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Вопросы обработки топографических карт среднего масштаба Монголии

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Аннотация. В статье рассмотрен вопрос, связанный с исправлением ошибок топографических карт среднего масштаба при переобразовании из системы координат СК-42 в систему WGS-84. Необходимость переобразования системы обусловлена постановлением правительства Монголии № 25 от 28 января 2009 года. Постановление предусматривает использование всемирной геодезической системы WGS-84, Балтийской системы высот и картографической проекции UTM для проведения геодезических съемочных работ и равития геодезических сетей на территории Монголии.

Ключевые слова: система координат, расчет проекции, способ Хельмерта, проекция, трансформирование

Research of processing for the medium scale topographic maps of Mongolia

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Abstract. Article Resolution #25 of the Government of Mongolia dated as of January 28, 2009 provides that the international geodesy coordinates of WGS-84 shall be used for geodesy measurement and processing, the Baltic sea structure shall be used for height network and the UTM reflex of the world horizontal merkater shall be used for large and medium scale topographic mapping respectively based on Articles 5.2.1 of the Geodesy and Mapping Law of Mongolia. There is a research rationale to adjust distortion generated from transferring procedure from TM projection of CS-42 (coordinate system 1942) reference system into UTM projection of WGS-84, an Earth-fixed terrestrial reference system.

Keywords*:* coordinate system, projection calculation, Helmert method*,* projection, transformation

Introduction

In order to create the topographic map that meets the resolution requirements, it is significant to choose a proper map projection fits for geographic features of Mongolia. Therefore, the research purpose is to develop a medium-scale topographic map meeting standard requirements. To reach this goal, the calculation and creation of the topographic base grid, and defining parameters used for translating elements on the grid are in need to be fulfilled.

In Mongolia, the work of translating parameters between coordinate systems has been carried out. But there is not an adequate performance in identifying parameters to translate medium-scale topographic mapping. In this circumstance, there is ongoing research to identify errors during translation of 1:200 000 scale topographic mapping and coordinate system into other scale maps. Conformal cylinder coordinate system is extensively used, but there is remote error when producing topographic map grid and calculating coordinate conversions [5].

The territory of Mongolia consists of 323 sheets of 1:200 000 scale. Calculation is executed using Microsoft Office Excel 2010 and production has completed by AutoCAD 2018, AutoCAD Land 2019, and ArcGIS 10.6.1 and ENVI 4.7.

WGS-84 system calculates the difference in rectangular coordinates that resulted from the UTM and TM projections. With this difference, graphs of length and area deflections are plotted [13] (Fig. 1, 2).

As length scales along the meridian line (m) and parallel line (n) of the conformal cylindrical projection is equal ($m = n$):

$$m = n = \frac{\beta}{r};\ p = m^2;\ \omega = 0, \tag{1}$$

Projection deflections are defined as follows:

$$m = n = 1,332;$$
$$p = m^2 = 1,774.$$

The deflection charts have been created with the assistance of m, n ($m = n$) and p.

1:200 000 scale topographic mapping grids on the TM and UTM projections for Mongolian geographic features, and defining distortions within the framework of confidence level 95%, the length and area distortions are 0.9997 and 0.994 respectively so that 0<P<1 is approved.

There is a distortion 1.8-2.3 km along the X axis and -0.09-0.08 km along the Y axis after overlaying 8832 points of calculated grids and printed map grids.

From this point on, each country needs to use the grid taken out from the result of computation of projection suitable for their own countries.

M projection of the rectangle in a 1: 200 000 scale L-46-II topographic map was performed:

– using Formula (3), 10-point geodetic coordinates on a map sheet L-46-II to be determined (Table 2).

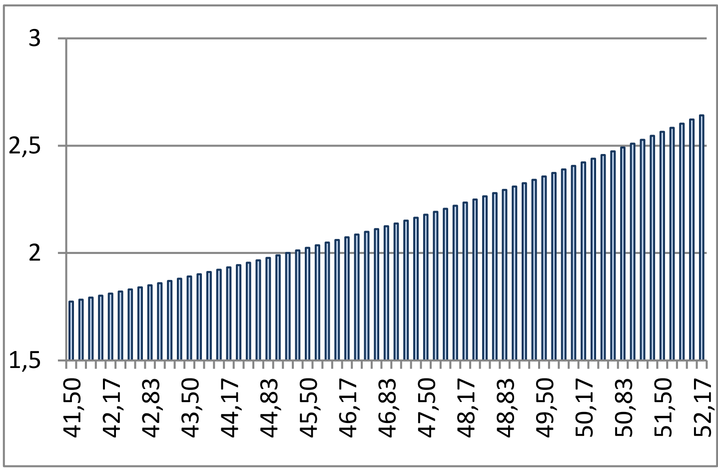
– in geodetic coordinates, the rectangular coordinates X, Y in the UTM projection estimated by formula (5) (Table 3).

The results of converted by formulas 3 and 5 from the geodetic coordinates of the WGS-84 coordinate system to the rectangular coordinates of the plane of the UTM projection are shown in Table 3.

p - Area deflection line

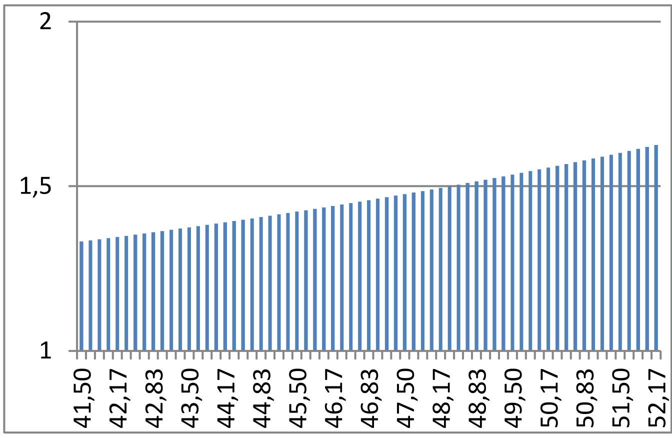
m - Length scale along the meridian line

φ - Latitude



Mean	2.158573447
Standard Error	0.971362544
Median	2.131002577
Mode	#N/A
Standard Deviation	0.251999902
Sample Variance	0.06350395
Kurtosis	1.108523591
Skewness	0.275183925
Range	0.858392111
Minimum	1.78277183
Maximum	2.641163941
Sum	138.1487006
Count	64
Confidence Level (95.0%)	0.99428214

Fig. 1. Area deflection chart



Mean	1.462204286
Standard Error	0.985577265
Median	1.455311864
Mode	#N/A
Standard Deviation	0.084618121
Sample Variance	0.007160226
Skewness	0.203514089
Range	0.287352322
Minimum	1.331798096
Maximum	1.619150418
Sum	93.58107432
Count	64
Confidence Level (95.0%)	0.997136978

Fig. 2. Length deflection chart

The test task of translating the geodetic coordinates of the 1942 system to the UT

Table 2

Conversions from the CS-42 system to the WGS-84 system

№	CS-42 system, Geodetic coordinates		WGS-84 system, Geodetic coordinates	
	B	L	B	L
1	47°20'00	91°00'00	47°20'01.691	90°59'59.422
2	48°00'00	91°00'00	48°00'01.749	90°59'59.400
3	48°00'00	91°15'00	48°00'01.753	91°14'59.429
4	48°00'00	91°30'00	48°00'01.757	91°29'59.459
5	48°00'00	91°45'00	48°00'01.761	91°44'59.489
6	48°00'00	92°00'00	48°00'01.764	91°59'59.519
7	47°20'00	92°00'00	47°20'01.706	91°59'59.540
8	47°20'00	91°45'00	47°20'01.702	91°44'59.510
9	47°20'00	91°30'00	47°20'01.699	91°29'59.481
10	47°20'00	91°15'00	47°20'01.695	91°14'59.451

Table 3

The results of conversion of Geodetic coordinates to rectangular coordinates

№	WGS-84 system, Geodetic coordinates		WGS-84 system, Rectangular coordinates	
	B	L	X	Y
1	47°20'01.690	90°59'59.422	5244199.393	348888.759
2	48°00'01.749	90°59'59.400	5318289.961	350801.097
3	48°00'01.753	91°14'59.429	5317836.356	369449.383
4	48°00'01.757	91°29'59.459	5317443.272	388097.930
5	48°00'01.753	91°14'59.429	5317836.356	369449.385
6	48°00'01.764	91°59'59.519	5316838.616	425395.644
7	47°20'01.706	91°59'59.540	5242744.935	424439.877
8	47°20'01.702	91°44'59.510	5243017.597	405551.853
9	47°20'01.699	91°29'59.481	5243350.886	386663.972
10	47°20'01.695	91°14'59.451	5243744.813	367776.264

By above method, on grid 238 map sheet with a scale of 1: 200 000, the grid was determined and the grid rectangles were identified in the UTM projection of the WGS-84 system (Fig. 3).

When implementing a linear referencing out of five types of georeferencing it shows the result that $RMS_x = 44.3$ m and $RMS_y = 40$ m cannot meet the requirements of accuracy (Fig. 4). The reason of this distortion is that the result of calculation is 0.25

mm and 0.2 mm along the X and Y axis respectively because the mathematical accuracy of topographic mapping must be less than 0.1 mm.

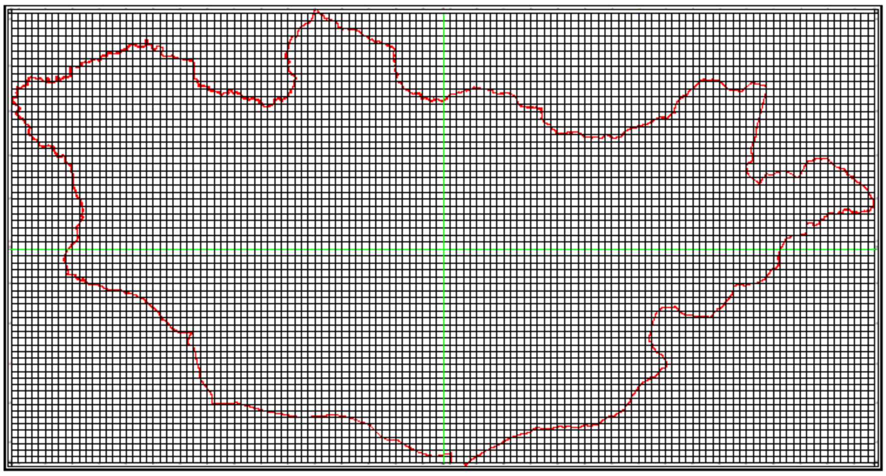


Fig. 3. WGS system UTM projection, coordinate grids of topographic map

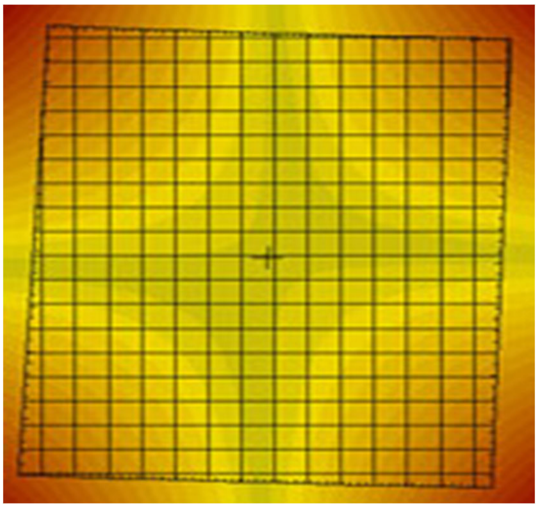


Fig.4. The polynomial conversion at 4th degree

Therefore, the polynomial and affine referencing were experimented and the result was $RMS_x = 43.3$ m and $RMS_y = 40.0$ m after the affine conversion, $RMS_x = 12$ m and $RMS_y = 20$ m after the polynomial conversion at 4th degree, $RMS_x = 12$ m, RMS_y=16 m at 5th degree and $RMS_x = RMS_y = 0$ at 10th degree respectively (Fig. 5).

From this perspective, it is obvious that using the conversion at 4th degree is appropriate because the deviation is minimum if the degree of polynomial reference is lower.

Also, the conversion of polynomy has higher resolution than the conversion of affin. RMS equals 0 at the points of the state geodesy network according to the references of linear and "nonlinear rubber paper". When evaluating the results of nonlinear referencing the distortion scale was identified as 20 m at the corners and 0m at the center of the map board. The following conclusions can be derived from the matrix of deviation. It is determined that polynomial referencing called “nonlinear rubber paper” has the least distortion at the spatial referencing for the medium scale topographic map of Mongolia.

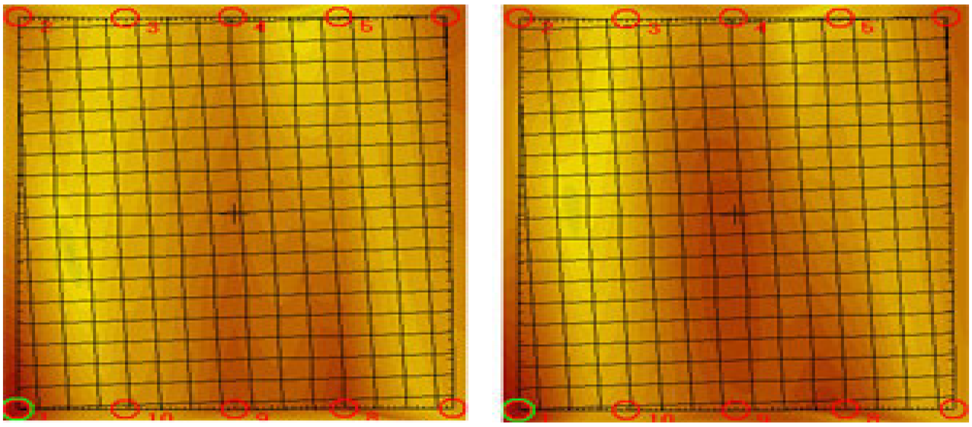


Fig. 5. The polynomial conversion at 10th degree

Topographic mapping system of Mongolia and the conversion of projection

The task of transforming the geodetic coordinates of the 1942 system to the UTM projection of the plane rectangle in a 1:200 000 scale L-46-II topographic map was performed:

– 10-point geodetic coordinate on the L-46-II map sheet tablet to be determined;

– The rectangular coordinates X, Y in the UTM projection by the geodetic coordinates to be found.

UTM and TM projections are types of transverse cylindrical projections on marketers. In the UTM projection the scale on the average will be m = 0.9996 and the further away from the average the magnification will be m = 1.

Reverse conversion is performed in the following sequence including:

– $B'_X = \frac{(X)}{a}$ find first approximate value;

– $s = a[A'B - B' \sin 4B - D' \sin 6B + \sin 8B]$;

– $B'_2 = \frac{X - S}{a} + B'_1$;

– $-4e'^4 \cos^4 B' - 9 \cdot \mathrm{tg}^2 B' \cdot e'^2 \cos^2 B'$;

– in case of $(X - S) \ll 0.001$ B'_n result will be determined by M, N. Next you find the latitude and longitude value;

– in case of $(X - S)) < 0.001$ repeat the description back to B. After determine B' conversion shall be use following formula.

By above method, in grid 323 map sheet with a scale of 1: 200 000 the grid was identified by the rectangular coordinates of UTM projection in the WGS-84 system.

Conversion of geodetic data of the large and medium scale topographic maps is one of the very important issues. The rectangular coordinates of 25 points of the base network of 1:200 000 scale topographic map, which was geo-referenced, was determined (Fig. 6).

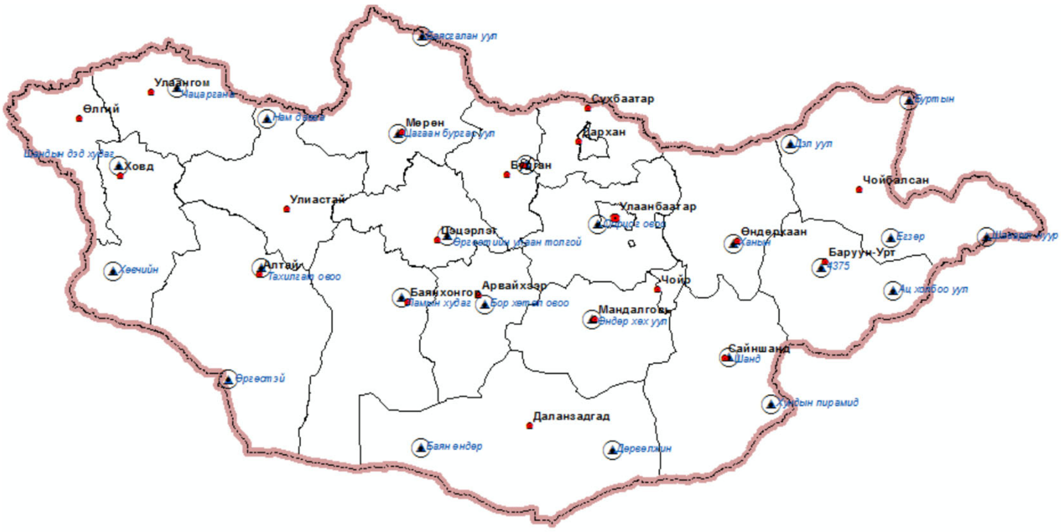


Fig. 6. Location of GNSS/GPS points on base network in Mongolia

These defined coordinates were compared with the points on base network catalogue issued from Agency for Land Administration and Management, Geodesy and Cartography then, it met the accuracy requirements so that the coordinates of 63 points were decided to be used for specifying the converion parameters [1] .

The conversion of geodetic network points from the old system to the new system was performed using Helmert's method and SEVEN PAR 7.0 conversion software [3]:

$$\begin{pmatrix} X_{WGS-84} \\ Y_{WGS-84} \\ Z_{WGS-84} \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \mu \cdot R \begin{pmatrix} X_{CS-42} \\ Y_{CS-42} \\ Z_{CS-42} \end{pmatrix} \qquad (2)$$

where $R = \begin{pmatrix} 1 & -\omega_z & \omega_y \\ \omega_z & 1 & -\omega_x \\ -\omega_y & \omega_x & 1 \end{pmatrix}$

$$\mu = 1 + m$$

$$X_{WGS-84} = X_{CS-42} + \Delta X + \omega_y Z_{CS-42} - \omega_z Y_{CS-42} + mX_{CS-42}$$

$$Y_{WGS-84} = Y_{CS-42} + \Delta Y - \omega_x Z_{CS-42} + \omega_z X_{CS-42} + mY_{CS-42}$$

$$Z_{WGS-84} = Z_{CS-42} + \Delta Z + \omega_x Y_{CS-42} - \omega_y X_{CS-42} + mZ_{CS-42}$$

(ΔX, ΔY, ΔZ, ω_x, ω_y, ω_z and m) = Helmert's parameter for converting from one system to another (Fig. 7)

ΔX, ΔY, ΔZ = second system starting point coordinates, angular parameters ω_x, ω_y, ω_z a ZOY and ZOX vertical X, equals to the angle of rotation of the axis counterclockwise. The conversion error is not less than 1–2 mm [18].

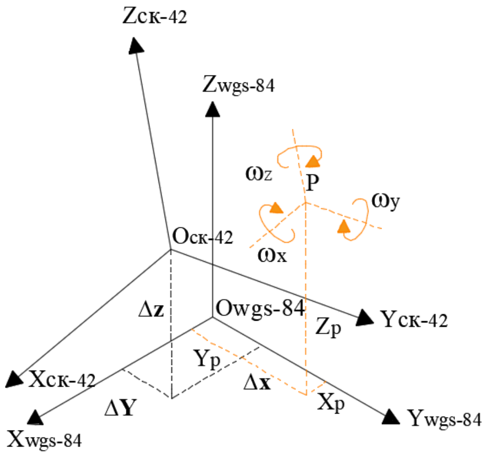


Fig. 8. Graphic shows coordination reversed axle

For this case the conversion error is not less than 1–2 mm.

When defining seven parameters for the conversion within geo-reference of Mongolia, the parameters are showed up as Δx = 30.5 m, Δy = -118.4 m, Δz = -132.6 m, ω_x = -1.43", ω_y = -1.21", ω_z = -1.89" and m = 0.00001098 with the help of software SEVENPAR 7.02.

After examining and measuring the points, transferred with the help of seven parameters, in the static mode of GPS network [10], RINEX file was calculated in the service of ONLINE AUSPOS (International calculation of GPS measurement outcome) and met the accuracy requirements of the medium-scale topographic map [2, 19] (Table 4).

Table 4

The results of field measurements

Solution	Vector Identifier	Length	Error	Vector Components		95% Error	SV	PDOP	QA
Fixed	UB01 - 0177	6898.233	0.033	X	6616.161	0.014	18	1.1	
	16/10/23 10:54:00.00			Y	1952.430	0.014			
	+21:05:45.00			Z	6.789	0.014			
Fixed	UB01 - 4153	4894.155	0.024	X	-4778.995	0.010	18	1.1	
	16/10/23 08:09:15.00			Y	-960.886	0.010			
	+23:50:30.00			Z	-436.639	0.010			
Fixed	4153 - 0177	11770.028	0.057	X	11395.152	0.023	18	1.1	
	16/10/23 10:54:00.00			Y	2913.318				
	+21:33:30.00			Z	443.428	0.023			

Conclusions

This research aims to enhance the error accuracy when creating a topographic mapping grid through the mathematical basis-calculation of projection after converting the medium scale topographic maps of Mongolia from CS-42 into WGS-84. While the process of converting and calculating, the following results arose.

There are possibilities to enhance the baseline error accuracy of the previous topographic maps during the conversion to the digital formation thanks to the study of the projection of the medium-scale topographic map of Mongolia and the development of the methodology for the calculation of mapping grids. 1:200 000 scale topographic mapping grids on the TM and UTM projections for Mongolian geographic features, and defining distortions within the framework of confidence level 95%, the length and area distortions are 0.9997 and 0.994 respectively so that $0<P<1$ is approved. Parameters of geo-referencing of Mongolia generated as $\Delta x = 30.5$ m; $\Delta y = -118.4$ m; $\Delta z = 132.6$ m; $\omega_x = -1.43''$; $\omega_y = -1.21''$; $\omega_z = -1.89''$; and $m = 0.00001098$ with the help of SEVENPAR 7.02 and the methodology of Helmert. This shows the accuracy of requirements of topographic mapping projection was met by measuring the points of GPS network at static mode.

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