NEW APPROACHES TO TOPOGRAPHIC GRAVITY CORRECTIONS

Ruizhong Jia, PetRos EiKon, Brampton, Ontario, Canada
Laura Davis, PetRos EiKon, Brampton, Ontario, Canada
R. W. Groom, PetRos EiKon, Brampton, Ontario, Canada

Abstract

The conventional approach of computing a gravity topographic correction from digital elevation models (DEM) involves creating a correction grid at a station by means of interpolation. Obviously, the interpolation process introduces errors in the estimated elevation of the grid points that result in noise of the computed topographic correction. We have developed a new technique to compute the topographic correction by directly utilizing a DEM without creating a grid at each station. Our method avoids the noise introduced in the interpolated elevation of each grid point. Based on a real survey in an area of high relief, we utilized both our technique and the conventional approach to compute the regional topographic corrections with a GTOPO30 DEM produced by the U.S. Geological Survey. The discrepancies between the results of our method and the results generated with the conventional method are partly attributed to the noise introduced in the estimated elevations at the grid points by interpolation. It is shown that the conventional method is dependent upon the grid setting. Our technique does not involve preparing a correction grid at a station and therefore avoids this difficulty. Our method is more efficient because no additional correction grids need to be created by interpolation.

Introduction

The computation of a gravity topographic correction is a necessary operation particularly in an area of high relief. The classical method to compute the topographic correction employing fan-shaped prisms was developed in (Hayford and Bowie, 1912) and (Hammer, 1939). The computer-oriented terrain correction algorithms utilizing rectangular prisms to represent topography were developed in (Bott, 1959), (Kane, 1962), (Nagy, 1966), and (Plouff , 1966, 1977). In (Zhou et al, 1990) the topographic correction by discretizing topography into dipping triangular elements was computed. However, all these methods involve creating a correction grid at a station by means of interpolation. To implement the methods, care must be exercised to ensure that a correction grid is set properly as the topographic correction is affected by the grid setting. Obviously, the interpolation process introduces errors in the elevation of the grid points that eventually result in noise of the computed topographic corrections. We have developed a new technique to compute the topographic correction by directly utilizing a DEM without creating a grid at each station. The DEM utilized in our technique may not necessarily be a spatially regular grid. Many widely available DEMs, such as GTOPO30 and National Elevation Data (NED) produced by the U.S. Geological Survey, are initially regularly gridded elevation data in terms of longitude and latitude and become irregular when transformed into UTM grid coordinates. We applied our technique to a real gravity survey utilizing a GTOPO30 DEM. We also employed the conventional approach to compute the topographic corrections by creating grids with natural neighbor interpolation.

Method

We computed topographic corrections utilizing a DEM grid. The grid is not required to be spatially regular. It can be created from the measured elevation of a survey by interpolation or obtained from various sources, including the U.S. Geological Survey's websites. Our aim is to demonstrate the difference between the topographic corrections generated directly from the DEM grid and the corrections produced by interpolating DEM data onto a grid at each station. We first compute the topographic effect directly from a DEM without generating any additional grids by interpolation. At a given station, we consider the region enclosed by two squares that are centered on the station, one square has the dimension specified by an inner radius and the other square's dimension is determined by an outer radius (Figure 1). Note that the boundary of the region is formed by the intersection points between the edges of the squares and the sides of DEM grid cells. To compute the topographic effect of the cells located at the boundary, the elevations of the boundary points have to be estimated utilizing an interpolation technique. We experimented with linear interpolation, natural neighbor and bicubic interpolation to estimate the elevations of the intersection points. The basic properties of natural neighbor interpolation are that it is local, using only a subset of samples that surround a query point, and that interpolated heights are guaranteed to be within the range of the samples used. Bicubic interpolation is an extension of cubic interpolation for interpolating data points on a regular grid. The interpolated surface is smooth in all directions. To make comparisons between the corrections of our technique and the results of the conventional approach, we also computed the topographic correction at each individual station by interpolating the DEM data onto a grid mesh utilizing natural neighbor interpolation. In our calculation, the topographic effect of each grid cell is the gravitational effect of the polyhedron whose top is defined by the elevations of the 4 corners of the cell. Note that the top of the polyhedron is not necessarily flat and we take it into consideration to enhance the accuracy of our computation. This polyhedron is split into two triangle-based polyhedrons and their gravitational effects were computed utilizing the analytical expressions for an arbitrary polyhedron (M. Okabe, 1979).

Examples

We computed the topographic correction of a real ground gravity survey. The stations were located 15 m apart and the survey lines were north-south. The survey is in an area of high relief with an elevation variation of over 3 km. Only the regional topographic corrections were computed as the fine local DEMs for this area were not available. A GTOPO30 grid was utilized for the computation of the topographic correction. GTOPO30 is a DEM with a horizontal grid spacing of 30 arc seconds, or approximately 1 kilometer. The correction is computed between 1 km and 22 km from a station. A constant density of 2.67 grams/cc was utilized for the computation. The measured elevation of the gravity station was not used in the computation, as there were significant discrepancies between the measured elevation and the GTOPO30 DEM data. Instead, the elevations at the horizontal locations of the stations utilized in the computation were estimated with natural neighbor interpolation.

We first computed the topographic corrections with our technique, that is, directly from a DEM grid without creating any additional correction grids. We computed the topographic effects of the grid cells of the DEM enclosed by two squares which are centered on the given station and have dimensions specified by an inner radius of 1 km and an outer radius of 22 km, respectively (Figure 1). In the computation, the elevations of the boundary points were estimated by one of three interpolation techniques: linear interpolation, natural neighbor interpolation and bicubic interpolation. We noticed that the difference in elevation at certain boundary points was up to 200 m depending on the interpolation. The computed topographic corrections for a profile are displayed in Figure 2. It can be seen that the difference in the corrections was within 0.05 mGal, indicating that the topographic corrections utilizing the original DEM are consistent regardless of the interpolation technique utilized to estimate the elevations of the boundary points. We then calculated topographic effects utilizing the conventional approach by creating a correction grid mesh centered on the station for which the correction was calculated. Natural neighbor interpolation was utilized in creating the correction grids. The computation was done with the inner distance of 1 km and the outer distance of 22 km and the density of 2.67

grams/cc was utilized. More specifically, a square region of 44 km by 44 km centered on the station was gridded with cells of 1 km by 1 km. The correction was computed for all the cells enclosed by two squares that are centered on the station and have side lengths of 2 km and 44 km, respectively. The result is also displayed in Figure 2. There are differences of up to 0.6 mGal between the results of our technique and the result of the conventional method. The discrepancies between the results of our method and the result generated with the conventional method are partly attributed to the noise introduced in the estimated elevations at the grid points by interpolation. Note that the computed topographic corrections along the profile were proportional to the station elevations utilized in the computation (Figures 2 and 3), as in many cases observed in (Kane, 1962).

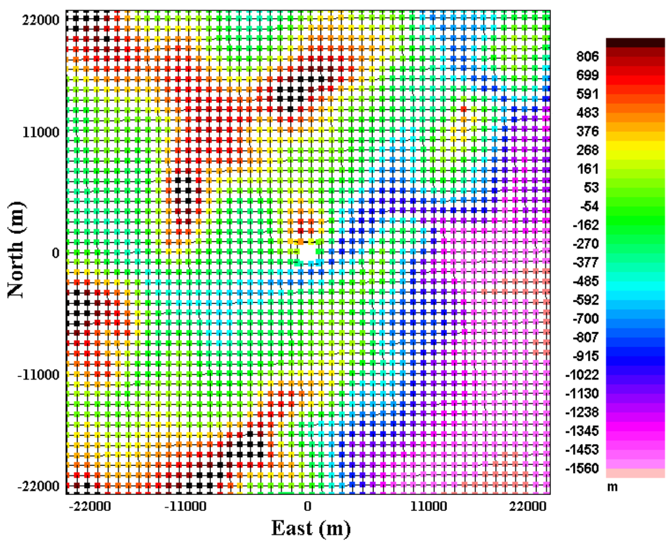

Figure 1: The region enclosed by two squares centered on the station located at the origin. One square has a dimension specified by the inner radius of 1 km and the other's dimension is specified by the outer radius of 22 km. The legend indicates the variation of the DEM elevation with respect to the given station.

To see how the grid setting affects the topographic correction, we computed the topographic correction with the conventional method utilizing natural neighbor interpolation to create a correction grid at a station, which has cell size of 0.92 km by 0.92 km, the average size of the original GTOPO30 DEM grid. The computation was done with the inner radius of 1 km and an outer radius of 22 km. In other words, the topographic effects of the grid cells enclosed by two squares which are centered on the given station and have dimensions specified by the inner radius of 1 km and an outer radius of 22 km were computed. Note that the intersection points between the edges of the squares and the sides of the grid cells are not at the grid points. Therefore the elevations of the intersection points have to be estimated utilizing an interpolation technique. We only give the results of a linear interpolation as the corrections produced with other techniques such as natural neighbor interpolation and bicubic interpolation were similar with differences below 0.04 mGal. The corrections obtained with the conventional method utilizing a grid of cell size 0.92 km by 0.92 km are displayed in Figure 4. It is seen that there is a discrepancy of up to 0.36 mGal between the corrections generated with cell sizes of 0.92 km and 1 km. This demonstrates that the conventional method is dependent upon the way the grid is set. Obviously, our technique does not involve preparing a grid and therefore avoids such difficulty.

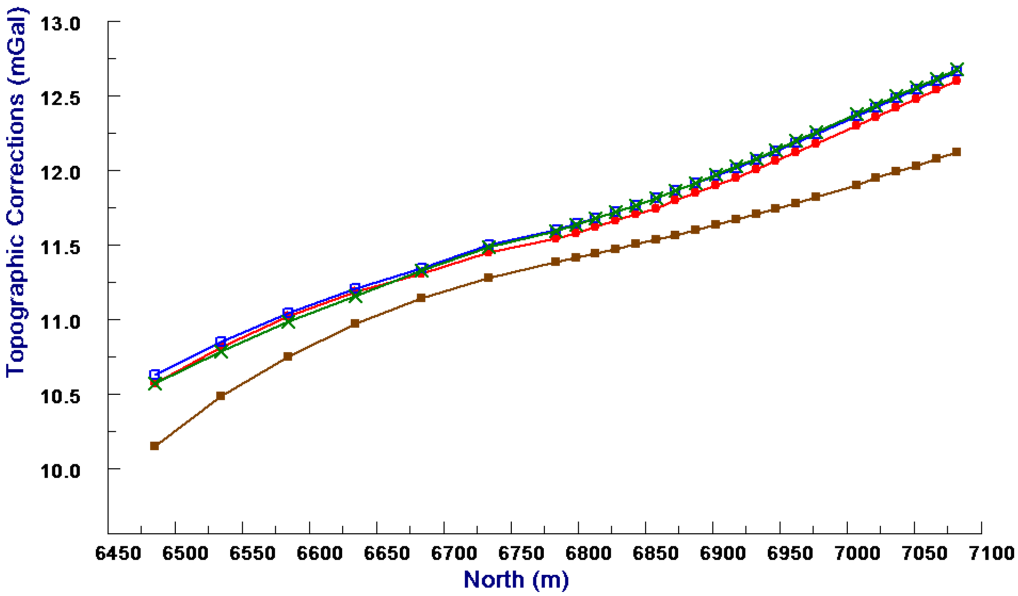

Figure 2: The topographic corrections of a profile computed with our method and the conventional method. The red, blue and green curves are the results obtained with our technique utilizing linear interpolation, natural neighbor interpolation, and bicubic interpolation, respectively, to estimate the elevations of the points that are at the boundary. The brown curve represents the results generated with the conventional method utilizing natural neighbor interpolation to create grids of cell size 1 km by 1 km. The computation was done with the inner distance of 1 km and the outer distance of 22 km and the density of 2.67 grams/cc was utilized.

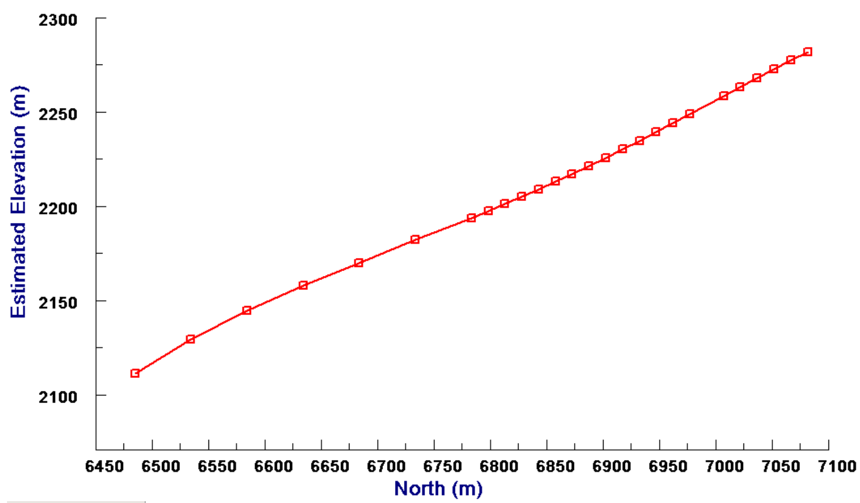

Figure 3: The station elevation utilized in the computation of the topographic corrections were estimated by natural neighbor interpolation.

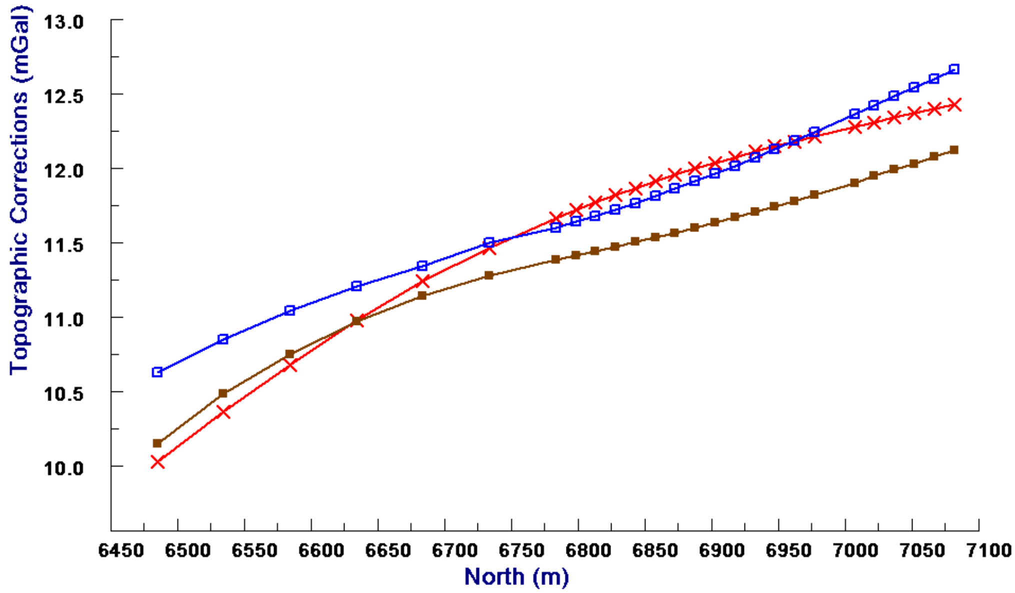

Figure 4: The topographic corrections computed with our method and the conventional method. The blue curve is the result obtained with our technique utilizing natural neighbor interpolation to estimate the elevations of the points that are at the boundary. The brown curve represents the results generated with the conventional method utilizing natural neighbor interpolation to create grids of cell size 1 km by 1 km. The red curve shows the results generated with the conventional method utilizing natural neighbor interpolation to create grids of cell size 0.92 km by 0.92 km. The computation was done with the inner distance of 1 km and the outer distance of 22 km and the density of 2.67 grams/cc was utilized.

Conclusions

We have developed a new technique to compute the topographic correction by directly utilizing a DEM without creating a grid at each station, as opposed to the conventional method. Our method avoids the noise introduced in the interpolated elevation of each grid point at a station and is more efficient because no additional correction grids need to be created by interpolation. We applied this technique to a real gravity survey and our results shown that its corrections were consistent regardless of the interpolation technique utilized to estimate the elevations of the boundary points. The discrepancies between the results of our method and the results generated with the conventional method are partly attributed to the noise introduced in the elevations of the correction grid points by interpolation. The conventional method involves properly setting the grid. Our technique does not involve preparing a correction grid at a station and therefore avoids such difficulty.

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