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Results of the First Two Years of VLBI Observations at the Svetloe Observatory within the Framework of International Geodynamical Programs

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Abstract—We present the results of processing the VLBI observations performed at the Svetloe Observatory of the Institute of Applied Astronomy (IAA), Russian Academy of Sciences, in the period 2003–2005 within the framework of geodynamical programs of the International VLBI Service (IVS) for geodesy and astrometry. We analyzed the observations at the Svetloe Observatory, together with the observations at other stations of the global IVS network, at the IAA using a modified OCCAM package. The package uses new reduction models that decrease the systematic errors of the results. The motion of the stations, primarily of the Svetloe Observatory, is investigated to study the global geotectonic processes. Highly accurate estimates of the coordinate and baseline length variations have been obtained for the first time in Russia from observations at a Russian VLBI station. We determined the coordinates and velocity of the Svetloe VLBI station with errors of ∼2 mm and 3 mm yr^{-1}, respectively, and the baseline lengths between the stations with a sufficiently long observational history with an accuracy of 1–3 mm. The results are shown to be in good agreement with currently available models for the motion of tectonic plates.

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INTRODUCTION

The Svetloe Radio Astronomy Observatory (RAO), the first observatory of the Russian Quasar VLBI network, is located in the Priozersk district of Leningrad oblast. It was created primarily for regular VLBI observations under programs of astrometry, geodynamics, and space geodesy (Finkelstein 2001). The observatory is equipped with all the necessary modern instrumentation for VLBI observations of extragalactic radio sources. The observatory has been built and is operated by the Institute of Applied Astronomy (IAA), Russian Academy of Sciences.

The observational facilities of the observatory were described by Finkelstein (2001) and Finkelstein *et al.* (2003). They have been developed further since then. First, new cryoelectronic amplifiers designed for the 13- and 3.5-cm bands were installed in 2004. The noise temperatures of the radiometers are 10 and 7 K, respectively. As a result, the sensitivity of the radio telescope at the Svetloe Observatory increased and reached $\mathrm{SEFD}_{3.5\,\mathrm{cm}} = 280$ Jy and $\mathrm{SEFD}_{13\,\mathrm{cm}} = 250$ Jy in astrometric VLBI observations.

Second, a new Mark-5A hard-disk-based recording system was installed at Svetloe; it replaced the magnetic-tape-based recording system, thus increasing the system's reliability and recording rate (up to 1 GB s^{-1}). Since the accuracy of VLBI measurements directly depends on the recording band, the installation of the new terminal enhances the capabilities of the observatory in obtaining high-precision astrometric and astrophysical information. In addition, the S2 Canadian Data Acquisition System (DAS) was installed at Svetloe in 2004; in combination with the recording terminal of the same standard available at the observatory, DAS allows us to participate in international programs together with other stations of the global VLBI network that use terminals of this type.

The Svetloe RAO (with the international name SVETLOE) has been participating in programs of the International VLBI Service for Geodesy and Astrometry (IVS) on a regular basis since March 2003 (Finkelstein *et al.* 2003). The observations are an international collaboration. After the termination of an observing session, the magnetic tapes or disks with recorded information from all stations (usually

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Table 1. Stations that participated in the IVS observations together with the Svetloe Station

Station	Location	L, km	N_s	N_0	N_g
ALGOPARK	Canada	6256	64	5393	5053
CRIMEA	Ukraine	1811	5	505	421
CTVASTJ	Canada	5061	10	905	417
DSS15	USA	8232	2	121	101
DSS45	Australia	11 734	1	30	24
DSS65	Spain	3192	6	650	587
EFLSBERG	Germany	1804	2	315	284
FORTLEZA	Brazil	8428	57	2257	1920
GGAO7108	USA	6767	8	35	18
GILCREEK	USA, Alaska	5854	48	4982	4522
HARTRAO	South Africa	8697	5	183	169
HOBART26	Australia	11 933	5	51	42
KASHIM34	Japan	7174	6	530	465
KOKEE	USA, Hawaii	9561	56	3339	3028
MATERA	Italy	2374	12	1315	1037
MEDICINA	Italy	2140	12	2080	1785
METSAHOV	Finland	299	5	384	0
NOTO	Italy	2809	7	969	828
NYALES20	Norway, Spitsbergen	2133	48	7200	6657
OHIGGINS	Antarctica	11 958	1	3	0
ONSALA60	Sweden	1080	18	2638	2258
PARKES	Australia	11 634	1	4	1
SESHAN25	China	6761	2	122	113
TIGOCONC	Chile	11 413	29	383	239
TSUKUB32	Japan	7141	7	871	778
URUMQI	China	4127	9	943	628
WESTFORD	USA	6269	8	730	562
WETTZELL	Germany	1655	66	10296	9524
YEBES	Spain	3130	2	190	167
YLOW7296	Canada	5807	9	520	454

Note. L is the baseline length between the Svetloe RAO and the station, N_s is the number of sessions, N_0 is the number of observations on the corresponding baseline, and N_g is the number of observations accepted for processing.

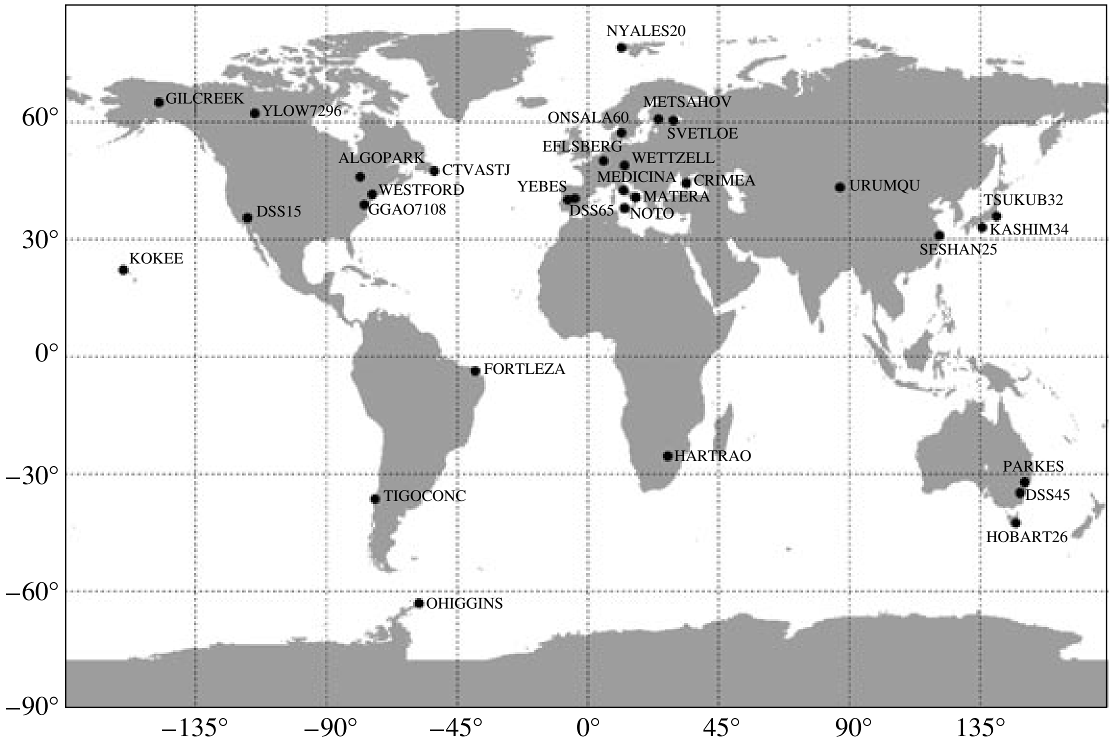

Fig. 1. Stations of the international VLBI network involved in the geodynamic experiments.

located on different continents) are collected at one of the IVS correlation processing centers: the US Naval Observatory, the Max Planck Institute (Germany), the Haystack Observatory (USA) for Mark-4 and Mark-5 data or DRAO (Canada) for S2 data, where the final interferometric quantities (delay and fringe rate) are obtained.

Within the framework of these programs, the research at the IAA is conducted mainly in four directions: determining the Earth's rotation parameters, determining the coordinates of the stations (the terrestrial coordinate system) and their regular and peculiar motions, determining the coordinates of radio sources (the celestial coordinate system), and studying the parameters of the troposphere. In this paper, we describe the first results of studying the motions of the Svetloe Station and the changes in the baseline length between Svetloe and other IVS stations based on the first two years of observations at the Svetloe RAO and their processing at the IAA. The analysis covers the observations carried out from March 2003 through May 2005.

OBSERVATIONAL DATA

From March 6, 2003, until May 26, 2005, the Svetloe RAO participated in 108 observing sessions, 98 of which had been correlated by the time this paper was prepared. Thirteen of these sessions were conducted as part of the Intensive program (one-hour sessions on one baseline for on-line determination of Universal Time). Since these sessions do not carry significant geophysical information, we did not use them in this paper. Thus, 85 24-h sessions on global observational networks were included in the processing.

A total of 30 more stations performed observations in the VLBI sessions with the participation of Svetloe (Table 1, Fig. 1). About 158 000 observations (interferometric delays) of 150 radio sources on 289 baselines were obtained, and 136 000 observations were used in the final analysis; the rest were rejected during the correlation processing.

A total of 47 stations participated in the IVS observations in 2004. Table 2 lists the most active and best (in quality) ones. The table shows that the Svetloe Observatory is surely among the top ten leading VLBI stations of the IVS network.

PROCESSING RESULTS

Secondary processing of the observations was performed to improve the coordinates of the Svetloe radio telescope, to study their variations, and to determine the baseline length between Svetloe and other IVS stations. As was pointed out above, we used only 24-h sessions in our analysis, since they carry basic astrometric and geodynamic information.

Table 2. Statistics of observations of the leading IVS stations for 2004

Number of sessions		Number of observations		Fraction of good observations, %	
All sessions					
WETTZELL	378	WETTZELL	82 277	ALGOPARK	91.9
KOKEE	291	GILCREEK	64 734	WETTZELL	91.8
TSUKUB32	95	WESTFORD	51 367	NYALES20	91.5
GILCREEK	88	NYALES20	45 582	DSS45	91.4
TIGOCONC	87	KOKEE	36 725	KOKEE	90.1
NYALES20	68	TSUKUB32	33 685	GILCREEK	88.5
FORTLEZA	65	ALGOPARK	27 820	VLBA	87.9
WESTFORD	64	MEDICINA	24 836	SVETLOE	87.8
ALGOPARK	60	SVETLOE	23 458	TSUKUB32	87.5
SVETLOE	55	ONSALA60	18 829	FORTLEZA	87.1
HARTRAO	46	TIGOCONC	18 366	SINTOTU3	87.0
HOBART26	29	FORTLEZA	14 187	MEDICINA	86.0
24-h sessions					
WETTZELL	116	WETTZELL	77 219	ALGOPARK	91.9
GILCREEK	88	GILCREEK	64 734	NYALES20	91.5
TIGOCONC	87	WESTFORD	51 367	WETTZELL	91.5
KOKEE	76	NYALES20	45 582	DSS45	91.4
NYALES20	68	KOKEE	32 927	KOKEE	89.4
FORTLEZA	65	TSUKUB32	32 259	GILCREEK	88.5
WESTFORD	64	ALGOPARK	27 820	VLBA	87.9
ALGOPARK	60	MEDICINA	24 836	SVETLOE	87.8
HARTRAO	46	SVETLOE	23 292	FORTLEZA	87.1
SVETLOE	44	ONSALA60	18 829	TSUKUB32	87.1
TSUKUB32	37	TIGOCONC	18 366	SINTOTU3	87.0
HOBART26	29	FORTLEZA	14 187	MEDICINA	86.0

Table 3. Geocentric coordinates for the epoch 2004.2896 and velocity of the Svetloe Station

Coordinates, m			Velocity, mm yr^{-1}			Annual term, mm		
X	Y	Z	V_X	V_Y	V_Z	X	Y	Z
2730173.8326 ± 0.0011	1562442.6820 ± 0.0008	5529969.0754 ± 0.0019	-20.8 ± 1.8	14.5 ± 1.3	1.0 ± 3.0	2.9 ± 1.7	4.3 ± 1.2	7.3 ± 2.7

Note. The last columns give the amplitude of the variations in the Station's coordinates with an annual period.

For various reasons, we excluded three sessions from the processing; the data from 82 sessions were processed.

We processed the data using the OCCAM/GROSS package (Malkin and Skurikhina 2005). Compared to the version used to process the observations of the first global astrometric experiment in March 2003 (Finkelstein *et al.* 2003), some

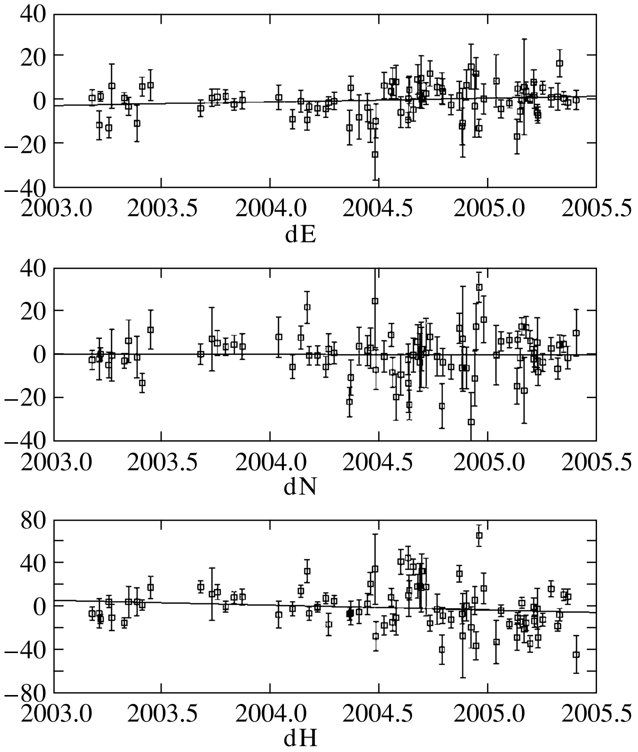

Fig. 2. Variation in the SVETLOE coordinates from March 2003 until May 2005 in the eastern (dE), northern (dN), and vertical (dH) directions relative to the NNR-NUVEL-1A model of tectonic plate motion, mm.

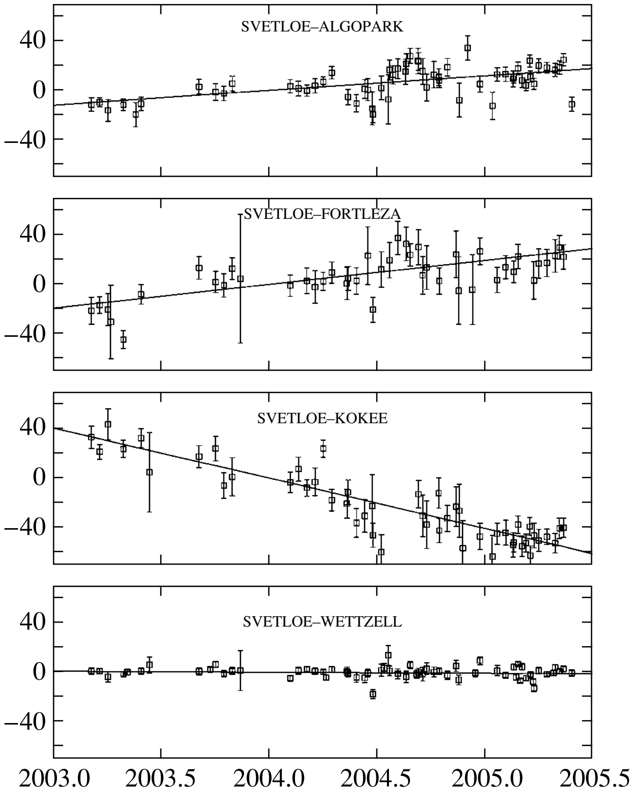

Fig. 3. Variation in the baselines between the Svetloe RAO and IVS network stations located on different tectonic plates: ALGOPARK (North American, NOAM), FORTLEZA (South American, SOAM), KOKEE (Pacific, PCFC), WETTZELL (Eurasian EURA).

improvements were made to the package; the most important of them are new models for the Earth's crust deformation due to the atmospheric loading and the mapping function that describes the dependence of the tropospheric delay on the zenith distance. To calculate the atmospheric loading, we used a model based on the numerical integration of the global meteorological field developed at the Goddard Space Flight Center (GSFC), United States (Petrov and Boy 2004), and the corresponding data files calculated at GSFC. To calculate the mapping function, we also used a model based on the numerical integration of the global meteorological field developed at Vienna Technical University (TUW), Austria (Boehm and Schuh 2004), and the data files calculated there.

Figure 2 shows the variations in the coordinates of the radio telescope (the point of intersection between the azimuthal and elevation axes) in the local coordinate system determined from observations in individual sessions. Analysis of the time series of coordinates of the observatory shows that they contain a noticeable seasonal component; disregarding it can distort the coordinate and velocity estimates for the station when using the standard (in such cases) linear model. Therefore, as the final result, we accepted the model of motion for the station that includes the linear (constant velocity) and seasonal (with an annual period) components. The derived parameters of motion for the radio telescope are given in Table 3.

It is interesting to compare our velocity estimates with the results of processing the GPS observations at the Svetloe Observatory (the SVTL Station of the GPS network) performed since 1996. These observations are processed weekly at the EPN Central Bureau (EUREF Permanent Network, http://www.epncb.oma.be/) and are then reprocessed at IAA using an improved technique (Panafidina and Malkin 2004). The results of our comparison are presented in Table 4, which also lists the velocities predicted by the two best known current models of tectonic (lithospheric) plate motion, NNR-NUVEL-1A (DeMets *et al.* 1994) and APKIM (Drewes 1998). The former was included in the standards of the International Earth Rotation Service (IERS Conventions 2003), which is a collection of astronomical and geophysical models recommended for use in astrometric and geodynamic invastigations that are based on the methods of space geodesy (McCarthy

Table 4. Velocity of the Svetloe Observatory from various data: geocentric (V_X, V_Y, V_Z) and topocentric (V_{East}, V_{North}, V_{Height}) components, mm yr^{-1}

Source	V_X	V_Y	V_Z	V_{East}	V_{North}	V_{Height}
This paper	-20.8 ± 1.8	14.5 ± 1.3	1.0 ± 3.0	22.9 ± 1.4	9.9 ± 2.1	-4.4 ± 2.7
GPS/SVTL	-18.4 ± 0.1	14.2 ± 0.1	5.0 ± 0.2	21.4 ± 0.1	10.2 ± 0.1	0.0 ± 0.2
NNR-NUVEL-1A	−18.2	14.0	5.0	21.2	10.2	0.0
APKIM	−19.8	14.5	5.7	22.4	11.5	0.0

Table 5. Baseline lengths between the Svetloe VLBI Station and other stations of the global VLBI network and rates of their change

Station	Baseline length, m (epoch 2004.0)	Rate, m yr^{-1}	Plate motion model	
			NUVEL	APKIM
ALGOPARK	$6\,255\,567.6432 \pm 0.0013$	0.0119 ± 0.0017	0.0146	0.0144
CRIMEA	$1\,810\,877.6098 \pm 0.0033$			
CTVASTJ	$5\,061\,439.8166 \pm 0.0046$			
DSS15	$8\,232\,230.0920 \pm 0.0006$			
DSS45	$1\,173\,4020.5392 \pm 0.0179$			
DSS65	$3\,192\,391.5697 \pm 0.0042$			
FORTLEZA	$8\,428\,008.6897 \pm 0.0024$	0.0104 ± 0.0025	0.0117	0.0123
GGAO7108	$6\,767\,247.5108 \pm 0.0509$			
GILCREEK	$5\,853\,689.1378 \pm 0.0018$	0.0091 ± 0.0024	0.0097	0.0079
HARTRAO	$8\,697\,010.3231 \pm 0.0085$			
HOBART26	$11\,933\,358.4939 \pm 0.0039$			
KASHIM34	$7\,173\,755.4455 \pm 0.0078$			
KOKEE	$9\,561\,115.3917 \pm 0.0020$	-0.0411 ± 0.0026	−0.0332	−0.0335
MATERA	$2\,373\,640.0962 \pm 0.0023$			
MEDICINA	$2\,139\,526.9543 \pm 0.0015$	0.0027 ± 0.0027	0.0000	0.0000
NOTO	$2\,808\,545.4672 \pm 0.0026$			
NYALES20	$2\,133\,122.9993 \pm 0.0010$	0.0009 ± 0.0013	0.0000	0.0000
ONSALA60	$1\,079\,812.9375 \pm 0.0007$	-0.0005 ± 0.0015	0.0000	0.0000
PARKES	$11\,633\,925.3378 \pm 0.0456$			
SESHAN25	$6\,760\,938.2588 \pm 0.0029$			
TIGOCONC	$11\,412\,934.0852 \pm 0.0069$			
TSUKUB32	$7\,140\,832.1261 \pm 0.0085$			
URUMQI	$4\,127\,151.1210 \pm 0.0036$			
WESTFORD	$6\,269\,171.0912 \pm 0.0044$			
WETTZELL	$1\,654\,774.8530 \pm 0.0010$	-0.0008 ± 0.0008	0.0000	0.0000
YEBES	$3\,129\,769.5995 \pm 0.0028$			
YLOW7296	$5\,807\,450.7585 \pm 0.0044$			

and Petit 2004). Note that the difference in the errors of the velocity from VLBI and GPS data can be explained mainly by a difference in the durations of the observations.

Comparing the various velocity estimates for the Svetloe Observatory, we can note their satisfactory agreement. The discrepancy in the horizontal velocity components is at the error level, while the discrepancy in the vertical velocity components slightly exceeds this level, although the observing period (2 years) for such studies is too short to draw firm conclusions. Undoubtedly, the estimates obtained will be improved significantly as the observations continue.

However, one might also expect a real difference in the vertical velocities of the observatory determined from different observational data attributable to the instability of the reference point of the RTF-32 radio antenna or the basement of the GPS antenna, which is mounted on the roof of the laboratory building. To elucidate this question, regular measurements on the mutual alignment of the VLBI and GPS antennas will be organized; for this purpose, a local geodetic network has been created at the observatory.

The results of determining the baseline lengths between the Svetloe Station and other stations of the global network are given in Table 5. For baselines with a sufficient number (more than ten sessions) and duration (more than 1 year) of observations, we also estimated the rates of change in the baseline lengths. For comparison, the table lists the rates predicted by the models of tectonic plate motion.

As an example, Fig. 3 shows the estimated change in the baseline lengths between the Svetloe RAO and four other IVS network stations located on different tectonic plates.

CONCLUSIONS

We analyzed the VLBI observations at the Svetloe RAO of the Institute of Applied Astronomy, Russian Academy of Sciences, performed over the first 2 years of participation of the observatory in international geodynamic programs. Basically, this is the first experience of full participation of Russian institutes in such studies, not counting the isolated experiments carried in the 1970s largely to demonstrate the potentialities of the VLBI method. Our analysis showed that the Russian observations and their processing have an up-to-date quality. Despite the relatively short observing period for such studies, scientifically significant results have already been obtained. The rate of change in the baseline lengths that we found is close to that predicted by current models of the global terrestrial crust tectonics. At the same time, the accuracy of currently available observations already approaches the discrepancy between the models, 1–2 mm yr^{-1}. This makes the continuation of studies in this direction of current interest.

It should be noted that we presented only the results obtained from observations at the Svetloe RAO, the first station of the Russian Quasar VLBI network. At the same time, VLBI observations have already been performed at the Zelenchuk RAO, which began the IVS observations in the summer of 2005. The construction and equipping of the Badary Observatory have also been completed; test VLBI observations will begin there late in 2005. Putting into operation these three stations, which constitute the first part of the Quasar VLBI network, will make it possible to perform not only full-value measurements of all the Earth's rotation parameters, but also important and interesting geodynamic and geophysical studies, such as the study of internal deformations of the Eurasian plate and its rotation. Since the VLBI method provides the most accurate (in terms of the random and systematic errors) measurements of baseline lengths, the accumulation of observational data at Russian VLBI stations is of crucial importance for many fundamental and practical applications.

REFERENCES

1. J. Boehm and H. Schuh, in *IVS 2004 General Meeting Proceedings, 2004,* Ed. by N. R. Vandenberg and K. D. Baver, NASA/CP-2004-212255, p. 277.
2. C. DeMets, R. G. Gordon, and D. F. S. Stein, Geophys. Res. Lett. **21**, 2191 (1994).
3. H. Drewes, in *Proceedings of the IAG Symp. No. 119: Geodesy on the Move,* Ed. by R. Forsberg, M. Feissel, and R. Dietrich (Springer-Verlag, Berlin, Heidelberg, 1998), p. 377.
4. A. M. Finkelstein, Nauka Ross. **5**, 20 (2001).
5. A. M. Finkelstein, A. V. Ipatov, S. G. Smolentsev, *et al.*, Pis'ma Astron. Zh. **29**, 752 (2003) [Astrn. Lett. **29**, 667 (2003)].
6. *IERS Technical Note No. 32*, Ed. by D. D. McCarthy and G. Petit (*Verlag des Bundesamts für Kartographie und Geodäsie*, Frankfurt am Main, 2004).
7. Z. M. Malkin and E. A. Skurikhina, Tr. Inst. Prikl. Astron., Ross. Akad. Nauk **12**, 42 (2005).
8. N. A. Panafidina and Z. M. Malkin, Tr. Inst. Prikl. Astron., Ross. Akad. Nauk **11**, 14 (2004).
9. L. Petrov and J.-P. Boy, J. Geophys. Res. **109**, 1 (2004).

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