GNSS Data Processing Package to address climate change and disaster-induced challenges in safeguarding land rights

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Key words: GNSS, VRS, RTK, NTRIP caster

SUMMARY

Living in the context of global climate change and increasing frequency of natural disasters requires paying special attention to the protection of land rights. To enhance the capabilities of local authorities, surveyors and their organizations, it is necessary to quickly equip them with software and hardware tools that can be used in assessing and mitigating the consequences of natural disasters. The universal means used in all these works are sets of instruments for precise navigation on the ground, which make it possible to measure areas of destruction and possible violations of the boundaries of existing land plots.

The Russian Company "Progress" is engaged in research and development in the field of microelectronics and navigation equipment and presents new software developments of the ProGeo family. ProGeo software package is a versatile tool for processing GNSS measurements and can be used in any field requiring high-precision coordinate determination through global satellite navigation. This includes geodetic work related to construction, mineral extraction and transportation, coordinate determination related to cartography, cadaster, and precision agriculture. The features of ProGeo software become especially important when working in areas affected by natural disasters. Natural disasters often lead to the creation of zones with destroyed infrastructure. While deploying communication devices via satellite systems in such areas is not usually very challenging and is done as a priority, restoring infrastructure for high-precision positioning using satellite navigation systems takes significantly more time. This article pays special attention to the ProGeoNet software suite, which has characteristics that provide a distinct advantage when used in disaster-affected zones.

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1. INTRODUCTION

The primary method for high-precision coordinate determination using geodetic-class satellite receivers, including in disaster areas, is Real-Time Kinematics (RTK). Data from reference (base) stations are transmitted to the user's receiver via mobile communication, with satellite communication used if necessary. In everyday practice, reference (base) stations are installed with a density sufficient to obtain a fixed solution in areas of active economic activity.

In the case of natural disasters, areas may arise where there are no operational reference stations. The ProGeoNet software, utilizing the virtual station service, allows for high-precision fixed solutions even when reference stations are more than 100 km apart. This ensures the provision of RTK solutions with standard accuracy in disaster zones by using reference stations located outside the affected area. These advantages will make it possible to carry out geodetic determinations in areas with destroyed infrastructure, determine the boundaries of destruction, assess the volume of debris and garbage, and resolve legal issues related to the boundaries of land holdings.

2. PROGEONET SUITE

In most cases, the ProGeoNet software suite will provide full functionality for differential correction station networks, even if some stations are out of service. The suite includes the following modules:

- NTRIP caster
- Base station monitoring
- Virtual Reference Station (VRS) service
- Coordinate system database

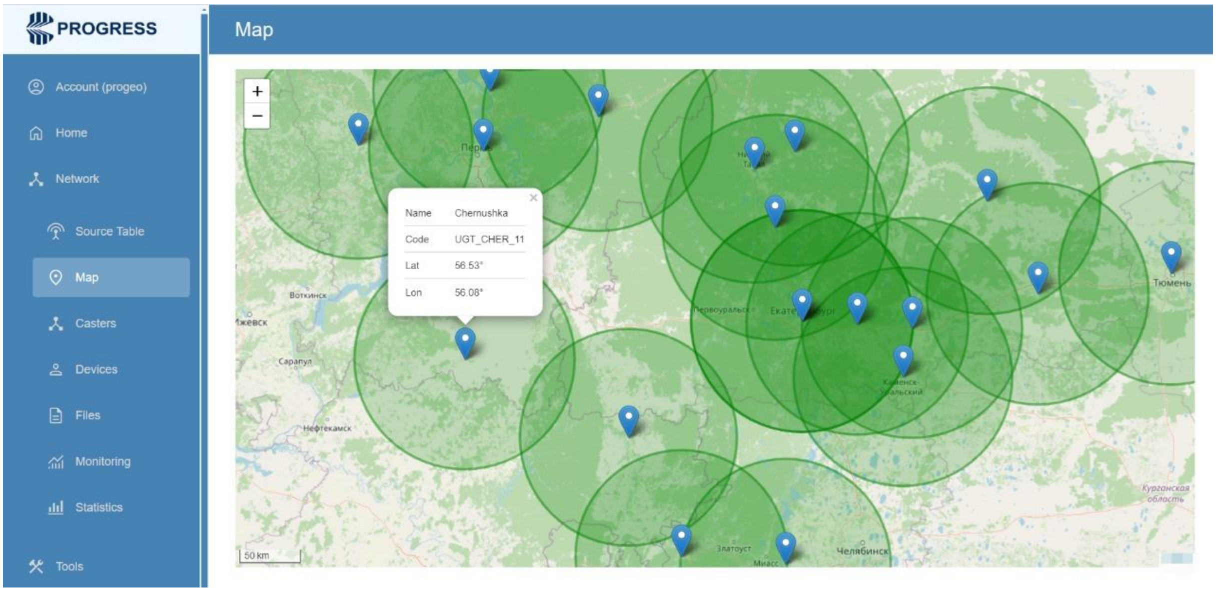


Fig. 1 Map of Base Stations

The main options of the NTRIP caster are reflected on the left panel (Fig. 1) and include: a personal account for registration, authorization, viewing current data traffic information and financial balance; a map of continuously operating base stations; a list of casters, a connection table for selecting the required base station; a list of connected satellite receivers; a catalog of base station data files in RTCM format; and statistics and graphs for monitoring the coordinates of base stations. Depending on the user's rights, access is provided to certain options, casters, and connection points, as well as the ability to download GNSS raw data files in RTCM or RINEX 2.11-3.05 formats. The RTCM data archive is expected to be stored for an extended period.

The main features are listed below.

2.1 NTRIP CASTER

NTRIP Caster includes following features:

- An internet service for transmitting information from base stations to consumers.
- Web-based management interface
- Versions for Linux and Windows
- NTRIP protocol version 2
- Data transmission in RTCM and MSM formats over a secure connection
- Stream and user administration
- Billing for connections by users and base stations
- Network scaling

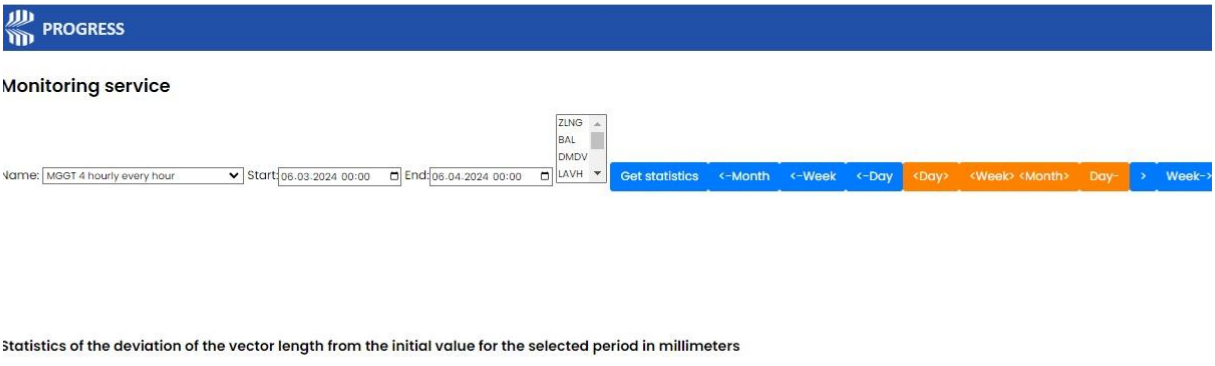
Scaling refers to the ability to add third-party receivers to existing base station networks under a business agreement. The coordinates of the added points are determined using the ProGeoOffice GNSS data post-processing software based on long sessions of satellite observations.

2.2 BASE STATION MONITORING

Monitoring tasks:

- Control of data completeness and detection of radio signal interference, which is especially important in the event of a natural disaster.
- Real-time processing of baseline data
- Recording mutual displacements of network points
- Determining velocities

Control of the information received by the server is necessary for the timely detection of outages or malfunctions of base stations, and to predict the periodicity of radio interference from external devices. Primary data quality control and filtering out gross measurements improve the accuracy and timeliness of meteorological parameter calculations, ensuring the continuity of the spatial field of corrective information when the network configuration changes or when there is a temporary degradation in data quality at individual stations.
The calculation of baseline vectors for the network of base stations, performed in real-time by epochs in kinematic mode, is essential for promptly identifying malfunctioning stations. The optimal configuration of the geodetic network is determined through preliminary testing and scenario tuning.
Mid-term data quality characteristics and potential shifts in points where GNSS base antennas are installed are assessed through regular, post-processing of vectors and network adjustment every four hours. Based on the χ^2-adjustment test and the τ-test for network baselines, a report on network functionality for the considered time period is generated. The report archive (Figure 2) is stored on the server.



Title ↑	Length, km	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00
BALB-DMDV	75	3	1	2	1	0	0	2	3	2	3	4	6	5	3	2	1	1	1	1	1	3	3	3	5	6	4	6	3	2	1	1	1
BALB-LAVH	92	0	3	3	4	5	2	8	7	6	9	9	8	8	6	4	5	7	9	8	6	1	2	2	0	3	1	0	1	1	4	5	3
BALB-NGNK	136	1	2	1	1	1	3	7	12	8	9	13	11	12	5	4	3	6	2	1	1	3	2	0	1	3	3	1	3	2	5	4	1
BALB-NRFM	23	3	2	1	4	1	2	1	1	1	1	1	1	2	3	0	1	2	0	2	3	2	1	1	3	4	3	4	3	1	3	5	6
BALB-PT04	92																																
BALB-RAMN	110	1	1	2	1	2	1	4	3	4	7	7	9	7	6	7	8	8	6	7	4	4	8	1	3	33	39	1	7	6	10	7	6
BALB-SFRN	131	1	3	3	3	5	4	5	7	6	9	9	10	12	4	3	5	7	4	4	2	4	4	5	6	7	10	6	4	5	9	7	5
BALB-SHEH	52	2	2	3	2	1	1	0	0	0	1	1	2	2	1	1	0	0	0	1	2	3	3	3	3	3	3	4	3	2	2	5	18
BALB-VORN	37	1	0	2	0	2	2	3	3	2	2	3	2	2	1	0	1	1	1	1	0	1	0	0	0	0	0	0	1	1	1	1	1
BALB-ZLNG	97	4	0	3	3	4	4	1	7	8	10	10	9	11	5	4	5	5	8	6	2	0	1	3	4	3	2	2	2	3	3	5	1
DMDV-BALB	75	3	1	2	1	0	0	2	3	2	3	4	6	5	3	2	1	1	1	1	1	3	3	3	5	6	4	6	3	2	1	1	1
DMDV-LAVH	50	3	2	2	3	4	3	2	4	5	5	7	7	4	4	6	7	8	6	8	7	3	3	3	3	2	0	2	1	1	0	0	2
DMDV-NGNK	64	0	3	0	2	3	2	2	4	5	4	5	5	7	5	6	4	4	4	3	1	1	2	0	1	1	2	0	1	2	1	1	1

Fig.2 3D deviations (mm) of base station coordinates relative to the catalog ones

From Figure 2, which presents information on the processing of vectors of varying lengths within the network over a 24-hour period, it is evident that the maximum deviations in coordinates from the original, resulting from the adjustment of the geodetic network, depend more on the time of day than on distance. More detailed information is available on our website at the following page: https://spo.progeo.expert/monitoringsolstat

Daily, as precise coordinate data and satellite timings become available, the coordinates of stations in the network are calculated using the PPP (Precise Point Positioning) method within the ITRF2014 coordinate system. Stations with the most stable radio signal reception are used as reference points during the adjustment. The algorithm for calculating absolute coordinates has been verified on the CORS US network. Additionally, over long time intervals, the displacement velocities of base stations are determined for all coordinate components. Below are the graphs showing the position changes of the P523 station from the CORS network in two horizontal components and in height relative to a fixed position:

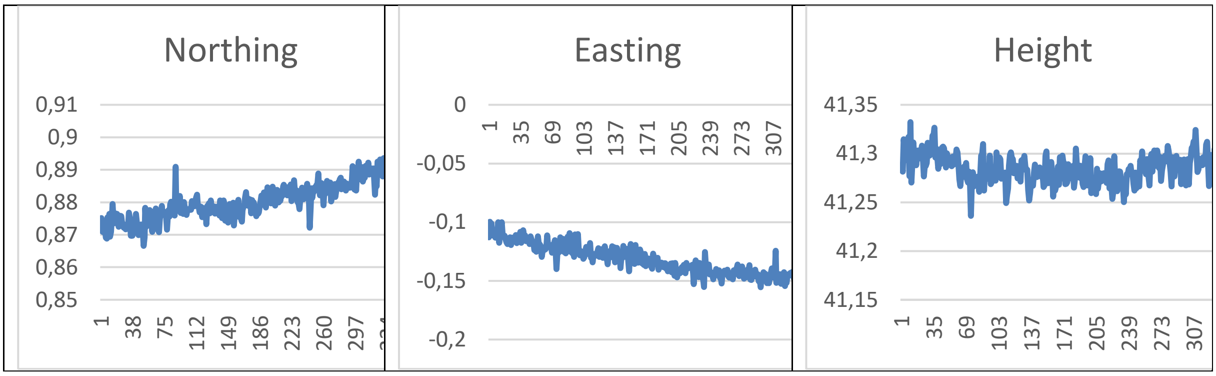


Fig.3 P523 station changes

Ten points were randomly selected in California, where high tectonic activity is observed. The period for which the coordinate velocities were calculated is the 365 days of 2023. As an example, we present the calculated velocity values for three of the ten points. As can be seen from the table, the obtained results are in good agreement with the velocities of these points published by the NGS (National Geodetic Survey).

Points	P066	P277	P523
NGS	-32, +27, +13	-25, +33, +19	-29, +31, +20
ProGeo	-33, +23, +12	-29, +29, +18	-30, +31, +17

The reliability and accuracy of the absolute coordinate calculations were also investigated by comparing the results of data processing using the ProGeoOffice GNSS software with the PPP method for CORS network points on the Trimble and JPL services.

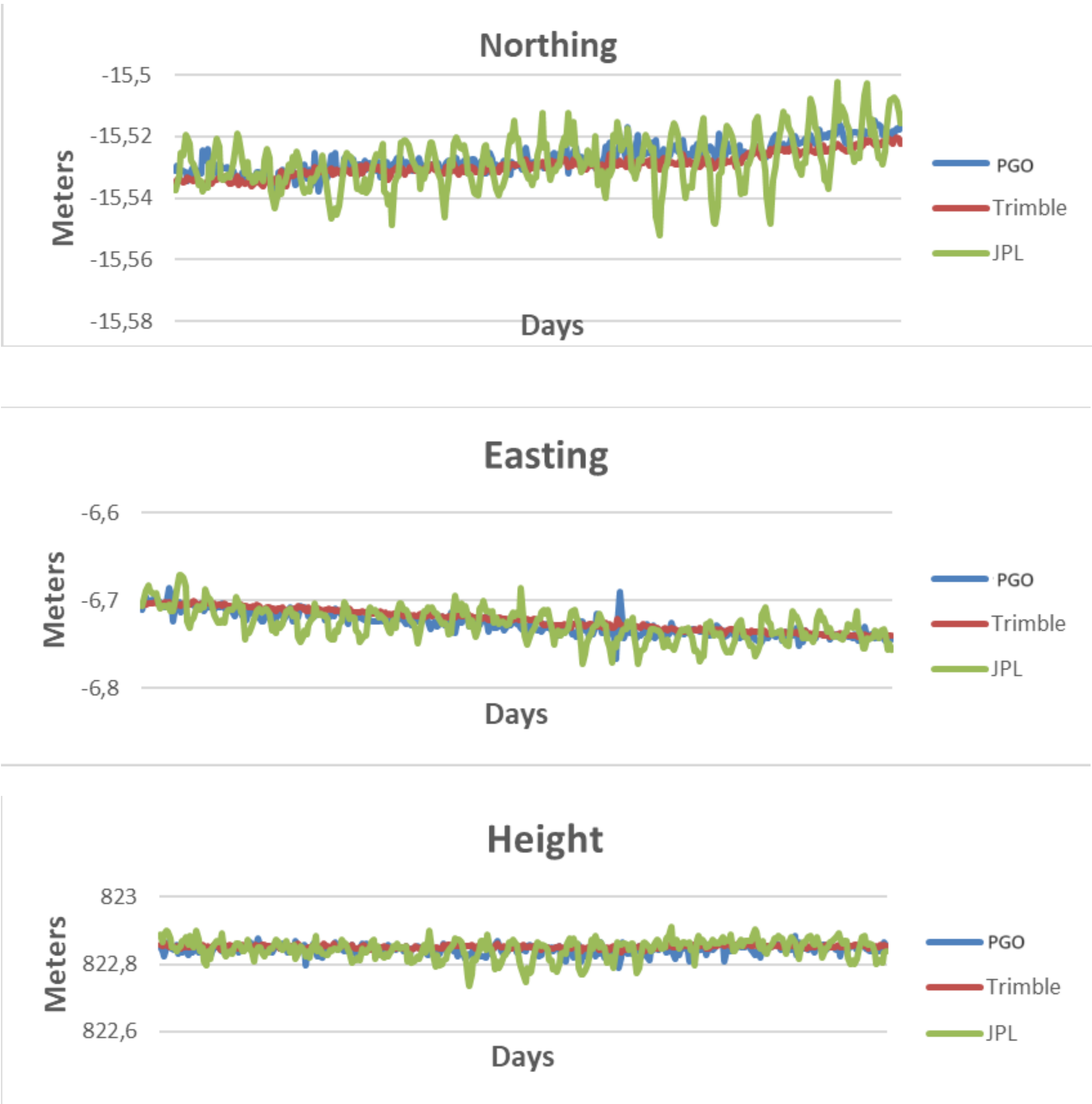


Fig.4 Comparison of coordinate calculations on Internet services using the PPP method

An example of one of the points shows that the smallest spread in coordinate determination is provided by the Trimble service, which may be due to the use of additional data on temperature, pressure, and atmospheric humidity provided by its own satellites. Nevertheless, the comparisons conducted confirm that the ProGeo service allows for the calculation of coordinates with high accuracy. There are plans to create regional velocity models for points across the Russian Federation. Information on the monitoring of points in some Russian networks can be found at https://spo.progeo.expert/monitoringsolstat and https://spo.progeo.expert/monitoringpppstat

2.3 VIRTUAL REFERENCE STATION (VRS) SERVICE

Base station data is processed in real-time to determine ionospheric and tropospheric delays of radio signals, which are used to build spatial fields of meteorological parameters in NRTK (VRS), FKP, and MAX technologies.

The influence of external conditions—primarily the ionosphere, which exceeds half the wavelength of the phase measurements (~20 cm)—prevents the quick and reliable calculation of integer ambiguities in phase measurements in RTK mode. As demonstrated by the experience of Northern Europe and Scandinavia, modern network services that determine meteorological corrections help to obtain accurate coordinates of points in a relatively short time (less than 15 seconds) at distances over 100 km from base stations. A virtual station is created a few meters from the field receiver, so the RTK algorithm ignores the independent calculation of ionospheric and tropospheric corrections. Due to the smaller number of unknowns and, consequently, the smaller size of the Kalman filter covariance matrix, the algorithm works more reliably, increasing the likelihood of obtaining a reliable fixed solution in adverse conditions, such as in urban areas or under dense tree canopies.

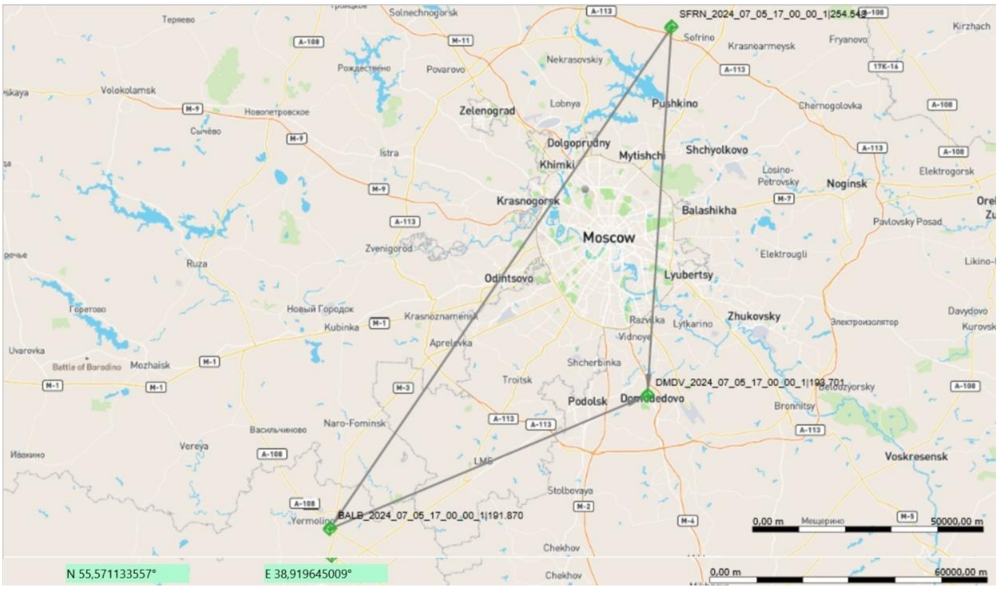


Fig.5 An VRS cluster scheme

3. RESULTS

The ProGeoNet service implements the VRS (Virtual Reference Station) technology, which demonstrates the particular advantage of using the ProGeoNet software suite in areas affected by natural disasters. As an example, let us consider the results of determining the coordinates of a Javad GrAnt-G5T antenna of a SinoGNSS K803 receiver on the roof of a company building relative to three points in the Moscow region network: SFRN, BALB, and DMDV. The mutual distances between the points range from 75 to 131 km. The nearest point, SFRN, is 39 km away. Using this base station, it is possible to obtain an accurate fixed solution within a few minutes. RTK operation relative to other base stations is practically impossible. The SFRN station was selected as the initial node for calculating the virtual base. The reception conditions at this point were unfavorable. A high-rise building is being constructed nearby, leading to frequent interference and GNSS signal reflections.

As shown in the table, during the testing period, using VRS had an advantage over working directly from base stations. However, the positive effect heavily depends on the level of interference at each point in the cluster, introducing additional risks in its use.

Comparison of RTK performance between real base stations and VRS

Time	BALB	DMDV, % *	SFRN, % *	VRS, % *
13.07.2024 11:00	0.00	0.00	71.00	94.28
13.07.2024 12:00	0.00	0.00	43.51	92.25
13.07.2024 13:00	0.00	12.60	98.90	93.08
13.07.2024 14:00	0.00	8.29	99.77	99.47
13.07.2024 15:00	0.00	1.63	45.29	94.92
13.07.2024 16:00	0.00	0.0	99.46	87.33
13.07.2024 17:00	0.00	0.0	76.77	73.98
13.07.2024 18:00	0.00	18.97	47.43	48.13

*** Percentage of fixed solutions**

The use of VRS technology significantly increases the likelihood of obtaining a fixed solution when reference stations are located at distances exceeding 100 km. In the event of a reference station failure in a disaster zone, the ProGeoNet software suite will identify stations whose data has become unreliable and exclude them from the network. There is a high probability that these program features, combined with VRS technology, will enable the continued acquisition of fixed RTK solutions in the disaster zone, even if some reference stations fail. This capability allows for the preservation and restoration of property rights to land plots even in the event of natural disasters and catastrophes that destroy nearby reference points and geodetic markers. Working with remote base stations becomes more reliable with the use of VRS technology.

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BIOGRAPHICAL NOTES

Yuri Noyanov is a software engineer and scientist within geodetic software development division of Progress company. He has a Ph.D. in Geodetic Science and Land Cadaster from the Moscow University of Geodesy and Carthography (MIIGAiK).

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