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GRAVITY TERRAIN CORRECTION FOR MAINLAND TERRITORY OF VIETNAM

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ABSTRACT: Terrain corrections for gravity data are a critical concern in rugged topography, because the magnitude of the corrections may be largely relative to the anomalies of interest. That is also important to determine the inner and outer radii beyond which the terrain effect can be neglected. Classical methods such as Lucaptrenco, Beriozkin and Prisivanco are indeed too slow with radius correction and are not extended while methods based on the Nagy's and Kane's are usually too approximate for the required accuracy. In order to achieve 0.1 mGal accuracy in terrain correction for mainland territory of Vietnam and reduce the computing time, the best inner and outer radii for terrain correction computation are 2 km and 70 km respectively. The results show that in nearly a half of the Vietnam territory, the terrain correction values ≥ 10 mGal, the corrections are smaller in the plain areas (less than 2 mGal) and higher in the mountainous region, in particular the correction reaches approximately 21 mGal in some locations of northern mountainous region. The complete Bouguer gravity map of mainland territory of Vietnam is reproduced based on the full terrain correction introduced in this paper.

Keywords: Terrain correction, Bouguer gravity anomaly.

INTRODUCTION

The computation of a gravity topographic correction is a necessary operation particularly in an area of high relief. But classical methods of terrain correction (Prisivanco, Lucaptrenco and Beriozkin) that have been used in Vietnam before show a corrected outer radius of no more than 7,290 m [1], thus neglecting the effect of terrain at the greater distance than this one.

Nowadays, terrain correction is mainly based on the Kane's (1962) [2] and Nagy's (1966) [3] algorithms with the radius correction implemented optionally. Theoretically, the distance for both of Bouguer and terrain correction is infinitive. In practice, a distance is commonly applied if the correction beyond this distance can be neglected. However, a question is that what the finite distance is? Dannes (1982) [4] emphasized that the distance may varies from area to area, depending on the topographic relief of the area under consideration. He used a distance of 52.6 km for the correction in the Washington, USA. In the Central Range of Japan, a distance of 80 km was used by Yamamoto Akihiko (2001) [5].

In Vietnam, the algorithms of Kane (1962) and Nagy (1966) were used by Cao Dinh Trieu, Le Van Dung (2006) [6] applied for the map of scale 50.000 for Yen Chau area, with an inner radius taken as 200 m and outer radius as 45 km. Recently, Tran Tuan Dung et al., (2012) [7] also applied the algorithm to calculate the seafloor topography in the East Vietnam Sea and adjacent areas with the outer radius of R = 100 km. However, for the calculation of terrain correction for the whole mainland territory of Vietnam, no gravity map with full terrain correction has been published. In this paper, our approach is to find the best distance for inner and outer radii in high mountainous areas in Vietnam.

DATA SOURCES AND COMPUTATION OF TERRAIN CORRECTION

Data sources

To calculate terrain correction of the mainland territory of Vietnam, the authors used the following data sources:

Topographic map in mainland of Vietnam territory at scale 1:500,000 (by Department of Surveying and Mapping).

Digital elevation model (DEM-30): provided by NASA, USA with distance point of 30” (approximately 1 km), with geodetic coordinates UTM - WGS84.

Data source of gravity points: Provided by the Department of Geology and Minerals of Vietnam and other units, including 42,591 points in the mainland territory of Vietnam.

Computation of terrain correction

Terrain correction is the most time-consuming calculation in the reduction of gravity data. Historically, terrain corrections were computed using Hammer (1939) [8] charts at each station. However, terrain corrections can now be computed efficiently from the regular grid of a DEM [2, 9]. Nowadays, there have been considerable enhancements in the capabilities of laptop computers; with digital terrain data and computers, terrain corrections can be calculated in a matter of minutes.

In this paper, terrain corrections are calculated using a combination of the methods described by Kane (1962) and Nagy (1966). The DEM data is sampled to a grid mesh centered on the station for which the correction is to be calculated. Kane (1962) suggested a calculation based on three zones, namely, the near zone, intermediate zone, and far zone. Various approaches for calculating the gravitational attraction of each zone are described below.

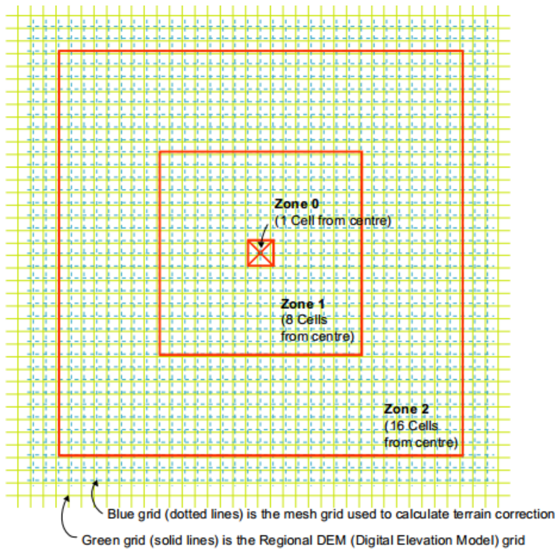

Fig. 1. Diagram of network division in the calculation of terrain correction

In the near zone, that is, 0 to 1 cell from the center, the terrain correction is calculated from the effects of four sloping triangular sections that describe the surface between the gravity station and the elevation at each diagonal corner. For each triangular section, the terrain correction is calculated by using the formula given below [2]:

$$g = G\rho_T\varphi\left(R-\sqrt{R^2+H^2}+\frac{H^2}{\sqrt{R^2+H^2}}\right) \quad (1)$$

Where g is the gravitational attraction; ρ_T - the terrain density; ϕ- the horizontal angle of the triangular section; *G*- the gravitational constant; *H*- the difference between the station elevation and the average elevation of the diagonal corner; *R*- the grid spacing.

The range of the intermediate zone is 2 to 8 cells from the station. The terrain effect is calculated for each cell by using the flat-topped square prism approach proposed by Nagy (1966) [3]. For each prism, the terrain correction is calculated using equation (2) as follows:

$$g = -G\rho_T \left|\left|\left| x\ln(y+r) + y\ln(x+r) + z\arctan\frac{zr}{xy} \right|_{X_1}^{X_2}\right|_{Y_1}^{Y_2}\right|_{Z_1}^{Z_2} \qquad (2)$$

Where g is the vertical component of the attraction; ρ_T - the terrain density; *G*- the gravitational constant; *r*- the distance between a unit mass and the station.

The region that extends beyond 8 cells is the far zone. The calculation of the terrain effect for this zone is based on the approximation of an annular ring segment to a square prism, as described by Kane (1962) [2]. The gravitational attraction is calculated from equation (3) as follows:

$$g = 2G\rho_T A^2 \frac{(R_2 - R_1 + \sqrt{R_1^2 + H^2} - \sqrt{R_2^2 + H^2})}{(R_2^2 - R_1^2)} \qquad (3)$$

Where g is the gravitational attraction; ρ_T - the terrain density; *A*- the length of the horizontal side of the prism; R_1 - the radius of the inner circle of the annular ring; R_2 - the radius of the outer circle of the annular ring; *H*- the height of the annular ring or prism.

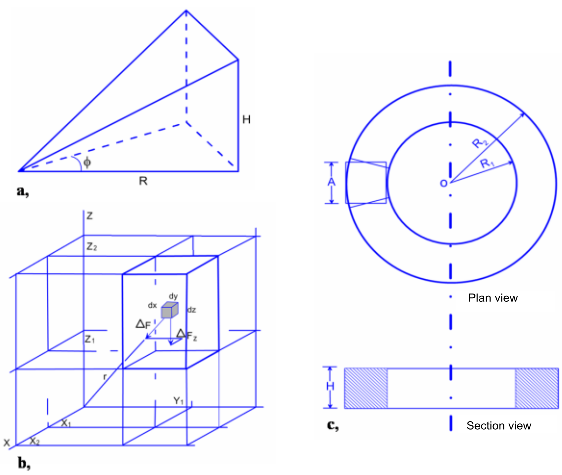

Fig. 2. Geometry of the body used for terrain correction: a- Zone 1; b- Zone 2, c- Zone 3

The total terrain correction at each station is the summation of the local and regional terrain corrections. Both these corrections can be calculated from the DEM. A precise DEM surrounding the station is used to calculate the local terrain correction from zero to a certain distance, this distance is called the inner distance. A coarse DEM is then applied to calculate the terrain correction for the region that extends significantly beyond the inner distance. The distance to which the regional correction should be calculated is called the outer distance. In practical computations, the calculation of the regional correction is the most computationally expensive component of the calculation.

Since about 70% areas of Vietnam are occupied by mountain ranges and more than a half of our gravity stations are located in higher relief areas, so the finite distance should be decided very carefully. To improve the accuracy of terrain correction and reduce computing time, we need to define the inner radius (*r*) and the outer radius (*R*) that satisfy the accuracy requirement of terrain correction (Note that the choice of radius will also depend on the roughness of the terrain under study area). To see how the inner and outer radii affect the terrain correction, we selected 10 stations in the Northwest region and 4 stations in the Tay Nguyen region. Almost stations were located at elevation of 500 m or greater.

Definition of the inner radius (r) for terrain correction

Since inner radius of (*r*) depends largely on the complexity of topography. To determine the optimal radius (*r*), the following steps are necessary to optimize (*r*) for a given study area:

Firstly, select some stations located in the study area and calculate the terrain effect with *r* changing from the minimum value to a maximum value.

Secondly, construct the graphs demonstrating the relation between the correction values and distance *r*.

Finally, the distance *r* corresponding to the maximum value of correction on the graphs is accepted as the optimal radius of inner zone.

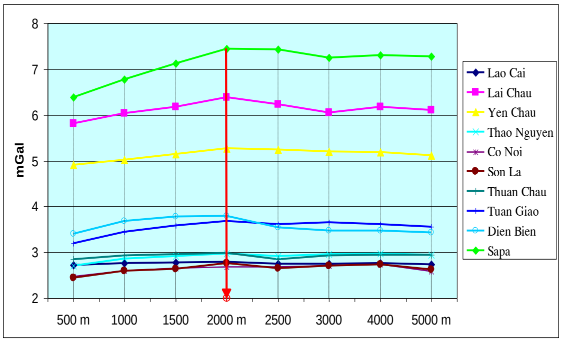

Fig. 3. Definition of inner zone for terrain correction for Vietnam's Northwest mountain area

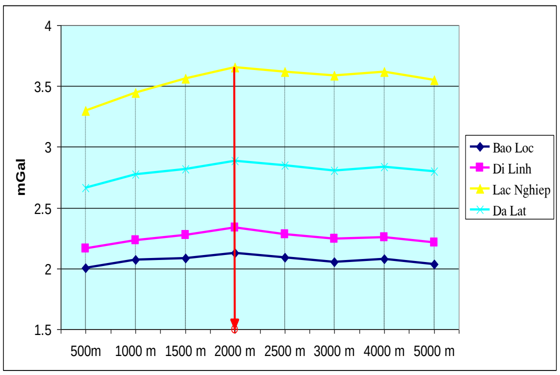

Fig. 4. Definition of inner zone for terrain correction for Vietnam's Tay Nguyen mountain area

Fig. 3 and fig. 4 show that in all cases the maximum values of correction were found at a distance of 2 km. Thus, for simplicity, the distance of 2 km was accepted as an optimum inner radius for the correction in the Vietnam territory.

Definition of outer radius (R) for terrain correction

To define the outer radius, the gravity terrain effect was calculated with R increasing from the observational point to 100 km by using an increment of 2.5 km. The results showed that from the distance R = 50 km the terrain effect was much slowly changed with increasing distance and became virtually unchanged from R = 70 km (fig. 5 and fig. 6). Since that the distance R = 70 km was accepted as the outer radius for the correction in this study.

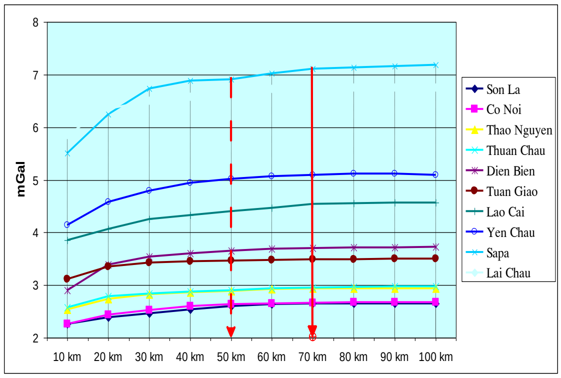

Fig. 5. Definition of outer zone for terrain correction for Vietnam's Northwest mountain area

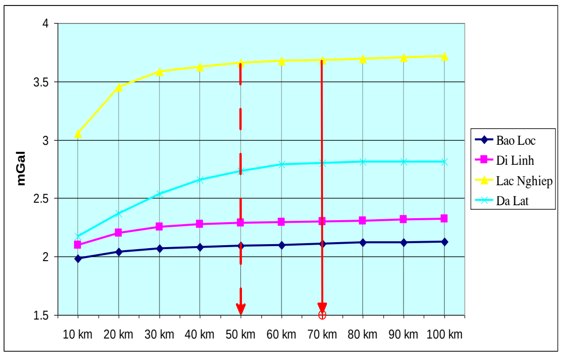

Fig. 6. Definition of outer zone for terrain correction for Vietnam's Tay Nguyen mountain area

RESULTS

Map of terrain correction value for mainland territory of Vietnam

The chosen inner and outer radii as mentioned above and an average crustal rock density of 2.67 g/cm^3 were used for calculation of the terrain correction for the mainland of Vietnam territory and the map of terrain correction values was generated (fig. 7).

According to the results, in nearly a half of the Vietnam territory, the correction value is more than 10 mGal. The correction values less than 2 mGal just are found for the plain areas and the larger values are found for the mountainous region, in particular the maximum of correction value of approximately 21 mGal is found in the Northwestern region.

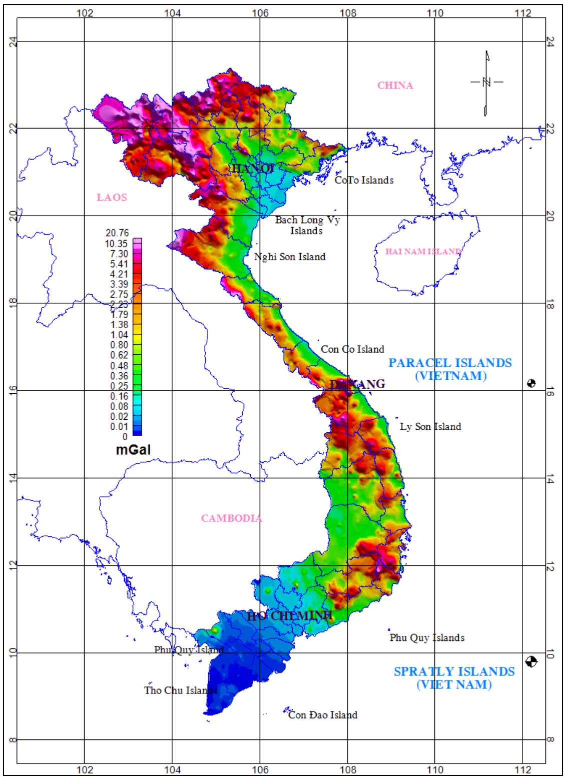

Fig. 7. The distribution of gravity terrain correction for mainland territory of Vietnam

Map of Bouguer gravity anomaly

The complete Bouguer gravity anomalies on the whole territory of Vietnam were calculated with full terrain correction using the International formula 1980:

$$\Delta g_B = g_{qs} - g_0 + (0.3086 - 0.0419 * \rho) H + \sigma_{dh}$$

Where: g_{qs}: The value of gravity at the point of observation; g_0: Normal gravity value is calculated by using the International formula 1980 [10]; ρ: An average crustal rock density of 2.67 g/cm^3; H: Station elevation in meter; σ_{dh}: The value of computed terrain correction.

The increasing tendency of Bouguer anomaly values from West to East is clearly reflected on the map of gravity anomalies obtained from the calculations (fig. 8); while the horizontal gradients are much higher for the anomalies distributed in the West in comparison with those in the East. Most of the mountainous areas are covered by negative anomalies with the lowest value reaching (-175 mGal) in Meo Vac - Ha Giang, Sapa - Lao Cai and Muong Te - Lai Chau areas. The positive anomalies are dominantly observed in the plain areas and the largest size anomaly is distributed in the southern part of Vietnam with the maximum positive value reaching (+20 mGal) in Rach Goc - Ca Mau, Bien Hoa, Long An areas.

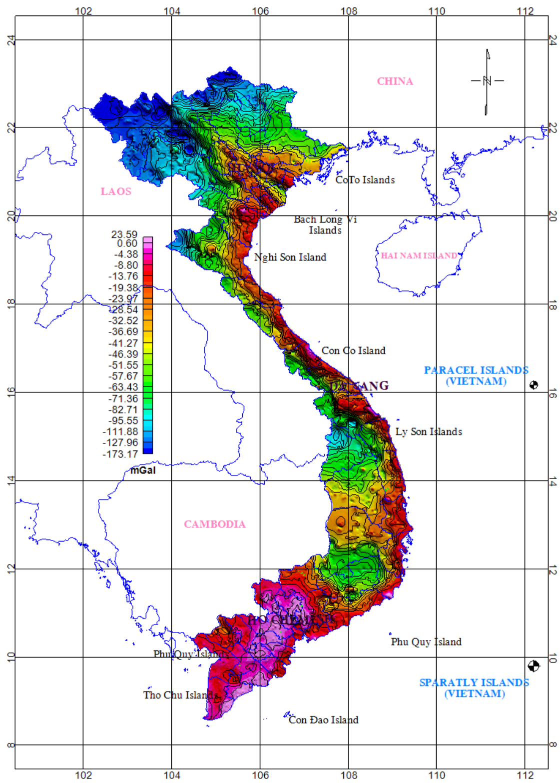

Fig. 8. Bouguer gravity anomaly map for mainland territory of Vietnam at scale 1:500,000

CONCLUSION

The chosen inner and outer radii for topographic correction allowed us to obtain a full terrain correction for the territory of Vietnam.

It is necessary to include the full terrain correction in the calculations of complete gravity Bouguer anomalies, since nearly a half of Vietnam territory is bearing the terrain correction values more than 10 mGal, in particular the maximum correction reaches a big value (approximately 21 mGal) for the mountainous region of northern Vietnam.

A more comprehensive map of gravity Bouguer anomalies obtained by this study provides a more improved data source that is useful for different research works in geophysics and geology.

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