Geoid Determination and Gravity Works in Nepal

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Gravity, Geoid, Geopotential Model, Gravity Anomalies

ABSTRACT

Gravimetric geoid plays the important role in the process of local/regional geoidal undulation determination. This approach uses the residual gravity anomalies determined by the surface gravity measurement using the gravimeter together with best fit geopotential model, with the geoid undulations over the oceans determined from the method of satellite altimetry. Mass distribution, position and elevation are prominent factors affecting the surface gravity. These information in combination with geopotential model helps in satellite orbit determination, oil, mineral and gas exploration supporting in the national economy. The preliminary geoid thus computed using airborne gravity and other surface gravity observation and the accuracy of computed geoid was likely at the 10-20cm in the interior of Nepal but higher near the border due to lack of data in China and India. The geoid thus defined is significantly improved relative to EGM –08 geoid.

1. INTRODUCTION:

Survey Department introduced global positioning system (GPS) survey to establish geodetic controls since 1991. This technology has become much more efficient and accurate with reference to World Geodetic System 1984 (WGS 84). It has been widely used in the positioning of the higher order controls and its densification in the country such as First, Second and third order geodetic controls. In the contrary it has also created a challenge of the conversion of position and heights in Everest Spheroid 1830, based on Nepal Datum. This is the national datum of the country on which all the mapping activities are referred.

In the positioning technique of GPS which is now replaced by Global Navigation Satellite System (GNSS) -more satellite constellation used in positioning in its relative carrier-phase mode provides three- dimensional coordinates of latitude, longitude and ellipsoidal height relative to known fixed point in the WGS84. For the transformation of horizontal coordinates (latitude, longitude or easting and northing) Survey Department has been using National Transformation Parameter developed by Mr. Manandhar (Manandhar N, (2072) A Review of Geodetic Datums of Nepal and Transformation Parameters for Wgs84 to Geodetic Datum of Nepal, Nepalese Journal of Geoinformatics, Vol 14)

The ellipsoidal height component must also have to be transformed to an orthometric height using information of geoid- WGS84-ellipsoid separation at each GPS point. Survey Department, Geodetic Survey Division has been using only the horizontal component (latitude and longitude) of the GPS output although the vertical component (height) is one of the vital informational product of the survey however this requirement is fulfilled by conventional method of spirit leveling till today. In order to overcome the use of spirit leveling which is one of the very costly and time consuming technique in height determination process, the gravimetric geoid plays the major role in the process orthometric height determination from ellipsoidal height. (Manandhar N, (2067) Surface Gravity Information of Nepal and its Role in Gravimetric Geoid Determination and Refinement, Nepalese Journal of Geoinformatics, Vol 9).

2. GRAVITY:

A body rotating with the earth experiences the gravitational force of the masses of the earth as well as the centrifugal force due to the Earth's rotation. The resultant force of is called of gravity, simply called gravity. [Torge, Geodesy]

Gravity = Gravitational attraction + Centrifugal Acceleration.

Gravity has the dimension of an acceleration with the corresponding SI units of m/s2. The units of gravity most commonly used in geodesy/ gravimetry/ geophysics/geology is the "gal", which is named after Galileo Galilei.

We need to deal with very small differences in gravity between points on the earth surface and with high accuracy up to 9 significant digits- the most commonly used unit is rather the "mgal".

1 gal=10^{-2} m/s^2 = 1 cm/s^2

1 mgal = 1/1000 gal = 10^{-3} gal

1 mgal = 1/1000 mgal= 10^{-3}mgal = 10^{-6}gal

The approximate vale of **g**any where on the surface of the earth is 981 gal=981x1000mgal=981000mgal.

3. GEOPOTENTIAL MODELS/ GRAVITY MODEL

Geopotential models are gravitational model of the earth gravity field. Earth gravitational potential (V) is represented by a spherical harmonic expansion where the potential coefficient in the expansion have been determined by various techniques. The gravity field information obtained from these geopotential model has applications in different areas such as precise satellites orbital determination, oil mineral and gas deposition exploration, geophysical and geological perspective and in surveying and mapping community.

In the field of surveying and mapping community, the geopotential models are used to derive the geoid undulation. The geoid undulations thus derived from geopotential model are used to translate GPS determined ellipsoidal heights into orthometric height referred the MSL. The chronological development of the geopotential models are as follows OSU91A, JGM-3, EGM96, EGM08, EGM 2020.

3.1 OSU91A:

This is the first earth geopotential model developed by the Ohio State University in 1970, spherical harmonic representations up to degree 180 were estimated. In 1980, expansion up to degree 360 is obtained. In 1991, Rapp, Wang and Palvis (1991) reported a degree 360 model that was based on:

- Satellite developed model GEM-T2 [Goddard Earth model]
- Sea surface height from GEOSAT–altimeter data
- Gravity anomalies from satellite altimeter data
- Surface gravity data
- Topographic information

And they release model called OSU91A.

The major limitation of OSU91A was lack of presice surface gravity over large continental regions-for instance most of the Asia.

3.2 JGM- 3 (Joint Gravity Model)

Since 1991, improvements have been continued on the development of 'low degree' (to 70) combination models. Examples are JGM-1 and JGM-2. These geopotential models were developed to aid the orbit of the TOPEX/POSEIDON (T/P) Satellites.

Finally, JGM-3 Model developed which is improved model over JGM-1 and JGM-2

- Using Laser tracking data
- DORIS data
- GPS tracking of T/P satellites for the first time.

JGM-3 geoid provides more realistic ocean topography. It was developed by NASA GFSC and CSR (Texas University).

3.3 EGM96

This is a spherical harmonic model of the earth's gravitational potential complete to degree and order of 360. This is the composite model - low degree up to degree 70 and high degree from 71 to 360. EGM96 is superior to JGM-3 model. Data sources to develop this model are:

- Improved surface gravity data
- Altimeter derived anomalies from ERS-1 and GEOSAT geodetic mission.
- Extensive satellite tracking data
- GPS data
- NASA's tracking and TDRSS (Tracking and Data Relay Satellite System)
- The French DORLS System.
- USNAVY TRANET Doppler Tracking System
- Direct altimeter ranges from Topex/Poseidon, ERS-1, and GEOSAT.

The resolution of EGM96 is 30'x30', geoid undulation accuracy is better than 1m, and WGS84 as true three-dimensional reference system is used. Other by-products from EGM96 solutions are:

- Estimates of dynamic tide parameters,
- DOT- Dynamic Ocean Topography solutions
- 5'x5' global topographical models.

3.4 EGM08

Earth's gravitational model 2008 is developed by National Geospatial Intelligence Academy (NGA) USA with degree and order 2160. This model used 5'x5' gravity anomaly database, GRACE -derived satellite solutions. This model used latest modelling for the both land and marine area worldwide. Geoid undulation accuracy is of this model ±5cm to ±10cm. This model used of 30"x30" topographic model. Data sources are satellite only gravitational model, terrestrial gravity data, and satellite altimetry. In comparison to EGM96 the EGM 2008 represents improvement in quality by six times in resolution and three times to six times in accuracy.

3.5 EGM 2020

The preliminary work on next Earth Gravitational Model has been started jointly with National Geospatial-Intelligence Agency [NGA] together with international partners to replace EGM 2008.It will be an ellipsoidal harmonic model up to degree and order 2160. New data sources and procedures are adapted, updated gravity information from GRACE and GOCE will be used. Mathematically well treated satellite altimetry data, better gravity marine data along with full covariance adjustment technique will make this model robust resulting quality gravimetry database. This model will provide improved global average and resolution over lands.

4. CHARACTER OF GRAVITY:

The gravity is not constant throughout the Earth surface though average value of "g" is 981 gal. The variation of gravity is the function of following factors (Heiskanen, W. A. H. Moritz Physical Geodesy, Freeman San Francisco 1967)

- Mass distribution of earth,
- Latitude of a point and
- Elevation of a point.

4.1 Variation of gravity due to mass-distribution of the Earth:

Uneven mass distribution around on or below the surface of the earth, in other words the nonuniform density of earth topography causes the variation in gravity. Topography is composed of mountains, plain land, oceans, deserts, minerals, metals, deposited region etc. of which density is different. Mountains are mass surpluses region where as oceans are mass deficient area which causes gravity to vary.

4.2 Variation of gravity due to position (latitude) of a point:

The variation in the gravity is also experienced due to position (Latitude) of a point or region. The value of gravity (magnitude) varies as the latitude of points changes. The value of gravity calculated at a point situated at certain latitude is termed as the normal gravity. The gravity value is higher in polar region in comparison to gravity value in equatorial region.

The mathematical formula to derive of gravity adopted by IUGG in 1967 is given by

$$\gamma_0 = 978.031(1+0.0053024\sin^2\Phi - 0.0000059\sin^2 2\Phi) \text{ gal}$$

γ_0 = gravity at any point on the surface of the Earth

Φ = Latitude of the point

At equator $\Phi = 0^0$ $\gamma_a = 978.031$ gal

At pole $\Phi = 90^0$ $\gamma_b = 978.031+5.186 =$ 83.217 gal

4.3 Variation of gravity due to elevation of a point:

The variation in the gravity is also affected by elevation of the point. Variation of gravity due to elevation of a point can be estimated as follows. The value of gravity varies with height i.e. the distance of a point from the center of the Earth. The vertical gradient of gravity **δg/δh**is approximated by

$$\frac{\delta g}{\delta h} = \frac{2\gamma}{R} = \frac{2GM}{R3}$$

γ = mean gravity,

R = Mean radius of the Earth

δg/δh= -0.3086 where **h** is in meter and **g** is in mgal.

5. GRAVITY WORKS IN NEPAL

Gravity base was established in the country during 1981-84 British Military Survey.

The gravity reference system: ISGN 1971

Instruments used: LaCoste Romberg Model G gravimeter

Number of Stations observed: 21 out of 36 (MODUK)

Fundamental gravity base at Tribhuvan International Airport (TIA), Kathmandu was established designated as KATHMANDU J. IN 1981 gravity transfer from ISGN71 station BANGKOK to Kathmandu was made. At this time 45 gravity stations were surveyed at 35 different locations, mostly at the airports and accessible places around the country.

KATHMANDU J = 978661.22+-0.047 mgal

Total 375 gravity detail stations were established till now which includes both gravity survey from WNTMP and ENTMP.

5.1 First order gravity network of Nepal:

Number of first order gravity points: 36 points, 25 points in airport and airstrips and remaining 11 in government buildings, army barracks, and police stations.

5.2 Absolute gravity observation:

The Fundamental Absolute Gravity Stations (FAGS) was established in 1991 March/April at Nagarkot in assistance with above three organizations.

Purpose of establishing Absolute gravity station were

- To establish a reference datum for the local gravity network in Nepal.
- To establish points that may be remeasured to reveal changes of elevation in future years.

The absolute gravity value measured at Nagarkot

(FAGS -1). The corrected value of the FAGS -1 indoor point at ground level is 978494834.7 +-6.7microgal.

The gravity gradient at floor level (0 to 0.43m) was 4.4194microgal/cm.

Relative ties were made to three GPS points: Nagarkot, Kathmandu airport, and Simara airport. The relative differences from FAGS-1 to these points are as follows:

Nagarkot FAGS-1	**978494834.7+-6.7 mgal**
Nagarkot GPS	**-0.691+-0.002 mgal**
KATHMANDU J	**+166.469+-0.005 mgal**
SIMARA J	**+368.599 +- 0.017 mgal**
SIMARA GPS	**+368.706 +- 0.013 mgal**

The ties were undertaken using a pair of Model D LaCoste Romberg gravimeters. For Nagarkot GPS point which is less than 10m from the brick building where GPS measurements were made.

The absolute accuracy of the 1991 measurements is +- 6 microgals or approximately +- 1.5cm in elevation.

5.3 Eastern and Western Nepal Topographic Mapping Project (ENTMP & WNTMP) - Phase I

Gravity survey was done during WNTMP (Western Nepal Topographic Mapping Project) and ENTMP (Eastern Nepal Topographic Mapping Project).

During WNTMP, gravity observations were done in GPS points. Gravity values were observed in 56 stations and gravity value of 43 stations which are specified as old British and other points exists.

During ENTMP, gravity observations were done in GPS points. Gravity values were observed in 43 stations and gravity value of 95 stations which are specified as other gravity stations and 10 stations specified as other gravity stations exist.

The numbering of stations, latitude, longitude, ellipsoidal height, orthometric height, and gravity values can be found in WNTMP and ENTMP reports.

5.4 Airborne Gravimetry in Nepal

An airborne gravity survey of Nepal was carried out December 2010 in cooperation between DTU-Space, Survey Department of Nepal, and National Intelligence Agency- NGA USA.

Primary goals:

- To provide data for a new national geoid model, which will in turn support GPS surveying and national geodetic infrastructure.
- To provide gravity information for future global gravity field EGM 2020.

Secondary goals:

- To provide training of physical geodesy to Nepalese geodesists.
- To make an improved estimate of the geoid at Sagarmatha allowing an independent height determination by GPS.
- To collect airborne data which will provide an independent validation of GOCE and EGM08 in most mountainous part of the Earth.

5.5 Airborne gravity survey details:

Beech King Air aircraft by Danish Company COWI was used. 57 flightlines @ spacing of 6 nautical miles for 13 flight days during Dec 4-17, 2010 made.

Coverage of border regions of the country towards India and China was not possible. The survey operations were a major challenges due to excessive jet streams at altitude as well as occasional excessive mountains waves. Even a reflight attempts did not provide useful data due to persistent wind effects of Annapurna and Mustang valley regions. Surface gravimetry data of those regions should be used. The reported results appeared accurate to few mgal – despite the large 400 mgal above range of gravity anomaly changes from Indian plains to Tibetan plateau.

Instrument installed on aircraft: Lacoste Romberg S –type gravimeter which was controlled by Ultrasys Control System with a number of GPS receivers onboard the aircraft and on ground providing the necessary kinematic positioning.

Checkan –AM gravimeter alongside LCR gravimeter with the special goal to augment the LCR gravity data in expected turbulent conditions.

The airborne gravity reference point at Kathmandu airport tied to NOAA absolute gravity measurement at Survey Department and at Geodetic Observatory Nagarkot. The actual gravity values at altitude differ by 1000's of mgals from reference values due to the height changes and Eotvos corrections.

The overall accuracy of airborne gravity data collected was 3.3 mgal.

The preliminary geoid was computed and the accuracy of computed geoid was likely at the 10-20cm in the interior of Nepal but higher near the border due to lack of data in China and India. This preliminary geoid was compared to eight reasonable GPS-levelling precise data in the Kathmandu valley. It is seen that a significant geoid improvement has been obtained relative to the EGM-08 geoid.

The computed height of Sagarmatha which confirms the official Survey Department height 8848 m within range of +- 1m, based on an ellipsoid height of the snow summit of 8821.40 +- 0.03m.

6. GEOID DETERMINATION:

Following are the methods of geoid determination

- Astro-geodetic Method
- Gravimetric Method
- Geopotential model
- Satellite altimetry
- GPS or Doppler with levelling
- Analysis of low orbitals satellite
- Collocations (least square collocation)

Gravimetric method of geoid determination is of main importance and explained below.

6.1 Gravimetric method of geoid determination:

Gravity anomalies of uniformly distributed points over the terrain based on both distance and height of the topography of the earth can be used to determine the geoid of that area. Gravity observation is carried out on those well distributed points using gravimeter which is called surface gravity. Surface observed gravity values are needed to be reduced to the level of geoid (MSL Level) by applying:

- Free air correction
- Bouger Plate reduction
- Refined (Complete) Bouger Reduction/ Terrain correction

Then the reduced gravity value is now equivalent to gravity value at geoid. The gravity anomaly can then be calculated as follows:

$$\Delta g = g - \gamma_0$$

Δg = gravity anomaly

g (reduced) = reduced gravity value at the level of the geoid from the observed gravity

γ_0 = Normal gravity/ theoretical value of gravity at that latitude of point.

The gravity anomaly thus obtained is then used to determine geoidal separation (N) by Stoke's integral:

$$N = \frac{R}{4\pi\gamma}\iint \Delta g\, S(\Psi)\, d\sigma$$

R = Mean radius of the earth

γ = Mean normal gravity

dσ = Surface element

S(Ψ) is a called Stoke's formula and given by

$$S(\Psi) = 1 + COSEC(\Psi/2) - 6SIN(\Psi/2) - 5COS(\Psi) - COS(\Psi)\ln[SIN(\Psi/2) + SIN^2(\Psi/2)]$$

7. CONCLUSION:

The geoid from geopotential model is of global level geoid which could not be directly used for local level geoidal undulations determination. Thus we need to refine this global level geoid through airborne gravimetry and surface gravimetry observation of our terrain resulting reliable local level geoid. Gravimetric method of geoid determination uses the gravity anomalies from airborne and surface gravimetry both and provides geoidal undulation using Stoke's integral. There has been planning for the purpose of refinement of geoid around Sagarmatha regions for the computation of orthometric elevation of Sagarmatha from GPS heightening and geoidal undulations utilizing this approach. To refine the geoid around Sagarmatha, we need dense/extra surface gravimetry data which will improve the past geoid computed from 2010 airborne gravity geoid. The surface gravimetry observations were planned to take on 5km*5km grids, around that region.

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9.	Region maps (Nepali)	1:500 000	Whole Nepal	5	50
10.	Nepal (English)	1:500 000	Whole Nepal	3	50
11.	Nepal Map (Nepali)	1:1000 000	Nepal	1	50
12.	Nepal Map (Nepali)	1:2000 000	Nepal	1	15
13.	Nepal Map (English)	1:1000 000	Nepal	1	50
14.	Nepal Map (English)	1:2000 000	Nepal	1	15
15.	Physiographic Map	1:2000 000	Nepal	1	15
16.	Photo Map			1	150
17.	Wall Map (loosesheet)		Nepal	1 set	50
18.	VDC/Municipality Maps (Colour)		Whole Nepal	4181	50
19	VDC/Municipality Maps A4 Size		Whole Nepal	4181	5
20.	VDC/Municipality Maps A3 Size		Whole Nepal	4181	10
21.	Orthophoto Map		Urban Area (1:5000) and Semi Urban Area (1:10000)	-	1 000
22.	Outlined Administrative Map A4 size		Nepal	1	5

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