frac{GM}{R^2}(l-1)\right)^2 \sum_{m=1}^{l} \left(\sigma_{lm}^2(\bar{C}) + \sigma_{lm}^2(\bar{S})\right) \qquad (1)$$

Where GM is the products of the gravitational constant and the earth's mass; R is the mean radius of the earth; l is degree; m is order; σ_{lm}^2 is the variance in degree l and order m; $\bar{C}$ and $\bar{S}$ are cosine and sine SH coefficients.

Before the occurrence of a large earthquake of $Ms7.0$, a temporal gravity change can be as large as about $100 \times 10^{-8}\ ms^{-2}$. Since some previous studies show that, for a gravity change of $93 \times 10^{-8}\ ms^{-2}$ on the ground, a change of $20 \times 10^{-8}\ ms^{-2}$ can be observed at a satellite height of 450 km[9], the RMS error of gravity anomalies for such an earthquake should be less than $20 \times 10^{-8}\ ms^{-2}$ at such a height.

From GRACE we obtained the RMS error distribution of monthly time-series of SH coefficients for the two versions (Fig. 1 and 2). In these figures, the blue lines are the RMS errors of the monthly gravity field models, and the red lines are at $20 \times 10^{-8}\ ms^{-2}$. The blue line values in Fig. 1 are mostly larger than $20 \times 10^{-8}\ ms^{-2}$ above a degree of about 70, and less than $20 \times 10^{-8}\ ms^{-2}$ below this degree. All blue line values in figure 2 are less than $5 \times 10^{-8}\ ms^{-2}$. Thus we find that in using Release 01 data we should omit the SH coefficients above degree 70 approximately, and use coefficients below degree 60 only. In this paper, we used Release 04 products not only because of no truncation is needed but also because of its up-to-date status.

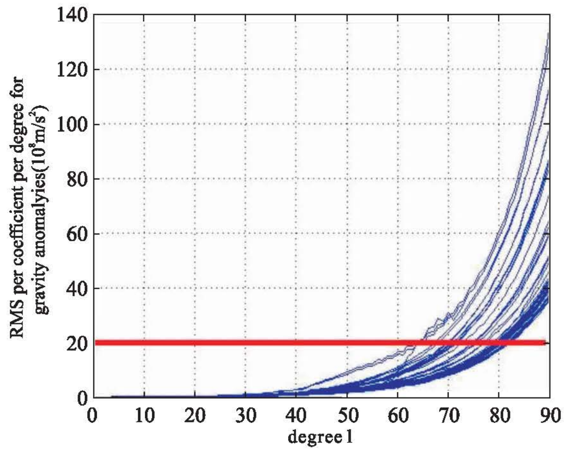

Figure 1 RMS error of gravity anomalies (Release 01)

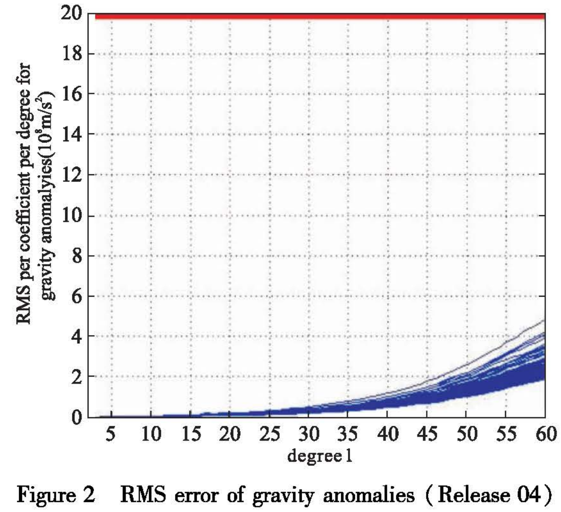

Figure 2 RMS error of gravity anomalies (Release 04)