New Russian Reference Frame: Status and Development

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Abstract

Federal Service of Geodesy and Cartography of Russia started to construct National Satellite Geodetic Network (NSGN) in 1999. Based on modern geodetic concepts and satellite technologies, NSGN has three levels: Fiducial Astronomo-Geodetic Network (FAGN), Precise Geodetic Network (PGN) and First-Order Satellite Geodetic Network (SGN-1).

The first fragment of NSGN (4 FAGN and 15 PGN points) that covers the centre of the European part of Russia has been created to the end of 1999.

The PGN network will be extended to the whole European part of Russia in the near future. The new NSGN points will be tied to the conventional Astronomo-Geodetic and Vertical (levelling) networks. This enables to connect global coordinate systems with national horizontal and vertical data. Also it allows the development of the vertical reference data where GPS/-GLONASS, precise levelling, and gravity observations are commonly used.

The new transformation between WGS84 and PZ-90 systems was determined as a result of the national and international projects.

Introduction

During the last years the Federal Service of Geodesy and Cartography of Russia (Roscartographia) makes the works on the construction of the geodetic networks of the qualitatively high level of precision using the satellite's navigation systems GLONASS and GPS. The creation of the state geodetic network is being made in correspondence with the adopted in 1995 "Conception of the passage of the topographic-geodetic service to the autonomous methods of satellite's coordinates determinations". The modern satellite navigation systems will permit to settle the problems of the creation of the basic network with higher operationability and precision in comparison with the traditional geodetic methods, which have been used earlier. The first results of the construction of the basic satellite geodetic network at the territory of Russia and the results of the coordinate transformation parameters determination of PZ-90 (GLONASS) and ITRF (GPS) are examined in the report.

1. Concept and Design of the Russian Satellite Geodetic Network

The new Russian State Geodetic Network includes three types of the newly created satellite networks and already existing traditional state geodetic network. The conjunction of the satellite networks includes the Fiducial astronomic-geodetic network (FAGN), Precision geodetic network (PGN) and the Satellite geodetic network of the 1st class (SGN-1). The traditional component of the newly formed structure must compose the Astronomic-geodetic network (more than 160 000 points of triangulation of the 1st and the 2nd classes) adjusted together with the given earlier data of the Space geodetic network (SGN) with 26 points and Doppler geodetic network (DGN) with 134 points as well as the geodetic networks of triangulation condensation of the 3rd and the 4th classes. The Astronomic-geodetic network (AGN) after the mentioned adjustment is the base of the newly formed reference network of coordinates SK-95, which is more precise and uniformed than the 1942 coordinate system.

While the works on construction of these networks and their processing are methodically correct, effective attraction of already existing scientific-technical potential it is possible to create the unified system of coordinate which permits to determine the mutual position of any points at the Russian territory with the precision of 1 to 5 cm practically for any comfortable user applications. The most important scientific and applied tasks to be resolved in result of the construction and development of FAGN, PGN and SGN-1 are the following:

1. Creation of the Earth fundamental geocentric coordinate system of and maintenance of it at the modern and perspective demands of the science and practice.
2. Formation and distribution of the modern state system of the geodetic coordinates and normal heights at all the territory of the country.
3. Study of Earth's shape and gravity field and their changes in time.
4. Research of Earth's surface deformation, which is preceding or accompanying the earthquakes, other dangerous natural catastrophes.
5. Support of the surface, sea and airspace navigation means, airspace monitoring of the natural and technogenic changes with the reference geodetic data.

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6. Geodetic support of the mapping of the country territory and the surrounding seas aquatories.
7. Geodetic support of the Earth land resources study and the land use, cadastre, construction, research and use of the natural resources.
8. Metrological support of the highly precise technical means of positioning and orientation.
9. Construction of the specially purposed precision networks.

The highest level of the new structure of the coordinate provision of the country territory is the fundamental astronomic-geodetic network. This one serves as the starting base for getting maximally precise and stable geodetic reference frame at the whole territory of the country.

FAGN practically guarantees the whole earth geocentric system of coordinates in the frame of the resolution of the tasks of the coordinates-time provision of the country (CTP). And its main functions are the following:

- creation and operational reproduction of the whole Earth geocentric coordinates system;
- minimisation of the possible errors in the being created PGN and SGN-1 in the regional and the global scales;
- experimental study and register of the deforming influence of the geodynamic precesses for the stability of the coordinate frame (reducing to the unique epoch);
- metrological support of the perspective tasks of practice (etaloning and attestation of the future highly precise space and other systems).

The realization of FAGN is to be the system of the geodetic points permanently or periodically determined in the unified coordinate system, practically realising the fundamental geodetic coordinates system and guaranteeing the solution of the earlier indicated scientific and practical tasks. The part of those points will be integrated into the global International GPS Service for Geodynamics (IGS).

The main goal of the periodically determined points of the FAGN, in the difference with the permanently working ones, is the provision of the demanded precision and unifity of expanding of the geocentric system of coordinates for the whole Russian territory. The distance between the adjoining points of FAGN must make 600 – 1000 kms, while the distance between the permanently working points, as a rule, is from 1 up to 2 thousands kilometres. The interval of the repeated observations at the periodically determined points of FAGN must in medium make 5 – 8 years and to be corrected taking into account the detected geodynamic processes. Roscartographia jointly with the Russian Academy of the Sciences and the State Committee for Standards makes the works on the FAGN construction.

The main functions of the Precise geodetic network are the propagation of the whole Earth geocentric system of coordinates for the whole country territory, liquidation of the regional deformation of AGN, determination of the parameters of the mutual orientation of the whole Earth geocentric and state reference system of the geodetic coordinates. With the creation of the PGN the base for the future research of the possible regional deformation of the Earth surface is being made. The distance between the adjoining points of PGN can be from 150 up to 300 km depending from the region of construction.

PGN together with FAGN is the base for the construction of SGN-1 and composition of the highly precise maps of the heights of the quasigeoid and modernisation of the normal heights system using the gravimetric information and levelling data.

The aim of SGN-1 is to provide the optimal conditions for realisation of precise and operational possibilities of the satellite equipment during the transaction of the Russian territory for both tradition geodetic and satellite methods of coordinate determination. SGN-1 represents the network of the simply achieving basic points with the density, enough for the use of all the possibilities of the satellite determination by the public users with the minimum of expenditures for the creation of the proper SGN-1. The SGN-1 network is being created first of all for the economically most developed regions. The distances between the adjoining points of SGN-1 can vary in enough large limits and in the economically developed regions can make 25 – 35 km. Besides of that the density and precision demands of SGN-1 can arise dependently from the geodynamic activity of its regions of construction.

In correspondence with the examined demands during 1999 – 2000 it is planned to build the satellite network at the territory of European part of Russia. The scheme of that network is shown at the Figure 1. At the scheme are shown already observed points during the Field Company of 1999 and the points, observation of which will be fulfilled in 2000.

All the FAGN and PGN points are combined with the 1st and 2nd classes levelling benchmarks. Such combination guarantees the possibility to control the levelling network and to create the unified system of determination of the normal heights. In this case eliminates the necessity to use the tide gauges as the initial points where the normal height for the given system of heights is being taken as zero. With this new approach the normal height will be equal to zero at that point of the Earth surface in which the real potential will be equal to the normal at the surface of the ellipsoid taken as normal. Thus the coordinate system and normal height system at the Earth surface will be realised by the same conjunction of FAGN points for Russian territory and GPS points for the whole Earth.

A problem of precise determination of quasigeoid heights can be solved by the joined analysis of GPS measurements and gravimetric data, if precise levelling data for the fundamental sites are known (even in different reference systems for different countries). In this case a unique reference system for normal heights may be established without any information on the initial national or continental reference points. The main idea of this approach is that by gravimetric data the quasigeoid heights V can be strictly estimated relative to the general Earth ellipsoid with a centre, superposed with the Earth centre of mass.(BURSHA et al.,1998). Its semimajor axis may be determined from the expression $\int_s V ds=0$, and therefore a surface of the general Earth ellipsoid and its potential U^0, considered like a *normal* one, determines the height reference system. In this case a *normal* height will be zero at those point of the physical surface of the Earth, where the real value of geopotential W_i is equal to the *normal* one U_i^o at the surface of the general Earth ellipsoid. Thus a requirement for the solution of the Molodensky border problem $W_0=U^0_0$ keeps itself automatically. (DEMIANOV, 1999*)*.

2. Processing Results of the First Field Campaign Observation

The realised by today processing of the observations had the following main aims:

- to choice the most convenient software for processing, which can provide not only the adequate precision of the received result simplicity but the adequate precision and comfort for use;
- previous evaluation of the precision of observed fragment of the satellite network including the aim of the possible precision or correction of the field works methods of realisation;
- evaluation of the necessity of the joint or separate processing of observations in FAGN and PGN;
- detection of the most weak points in the methods of processing of networks relatively to the specialities of their creation at the territory of Russia.

Here come the main results of the previous processing without an attempt to give the final and exact answers on all mentioned questions.

The processing was made significantly independently in some organisations in different compositions of the proceeded points and with the use of some software, not obligatorily destined for processing of those types of networks:

- United Institute of Physics of the Earth (GAMMIT software, joint processing of all points of observations of FAGN and PGN);
- National Geophysical Committee (GAMMIT software, processing of observations only of FAGN points);
- Moscow University of Geodesy and Cartography – MIIGAiK (BERNESE software, processing of observations only of FAGN points);
- Central Research Institute of Geodesy, Aerial Surveying and Cartography – TSNIIGAiK (GPSurvey software, joint processing of observations of all FAGN and PGN points.

In the final processing we have to use permanent IGS stations for the support of the unity and stability of the national coordinate system. The positions and velocities of those are known in the ITRS coordinate system. The observations of such points have included in the preliminary processing.

The next of IGS points the observations of which were included into processing in one or another variants:

GRAS (France), WSRT (The Netherlands), ONSA (Sweden), ZECK (Zelenchuk, Northern Caucasus), POL2 (Bishkek, Kirgizia), SELF (Almaty, Kazakhstan).

During the processing of the networks by GPSurvey the general adjustment of the baselines between the points was fulfilled with coordinate fixation only from one initial point ZWEN. The orientation and scale of network in this case were given by the way of use of precise ephemerides of GPS satellites. While calculating the parameters of the base lines from processing of the phase measurements as the additional parameters zenith tropospheric delays were evaluated at each 4 hours interval.

The precise ephemerides and evaluation of the tropospheric delays were used also in all the other variants of processing. While using the GAMMIT into the processing were included observations of the following permanent stations: GRAS, ONSA, POL2, SELE, WRST, ZECK, MDVO, ZWEN. The same points but WSRT were used while processing with BERNESE.

The scheme of network fragment is shown at Figure 2. While processing with GPSurvey were calculated practically all baselines between adjoining points of observation in PGN, as well between the adjoining points of FAGN. At the scheme the directions for distant points are shown with arrows.

The evaluation of the result accuracy was made by pair comparison of coordinates obtained by the different solutions.

In the Table 1 are given the results of solutions comparison obtained by different software. In the tables are given mean square errors on each from coordinates for the whole set of common points.

Table 1. Comparison of the different software solutions

1/1	Software package	Mean square residuals (m)		
		DB	DL	DH
1	GPSurvey & GAMMIT	0.0047	0.0058	0.0094
2	BERNESE & GAMMIT	0.0051	0.0052	0.0143
3	BERNESE & GPSurvey	0.001	0.0012	0.0085

Fig.1. The first fragment of the national satellite geodetic network of Russia Legend

– *FAGN stations created in 1999. Permanent and periodically active stations, consequently.*

– *PGN points created in 1999.*

– *FAGN stations planed to observation in 2000. Permanent and periodically active stations, consequently.*

– *PGN points planed to observation 2000.*

From all the sample of data follows that the main problem of PGN construction, most of all formed from in different times made fragments, consists in giving the unified coordinate system. For construction of the network of our country this problem is deepening by the practical absence in the Near-Ural and at the north of the Western Siberia of enough quantity of permanently working and in different places located points, positions of those can be reliable determined in the ITRS sistem.

In connection with the chois between software we have not unough basis for that choise. Now we can say only that GPSurvey has much more time for processing.

At the present time is being finished preliminary processing of observations using JPS PINNACLE software. Nowa days, as we think, that is practically the only one software which permits to proceed similar networks, constructed as by GPS satellites observations though by GLONASS observations. For a while we do not wait some high results from using GLONASS because for the period of the observation the GLONASS satellite constellation was very limited. But even in such conditions the received results can represent great enough methodical interest.

The principal importance during joint or parallel geodetic use of GPS and GLONASS systems have the questions linked with difference of coordinate systems, realised in each of these navigation systems e.s.WGS-84 and PZ-90.

3. Coordinate Transformations

The coordinate system PZ-90 at the territory of the former USSR was primarily realised by coordinates of 26 points of the space geodetic network (SGN), created by Military Topographic Service of the Ministry of Defence Headquarters by the results of observations of satellite system of GEO IK. In the system PZ-90 the coordinates of the tracking stations of GLONASS were determined by the way of their geodetic orientation to the SGN points. Later, during the exploitation of GLONASS system the tracking stations coordinates in the result of their own observations formed some independent, internally agreed coordinate system.

In this way, PZ-90 coordinate system in fact started to have two realisations fixed in one starting realisation by SGN points, let call it conditionally PZ-90 (SGN), and in the other – agreed coordinates of the tracking observation stations and, correspondently -- efemeries of GLONASS satellites. This realisation we will call PZ-90 (GLONASS). While using GPS we also in fact are dealing with two systems: WGS-84 and ITRF. In fact, the difference between two those systems is significantly less then in the previous case and the nature of those differences is a bit another. For the work in description those systems one can take as the practically coincident.

The fulfilled by the present time researches of that question showed that all the mentioned coordinates systems differs each from another (BAZLOV YU.A., et al, 1999, ŃUNNINGHAM J., CURTIS V.L., 1996, MISRA P.N., ABBOT R.I., 1994, MITRIKAS V.V., REVNIVIKH S.G., BYHANOV E.V., 1998). The dimensions of those differences not always can be rejected in the existing demands for the precision of navigation tasks solutions and even more for the geodesy tasks solutions.In correspondence with the Federal aimed program on the use of the satellite system GLONASS for the civilian users TSNIIGAiK fulfilled complex of work for the transformation parameters determination for coordinate systems used by satellite navigation systems GLONASS and GPS.

Taking into account the variety of approaches for the settlement of this task and its importance, in the work at the base of agreements for the scientific co-operation took part organisations of other establishments: Russian Academy of Sciences (INASAN), Russian Space Agency (TSPI) and The Ministry of Defence of Russia (TSNII-4).

In the aim of increasing the fidelity of parameters determination of mutual orientation of coordinate systems used by satellite systems GLONASS and GPS as well as coordinate system PZ-90, realised at the Russian territory by SGN points, the working program was organised parting from the necessity to receive some independent results.

For the transformation determinations between the coordinate systems WGS-84 (ITRF) and PZ-90 (in its realisation by the Russian satellite navigation system GLONASS) were made several independent determinations.

First of them in result of TSNIIGAiK's participation in the International GLONASS experiment IGEX, organised by the initiative of the international organisations in the aim of researching the possibilities of use of the Russian satellite system GLONASS for the navigation and geodesy. In the frames of IGEX project were organised simultaneous observations of GLONASS satellites at some tens of points situated in the different countries of the world. TSNIIGAiK in the frames of the participation in the project made interruptible GLONASS/GPS observations in medium during 1 --1,5 month at 5 points which participated in different international projects and situated at the territory of Russia in Saint-Petrsburg, Ekaterinburg, Yakutsk, Magadan and Petropavlovsk-Kamchatsky. The works made with partial organisational and financial support of the Institute of Navigation (ION) of the USA. The particularity of the made by TSNIIGAik observations consisted in the fact that all the measurements were made by dual frequency combined receivers GPS/GLONASS Legacy of the JPS company (ASHJAEE J., et al, 1999).

The second parameters determination of connection of coordinate systems WGS-84 and PZ-90 (GLONASS) was made following the results of the laser observation of ISZ system GLONASS. Those works were made by TSNII-4 of the MD of Russia. The evaluations of transformation parameters were received at the base of analyses of processing results of many years laser observations of ISZ system GLONASS.

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In the third variant of determination of transformation parameters of coordinate systems of WGS-84 and PZ-90 (GLONASS) were made using the results of GLONASS observations of TSNIIGAiK with the use of precision eferemies of GLONASS satellites. These determinations were made in TSPI of the Russian Space Agensy.

And finally in the forth variant were determined the transformation parameters of coordinate systems WGS-84 (ITRF) and PZ-90 in the variant of its starting realisation by geodetic points system, coordinates of which were determined by satellite observation results of the Russian Space geodetic complex GEOiK. For the resolution of this task were made satellite measurements at 9 SGN points situated at the different parts of the Russian territory; two points in the region of Saint-Petersburg and seven points in area of Moscow, Sarapul, Yakutsk, Magadan, Petro-pavlovsk-Kamchatsky, Irkutsk and Komsomolsk-at- Amur. By this way were determined coordinates of PGN points in the system WGS-84. (In these works in the part of processing of observations by GIPSY program took part INASAN).

In the aim of the further use of the fulfilled works results for updating the geodetic base everywhere where it was possible by the GPS measurements were determined the connections between relatively close situated points of SGN, AGN, permanently functioning GPS points of RAS and Gosstandard and levelling benchmarks.

With the aim of further use or the fulfilled works for updating the geodetic base everywhere where it is possible by GPS measurements were determined connections between relatively near situated points of SGN, AGN, permanently working GPS points of observations of the RAS and Statestandard and repers of nivelation of the 1st and the 2nd classes of the Main Height Data (MHB) of the country. Those connections permitted to rise the precision of coordinates determination of SGN points in system WGS-84 as well as to receive additional control of the points situation by hights and by this in future to have control of scale of coordinates systems WGS-84 and PZ-90 (SGN).

Table 2. Finding of transformation between PZ-90 and WGS-84 (ITRF)

1. Transformation between PZ-90 (GLONASS) and WGS-84 (ITRF)						
Dx(m)	Dy(m)	Dz(m)	1-m(ppm)	Wx (sec)	Wy (sec)	Wz (sec)
R.m.s. (m)	R.m.s. (m)	R.m.s. (m)	R.m.s. (ppm)	R.m.s. (sec)	R.m.s. (sec)	R.m.s. (sec)
1	2	3	4	5	6	7
1. Transformation determined by broadcast efemeries of GLONASS satellites obtained from the IGEX (BKG weekly reports) data						
-0.006	-0.103	-0.509	0.012	0.030	-0.006	-0.351
0.013	0.015	0.024	0.001	0.001	0.002	0.003
2. Transformation determined from GLONASS laser ranging results (TsNII 4 MO RF)						
-0.01	0.07	-1.58	0.34	0.005	-0.012	-0.359
0.2-0.3	0.2-0.3	0.2-0.3	-	0.015	0.01	0.01
3. Transformation obtained by the results of CNIIGAiK GLONASS observation using the pracise efemeries (solution of TSPI of the Russian Space Agensy)						
0.012	-0.018	-0.526	0.002	-0.008	-0.001	-0.348
0.06	0.06	0.03	-	0.007	0.006	0.017
2. Transformation between PZ-90 (SGN) and WGS-84 (ITRF)						
4. Transformation determined by CNIIGAiK						
-0.61	-0.19	-0.35	0.13	0	0.02	-0.15
0.32	0.12	0.28	0.05	0	0.01	0.01
5. Transformations received from (Bazlov Yu.A., et al, 1999)						
-1.08	-0.27	-0.90	-0.12	0	0	-0.16
0.21	0.21	0.33	0.06	0	0	0.01

In this way the fulfillment of the given task of determination of parameters of connection of three coordinates systems WGS-84, PZ-90 (SGN) and PZ-90 (GLONASS) were made by four independent methods, which in considerable degree arises the fidelity of the received results. In the table are given the main results of parameter determinations.

The received results approve the fact that two existing realizations of coordinates systems PZ-90 (SGN) and PZ-90 (GLONASS) differ considerably between them.

Besides the mutual openings were also detected differences of the scales of the indicated coordinate systems. For the analyses of the scales difference were calculated the lengths of the geocentrically radius-vectors of the geodetic points. Those lengths in the coordinate system PZ-90 became in medium for 1 m bigger than their estimations in ITRF system. Such difference can be provoked by two reasons: uncoinsiding of the beginning of coordinate systems or the difference of the scales. For detection of such difference were calculated lengths of the vectors of augmentation of coordinates between observation points. The received results approved supposition about the different scales of the mentioned coordinate systems. Also were made control determinations of geocentrical distances of the observation points with use of gravimmetric and levelling data. During this it was taken into account also the difference between the volumes of the big semiaxes of the Earth ellipsoid and reference ellipsoids in coordinate systems PZ-90 and ITRF. Those control calculations support the most high precision of the scale of coordinate system realised by ITRF in correspondence with the approved standard of the length unit.

Conclusion

During 1998 – 2000 Roscartographia fulfilled large scaled works on the construction of the national geodetic network. In the central part of the territory of Russia was built the first fragment of the precise geodetic network.

The experience of the fulfilled works demonstrated that the technologies in use provide the construction of the highly precise satellite network of the regional scale with the precision of determination of mutual spatial position not less than 1 cm, which is not practically possible for the used earlier classical methods. To this in significant degree contributed the use during the measurements of the modern satellite geodetic equipment of Javad Positioning Systems company.

The processing of the observations demonstrated good mutual agreement of results received by different program sets, which testify their high fidelity.

The analyses of the transformation parameters of coordinates used in GPS and GLONASS showed their significant difference. Were received statistically meaning estimations of longitude mutual derivation and diversity of scales of coordinate systems in use.

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