Velocities Validation in the New Russian Reference Frame GSC-2011

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SUMMARY

The new spatial reference frame GSC-2011 is being introduced in Russia. It will have replaced the previously used SC-95 and SC-42 by the end of 2016. By its definition the underlying coordinate system corresponds to ITRS in terms of origin location and axis orientation. Coordinates of reference points in GSC-2011 coincide with ones in ITRF2008 at one centimeter level at the reference epoch January 1, 2011, according to evaluation carried out by the Russian federal Center for Geodesy, Mapping and Spatial Data Infrastructure which is responsible for development and maintenance of the reference frame. Apparently, the quality of the velocity estimates has not been investigated previously despite its crucial meaning for preserving high level of integrity of the reference frame over long periods of time.

The paper presents results of consistency evaluation of the published GSC-2011 velocities set with the ITRF2008 velocity field and also with available tectonic plate motion models, such as GEODVEL, MORVEL, NUVEL-1A. It is shown that deviations are typically below 1 cm/year. The outliers have been detected particularly for Yekaterinburg (EKTR) and Vladivostok (VLDV) reference stations.

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1. INTRODUCTION

The new reference frame GSC-2011 has been officially introduced in the Russian Federation for geodesy and mapping. It will have replaced previous national reference frames by 2017. By its definition the underlying coordinate system corresponds to ITRS in terms of origin location and axis orientation. Coordinates of reference points in GSC-2011 coincide with ones in ITRF2008 at one centimeter level at the reference epoch January 1, 2011, according to evaluation carried out by the Russian federal Center for Geodesy, Mapping and Spatial Data Infrastructure which is responsible for development and maintenance of the reference frame.
The GSC-2011 is physically represented by the Russian State Geodetic Reference Network (SGN), which comprises more than 288 000 passive reference points. Only the top level of the SGN (FAGS) comprises 46 continuously operating reference stations (CORS) [1]. 33 of them are intended to be open for the users.

Currently the complete GSC-2011 dataset is being prepared for publishing. Only coordinates and velocities for 9 FAGS stations are available [2]. None of those stations either belong to the IGS tracking network or included into ITRF cataloque. Observation data from these stations have not been provided yet for the professional community. Therefore independent investigation of accuracy of the coordinates is impossible. The aim of the present study is to assess consistency of the preliminary published velocity set, shown in Table 1.

Table 1. Investigated GSC-2011 velocity set

№	Location	FAGS station ID	Velocity components in XYZ, mm/y			Velocity components in NEU, mm/y		
			V_X	V_Y	V_Z	V_E	V_N	V_U
1	Astrakhan	AST2	-21.8	13.7	7.4	25.4	8.3	2.3
2	Vladivostok	VLDV	-74.3	-21.8	-21.0	69.7	-38.4	10.3
3	Yekaterinburg	EKTR	-22.5	-10.6	-33.7	14.4	-1.6	-39.3
4	Moscow	CNG1	-25.1	8.9	-0.8	22.3	11.5	-8.8
5	Novosibirsk	NSK1	-28.2	4.8	2.4	28.6	0.3	2.7
6	Noyabrsk	NOYA	-26.0	4.7	0.9	26.3	2.2	-0.1
7	Rostov-on-Don	RSTZ	-21.4	12.2	6.5	23.1	10.8	-1.2
8	Samara	SAMR	-25.2	9.2	1.8	25.3	8.3	-4.0
9	Chita	CHI2	-37.3	-2.2	-5.2	35.1	-13.3	3.8

In Table 1 and further velocity components in East (E), North (N) and Up (U) directions are calculated on sphere.

2. VELOCITY VALIDATION

2.1 GSC-2011 versus plate motion models

As a first step GSC-2011 velocities were compared with the velocities calculated using tectonic plate motion models implemented in UNAVCO Plate Motion Calculator [3]. The results are presented in Table 2.

Table 2. Differences between GSC-2011 and modelled velocity values

Model	Absolute value of horizontal velocity difference (GSC-2011 - model), mm/y								
	AST2	CHI2	CNG1	EKTR	NOYA	NSK1	RSTZ	SAMR	VLDV
GEODVEL 2010	0.6	11.5	1.4	12.5	2.4	3.0	2.0	1.0	53.1
APKIM2005-DGFI	1.4	8.2	0.6	13.7	1.1	1.6	1.8	0.7	49.6
APKIM2005-IGN	2.0	9.5	1.1	14.2	0.9	1.3	2.1	1.3	50.6
CGPS 2004	1.0	9.6	1.2	13.1	1.7	2.1	2.3	0.5	50.3
GSRM v1.2	2.4	7.9	2.1	14.7	1.0	1.4	3.4	1.6	49.3
APKIM2000.0	0.7	11.2	0.7	13.0	1.8	2.1	1.7	0.4	52.5
HS2-NUVEL1A	2.8	14.0	3.3	10.5	5.3	6.3	3.2	3.5	55.8
HS3-NUVEL1A	2.7	13.7	3.3	10.9	5.2	6.1	3.3	3.4	55.4
ITRF2000 (2002)	0.9	11.0	1.3	13.0	1.8	2.2	2.2	0.6	52.4
ITRF2000 (2001)	0.6	11.4	1.4	12.6	2.3	2.8	2.0	0.9	53.0
MORVEL 2010	2.3	10.4	2.2	10.4	4.4	5.6	1.8	2.8	51.5
NUVEL 1	2.7	13.1	3.3	11.5	4.9	5.9	3.5	3.3	54.8
NUVEL 1A	2.8	13.7	3.3	10.9	5.2	6.1	3.3	3.4	55.4
REVEL 2000	1.2	10.2	2.0	12.5	2.5	2.9	2.7	1.4	50.4
Average	1.7	11.1	1.9	12.4	2.9	3.5	2.5	1.8	52.4
Standard deviation	0.9	2.0	1.0	1.4	1.7	2.0	0.7	1.2	2.3

Horizontal velocities of six points (AST2, CNG1, NOYZ, NSK1, RSTZ and SAMR) show good agreement with available plate motion models – nearly at the level of discrepancies between different models. Horizontal velocities of EKTR (Yekaterinburg), CHI2 (Chita) deviate from modelling results significantly. An outlier is detected for VLDV station (Vladivostok).

2.2 GSC2011 versus ITRF2008

At the second step the GSC-2011 velocities were compared to the ITRF2008 in order to validate vertical velocity components and to substantiate result obtained at the first step. None of the investigated stations either belong to the International GNSS Service (IGS) tracking network or included into ITRF cataloque. Therefore, ITRF2008 velocities [4] of the closest IGS stations were used for comparison at the reference epoch of January 1, 2011.

The density of IGS stations in North Eurasia is very low. In some cases distance between the investigated point and the reference point was greater than 2000 km. Also some points were located on the borders of different tectonic plates. Thus the applied approach was not rigorous but in the particular case it was useful. Results of comparison are provided in Table 3.

Table 3. Velocity difference of the closest reference points in GSC-2011 and ITRF2008

Region	GSC-2011	ITRF2008		Distance, km	Velocity difference GSC-2011 - ITRF2008			Speed difference, mm/y
	Point ID	Reference point ID	Solution number		ΔV_E, mm/y	ΔV_N, mm/y	ΔV_U, mm/y	
Europe	RSTZ	POLV	1	1901	0.7	-1.8	-1.1	2.2
		KHAR	1	1777	-0.4	-0.9	-0.3	1.0
		CRAO	1	2305	-0.9	-1.3	-1.6	2.2
		ZECK	1	1972	-2.4	-0.7	-2.4	3.5
		MIKL	1	2226	-0.3	-1.7	-1.4	2.2
	CNG1	MDVJ	1	26	-0.4	-0.3	-9.5	9.5
		MOBN	1	102	-0.8	-0.5	-10.3	10.3
		ZWEN	1	51	-0.7	-0.9	-6.7	6.8
	AST2	KHAR	1	967	1.9	-3.4	3.1	5.0
		ARTU	1	1336	0.4	2.0	1.4	2.5
		ZWEN	1	1305	2.4	-4.1	4.4	6.5
		ZECK	1	583	-0.1	-3.2	1.1	3.4
	SAMR	KHAR	1	1030	1.8	-3.4	-3.2	5.0
		ARTU	1	642	0.3	2.0	-4.9	5.3
		ZWEN	1	914	2.3	-4.1	-1.9	5.0
		ZECK	1	1226	-0.2	-3.2	-5.2	6.1
Ural and Siberia	NSK1	NVSK	1	25	1.5	1.4	1.2	2.4
	NOYA	ARTU	1	1202	1.3	-4.1	-1.0	4.4
		NVSK	1	1029	-0.7	3.2	-1.6	3.7
		NRIL	1	896	4.3	4.2	-1.7	6.2
	CHI2	IRKT	1	627	10.0	-6.6	3.4	12.4
		ULAB	1	656	7.1	-4.8	2.9	9.0

	EKTR	ARTU	1	139	-10.6	-7.8	-40.2	42.3
Far East	VLDV	KHAJ	1	614	47.4	-24.6	9.1	54.2
		YSSK	1	920	57.3	-25.6	9.2	63.4
		DAEJ	1	875	43.0	-25.9	9.0	51.0
		ULAB	1	2006	41.7	-29.9	9.3	52.2
		STK2	2	780	56.3	-23.3	12.8	62.2

Deviations of GSC-2011 velocity from ITRF2008 velocities of the closest stations have been averaged and compared to average deviation from modelled velocities. Results are provided in Table 4.

Table 4. Generalized results of the first and the second steps

Station	Average horizontal velocity difference absolute value, mm/y		Average difference of vertical velocity GSC-2011 vs. ITRF2008, mm/y
	GSC-2011 vs. models	GSC-2011 vs. ITRF2008	
RSTZ	2.0	1.4	-1.3
CNG1	1.6	0.8	-8.8
AST2	0.8	2.5	2.5
SAMR	1.3	2.4	-3.8
NSK1	3.4	2.0	1.2
NOYA	2.7	2.0	-1.4
CHI2	10.9	10.3	3.1
EKTR	12.3	13.2	-40.2
VLDV	52.4	55.5	9.9

Comparing values in the second and the third column of Table 4 one can see that the results obtained using plate motion models and ITRF2008 horizontal velocities are mostly at 1 mm/year level of agreement (nearly 3 mm/year for VLDV station). Therefore, it can be assumed that the result of vertical velocity components comparison in the last column of Table 4 is also trustworthy.

The second step have confirmed the detected deviation of GSC-2011 horizontal velocities for VLDV, EKTR, CHI2 stations and also have shown significant deviations in vertical components for stations VLDV, EKTR, CNG1.

For the station CNG1 the apparent difference in vertical velocity of 1 cm/year is presumably caused by local effects, because the three ITRF2008 reference points located nearby show no significant vertical movement.

2.3 GSC2011 versus PPP estimates for local stations

At the previous steps significant deviations of velocity were detected for VLDV, EKTR and CHI2 stations. Local CORS data were used to estimate ground point velocity in the vicinity of stations VLDV and EKTR. Two stations of SmartNet Russia [5] were involved: VLAD (Vladivostok) and EKAT (Yekaterinburg) located nearby VLDV and EKTR (37 km and 4 km respectively). Coordinates were estimated using 17 daily GPS and GLONASS observation files for each station on a time span of nearly 6 months using Precise Point Positioning online service PPP-CSRS [6]. Velocities and their standard deviations were estimated using linear regression. Estimates are compared to previously obtained results in Tables 5 and 6.

According to numbers in Table 5 one can assume that the vertical and horizontal velocity deviations from GEODVEL 2010 model and ITRF2008-derived values are caused by local geodynamical process which affects both EKAT and EKTR stations. It apparently does not influence the velocity of ARTU station, located more than 130 km away from EKAT and EKTR.

Table 5. Velocity of stations in the vicinity of Yekaterinburg

Station	Source	Velocity, mm/y		
		V_E	V_N	V_U
EKAT	PPP solution	16 ± 5 (95%)	12 ± 6 (95%)	-55 ± 18 (95%)
EKTR	GSC-2011	14	-2	-39
EKTR	GEODVEL 2010	25	5	-
ARTU	ITRF2008	25	6	1

Table 6. Velocity of stations in the vicinity of Vladivostok

Station	Source	Velocity, mm/y		
		V_E	V_N	V_U
VLAD	PPP solution	21 ± 7 (95%)	2 ± 6 (95%)	-35 ± 15 (95%)
VLDV	GSC-2011	70	-38	10
VLDV	GEODVEL 2010	23	-13	-
Average (KHAJ, YSSK, DAEJ, ULAB, STK2)	ITRF2008	21	-13	0

Results obtained for VLDV station are insufficient to make a reliable assumption about the reason of significant velocity deviation in GSC-2011 dataset.

3. CONCLUSIONS

The present study has been carried out to assess quality and reliability of the published GSC-2011 dataset. It has been shown that for 5 of 9 points' velocities in GSC-2011 are consistent with ITRF2008 velocity field and with available tectonic plate motion models [3]. Presumably models such as GEODVEL 2010 [7] can be used directly with GSC-2011 in European part of Russia.

Significant velocity inconsistencies have been detected for stations CNG1, EKTR, VLDV, CHI2. The largest apparent deviation is for VLDV station (more than 5 cm/year). A thorough investigation of GSC-2011 quality using complete observation data is necessary.

4. AKNOWLEDGEMENT

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