The State Geodetic Support System of the Russian Federation

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SUMMARY

The report presents an analysis of the current state and development prospects of the state system of geodetic support of the Russian Federation territory. The state geodetic support of Russia includes: the fundamental parameters of the Earth's figure and the external gravitational field of the Earth; geocentric coordinate systems: the Earth Parameters 1990 – PZ-90.11, the high-precision State Geodetic Reference Frame – GSK-2011 and the Baltic Elevation System (BSV-77), which are implemented on the Earth's surface by the structure of State Networks (Geodetic, Leveling, Gravimetric). An integral part of the state geodetic support system are models of the Earth's gravitational field, where one of the main ones is the quasigeoid model, which is the link between geodetic and normal heights. Information resources that promptly provide consumers with geospatial information are also part of the State Geodetic Support. All components of state geodetic support are inextricably linked with each other and cannot develop independently of each other.

АННОТАЦИЯ

В докладе представлен анализ современного состояния и перспективы развития государственной системы геодезического обеспечения территории Российской Федерации. Государственное геодезическое обеспечение России включает в себя: фундаментальные параметры фигуры Земли и внешнего гравитационного поля Земли; геоцентрические системы координат: ПЗ-90.11, ГСК-2011 и Балтийскую систему высот (БСВ-77), которые реализуются на поверхности Земли структурой государственных сетей (геодезической, высотной, гравиметрической). Неотъемлемой частью государственной системы геодезического обеспечения являются модели гравитационного поля Земли, где одной из главных является модель квазигеоида как связующее звено между геодезическими и нормальными высотами. Информационные ресурсы, оперативно предоставляющие потребителям геопространственную информацию, также являются частью Государственного геодезического обеспечения. Все составные части государственного геодезического обеспечения неразрывно связаны друг с другом и не могут развиваться независимо друг от друга.

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1. INTRODUCTION

The geodetic support system of the Russian Federation is understood to be the general set of parameters of the Earth's figure and the Earth's exterior gravitational field, implemented on the territory of the Russian Federation through the state reference frame and the structure of state networks.

2. REFERENCE FRAMES

Two state reference frames have been established on the territory of Russia by the Decree of the Government of the Russian Federation of 24.11.2016 No. 1240 "On Establishment of State Reference Frames, State Elevation System and State Gravimetric System":

geodetic reference frame of 2011 (hereinafter referred to as GSK-2011) for use in geodetic and cartographic works;

Earth-wide geocentric reference frame "Earth Parameters of 1990" (its modern implementation – PZ-90.11) for use in geodetic support of orbital flights and solving navigation problems for various purposes.

The current reality is that all modern implementations of national geocentric reference frames are based on the same International Terrestrial Reference System (ITRS) and its practical implementations (ITRF). The starting point is at the center of the Earth's mass. The orientation of the coordinate axes in the Earth's body is determined from observations of the International Earth Rotation and Reference Systems Service (IERS) and the International Association of Geodesy (IAG).

Both Russian reference frames are geocentric and universal, but they have some differences in the parameters of the Earth's figure and the exterior gravitational field (see Table 1).

Table 1 shows the parameters in which the reference frames diverge, no matching parameters are indicated.

Table 1. Fundamental geodetic constants and parameters of the common terrestrial ellipsoids of the two systems

Parameter	Designation	Unit of measurement	GSK-2011	PZ-90.11
Utilization			Regional (national)	Global
Epoch			01.01.2011	01.01.2010
Geocentric gravitational	*fM*	km^3/s^2	398 600,4415	398 600,4418

constant (including the atmosphere)				
Semi-Major Axis	*a*	*m*	6 378 136,500	6 378 136,00
Geometrical Flattening	α	-	1/298,2564151	1/298,257 84
Semi-Minor Axis	*b*	*m*	6 356 751,758	6 356 751,3618
Square of the First Numerical Eccentricity	e^2	-	0,006 694 3981	0,006 694 3662
Square of the Second Numerical Eccentricity	e'^2	-	0,006 739 5151	0,006 739 4828
Normal gravity potential at the reference ellipsoid	U_0	m^2/s^2	62 636 856,75	62 636 861,40
Normal gravity at the equator	γ_a	*mGal*	978 032,84	978 032,84
Normal gravity at the pole	γ_b	*mGal*	983 218,646	983 218,800
Coefficients in the formula of the normal gravity	β	-	0,005 302 43	0,005 302 40
	β_1	-	0,000 005 85	0,000 005 80
Coefficient of the 2nd spherical harmonic	J_2^0	-	1 082,636 14×10^{-6}	1 082,625 75×10^{-6}

3. STATE GEODETIC NETWORKS

The GSK-2011 reference frame is implemented on the Earth's surface by state networks of various purposes and accuracy. The basis of the state geodetic network is the state satellite geodetic network of a three-level structure, which includes the Basic Astronomical and Geodetic Network (hereinafter referred to as the BAGN); the High-precision Geodetic Network (hereinafter referred to as the HGN) and the Satellite Geodetic Network of the 1st class (hereinafter referred to as the SGN-1). The structure of the state geodetic network also includes triangulation, polygonometry and trilateration networks of 1st-4th classes created in the Soviet period, aligned with the points of BAGS, HGN and SGN-1.

3.1 State geodetic network of the highest accuracy class

The Basic Astronomical and Geodetic Network (BAGN) is the top level of the hierarchy of the state satellite network and serves as the initial geodetic basis for building satellite networks and practically implements the geocentric reference frame as part of solving problems of coordinate and time support.

In addition, the main functions of BAGN are:

reproduction of the Earth-wide geocentric reference frame GSK-2011;

elimination of possible global and regional distortions of HGN and SGN-1;

experimental identification and consideration of the deforming effect of geodynamic processes on the stability of the reference base;

metrological support of prospective practice requests.

According to the national standard of the Russian Federation GOST R 57374-2016 (Global navigation satellite system. Methods and technologies of geodetic works. Items of basic astronomical and geodetic network (BAGN). Specifications) [1] each BAGN point is a local network consisting of a one main, at least one working, two control and one gravimetric centres. At some BAGN points, the working center is combined with the main one. As an example, Figure 1 shows the BAGN point "Barentsburg", where the working center coincides with the main one and a gravimetric site is located nearby.

Figure 1. Main/working center of the BAGN point "Barentsburg" and the gravimetric site

The buried depth is at least 3 meters, the height of the ground part is 1,5-2 meters.

A satellite receiver and a highly stable frequency standard are placed in a heated room with a weather station installed on the roof. The point also includes at least two checkpoints, which are located no further than 5 km from the main center. Satellite receivers of the BAGN network receive signals from GLONASS, GPS, Galileo, BeiDou global satellite systems, as well as from geostationary satellites of the Quasi-Zenith Satellite System (QZSS) and GPS Aided GEO Augmented Navigation (GAGAN) series.

All BAGN points have coordinates in the GSK-2011 system, as well as the value of the normal height in the 1977 Baltic Elevation System, determined from I and II class levelling. The accuracy of the I and II class levelling is determined by admissible root-mean-square deviations per 1 km of double stroke: for I class – no more than ± 1-2 mm, for II class – no more than ± 2-4 mm. The gravity acceleration value is also determined at BAGN points using an absolute method (direct measurements) of at least 8 mGal and at satellite points using a relative method (measurement of differences) of at least 5 mGal, vertical gradient determination – no worse than 5 mGal.

There are currently 103 BAGN points (see Figure 2).

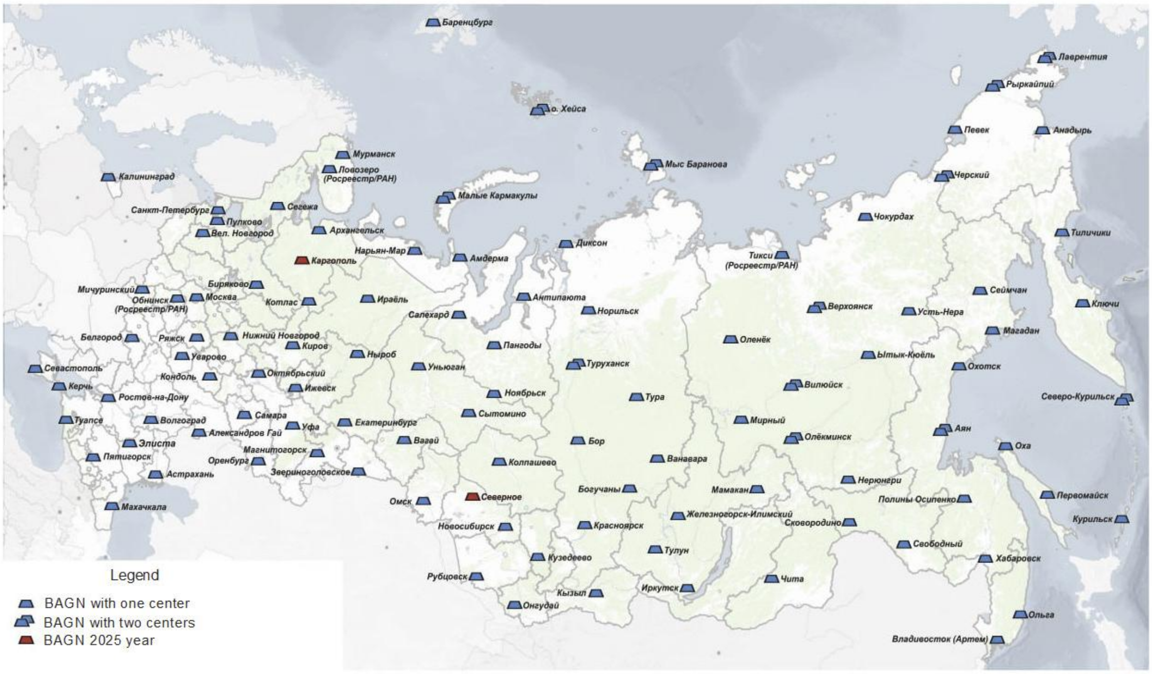


Figure 2. Location of BAGN points

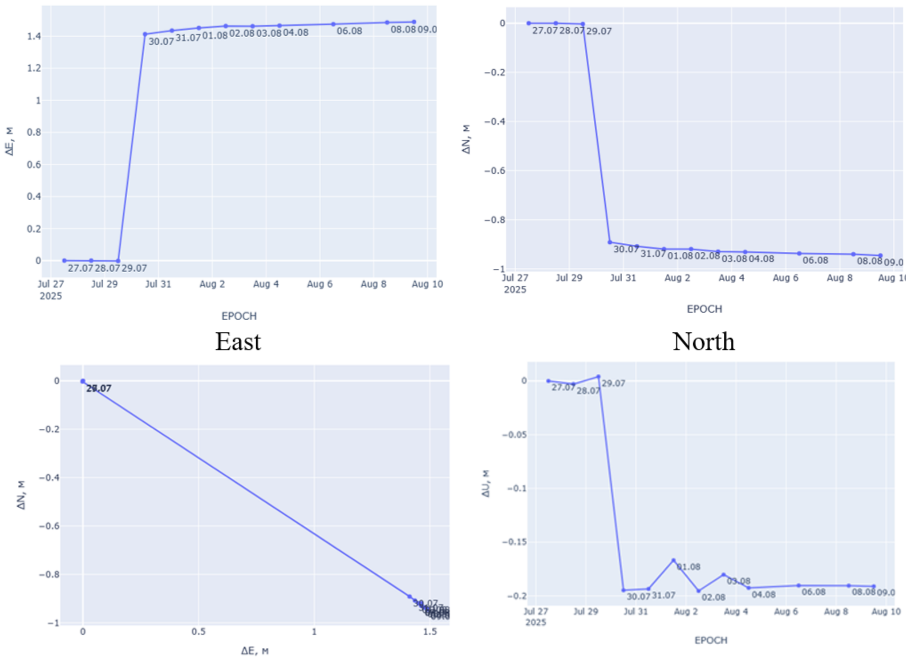
It is worth noting that 12 BAGN points located on Arctic islands and in hard-to-reach places, in order to ensure their continuous operation, have two working centres combined with the main ones, which are supplied with geodetic satellite equipment from different manufacturers (Leica and Javad) (see Figure 3).

The BAGN equation is carried out according to several programs based on 55 points of the international ITRF network. The BAGN points relative position error is estimated at 0.4 cm.

Figure 3. BAGN points on the Hayes Island (Franz Josef Land archipelago)

The role of BAGN stations in the study of earthquake processes is invaluable. On July 30, 2025, at 11:30 am local time, an earthquake occurred on the territory of Kamchatka Region and Sakhalin Region of Russia, which was recorded by BAGN points located in this region second by second.

Figure 4 shows the results of the shifts of the SVK-1 point located on Paramushir Island (North Kuril Ridge).



East

North

Total movement to the north-east

Vertical

Figure 4. The results of processing the data of the SVK-1 point at the time of the earthquake

3.2 High-precision Geodetic Network (HGN)

HGN is a second-level precision network which is based on BAGN points, created in fragments as needed, and is the basis for creating extensive geodetic networks and survey networks [2]. HGN is characterized by errors in determining the relative position for each of the planned coordinates of 3 mm + 5 × 10-8 D (where D is the distance between the points) and 5 mm + 7-10-8 D in geodetic height. The average distance between the points is 150-200 km. HGN working centers are laid in the same way as the main BAGN centers. HGN points are not equipped with permanent satellite receivers. But their coordinates are determined by satellite methods (the duration of the observation session is at least three days), and the top of the pylon is equipped with special attachments, a forced centering system for installing satellite antennas (see Figure 5), and a wall mark is located on the side of the pylon. The determination of normal heights of at least 2nd class (root-mean-square deviations per 1 km of double stroke no more than ± 2-4 mm) and gravity acceleration absolute value is being carried out at the HGN points.

A total of 396 HGN points are currently in operation.

Figure 5. HGN points

3.3 Satellite Geodetic Network of the 1st class (SGN-1)

SGN-1 is the third level in the modern structure of the state geodetic network (after BAGN and HGN). The SGN-1 is created in fragments as deemed necessary (the volume of the fragment is at least 3 points), primarily in economically developed regions of the country. SGN-1 points are created basing on BAGN and HGN in accordance with the requirements of national standard of the Russian Federation GOST R 57373-2016 (Global navigation satellite system. Methods and technologies of geodetic works. Items of the 1st class satellite geodesy network (SGC-1). Specifications) [3]. The average distance between SGN-1 points is 25-35 km.

The spatial position of the SGN-1 points is determined by the methods of relative satellite GLONASS and GPS definitions with RMSE (root mean square error). The relative position of any SGN-1 points in the plan does not exceed 3 mm + $1 \cdot 10^{-7}$, and in height no more than 5 mm+$2 \cdot 10^{-7} D$, where D is the length of the side in meters. At all centers of the SGN-1 point, the values of the normal height are determined, which are obtained from geometric leveling of not lower than II-III class with an error of no more than 1 cm. Satellite measurements at SGN-1 points are performed in static mode with simultaneous observation of at least 6 satellites. The duration of the observation session is at least 8 hours.

A total of 5 964 SGN-1 points are currently in operation.

3.4 Federal Network of Geodetic Stations (FNGS)

A major role in solving industrial tasks is played by the newly created Federal Network of Geodetic Stations, in respect of which the Federal Law No. 491-FZ of 04.08.2023 adds a special article 9 defining its regulatory framework to the Chapter 2 of Federal Law No. 431-FZ of 30.12.2015.

This network is a network of stationary, permanently operating GNSS receivers (satellite navigation) controlled by Public Law Company "Roscadastr", which provides highly accurate data for geodesists, engineers, scientists and other users, allowing them to determine coordinates with centimeter accuracy in real time (RTK) or in post-processing mode.

As of today, the Federal Network of Geodetic Stations (hereinafter referred to as FNGS) includes 2604 permanently operating geodetic stations. It should be noted that the FNGS is the result of a public-private partnership. State participation is represented by the federal segment of the FNGS. The private corporate part is represented by a network of differential base geodetic stations, which is aligned with the reliance on the BAGN network. The measurement information from all BAGN stations enters the FNGS information system, the core of which is a hardware and software complex. It is worth mentioning that the network of differential geodetic stations correlates with population density.

Data collection was started at the end of 2021. It is assumed that after accumulating a sufficient time interval of observations, it will be possible to use this network or part of it to estimate the speed of movement of the Earth's surface. This network is similar to the American network of geodetic stations CORS (Continuously Operating Reference Stations).

Furthermore, a network of permanently operating satellite stations is actively developing in Russia, which runs through active tectonic zones of the Russian territory. Currently, 33 such stations have been built.

In addition to the listed networks, which are based on satellite technologies, 300 000 points of geodetic networks built using classical terrestrial methods have retained their potential.

4. MAIN ELEVATION DATUM (MED)

The Main Elevation Datum (MED) consists of leveling points embedded in the ground or in the foundations and walls of buildings, and is used to establish an elevation reference frame. The Main Elevation Datum of Russia consists of state-owned leveling networks of I and II classes. These networks are created using specially developed programs that provide for performing the geometric leveling of I and II classes and extend a unified system of elevations above sea level to the entire country, calculated in the normal elevation system from datum of Kronshtadt gauge. The horizontal line on the copper plate mounted on the pier of the

Siniy bridge across the Obvodny (Privodnoy) Channel is assumed to be the datum of Kronshtadt gauge. The horizontal line on the copper plate mounted on the pier of the Siniy bridge across the Obvodny (Privodnoy) Channel is assumed to be the zero of the Kronstadt footstock. This system is called the Baltic system, installed in 1977 and is the elevation datum for all topographic surveys and engineering and geodetic works performed to meet the needs of the economy, science and defense of the country.

The main characteristics of the MED:

the I class leveling network contains 97 547 points;

the I class network includes 169 leveling polygons with a length of 148 000 km;

the perimeters of the polygons range from 0.2 to 4.7 thousand km;

the closure of measurements in I class leveling polygons is determined by a period of 20 to 40 years;

the analysis of the I class MED polygons showed that 21 of them have unacceptable inconsistencies;

the II class leveling network contains 124 931 points;

the I class network includes 860 leveling polygons with a length of 173 000 km.

5. GRAVIMETRIC NETWORKS

The system of state geodetic support for the territory of Russia also includes the state gravimetric network, which serves to extend the unified gravimetric system to the territory of the country.

The state gravimetric network is the basis for carrying out gravimetric research aimed at studying the gravitational field and the figure of the Earth and their changes over time, as well as for solving other scientific and economic tasks, including metrological support for gravimetric surveys.

The structure of the state gravimetric network includes:

1) the initial (main) gravimetric points located in Moscow (Protopopovsky Lane, Proto-g Lab) and Novosibirsk, where reference measurements are carried out, for example, a comparison of absolute gravimeters;

2) the state fundamental gravimetric network – 68 points;

3) the 1st class state gravimetric network – 394 points.

The coordinates, height, and gravity acceleration absolute value are determined at all BAGN points, so these BAGN points are simultaneously the fundamental gravimetric network points.

The points of the fundamental gravimetric network and the 1st class gravimetric network serve as the starting points for the development of gravimetric networks of the lower classes.

Repeated determinations at the points of the fundamental gravimetric network and BAGN points are carried out as deemed necessary, but at least once every 5-8 years. The determination of gravity acceleration by the absolute method is carried out no worse than 8 mGal, and no worse than 5 mGal by the relative method.

In Russia, a quasi-geoid model up to 2190 degrees of decomposition has been created, which is used to link normal and geodetic heights.

6. CONCLUSION

With the development of satellite methods and positioning technologies in geodesy, geodynamics and topography, the role and functional requirements for the state reference base – the state reference frame and the state geodetic networks – have changed significantly.

The construction of modern geodetic networks in the Russian Federation follows the classical principle of transition from higher-precision to lower-precision networks.

The vast territory of Russia with a number of sparsely populated northern regions makes it impractical for networks of differential geodetic stations to cover the entire territory of Russia in a uniform and dense manner, as is done in other, evenly and densely populated countries.

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BIOGRAPHICAL NOTES

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