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External calibration of GOCE data using regional terrestrial gravity data

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Abstract: This paper reports on a study of the methodology of external calibration of GOCE data, using regional terrestrial-gravity data. Three regions around the world are selected in the numerical experiments. The result indicates that this calibration method is feasible. The effect is best with an accuracy of scale factor at 10^{-2} level, in Australia, where the area is smooth and the gravity data points are dense. The accuracy is one order of magnitude lower in both Canada, where the area is smooth but the data points are sparse, and Norway, where the area is rather tough and the data points are sparse.

Key words: satellite gravity gradiometer; GOCE; external calibration; terrestrial gravity data; pre-process

1 Introduction

Since the successful launch of GOCE (Gravity field and Steady-state Ocean Circulation) Explorer satellite on 17th March 2009, theory and methodology of gravity field recovery, using Satellite Gravity Gradiometry (SGG) data, has become a hot issue in international geodesy research. A key step in obtaining clean data for recovering the earth's static gravity-field model of high accuracy is to pre-process high-quality SGG data.

Gradiometry, being sensitive and highly accurate, needs to be done in an ultra-stable environment. In real satellite observations, however, there are systematic errors caused by non-perfect SGG performance, including reading bias and scale-factor mismatch[1,2]. Such systematic errors should be calibrated before further processing of the SGG data[3-5]. One way of calibration is based on gravity data from certain external sources, including existing global-gravity models, regional terrestrial-gravity data, and high-low SST data[6].

In this paper, we report on a study on the methodology of external calibration of GOCE data, using regional terrestrial-gravity data. In the computational test, we used terrestrial-gravity data from three selected regions: Australia, Canada, and Norway. We analyzed the post-calibration relative accuracy and scale factors in these regions.

2 Methodology of external calibration

Most of the publications on external calibration of SGG data during the last decade used a-priori data, such as terrestrial-gravity data and gradients computed from terrestrial-gravity models, for estimation and reduction of systematic errors[7,8].

To calibrate possible systematic errors in the GOCE SGG data, Arabelos and Tscherning[9] and Tscherning[10,11] proposed a least-squares collocation (LSC) method in combination with some spherical-harmonic gravity model and terrestrial-gravity data. By this

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means, they estimated in the simulation tests the scale factors for the gradient components with the least expected error, and determined the required area size, resolution, and accuracy, with terrestrial-gravity data for calibration.

Base on the above-mentioned research, we describe first the methodology of external calibration in detail, and then the numerical experiments, using terrestrial-gravity data in the three selected regions.

The gravity-gradient data points can be defined with the anomalous potential as a linear equation

$$Y_i = L_i(T) + e_i \tag{1}$$

Where $L_i(T)$ is an appropriate function of the real gravity-gradient data, and e_i is the error of the data. The regional terrestrial-gravity data can reflect short-to-medium waves of gravity signal in more detail. To reduce long wavelength distortions and noise in the data, we first removed the long-wave signal, using the gravity model (EGM2008) as a reference. Then we upward-continued the residual signal to the satellite orbit height, using the LSC method. Lastly we restored the whole signal from the reference gravity model. This is the so-called remove-restore method. In this way we calculated the predicted values of the gravity gradient at different points of the GOCE orbit[2,4]:

$$\bar{T} = (\boldsymbol{C}_{pi})^{\mathrm{T}}(\boldsymbol{C}_{ij})^{-1}(y) \tag{2}$$

Where $\boldsymbol{C}_{ij}$ is the covariance matrix of observed value, and $\boldsymbol{C}_{pi}$ is the predicted value of the covariance function.

Thus we obtained two data sets, which are the model gravity gradients computed from the regional terrestrial-gravity data and the GOCE gravity gradients. We then applied Fourier analysis to the data sets to extract the MBW (Measurement Band Width) part of the gradients. The signal was therefore split into a number of subsections. Before the FFT (Fast Fourier Transform) analysis, splines were fitted to the intermediate periods, respectively, then, Fourier coefficients for the data sets were determined by:

$$F(k) = \frac{1}{T_N}\int_{t=0}^{T_N} g(t)e^{-ikt}\mathrm{d}t \tag{3}$$

Where $k = j\frac{2\pi}{T_N}$, T_N is length of the data spline, N is the number of observations $g(t)$. The Fourier coefficients a_j, b_j can be extracted as:

$$F(k) = \frac{a_j}{2} - i\frac{b_j}{2},\ j = 1, 2, \cdots \tag{4}$$

The coefficients multiplied with cosine or sine, respectively, were summed, which corresponds to a wave-number. Then the equivalent function in the MBW was computed as follow:

$$\bar{T}_{\mathrm{grad}}^{\mathrm{mbw}} = \sum_{j=j1}^{j2} F(k_j)e^{i\frac{2\pi j}{NJ}} \tag{5}$$

Where k is the wave-number, T_N is the period of the measurements, and $\bar{T}$ is the gravity-gradients signal.

The data sets were compared and the scale factors and error estimates were determined for all gradients in each track passing through the calibration areas as:

$$T_{\mathrm{grad}}^{\mathrm{MBW}}(t) - \bar{T}_{\mathrm{grad}}^{\mathrm{MBW}}(t) = (s-1)\ \bar{T}_{\mathrm{grad}}^{\mathrm{MBW}}(\mathrm{t}) \tag{6}$$

Where t is time corresponding to the each sampling point, and is the scale factor.

A least-squares adjustment was made for each spine passing through a calibration area, and the scale factor can be computed as:

$$S_{\mathrm{grad}} = \frac{\sum_{\mathrm{t=entry\_time}}^{\mathrm{exit\_time}} V^2(T_{\mathrm{grad}}^{\mathrm{mbw}}(t) - \bar{T}_{\mathrm{grad}}^{\mathrm{mbw}}(t))}{\sum_{\mathrm{t=entry\_time}}^{\mathrm{exit\_time}} \bar{T}_{\mathrm{grad}}^{\mathrm{mbw}}(t)} \tag{7}$$

Where v is the noise standard deviation of the gravity gradient.

Figure 1 shows a flow chart of external calibration of GOCE gravity gradient.

3 Gravity data

(1) Terrestrial-gravity data

We selected three regions in the world of different degrees of topographical roughness for computation: Australia (smooth; $-33° < \varphi < -23°$, $124° < \lambda <$