GEODETIC NETWORK AND GEOID MODEL OF MONGOLIA

D.Munkhtsetseg

Senior specialist in Geodesy, Geodesy and Cartography division,
Administration of Land affairs, construction, geodesy and cartography
Ulaanbaatar-211238, Chingeltei district, Barilgachdiin talbai 3, MONGOLIA
d_munkhtsetseg@yahoo.com

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ABSTRACT:

This paper outlines the geodetic network, transformation parameters and Geoid height model of the Mongolia. State, local and GPS coordinate systems which have been used in Mongolia since the 1950s. The primary GPS network of Mongolia was established in 1997-1998, adjustment of this network was performed in cooperation with National Land Survey /NLS/ of Sweden in 2000. 2D and 3D transformation parameter between State and GPS coordinate system, local and GPS coordinate system were calculated with an accuracy of 1-2 m, 30 cm accordingly. The geoid height model was produced based on the 2004-5 airborne gravity survey, surface gravimetry from various sources, and detailed digital terrain models from satellite radar interferometry (SRTM). Transformation parameters and geoid height model are used in different organizations to convert spatial database and digital data produced in state or local coordinate systems into GPS coordinate system.

1. INTRODUCTION

Three different coordinate systems have been used in Mongolia since 1950s are State, Local and GPS. The State coordinate system has been used to produce topographical maps covering whole country, while local coordinate system is used for creating Ulaanbaatar city map, and GPS coordinate system is used exclusively for cadastral mapping. Five different Geodetic networks have been established in Mongolia; Triangulation, Polygonometry, Gravity, Leveling /height/ and GPS networks. Triangulation, Gravity and Leveling networks were established in cooperation with former Soviet Union Red Army since 1950s. More than 25,000 triangulation network points, 141 gravity and 3,000 leveling network benchmarks were used to produce topographical maps with scale 1:100,000, which is largest scale map covering whole country.

Mongolian GPS network - Monref97 was established in 1997-1998. This primary GPS network has 34 points, which also exists in higher order triangulation and gravity network points.
The Mongolian Government started land privatization from 2003 and cadastral maps were produced for this purpose based on GPS coordinate system.

Because of three different coordinate systems, users were having difficulties with digital data production. In order to ease data exchange, to implement GPS technology and satellite imagery in all areas, and to improve cooperation between different organizations the Administration of Land affairs, geodesy and cartography /ALAGaC/, a Government agency, has decided to use only GPS coordinate system in Mongolia.

2D and 3D transformation parameters have been calculated to convert topographical maps and other spatial data produced in State and local coordinates systems into GPS coordinate system. In 2000-2003 when calculated transformation parameter used only Monref97 points' data. 3-4 m accuracy was achieved.

After densification of Monref97 more data were used, but accuracy was not better than 1-2 m for zone calculation of transformation parameter. The Mongolian Mining authority calculated transformation parameter between State and GPS coordinate system in 2007 with accuracy of 1-2 m with assistance from World Bank project to convert mining cadastral coordinate system into GPS coordinate system. Modcon application has been developed for conversion between two coordinate systems. 2D transformation parameter between State and GPS coordinate system with accuracy 1-2m used to convert 1:100,000 scale digital topographic maps into GPS coordinate system, which have been updated using satellite images. Transformation parameter between local and GPS coordinate systems was calculated with 0.30m accuracy which exceeds requirement stated in the Mongolian law on Cadastral mapping and land registry. Without geoidal height model only 2D GPS coordinates were used. Therefore, Mongolian government implemented airborne gravity survey project in 2004-2005 and Geoidal height model was produced with accuracy of 15-20 cm for whole country and 2-5 cm in Ulaanbaatar city.

The project was financed by USA Government and implemented by Danish, Norwegian and Mongolian specialists.

2. GEODETIC NETWORK AND COORDINATE SYSTEMS USED IN MONGOLIA

2.1. State coordinate system

The Mongolian triangulation /Figure1/, gravity /Figure2/ and leveling /Figure3/ networks were connected to Russian higher order /class/ triangulation, gravity and leveling network points. Network measurement and adjustment were carried out by Russian specialists in 1940-1960.
The height system of Mongolia is at Baltic sea level.
Topographic maps with scale 1:25000-1:1000000 have been produced in state coordinate system connecting to the Mongolian triangulation and leveling network points since

* Corresponding author. d_munkhtsetseg@yahoo.com

1960s. This system has following geodetic definition:

- Datum: Pulkovo1942
- Ellipsoid: Krassovsky
- Projection: Gauss-Kruger
  - Longitude of origin: 87,93,99,105,111,117
  - Latitude of origin: 0
  - False Easting: 500000.0
  - False Northing: 0
  - Scale factor: 1.0
- Height system: Baltic sea level

All above mentioned maps were produced by analogue methods and they are paper maps only.
In 2004-2007 all 1209 sheets of 1:100000, over 600 sheets of 1:25000 scale topographical maps were digitized.

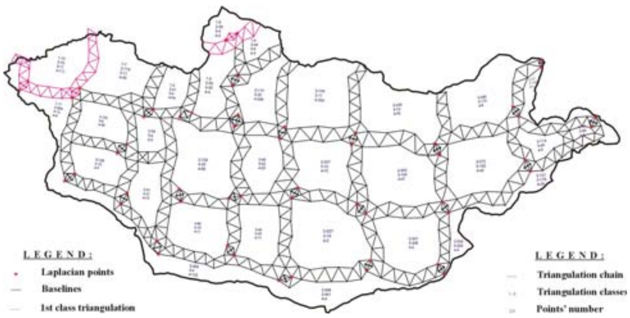

Figure 1 - Triangulation network of Mongolia

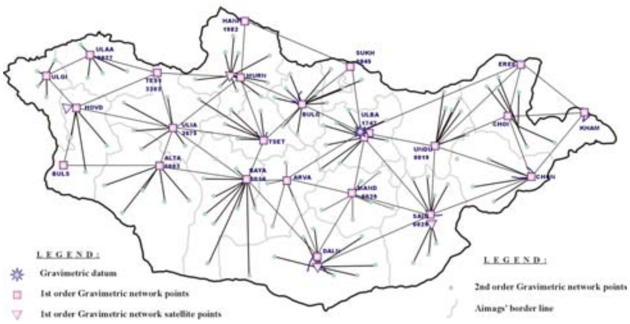

Figure 2 - Gravity network of Mongolia

Figure 3 - Levelling network of Mongolia

2.2. Local coordinate system

The triangulation network /Figure 4/ of capital city was established in 1954 in local coordinate system. The network consists of 56 points. Based on this triangulation network poligonometry network with about 1000 points was established.
UB city's 1:500-1:10000 scale topographic maps were produced since 1970s in local coordinate system, which does not have any geodetic definition: no ellipsoid, no projection and no connection to the state coordinate system.
The origin point of the local coordinate system is already destroyed.
UB city's leveling and gravity network was established in 2003 connecting to higher order leveling and gravity network points.

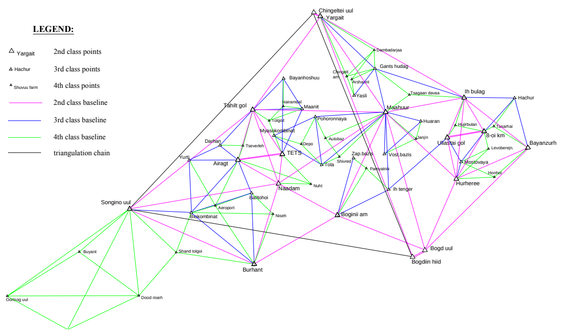

Figure 4 – UB city's triangulation network

2.3. GPS network and GPS coordinate system

Mongolian GPS network - Monref97 /Figure-5/ was established in 1997-1998, which has been densified in 2003-2006 as four different sub-networks for Agricilture, Western, Hangay and Gobi-Eastern regions. /Figure-6/

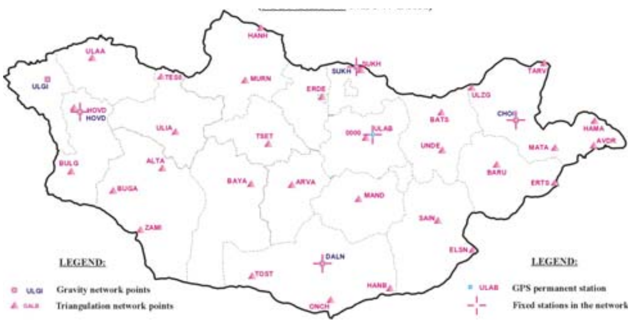

Figure 5 - GPS network of Mongolia /Monref97/

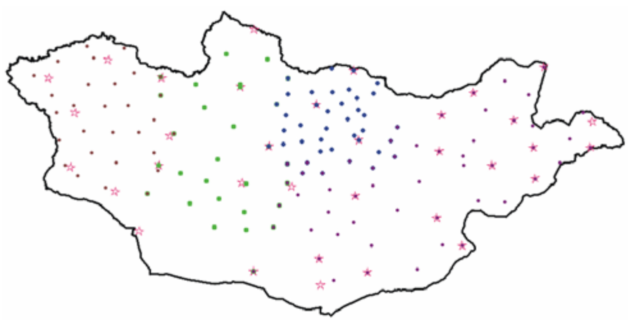

Figure 6 – Densification of Monref97

Ulaanbaatar city's GPS network /Figure-7/ was established in 2002 as a densification of Monref97, which consists of 38 points.

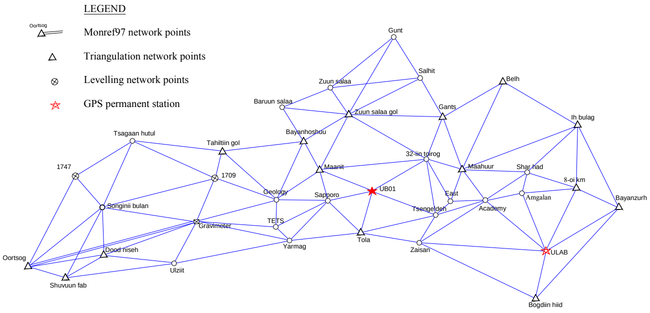

Figure 7 - GPS network of Ulaanbaatar city

There are about 1500 points of GPS network /Monref97/. Existing triangulation, gravity and leveling network points were occupied for GPS network establishment. 24 hours observations carried out on the primary and secondary order GPS network points. The primary and secondary order GPS network adjustment was done in cooperation with National Land Survey /NLS/ of Sweden within SIDA project. RMS error of GPS network is about 10-20 mm. IRKT, BJFS, LHAS, NVSK, ULAB - IGS stations' data and their coordinates were used as control points in GPS network adjustment in Bernese 5.0.

Mongolia-China border line was clarified in 2002-2003 by the Mongolian and Chinese government. Within this project 6-18 hours GPS observation was carried out on 60 triangulation and 12 levelling network points /Figure-8/ in Mongolia as well as in China.

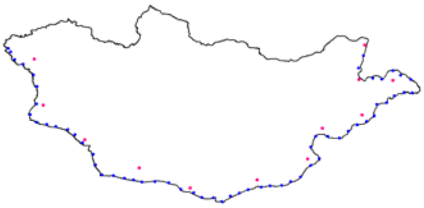

Figure 8 - GPS network established along Mongolian-China border line

Mongolian and Russian geodetic organizations have been carried out 72 hour GPS observation on Mongolian and Russian levelling network's junction points /Figure-9/ in 2002.

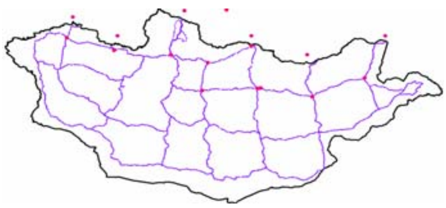

Figure 9 - GPS observation carried out in cooperation with Russian Geodetic organization

Cadastral maps with scale 1:1000, 1:2000, 1:25000 for land privatization in Ulaanbaatar and other province, subprovince centers and agriculture regions were produced in GPS coordinate system since 2002.

3. TRANSFORMATION BETWEEN COORDINATE SYSTEMS

ALAGaC in cooperation with NLS of Sweden calculated transformation parameter between State and GPS coordinate systems as well as between Local and GPS coordinate systems in 2000-2003.

3.1. Transformation between State and GPS coordinate systems

GPS network, which consists of 20 triangulation points, was established in 2007 by the Mongolian Mining authority within World bank project to increase accuracy of transformation parameter between Pulkovo1942 and WGS84 coordinate system. 1-2 m accuracy /Table 1/ transformation parameter between Pulkovo1942 and WGS84 coordinate system has been calculated using 130 points' data /Figure 10/.

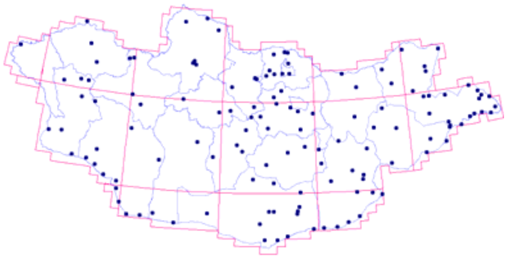

Figure 10 – Points used to calculate transformation parameter between State and GPS coordinate system

Table 1. Transformation parameter accuracy for zone calculation

No	Data	Zone No				
		46	47	48	49	50
Transformation parameters calculated in 2005						
1.	Used points for transformation	7	8	28	6	8
2.	RMS /m/	0,95	2,59	1,07	1,79	1,63
3.	Weighted mean /m/	1,45	3,67	1,14	3,10	2,31
Transformation parameters calculated in 2008						
1.	Used points	13	18	40	23	21
2.	RMS /m/	2,33	2,16	1,44	1,83	1,53
3.	Weighted mean /m/	2,80	2,38	1,52	2,01	1,67

3.2. Transformation between Local and GPS coordinate systems

UB city's 15 triangulation network points' data /Figure 11/ were used for the calculation of transformation parameter between local and GPS coordinate system.

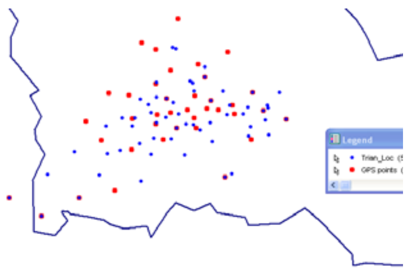

Figure 11 – Ulaanbaatar city's triangulation and GPS network points

The transformation parameter was achieved with accuracy of 30 cm, which is not enough for 1:500 scale topographic map conversion into GPS coordinate system. So this accuracy should be improved measuring by GPS on more triangulation points of Ulaanbaatar city.

4. GEOID HEIGHT MODEL OF MONGOLIA

4.1. Airborne gravity survey

A complete airborne gravity survey of Mongolia was carried out in two fall campaigns 2004-5 by the Danish National Space Center, in cooperation with ALAGaC (Mongolian Administration of Land Affairs, Geodesy and Carthography), MonMap, NGA (USA) and the University of Bergen, Norway.
The airborne gravity survey (Figure 12) was carried out using an Air Greenland Twin Otter in 2004, and a Cessna Caravan aircraft in 2005. A total of 420 flight-hours were flown at a track spacing of 10 nautical miles. Because of the rough topography of Mongolia, flight elevations of individual flight lines varied between 2100 m and 4800 m, necessitating a formal downward continuation.

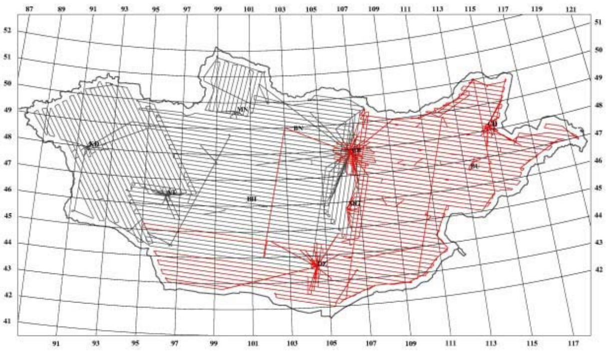

Figure 12 – Airborne gravity survey lines of the 2004-5 survey, showing the Western Mongolia 2004 flights in black, and the Eastern Mongolia 2005 flights in red.

The primary purpose of the airborne survey was to provide data for global earth gravity models (EGM06), with the additional purpose to generate a new geoid of Mongolia, as part of the ongoing GPS modernization of the geodetic infrastructure, as well as training Mongolian scientists in the computation and maintenance of geoids fitted to GPS/leveling.
The estimated r.m.s. accuracy of the airborne gravity free-air anomaly data, as judged from cross-over adjustments (cf. Table 2), was 2.2 and 2.4 mGal for 2004 and 2005, respectively, indicating a slightly better performance over the mountains with the Twin Otter aircraft compared to the Cessna Caravan. No cross-over adjustment was performed in the final data set.

Table 2. Statistics of the cross-over errors of the airborne gravity survey of Mongolia, without downward continuation.

Year	No of x-ings	Max diff.	RMS diff.	RMS error
2004	201	9.5	3.1	2.2
2005	206	10.0	3.4	2.4

Taking account the harmonic continuation effect, continuing the airborne data to a common level of 3000 m, as outlined below, the r.m.s. error estimate from the cross-over analysis decrease to an average value of 2.2 mGal for the entire survey. With the inherent filtering applied in the airborne gravity processing, the along-track resolution is around 6 km, depending on the track (ground speeds varied significantly on tracks as a function of wind).

Figure 13 shows the airborne gravity anomalies. The correlation of free-air anomalies to topography is evident.

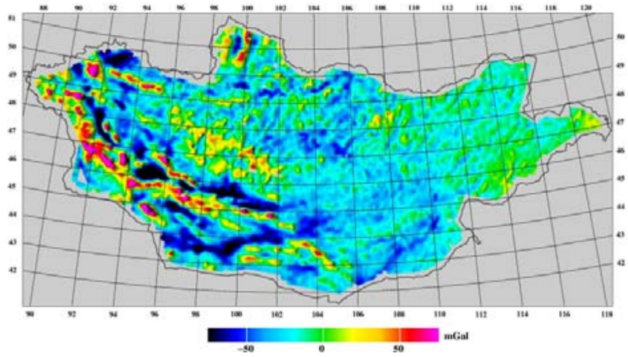

Figure 13 - Airborne free-air anomalies at altitude from airborne gravity survey. Colour scale is from –75 to 75 mGal.

4.2. Downward continuation of airborne data and merging with surface data

All processing has been done using the remove-restore method, where the gravity anomalies have been split into three terms

$$\Delta g = \Delta g_1 + \Delta g_2 + \Delta g_3$$

where the first term is a spherical harmonic reference field, the second term the terrain effects, and the third part the residual gravity.

For the spherical harmonic reference field a composite model of the GGM02S satellite-only field from GRACE (Tapley et al., 2004) and EGM96 (Lemoine et al., 1996) has been used. The GGM02S and EGM96 have been merged, so that GRACE data are used for harmonic degrees below 90, and EGM96 for harmonic degrees above 100, with a linear transition in between. A remove-restore method is used for terrain and global spherical harmonic reference models, with the residual gravity field signal downward continued by least-squares collocation, and the geoid and quasi-geoid computed by spherical Fourier methods. For reference field a GRACE and EGM96 combination field is used, and the geoid assessed using a subset of available GPS-leveling data, indicating that recent GRACE fields still have detectable problems in the harmonic wavelength band 50-100. The gravimetric geoid model /Figure 14/ computed refers to a global vertical datum; the Kronstadt Baltic Sea level data used in Mongolia shows a difference of more than one meter to the global datum, and therefore it is essential to fit the gravimetric geoid to local height data to obtain an operational geoid model for GPS use.

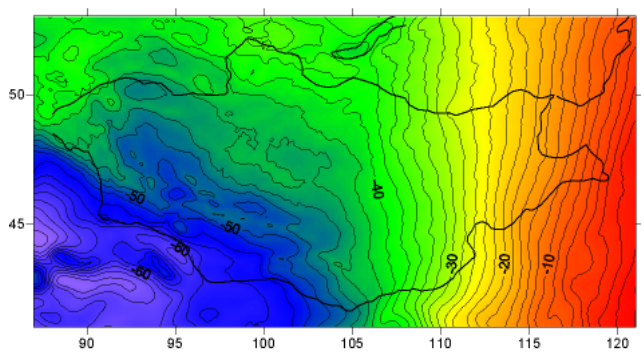

Figure 14 - Computed gravimetric quasigeoid of Mongolia.

For calculation of Mongolian geoid model were used following data:

- Airborne gravity data, taken in 2004-2005 within this

project
- Land gravity data, taken by Mongolian Geology authority since 1970's until 2005
- Mongolian gravity network points' data
- Absolute gravity measurement data collected in 2006-2007
- Grace satellite data
- EGM96 data
- Shuttle Radar Topographic Mission (SRTM) for Mongolia /1 sec, 3 sec/
- GPS network points' data
- Leveling network points' data

Table 3. Statistics of the gravity data reductions. Unit mGal.

Data	Mean	Std.dev.
Airborne gravity data	-17.1	25.9
Airborne minus ref. field	0.2	19.5
Airbore minus ref. and RTM	0.1	11.9
GETECH interpolated surface gravimetry data	9.0	19.0
Surface minus ref. and RTM	12.9	11.4

4.3. Geoid fit to GPS and leveling

The subsequent fitting of the geoid to GPS/levelling has been done at the 5 cm level, but major errors are apparent in some regions, likely due to a combination of geoid, levelling and GPS errors.

Gravimetric geoids needs to be fitted to local GPS-levelling data for operational GPS heighting use, to eliminate datum differences, residual long-wavelength geoid errors, as well as systematic errors in the levelling.

In Mongolia the basic height system is the Kronstadt datum, i.e. tied to the Baltic Sea level through the Russian leveling network. The first order leveling network is shown in Fig. 10. Recently a new national fundamental GPS network (MONREF97), tied to ITRF and processed by Bernese software, has been established. The MONREF network has been used to tie in leveling points by GPS. Quasi-geoid heights can be derived at such leveled GPS points by

$$\xi_{GPS} = h - H^*$$

where h is the ellipsoidal height and H* the normal height.

Table 4. Statistics of the quasigeoid fit to GPS. Unit meter.

58 GPS levelling points	Mean	Std.dev.
GPS quasigeoid (h – H)	-39.57	8.50
Quasigeoid difference $\zeta - \zeta_{GPS}$	1.14	0.20

It is seen from Table 3 that the Kronstadt system in Mongolia is apparently offset from the implicit global vertical system of the gravimetric geoid computation by 1.14 m. It is also seen that a fairly large standard deviation of 20 cm exists in the r.m.s. GPS-leveling comparison. This is likely to a large degree due to errors in the leveling, where some loops are known to have large misclosures.

The overall r.m.s. of the fitted geoid at the control points is 6.8 cm, and comparisons to local, independent GPS data indicate that the new GPS-fitted quasigeoid is accurate to 10 cm over much of Mongolia.

5. CONCLUSIONS

The Mongolian government approved a GPS coordinate system, Baltic sea level and UTM projection as an official and unique coordinate system in Mongolia on 28 January 2009 by resolution N28.

1-2 m accuracy transformation between State and GPS coordinate system was used to transfer 1:25000-1:100000 scale topographic maps into GPS coordinate system.

In 2004-5 Mongolia was successfully covered by an airborne gravity survey at 10 n.m. spacing, The overall survey accuracy, without any internal cross-over adjustment commonly used to improve error statistics, are estimated at 2.2 mGal, with essentially no bias relative to GRACE.

The accuracy estimates of the gravimetric quasigeoid, computed by a formal least squares estimation on a manageable subset of the available data, have similarly indicated formal geoid errors in the interior of Mongolia at the 10 cm level.

A Mongolian geoid height model was produced with 16 cm accuracy for whole country and 2-5 cm accuracy for Ulaanbaatar city, which has increased the productivity in the field surveying 2 times.

Transformation parameters and the Geoid height model are accessible from ALAGaC web page for the public.

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