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Analysis of the merged quasi-geoid of neighbouring areas

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ABSTRACT

Employing the merged quasi-geoid, we analyses the causes of systematic errors in modelling of quasi-geoid of neighbouring areas in the paper, and the efficient method is introduced to improve the accuracy of quasi-geoid. First, the systematic error is weakened with the moving window method applied to established quasi-geoids in two adjacent regions, and the accuracy of the merged quasi-geoid in the stitching region is checked using the measured GPS benchmark data; Second, the whole quasi-geoid is recomputed with data obtained from two adjacent regions if the accuracy of the quasi-geoid obtained from the first step in the stitching region is low; Finally, the quasi-geoids in two adjacent regions are recomputed respectively using GPS benchmark data of own region and adjacent region with the same solution if the accuracy of whole quasi-geoid obtained from the second step also is low. Actual data sets from Sichuan Province and Chongqing City are employed to test the moving window method. It is shown that the quasi-geoid models with high resolution and accuracy were obtained.

1. Introduction

With the development of the corresponding theory and technology, the quasi-geoid can be gained with the high resolution and accuracy [1–6]. Today, gravity data from areas previously lacking this information can be collected by airborne gravimetry. However, the precise engineering involved requires a more advanced quasi-geoid model, causing many countries to develop a series of geoid models. Now the quasi-geoid model of China (CQG2000) cannot satisfy the needs of production and research. Thus, the development of a more precise quasi-geoid model at the scale of province or city has been initiated throughout the country. To date, the model with a precision of centimetres for most areas has been achieved, and its application has provided numerous social and economic benefits. Provincial and municipal quasi-geoid models are typically based on the characteristics of the respective areas, seldom considering the relationship between different areas. In addition, the variety of available gravity models, GPS benchmark data and calculation methods leads to great obstacles in applying their results to important interregional projects. For the purposes of interregional production and research, it is important to establish a seamless interregional quasi-geoid model that can recalculate and combine existing quasi-geoids. Previous research has focused on the merged quasi-geoid, such as the principles and formulas [7–11], and the method based on the fitting-piecing technique, which allowed for the effective assembly of the quasi-geoids [12]. However, the results obtained from provincial and municipal quasi-geoid assembly are scarce. Based on the aforementioned deficiency, an effective assembly method is introduced to resolve the systematic errors that arise from the assembly of various quasi-geoids from neighbouring areas. First, the various established quasi-geoids are compared and analysed. All these quasi-geoids are then merged using the moving window method with GPS benchmark data to check the accuracy. If the accuracy of the stitching quasi-geoid from the previous step does not satisfy our criteria, the quasi-geoid is again computed with the new whole gravity quasi-geoid better approaching adjacent regions and GPS benchmark data of adjacent regions. Finally, the calculation method is tested with the strictly precise quasi-geoid results obtained for Sichuan and Chongqing.

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2. The reasons for systematic errors

Previously, researchers generally considered their own application of provincial and municipal quasi-geoids but rarely considered the cross-regional application of the quasi-geoids, which could lead to deficiencies in interregional construction. The reasons for these systematic errors are as follows:

1) Basic data. (a) GPS benchmark data: Due to variations in the precise determination time of quasi-geoid, there were different GPS benchmark data to be used in the quasi-geoid of neighbouring areas; with the influence of many factors, such as the environment, the accuracy of GPS benchmark data located in neighbouring areas are different. (b) Topography data: Based on the different updating times of DEM data, topography data with different levels of accuracy. (c) Gravity data: Similar to the case of topography data, gravity data with different levels of accuracy. In a word, the accuracy and resolution of basic data can be the key factors, which directly determine the accuracy of quasi-geoid.
2) Gravity quasi-geoid model. Because of the refining time of neighbouring areas, the gravitational field models used are different, and the accuracies of these models in different regions are also different [13]. To approximate the real change in local quasi-geoids, gravity quasi-geoid models with different integral radii and topographic corrections may be used in the neighbouring areas. Similarly the accuracy and resolution of gravity quasi-geoid model can also be the key factors, which are more valuable to quasi-geoid in the mountain.
3) Fitting method. Different fitting methods are used to approximate the quasi-geoid according to different principles. Under the same condition, the effects of different fitting methods have large difference, such as adaptive least square collocation and polynomial [14–17].

3. Moving window method

To eliminate the sudden change in the stitching region, we used the moving window method to obtain smooth quasi-geoid [17]. The area of several kilometres on both sides of the common borderline between two regions is the scope of the stitching region. This algorithm takes the point located in the stitching regionas its centre and establishes a matrix L_k^r with the moving window dimension $(2n+1)\times(2n+1)$, where L is composed of quasi-geoid grid values, k is the sequence of points located in the stitching region and r represents the region which the quasi-geoid values belong to. We then calculated the weighted mean of values at all of the points as follows:

1) Setting the border point “o” as the centre, we calculated L_k^a, L_k^b with dimension $(2n+1)\times(2n+1)$, where “a” and “b” represent areas.
2) Taking o as the origin, we established a coordinate system in which every quadrant had $n\times n$ points; that is, there were n points on the axes in both the positive and negative directions. Based on the $n\times n$ points in each quadrant, we determined the axis of symmetry for this calculation.
3) Setting the axis of symmetry as the centre (vertical), we defined the left side and right side of the axis of symmetry as section a and b respectively. In the calculation process, the value $W_{i,j}^a$ for section a is 1.0. The value $W_{i,j}^b$ for section b, which extends to section a, is $\frac{n+1-j}{n+1}$, where j is the number of grid from the point to the axis of symmetry and i is the number of line in this window. On the axis of symmetry, both $W_{i,j}^a$ and $W_{i,j}^b$ are 1.0; thus, the quasi-geoid result of any grid point in the moving window is $L_{i,j} = \frac{(L_k^a)_{i,j}W_{i,j}^a+(L_k^b)_{i,j}W_{i,j}^b}{W_{i,j}^a+W_{i,j}^b}$. In addition, we set the weight value of this point in the present window as $W_{i,j}^k = \frac{1.0}{\sqrt{(i-n-1)^2+j^2}}$.
4) Comparing the quasi-geoid values of grid point $L_{i,j}$ in windows $k-1$ and k. If $W_{i,j}^k > W_{i,j}^{k-1}$, we take the result of window k; otherwise, if $W_{i,j}^k = W_{i,j}^{k-1}$, we take the result of window as $k-1$. This procedure is continued to the end of the present window.
5) Subsequently, we go back to step 1 and initiate the next window circulation.

Moving window method can smooth the difference of quasi-geoid grid to reduce the systematic error in neighbour areas by adjusting the weight of the different quasi-geoid grid, improve the reliability of quasi-geoid along the borderline.

4. Merged Quasi-Geoid

The quasi-geoids of these areas show some deviations in the overlapped areas for the data, methods and models used in neighbouring areas are different. If the systematic errors are not eliminated or reduced, the application of research results may be limited. Taking the borderline of neighbouring areas as the symmetry axis, we selected the left/right (up/down) part as symmetrical area and obtained the grid data with the moving window dimension $(2n+1)\times(2n+1)$ for smooth processing.

As for the quasi-geoid grid points in the stitching region, the moving window method is used to calculate the piecing quasi-geoid of grid points along the borderline. The quasi-geoid value of grid points outside the stitching region are still use the result of the established quasi-geoid located in respective region. This method can reduce the effects of systematic errors and improve the applicability of results. An adjustment method with constraints can also be used to merge quasi-geoid of neighbouring areas, which can increase the practicability of quasi-geoid [17]. However, because the data and models of the quasi-geoids are different, those methods only eliminate part of the effects of the systematic errors. To evaluate the splicing result, GPS benchmark data along two sides of the borderline are used. If the accuracy is sufficiently high, the splicing result will be used as the final quasi-geoid grid model. Otherwise, the quasi-geoid model will be recalculated.

With the gravity, topography and other fundamental data of neighbouring areas, Earth Gravitational Model 2008 is applied to obtain an accurate gravity quasi-geoid. GPS benchmark data and spline fitting method are also used to approximate the real change of quasi-geoid between neighbouring areas, and the newly established quasi-geoid model is analysed and compared with the existing quasi-geoid model of each region. If the discrepancy between the newly established quasi-geoid and the existing quasi-geoid is not resolved, the cause of the discrepancy need to be analysed and the scheme of quasi-geoid refinement will be redesigned.

The distribution densities of GPS benchmark data in different area are different. For this reason, although a similar fitting method is adopted, the fitting parameters of the whole calculation may differ greatly from the fitting parameters of the zoning calculation, which may lead to differences in the resulting quasi-geoids. To maintain the conformity of all of the results, the method of zoning calculation is used to achieve the quasi-geoid of each region and the quasi-geoid of neighbouring areas are merged into a quasi-geoid of relatively large region.

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