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Prospective Development of the Russian Geodetic Reference Network as a Component Part of the Unified System for Positioning, Navigation, and Timing

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Abstract—Proposals for improving the structure of the Russian geodetic reference network as a physical implementation of the terrestrial reference frame and one of the most important components of a unified system for positioning, navigation, and timing.

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INTRODUCTION

Geodetic reference networks (GRN) implementing the terrestrial reference frame is one of the most important components of the unified system for positioning, navigation, and timing (PNT) [1]. The concept of the terrestrial reference frame includes theoretical definition of the reference system and the catalog of numerical values of the coordinates and velocities of the geodetic network points. At present, the global trend is gradual change over from passive geodetic networks, in which geodetic points only provide information of coordinates, to active geodetic networks, in which geodetic points are equipped with automatic measurement systems capable of providing year-round measurements with high frequency, mostly in real time. A prime example of active geodetic networks is networks of continuously operating reference stations (CORS) of global navigation satellite systems (GNSS) providing consumers with differential correction data in addition to raw measurement data. Thus, modern active geodetic networks can be assigned to both segments of the unified PNT system: the one involved in fundamental problems and the other one, dealing with formation of artificial navigation fields. Characteristics of a geodetic reference network specify a limiting accuracy of terrestrial reference frames, determine the availability of high-accuracy positioning to consumers in handling many practical problems relating to topography, cadastre, engineering geodesy, development and maintenance of geographic information systems, high-precision navigation, etc.

The geocentric coordinate system GCS-2011 was officially adopted in the Russian Federation to solve problems of geodesy and cartography. On January 1, 2017, it will replace the previous coordinate systems SC-95 and SC-42 [2]. The GSC-2011 reference frame is physically represented by the state geodetic network (SGN) of the Russian Federation. As of January 1, 2015, the SGN comprised about 288 000 passive points and only 46 CORS belonging to the highest SGN class—the fundamental astronomical and geodetic network (FAGN) [3]. The density of base stations included in the SGN is insufficient to provide for effective geodetic support of Russian consumers, taking into consideration the fact that, for some time, relative positioning techniques will still be the main methods in high-accuracy GNSS-aided surveying.

Since there are not so many CORS, it is difficult to take into account the evolution of the reference frame of GCS-2011 due to the crustal block motion. The travel rate of FAGN points in GCS-2011 [4] is a few centimeters per year, which is numerically close to the rates in the International Terrestrial Reference Frame (ITRF); however, for some points, particularly, those in the Urals and the Far East, the rates may be quite different. Taking adequate account of the reference frame evolution requires the development and adoption of a detailed model of crustal block motion as a standard one. The development of such a model and its maintenance at the centimeter accuracy level requires geodetic monitoring data with high spatial and temporal resolution. Although CORS are a valuable source of such data, they are insufficient in number to solve this problem.

In addition to the 46 FAGN stations in Russia, currently there are more than a thousand CORS outside the SGN that were established and are operated by various public and private companies as well as local and regional authorities. GNSS measurement data are available from the station operators directly or via

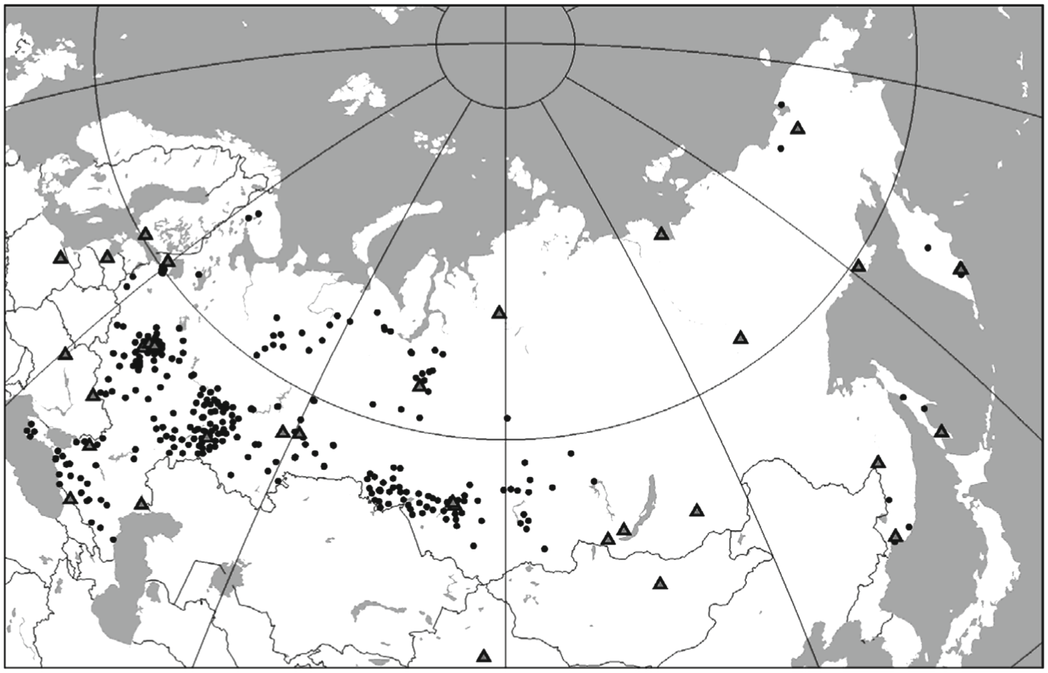

Fig. 1. Continuously operating reference stations.

CORS aggregator systems, e.g., HIVE [5] and SmartNet Russia [6]. Location of the stations accessible via the above systems and positions of the FAGS stations [7] are shown in Fig. 1.

The strategy for the development of geodesy and cartography up to 2020 [8] provides for the establishment of a federal differential GNSS network. Currently, the initiative to create Noncommercial partnership of operators of high-accuracy satellite positioning networks is under way, which is expected to be the basis for deployment of The national network of high-precision positioning (NNHPP) incorporating 1200 CORS [9].

As of now, there are no effective technological normative documents in Russia to regulate the deployment, adjustment and application of CORS networks, which is why the data quality and the position accuracy level of such stations can vary considerably.

THE PROPOSED STRUCTURE OF THE GEODETIC REFERENCE NETWORK

The structure of the national geodetic reference frame and the geodetic network implementing it should be aimed at the optimum application of the advanced methods for positioning and synchronization, in particular, Precise Point Positioning (PPP), Real Time Kinematic (RTK), and PPP-RTK, including implementation of chronometric leveling [10]. The modern geodetic network is an integral part of two systems: the PNT system and the Earth observing system (GGOS, GEOSS) [11]. The equipment and density of the network should be determined for each region of Russia, depending on the problems to be solved by these two systems. CORS should play the main role in the structure of the geodetic network. The infrastructure of the existing CORS should be used as a basis for establishing multifunctional automated points of complex geophysical observations, including GNSS measurements, leveling, gravimetric and meteorological measurements.

It is proposed that the SGN and independent CORS should merge into a broader infrastructure to implement the terrestrial reference frame, allow for fulfillment of the PNT tasks and geophysical data acquisition. Also, this infrastructure should include ground-based navigation systems to backup GNSS and improve the PNT reliability. The existing passive geodetic network must also be maintained for this purpose.

The geodetic network implementing the unified reference frame should have a two-level structure.

The first level of the GRN should ensure PNT tasks and geophysical observations with the highest attainable precision and maximum efficiency within the country and the neighboring territories. This level should combine the following component parts:

—the fundamental astronomical and geodetic network;

—the high-accuracy geodetic network (HAGN);

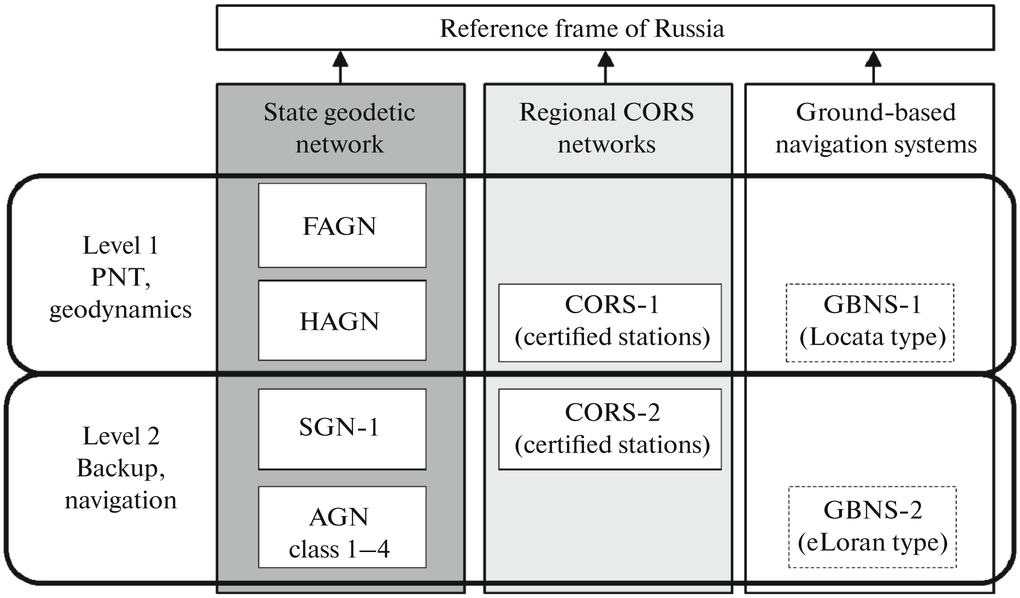

Fig. 2. Geodetic reference networks in the structure of the unified reference frame of Russia.

—certified regional networks of base stations (CORS-1);

—Locata-type ground-based navigation systems (GBNS-1) of [12].

These systems are quite diverse. All of them, except for the HAGN, are active geodetic networks. Common to all these systems is that they are potentially suitable for positioning with centimeter-level errors, which is comparable with the positioning accuracy of the FAGN geodetic points. Of importance is to ensure the consistency in the coordinate values of the points, in other words, to ensure high accuracy of the internal geometry of the geodetic network in order to avoid its deformation. Otherwise, the errors in determining the relative position of the points will affect the PNT accuracy. Therefore, it is necessary to (virtually) unite the above-listed networks and adjust them as a unified geodetic structure—the first level of the proposed GRN structure. Thus, we will succeed in ensuring coherence of the reference frame and minimize its apparent deformation. It should be noted that the reference frame deformation was probably the most crucial issue in implementations of the previously used state coordinate systems, including the SC-95.

The second level of the GRN is mostly an auxiliary one as it provides duplication of the first-level network functions to enhance the reliability of the unified PNT system. This second level includes:

—the satellite geodetic network of class 1 (SGN-1);

—the classical astronomical and geodetic network of class 1–4 (AGN);

—uncertified CORS (CORS -2 – candidate stations);

—eLoran-type ground-based navigation systems (GBNS-2) [13].

It is planned that there will be three independent complementary segments of the unified GRN:

—state geodetic network (FAGN, HAGN, SGN-1, AGN);

—federal CORS network (independent CORS networks and individual stations transmitting data to a single information center);

—prospective segment of ground-based navigation systems. The described structure is shown in Fig. 2.

ADJUSTMENT OF THE UNIFIED GEODETIC NETWORK

The following order of GRN adjustment seems to be optimal:

—adjustment of FAGN based on the geodetic network of the International Earth Rotation and Reference Systems Service implementing ITRF;

—adjustment of the first-level GRN as a unified geodetic formation with fixation of previously determined coordinates of FAGN points;

—adjustment of individual networks of the second-level GRN based on the first level (periodical adjustment by fragments is permissible).

Adjustment of the first-level geodetic reference network (GRN-1) should be performed with high periodicity for monitoring stability of points as well as continuous refinement of their velocities. This is necessary to maintain the reference frame at a specified level of accuracy for a long time. Adjustment of the continuously operating part of the GRN-1 should be organized in accordance with the practice of the International GNSS Service (IGS), namely: the coordinates of the points are estimated from measurements by independent data analysis centers every week, then, in the main center, the results are compared, checked, and weighed solution is calculated. Based on the results of weekly monitoring, in the case that significant changes are revealed, the main center takes a decision to make corrections in the official catalog of point coordinates and velocities in GCS-2011. In so doing, all the information about the changes made must be preserved. Estimation for CORS-2 points is performed in a similar manner. The decision on including the points satisfying the requirements of stability and quality of measurement data into CORS-1 network is taken on the basis of statistics accumulated over a long time. Geodetic connection of the second-level networks to GRN-1, except for CORS-2, should be performed by organizations responsible for the operation and maintenance of these networks. Special attention should be paid to estimation of the point coordinate accuracy.

Obviously, the Centre of Geodesy, Cartography, and Spacial Data Infrastructure should continue fulfilling the role of the main center for analysis and data processing. Organizations with appropriate technological capability and experience in processing spatial measurement data, such as the Information and Analysis Center for Positioning, Navigation and Timing (TsNIIMASH), the affiliated branch "Precision Navigation and Ballistic Support" of "RPC "PSI", can also serve as data analysis centers. Such a center could be established on the basis of the Siberian State University of Geosystems and Technologies, which also possesses up-to-date technologies, hardware and software, including the Bernese software, and significant experience in adjustment of geodetic networks.

PROSPECTS

Continuous monitoring of the GRN-1 points position will make it possible to obtain time series of coordinate values and use them to simulate changes in time-varying velocities of the Earth's surface points on the Russian territory. These data, along with observations of the Earth surface deformations on the geodynamic testing grounds of the Russian Academy of Sciences, the Federal Service for State Registration, Cadastre and Cartography, and other organizations will significantly refine the model of tectonic block motions on the territory of the Russian Federation, the models of regional seasonal and tidal deformations of the Earth's surface. In turn, these models will help further improve the accuracy of fulfilling the PNT tasks, including applied geodesy applications. As of January 1, 2015, FAGN CORS comprised only 8 stations of the System of Differential Correction and Monitoring [3].

Formation of GRN-1 and the use of a denser network of stations in practice on the territory of the Russian Federation will increase the efficiency and make the scope of the GNSS augmentation wider. In particular, it will allow for monitoring of such atmospheric parameters as water vapor content and concentration of free electrons, which will contribute to obtaining higher accuracy of weather forecasts [14]. It will also make possible to refine regional ionosphere models in real time.

It should be noted that the lack of precision of the ionosphere state models is one of the major constraints to the implementation of high-precision positioning technology with the use of mass-market single-frequency GNSS equipment, such as smartphones, car and portable navigators with integrated GNSS modules. Potentially, some modifications of these devices may have centimeter positioning accuracy [15].

The proposed GRN structure is focused on the implementation of advanced methods of surveying, namely, satellite chronometric leveling [10]. This method consists in determining the normal, orthometric, and dynamic height differences from gravitational variation of proper time rate of the high-precision clock connected to the GNSS receiver. Currently, high-precision determination of normal heights is only possible with the use of the laborious method of geometric leveling.

The necessary conditions for satellite chronometric leveling in most parts of Russia at the first stage may be provided by placing frequency standards with relative instability of 10^{-18} at FAGN points relating to the State Service for Time and frequency (SSTF): Mendeleevo (MDVJ), Novosibirsk (NOVM), Irkutsk (IRKJ, IRKT), Khabarovsk (KHAJ). In the future, provision of such frequency standards at all FAGN points is expected to ensure sufficient coverage of the Russian territory.

CONCLUSIONS

The proposals on the developing geodetic reference networks as part of a unified infrastructure are aimed at implementing high-accuracy reference frame of Russia, meeting the present-day and prospective requirements for the PNT system and the system of Earth observation.

It is expected that the proposed GRN structure will enable the maximum efficient and prompt provision of information to users and long-term maintenance of the reference frame in a proper state due to continuous monitoring of the first-level network and refinement of geodynamic models; it will also provide for effective application of satellite chronometric leveling.

The proposed structure will provide the most efficient use of the existing Russian GNSS infrastructure and lay the basis for its flexible development exactly in the regions where it is in demand.

Currently, the research team of the Siberian State University of Geosystems and Technology is preparing for adjustment of the GRN-1 network, which is an important practical step towards the unification of the existing Russian continuously operating reference stations, and formation of a unified of high-accuracy reference frame GCS-2011 accessible for consumers.

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