Deployment of differential global positioning system in regional gravity surveys

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This note presents the deployment of differential global positioning system in regional gravity surveys. The high-precision three-dimensional (latitude, longitude and elevation) real-time global satellite navigation system data play a key role in the processing of gravity data in the form of 'elevation correction'. A suitable method has been developed to maintain accuracy in the elevation data and subsequently the gravity observations. The data acquired during this survey are used to map the obvious geological province areas in the northwestern part of India and for the preparation of Bouguer gravity contour map of India with 1 mGal interval under National Geophysical Mapping of the Geological Survey of India in a phased manner.

This note describes the deployment of state-of-the-art-technology in differential global positioning system (DGPS) in regional gravity surveys and the measurement of elevation of the gravity stations. In gravity surveys, the gravity station requires accurate position (latitude and longitude) and elevation for processing the gravity data. Earlier, the elevation of gravity stations was determined by conventional method of spirit level, dumpy level and auto-levelling techniques. At present, satellite-based technology is available for minimum closing error and cost of the survey. The satellite-based navigation system, i.e. DGPS provides more accurate horizontal and vertical position and provides accurate elevation in advance for processing of gravity data.

Geodetic reference system

The earth can be equated to a sphere/spheroid/ellipsoid depending on the physical problem being dealt with. But in gravity prospecting, even small changes in elevation can distort the earth's gravity field. So proper care has to be taken to overcome the above problem[1]. The equipotential surface of the earth's gravity field with respect to Mean Sea Level (MSL) is called the 'geoid' (*N*). The geoidal surface is an irregular surface as any other equipotential surface of the earth's gravity field. The mathematical surface that best fits the geoid is called 'ellipsoid' (*h*) (Figure 1). The ellipsoid lies below the geoidal level in elevated regions and above the MSL over oceans. The undulation *N* of the geoid is the distance to the geoid from the ellipsoid surface[2].

In the present study, the orthometric height was computed using the EGM-96 model. The determination of the geoid undulation *N* mainly depends on the accurate determination of the orthometric and geometric (ellipsoidal-World Geodetic System 1984; WGS84) heights of the observations[1]. It also depends on the number of available points, their distribution in the area and the smoothness of the geoid surface in the region.

Importance of accuracy in elevation for gravity data processing

The Geological Survey of India (GSI) has undertaken the National Geophysical Mapping (NGPM) throughout the country in a phased manner. Priority is being given to obvious geological province (OGP) areas in India. These surveys are being carried out by occupying one gravity station every 2.5 sq. km. Accuracy in the elevation of these gravity stations is an essential input for processing of gravity data/calculating the Bouguer gravity anomalies. The DGPS technology provides the required accuracy in positioning as well as elevation of the gravity stations. In the DGPS survey, two different modes are available: real time kinematic (RTK) and post-processing kinematic (PPK) respectively. In both the modes, accuracy in elevation is of the order of centimetres. The maximum baseline length is 10 and 80 km in the RTK and PPK modes respectively[3], by which a larger area can be covered at a stretch in PPK mode operation. In general, the local datum is available for most of the advanced countries, but in India we are still using WGS84 because local datum is yet to be established. WGS84 datum is compatible/convertible with any other established geoid model. This implies that a single point can have more

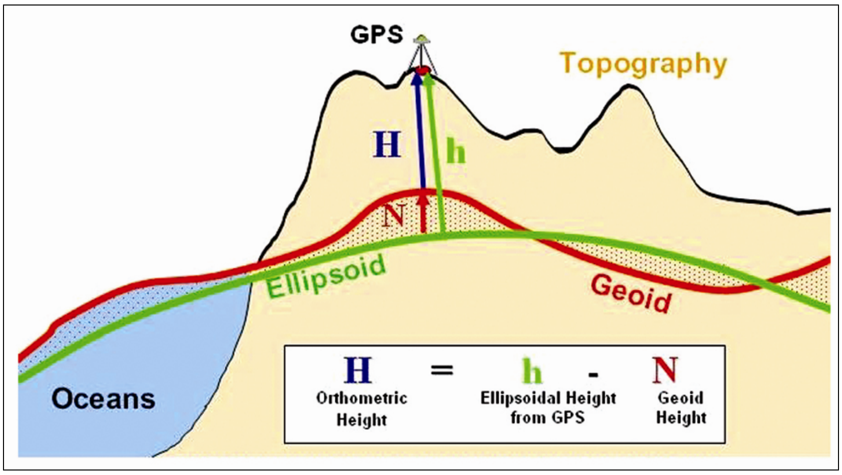

Figure 1. Geoid–ellipsoid relationships. In general, the orthometric height (*H*) can be calculated using the formula $H = h - N$, where *h* is the ellipsoidal height from the global positioning system (GPS) and *N* is the geoid height. After ref. 2.

than one set of coordinates by virtue of the effect of the geodetic datum used (Table 1)[4].

It is important to ensure that the correct datum and ellipsoid parameters are applied in gravity data reduction. Geographic coordinates in some countries can differ from WGS84 to their own established geoid model by up to 1 km. This can be significant in computing the gravity data. Therefore, it is suggested that WGS84 coordinates should invariably be used for gravity data processing till one's own datum is established.

Method for establishment of DGPS control network

An appreciable triangulation method has been developed and followed in the present study for establishment of control network. DGPS is a system consisting of a base receiver and one or more rover receivers. The GPS base station should keep at known point (Bench Mark – BM) in continuous recording mode. The observations were made in the field using moving receiver caller rover. The DGPS raw data has been processed using suitable software (Leica Geo 8.3) after downloading the data sets from receivers (base and rover). The control networks are established by static method by keeping the one GPS receiver at known position for 45 min in continuous mode. The baseline length (distance between base and rover) of adjacent of the triangle is maintained at 10–20 km with 45 min data-logging interval. The rover can be moved with the vehicle to make the observations (Figure 2).

The present DGPS survey has been carried out in and around Bijaynagar, Bhilwara district, Rajasthan, India as a part of the national regional gravity surveys of the GSI for measuring accurate elevation of the gravity observations. Initially, the DGPS base station was kept in continuous recording mode at a known location (Magras village) and the rover was moved to another location (milk dairy at Ghorakheda). This arrangement was continuous recording for 45 min for forming the triangle for 45 min. After logging data, the rover was moved to another place about 8 km away by keeping the base station at the same place to form the triangle (Figure 2). The corners of the triangle can be treated as control points for future surveys. In the present study CG-5 gravimeter (Scintrex-Canada make) was used for acquiring the quality of gravity data. High-accuracy DGPS receivers are essential to record precise elevation data (Figure 3) and this technology has enhanced the target coverage in regional gravity surveys.

As the study area has undulating terrain, it was felt necessary to conduct the survey in PPK mode. However, few gravity stations were re-occupied by RTK mode also (Table 2). The RTK mode is more suitable for areas which are free from undulations as well as obstacles, i.e. mounts and hill ranges. The results obtained from RTK mode were quite encouraging and acceptable, but had limitations up to the baseline length <10 km and RTK mode is best suitable for detailed studies. In the regional gravity surveys, majority of the area was covered by PPK mode of operation.

Table 1. Coordinates in two different reference systems[4]

Country	Latitude	Longitude	Altitude	Reference system
Brazil	19°45′43.3491″	48°06′05.6732″	754.1502	WGS84
	19°45′41.6527″	48°06′04.0636″	763.2821	SAD69
	35°10′29.0200″	59°15′46.6400″	45.9100	WGS84
Argentina	35°10′27.3088″	59°15′44.4610″	31.9277	SAD69
	5°16′42.0800″	61°08′04.8600″	1254.5400	WGS84
Venezuela	5°16′43.2237″	61°08′03.0228″	1271.0418	SAD69

Table 2. Differential global positioning system (DGPS) accuracy with real time kinematic (RTK) and post-processing kinematic (PPK) modes at a field camp, Bhilwara district, Rajasthan (A. V. Kulkarni *et al.*, unpublished)

Station ID	Latitude (N)	Longitude (E)	Elevation (m) RTK mode	Elevation (m) PPK mode	Difference in elevation (m)
GP-2	25°43′19.00″	74°37′17.00″	433.6460	433.5000	0.1460
GP-11	25°41′45.15″	74°37′22.41″	433.0018	432.8787	0.1231
GP-12	25°41′39.81″	74°38′27.16″	424.8491	425.0604	–0.2113
Ghorakheda	25°40′57.18″	74°37′46.83″	430.6242	430.8259	–0.2017

Significance of DGPS in gravity survey

In gravity processing, gravity station requires accurate position (latitude and longitude) and elevation for applying latitude and elevation corrections respectively. The free-air and Bouguer corrections are dependent on accuracy of the elevation of the gravity station and are applied simultaneously for computing Bouguer anomaly. The Bouguer and free-air gravity anomalies are calculated by the simple expression: $(0.3086–0.04189d) \times h$, where h is the elevation of the gravity station and d is the density of topographic masses above MSL, which is taken as 2.67 g/cm^3 in the present case. The difference in the geoid and spheroid surfaces can be as large as ~100 m and this generates a maximum indirect effect of ~30 mGal in free air or ~20 mGal in Bouguer[4]. Considering the above, the elevation of gravity stations will play a key role in the calculation of Bouguer anomalies. Hence, in the present study few of the gravity stations repeatedly checked for quality of data and maintain accuracy (Table 3). In the present study, the high-resolution Bouguer gravity survey (Figure 4) brought out a prominent elliptical-shaped NE–SW disposed high gravity with two distinct closures which are separated by a moderate gravity contour. After applying the different filters to the gravity data, the high gravity closure can be interpreted as deep-seated tectonic contact/lineaments or due to the presence of high-density material at the lower crustal level. The coordinates of the map are not given due to data security. The method deployed in regional gravity surveys is useful and fulfils the requirement of providing accuracy in elevation data.

Conclusion

This note highlights the efficacy of DGPS technology in regional gravity surveys and the accurate values of latitude,

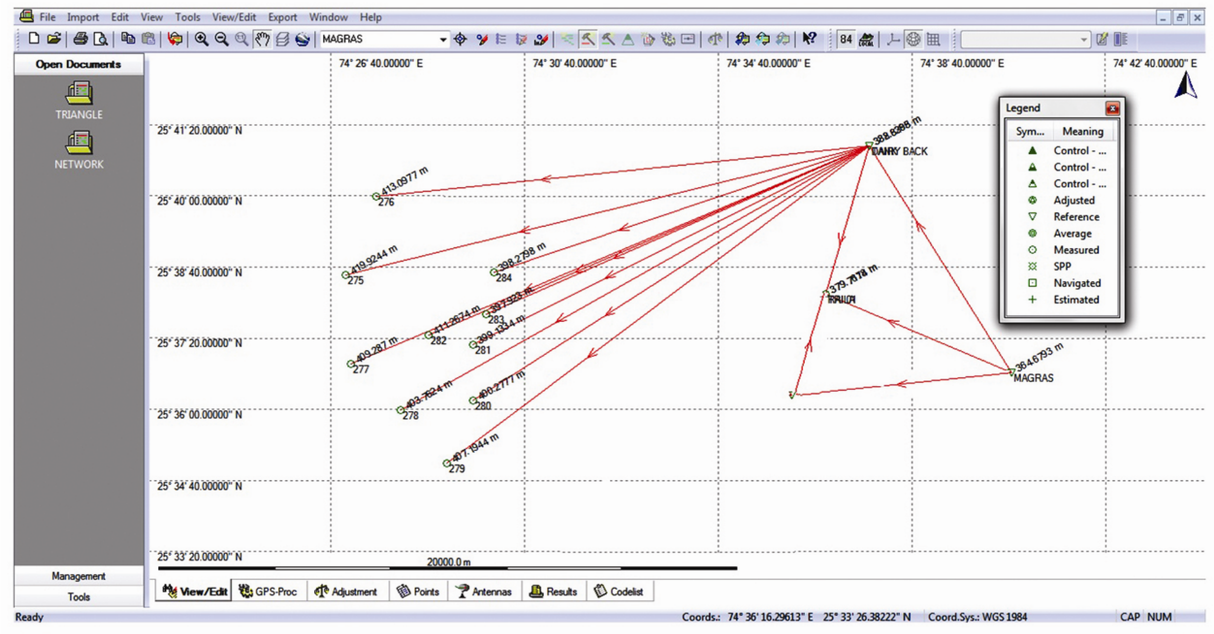

Figure 2. Establishment of DGPS control network points using triangulation method.

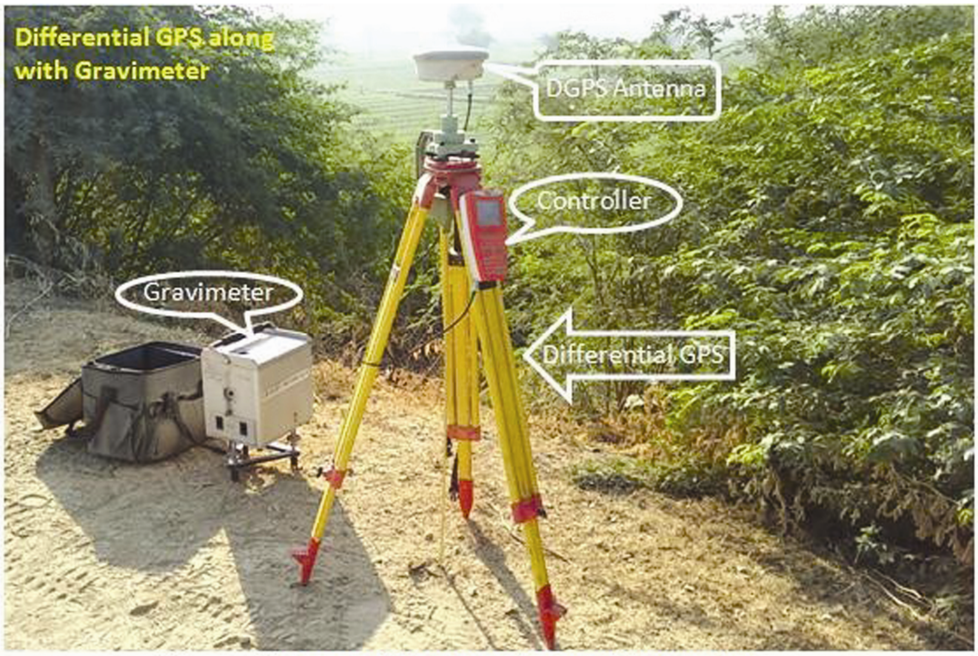

Figure 3. Differential GPS (DGPS) along with gravimeter.

Table 3. Repetition of the few elevation values with DGPS (A. V. Kulkarni *et al.*, unpublished)

Station ID	Latitude (N)	Longitude (E)	Day 1 Elevation (m)	Day 2 Elevation (m)	Difference (m)
144	25°35′12.20″	74°35′14.65″	442.8150	442.7712	+0.0438
285	25°35′52.78″	74°27′11.44″	449.8443	449.8106	+0.0337
510	25°42′11.65″	74°03′40.56″	586.4900	586.7076	–0.2176
515	25°40′15.96″	74°01′38.30″	627.7966	627.4914	+0.3052
518	25°38′44.5″	74°00′17.09″	625.0219	625.2291	–0.2072
614	25°38′52.19″	74°09′46.8″	557.5230	557.4300	+0.0930

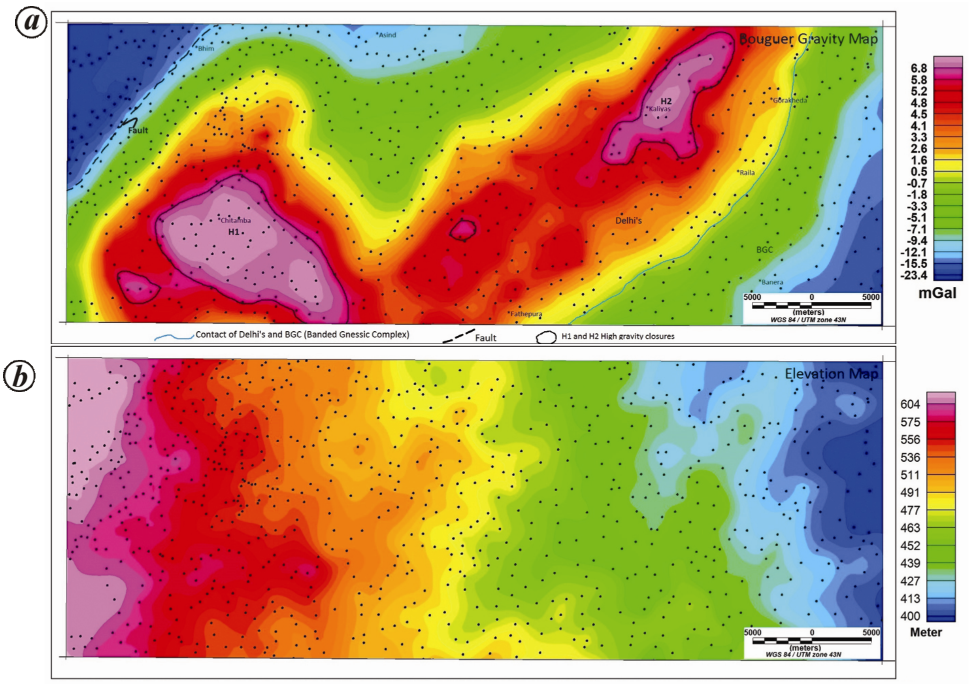

Figure 4. (***a***) Bouguer gravity and (***b***) elevation contour maps of the study area. Hatched line indicates the interpreted fault and blue line represents the contact of Delhi Super Group and Banded Gneissic Complex.

longitude and elevation were used in the processing of the gravity data. The use of DGPS technology has also enhanced the quality of gravity results which are essential for conceptual study of subsurface features. In the present study area, several regional features inferred from regional gravity surveys were reported by earlier workers. The present close interval gravity survey delineated the small gravity features like (H1 and H2), which are more significant for future mineral target areas. It is also inferred a fault (F1) feature extended to several kilometers and it is not reported by earlier workers.

1. National Imagery and Mapping Agency, *World Geodetic System 1984 (WGS-84). Its Definition and Relationships with Local Geodetic Systems*, NIMA, Bethesda, 2000, 3rd edn.
2. Radhakrishna Murthy, I. V., *Gravity and Magnetic Methods in Exploration Geophysics*, Memoir No. 48, Geological Society of India, 1998.
3. Chen, T., Ferguson, J. and Aiken, C., *Leading Edge*, 2005, **24**, 702–704.
4. Derek Fairhead, J. and Green, C. M., *Leading Edge*, 2003, **22**(10), 954–959.

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