International Cartographic Association
Association Cartographique Internationale

Development of Geoid Model and comparative evaluation

Upendra Nath Mishra[a,*]

[a] Director, Survey of India – un1112222002@yahoo.co.in

[*] Corresponding author

Key words: Geoid Undulation, Bouguer Anomaly, Height Anomaly, Polynomial Regression, Deflection of Vertical

Abstract:

Geoid related heights (orthometric height) are required for engineering projects where as modern, easy, economic and ubiquitous technology such as Global Navigational Satellite System (GNSS) provides height above ellipsoid (ellipsoidal height). Thus estimation of separation between Geoid and ellipsoid surfaces (geoid undulation) which varies from point to point throughout the globe is needed to derive orthometric height from ellipsoidal height. This estimation is done through geoid modeling in geodetic surveying. Unlike an ellipsoid, the geoid is not a smooth mathematical surface, is not directly observable and estimating it may vary as knowledge improves. A number of global, regional and local geoid models have already been developed in the World. The development of a number of geoid models is a continuous effort to develop a model having better accuracy with the ultimate goal to achieve a model as accurate as leveling or close to leveling.

There are three methods for geoid modeling (i) Gravimetric (ii) Astrogeodetic and (iii) Geometric. While magnitude of gravity is the primary field observed geodetic data required in gravimetric method, the direction of gravity { i.e. deflection of vertical (Venicek, 1980)} is in astro-geodetic method and leveling height and ellipsoidal heights are for geometric method. Gravimetric method is based on gravity data of the earth surface which is collected through terrestrial field observation or through satellite gravity missions such as CHAMP, GRACE and GOCE etc. Least Square Collocation (LSC) has been adopted for computation in four broad steps-derivation of local covariance model (Arabelos D and Tscherning C. C., 2003), prediction of gravity at the points where geoid undulation is known, conversion of gravity anomaly to height anomaly (Heiskanen and Moritz, 1967), prediction of geoid undulation at desired location using local covariance model and a few steps of remove-compute-restore operation. In astrogeodetic method, the basic quantity deflection of vertical (the deviation of plumb line from ellipsoidal normal), is obtained from astronomical latitude, longitude (Muller Ivan I, 1969) and geodetic latitude and longitude. Geoid undulation of a number of points is computed by applying a methodology termed ‘astronomical leveling’. A best fitting curve is obtained using polynomial regression technique (Soycan Matin, 2003) which is the realization of geoid. In geometric method, a best fitting polynomial curve is derived following least square concept and using the actual geoid undulation of a number of points.

Collection of geodetic data from field is a costly affair. There are global geoid models available, but they are not accurate enough to meet the engineering project needs of an area or a region due to omission and commission errors in their development. Therefore, it is imperative to study all possible methods of geoid modeling to obtain the cost effective and appropriately accurate geoid model for an area or a region. In this study an attempt has been made to evaluate the accuracy and economy of the methods of geoid modeling and their comparison among themselves as well as with global models to adopt the most suitable geoid model for a project or a region.

The study area is in Dehradun region (bounded by geographic location 30^0 10´, 77^0 45´ - 30^0 30´, 78^0 11´), a terrain highly undulating (area extent about 600 km^2 and elevation range 410-1600m) and tectonically active. For this region, three geoid models have been developed using the above three methods.

These geoid models have been developed after collecting astronomical data, GPS data, gravity data and leveling data from field with precise instruments such as dual frequency geodetic GPS receivers which are capable of providing horizontal accuracy 1 cm + 1 ppm and vertical accuracy 2 cm + 1 ppm, digital level having least count 0.1 mm, relative gravimeter having reading resolution 1μgal and T-3 theodolite with least count 0.2 second. 18 GPS stations and leveling BM each, 45 gravity stations and 8 astronomical stations in Dehradun have been used. The software GRAVSOFT, Level Net Adjustment Programme and Stellarium have been applied.

Abstracts of the International Cartographic Association, 6, 167, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa.
https://doi.org/10.5194/ica-abs-6-167-2023 |

The accuracy of developed models has been analyzed by comparing the accuracy of models among themselves as well as with the best available existing global geoid models. This has been done by computing geoid undulation at test points from developed model as well as global models and their deviation (departures) from the actual values of geoid undulation at test points. These deviations indicate error in model at test points and summarized in Table 1 below. Statistics of the errors namely maximum, minimum, Root Mean Square Error (RMSE) (Mikhail and Gracie, 1981) and modulus of Mean of errors were computed. RMSE and modulus of Mean of errors give fair estimation of the accuracy of the model. Lesser the value of the statistics better is accuracy.

Area of Study		Developed Models			Global Models		
	Statistics	Geometric Geoid Model (m)	Gravimetric Geoid Model (m)	Astro-Geodetic Geoid Model (m)	Eigen6C4 Global Geoid Model (m)	Eigen6C3stat Global Geoid Model (m)	EGM2008 Global Geoid Model (m)
Dehradun	Max	0.162	0.266	0.207	0.275	0.293	0.287
	Min	0.003	0.023	0.046	0.056	0.122	0.056
	RMSE	0.074	0.190	0.132	0.195	0.197	0.208
	Mean	0.057	0.175	0.124	0.175	0.187	0.197

Table 1. Statistics of Difference of geoid undulations obtained from Developed Models and Global Geoid Models from True Geoid Undulations at Test Points.

It has been found that even about 5 centimeter accurate geoid model is a distinct possibility in Indian context. The study gives an insight into the most economical solution for contouring on large scale topographical maps and Digital Elevation Model (DEM) without resorting to extensive costly leveling work.

References

Arabelos, D. and Tscherning, C. C., 2003. Globally covering a-priori regional gravity covariance models. Advanced Geosciences, 1,143-147, doi: 10:5194.

Heiskanen, Weikko, A. and Helmert, Moritz, 1967. *Physical Geodesy*, W. H. Freeman & Co., Sanfrancisco.

Mikhail, E.M. and Gracie, G., 1981. *Analysis & Adjustment of Survey Measurements*, Van NostrandReinhld Company, pp.368-380.

Mueller, Ivan, I., Eichhorn, Heinrich, 1969. *Spherical and Practical Astronomy as applied to Geodesy*; Frederick UNGAR Publishing Co., New York.

Soycan, Metin and Soycan, MSC, Arzu, 2003. Surface modeling for GPS-levelling geoid determination. Newton's Bulletin 1, France, pp. 41-52.

Vanicek, Petr and Edward, Krakiwsky, 1980. *Geodesy the Concepts*, North Holland Publishing Company, Amsterdam, New York, Oxford.

Abstracts of the International Cartographic Association, 6, 167, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa.
https://doi.org/10.5194/ica-abs-6-167-2023