THE FIRST RESULTS OF VLBI OBSERVATIONS AT THE SVETLOE OBSERVATORY IN THE FRAMEWORK OF THE IVS OBSERVING PROGRAMS

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ABSTRACT. In this paper results of the first 10 geodetic VLBI sessions observed at the Svetloe Radio Astronomical Observatory (SvRAO) of the Institute of Applied Astronomy (IAA) since March 2003 in the framework of the IVS observing programs after installation of Mark 3A terminal in cooperation with NASA. Analysis of observations has been performed at the IAA using OCCAM/GROSS software. The processing of the observations allowed us to determine with high accuracy both the coordinates of the SvRAO and Earth orientation parameters. It is also shown that including Svetloe observatory in the IVS network yields essential improvement of the accuracy of determination of the EOP. Obtained results show high quality of both observations and analysis made at the IAA.

1. INTRODUCTION

Svetloe Radio Astronomical Observatory (SvRAO) was founded by the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) as the first station of the Russian VLBI network QUASAR. It is located near Svetloe village in the Karelian Neck about 100 km towards North of St.Petersburg, and is primarily intended for regular VLBI observations in the framework of domestic and international programs on astrometry, geodynamics and space geodesy (Finkelstein, 2001).

Until the end of 2002 SvRAO was equipped with only terminal, Canadian S2, with Data Acquisition System developed at the IAA. Using this terminal, SvRAO participated in a number of VLBI programs in collaboration with other VLBI stations in China, Canada and Australia, also with the second IAA VLBI station, Zelenchukskaya, located in the North Caucasus.

In 2002, according to the Agreement between the RAS and NASA, Mark 3A terminal was installed at SvRAO, and since 2003 the observatory started regular VLBI observations in the framework of the IVS (International VLBI Service for Geodesy and Astrometry) astrometry and geodynamics programs. Starting in the regular IVS programs is a result of nearly 15 years of efforts by the IAA, and this is a major milestone for us.

2. VLBI EQUIPMENT OF THE SVRAO

The basic instrument of the SvRAO is a new generation fully steerable radio telescope with homology backup structure. Quasi-paraboloid main dish has diameter of 32 m and focal length of 11.4 m, and the secondary mirror is an asymmetrical modified hyperboloid with the diameter of 4 m. Radio telescope has two operational slewing velocities: fast (azimuth speed $1.5\,^\circ$/s , elevation speed $0.8\,^\circ$/s) and slow (azimuth speed $1.5'$/s, elevation speed $0.8'$/s). Cable system provides azimuth range $\pm 270^\circ$ of North direction and elevation range (-5° — $+90^\circ$).

The radio telescope is equipped with 5 low-noise cooled receivers with HEMT amplifiers for wavelengths 1.35, 3.5, 6.0, 13 and 18/21 cm for observations in the left and right circular polarizations (Ipatov *et al.*, 1994). To provide the low noise temperature of the "radio telescope — radiometer" system not higher than 50–70 K some input lines of all bandwidth have to be cooled at 20 K. The micro-cryogenic closed circle refrigerators are used for the cooling of low noise amplifiers of all ranges at 20 K.

To be able to switch frequency band and provide multi-band observations quasi simultaneously, the input horns for different wavelengths are located above the circle of 3-meter diameter and the fast switching is achieved by turning of the secondary mirror at certain angle around the radio telescope axis. To maintain simultaneous receiving at the S and X bands in both orthogonal polarizations (to eliminate ionosphere effects), which is essential for realization of astrometric, geodynamical and geodetic programs, the special combined horn has been constructed. The working ranges of intermediate frequencies of these cryo electronic radiometers are 130–480 MHz and 130–890 MHz for X and S bands correspondingly. The noise temperature at the input of cryostat is 15 K and total noise temperatures of "radio telescope — radiometer" system are not higher 50 K for S band and 70 K for X band at the elevations above 20°.

The signal from the radiometer output is transmitted along the phase stable coaxial lines connecting the focal cabin of radio telescope with 14-channel Mark 3A terminal located at the laboratory building. The registration is fulfilled on the magnetic tapes with the use of 24-track tape recorder Honeywell. One tape is provided the tape recording of 18-24 hours of observations depending on program.

Svetloe VLBI site is provided with a qualitative system of time-frequency synchronization, consisting of 4 H-masers with long-time stability about $(3 - 5) \times 10^{-15}$. One H-maser operates constantly and each other can be switched on during one hour and will achieve all nominal technical parameters during 24 hours. The synchronization of the local time scale with Universal Time is realized with the use of GPS and GLONASS receivers with the accuracy (30–50) ns.

The phase calibration system — generator of picosecond impulses includes two basic units: pulse generator of harmonics on semiconductor diode and circuit producing 1 MHz reference signal with rectangular wavefront from the harmonic signal with the frequency of 5 MHz provided by the H-maser. The measurement of the delay of 5 MHz reference signal in cable system is provided by phase comparator.

Automatic meteorological data system measures atmospheric pressure, direction and velocity of wind, temperature and humidity of air. These data are recorded in log-file of the media.

All systems of the radio telescope are united in general complex with the help of central computer with specialized software, permitting the automatic carrying out of observations. The basis of this software is the Mark IV Field System, Version 9.5.17, being the international standard for VLBI (Himwich, 2000). It was added by site-oriented interface for the control of dish, radiometers and radiometric registration. Software for this interface was developed in Linux media with the use of SNAP language fully integrated in FS media for VLBI and single dish modes.

3. OBSERVATIONS AND RESULTS

The first regular IVS session at Svetloe was observed on March 6, 2003 (Finkelstein *et al.*, 2003). To Sep 1, 2003 Svetloe participated in 14 IVS sessions — 10 R4 sessions (determination of EOP), 3 TRF sessions (improvement of the terrestrial reference frame), 1 EURO session (investigation of crustal deformations in Europe). Four R4 sessions were not correlated in time because of delay in tape delivering due to customs problems. List of sessions and related statistics are presented in Table 1.

Table 1: VLBI sessions observed at Svetloe in March–August 2003.

Session code	Date	Number of stations	Number of sources	Number of scans	Number of observations
R4061	Mar 6	8	36	313	2373
T2015	Mar 18	7	44	348	2079
R4063	Mar 20	8	34	332	2902
R4065	Apr 3	8	44	322	2305
T2016	Apr 8	7	38	231	1067
R4069	Apr 29	8	47	340	2693
EURO68	May 6	9	53	324	5433
T2017	May 20	8	54	542	1985
R4073	May 29	8	54	399	2306
R4075	Jun 12	5	43	203	658
R4079	Jul 10	correlated without Svetloe			
R4081	Jul 24	correlated without Svetloe			
R4083	Aug 7	correlated without Svetloe			
R4085	Aug 21	correlated without Svetloe			
Total		22	94	3354	23801

Schedule files for these sessions were prepared at the NASA Goddard Space Flight Center (GSFC) for the R4 program, and at the Geodetic Institute of the University of Bonn for the T2 and EURO programs.

Correlation of the observations was made at the USNO correlator, except two sessions EURO68 and T2017 which was correlated at the Bonn correlator. The processing factor which is equal to ratio of correlation time to session duration was between 1.0 and 4.2 depending on quality of data and number of stations. The time delay between observations and availability of correlated data was 10–14 days for R4 sessions and ≈2–4 months for T2 and EURO sessions.

During those 10 IVS sessions observed with the participation of SvRAO 23801 observations were obtained, 20596 of them are good, i.e. suitable for scientific analysis. These observations were obtained at 22 VLBI stations, and 113 baselines of length from 99 km (DSS65–YEBES) to 12,496 km (DSS45–YEBES). Station statistics is presented in Table 2.

Scientific analysis of observations has been performed at the IAA using OCCAM/GROSS software (Malkin *et al.*, 2000). The analysis was aimed to compute accurate coordinates of Svetloe radio telescope reference point and the EOP, in accordance with the goal of the corresponding IVS programs. A priori coordinates of the Svetloe radio telescope were obtained from the processing of the GPS observations collected at the permanent GPS station SVTL installed at Svetloe, and geodetic survey on the local geodetic network (Smolentsev *et al.*, 2001). Geocentric coordinates of the Svetloe radio telescope reference point obtained at the IAA are presented in Table 3.

Coordinates are referred to the ITRF2000 at epoch 2003.30. For this computation coordinates of all stations except Svetloe were fixed to VTRF2003 values with only exception of

Table 2: List of participating stations (D – distance from Svetloe, Nsess –number of sessions, Nobs – number of observations, Ngood – number of good observations, Nav – average number of observations per session, Pg – percentage of good observations).

Station	Location	D	Nsess	Nobs	Ngood	Nav	Pg
ALGOPARK	Canada	6256	6	3749	3412	569	91.0
CRIMEA	Ukraine	1811	3	968	779	260	80.5
DSS45	Australia	11734	1	505	401	401	79.4
DSS65	Spain	3192	1	1269	1158	1158	91.3
FORTLEZA	Brazil	8428	7	2359	2099	300	89.0
GGAO7108	USA	6767	2	91	47	24	51.6
GILCREEK	USA, Alaska	5854	5	3658	3446	689	94.2
KASHIM34	Japan	7174	1	608	513	513	84.4
KOKEE	USA, Hawaii	9561	6	2789	2516	419	90.2
MATERA	Italy	2374	9	6183	4973	553	80.4
MEDICINA	Italy	2140	2	2069	1771	886	85.6
NOTO	Italy	2809	1	1420	1227	1227	86.4
NYALES20	Norway, Spitsbergen	2133	6	5103	4585	764	89.8
ONSALA60	Sweden	1080	1	1396	1135	1135	81.3
SESHAN25	China	6761	1	569	492	492	86.5
SVETLOE	Russia	—	10	5671	4866	487	85.8
TSUKUB32	Japan	7141	2	1321	1165	583	88.2
URUMQI	China	4127	2	1116	823	412	73.7
WESTFORD	USA	6269	1	283	204	204	72.1
WETTZELL	Germany	1655	7	4844	4284	612	88.4
YEBES	Spain	3130	2	1427	1100	550	77.1
YLOW7296	Canada	5807	1	204	196	196	96.1

Table 3: Svetloe coordinates at the epoch 2003.30 aligned to ITRF2000.

Analysis center	X, m	Y, m	Z, m
IAA	2730173.850	1562442.667	5529969.064
	±1	±1	±2
VTRF	.850	.668	.071
	±3	±2	±6
MAO	.838	.670	.070
	±2	±1	±3
GSFC	.849	.666	.063
	±1	±1	±2

coordinates of the station Gilmore Creek which was corrected for the jump in station position due to the earthquake happened in November 2002 resulted in station displacement of about 6 cm.

For comparison, coordinates given in the IVS reference system VTRF2003 (Nothnagel, 2003), and those computed at the Main Astronomical Observatory (MAO), Kiev, Ukraina (Bolotin, 2003) are also given in Table 3. New GSFC estimate of Svetloe coordinates obtained and kindly provided by Daniel MacMillan (personal communication) is also included in the Table.

Solutions IAA (present work), MAO and GSFC are obtained from processing of 10–11 observing sessions, VTRF solution is obtained by means of Helmert transformation of the GSF2002B solution (Nothnagel, 2003), which, in turn, was computed using observations of only one IVS session at Svetloe. For this reason accuracy of the VTRF coordinates of Svetloe is much worse than for other solutions. However, it is the official IVS reference frame.

During the analysis we also computed baseline length for all participated stations. Of course, especially interesting for us were baselines including Svetloe station. They are shown in Table 4.

Table 4: Baseline lengths (E – formal error, R – repeatability).

Baseline Svetloe —	Number of sessions	Length, m	E, m	R, m
ALGOPARK	6	6255567.6332	0.0022	0.0025
CRIMEA	2	1810877.6189	0.0035	0.0049
DSS45	1	11734020.5530	0.0169	
DSS65	1	3192391.5652	0.0034	
FORTLEZA	7	8428008.6707	0.0037	0.0075
GGAO7108	1	6767247.5654	0.1350	
GILCREEK	5	5853689.1323	0.0021	0.0061
KASHIM34	1	7173755.4896	0.0110	
KOKEE	6	9561115.4135	0.0035	0.0061
MATERA	9	2373640.0976	0.0011	0.0019
MEDICINA	2	2139526.9600	0.0024	0.0055
NOTO	1	2808545.4754	0.0031	
NYALES20	6	2133122.9961	0.0011	0.0016
ONSALA60	1	1079812.9364	0.0026	
SESHAN25	1	6760938.2673	0.0103	
TSUKUB32	2	7140832.1563	0.0043	0.0003
URUMQI	2	4127151.1133	0.0043	0.0018
WESTFORD	1	6269171.0929	0.0137	
WETTZELL	7	1654774.8541	0.0010	0.0006
YEBES	2	3129769.6024	0.0043	0.0044
YLOW7296	1	5807450.7252	0.0163	

It should be mentioned that in 2003 station Svetloe was included in the IVS network as tagged along station. i.e supplementary to the regular IVS R4 network. Figure 1 show a typical configuration of the R4 network in 2003. One can see that Svetloe is located near other european stations, and thus does not strengthen substantially the network geometry. So, no significant improvement of the results obtained at the R4 network can be expected after inclusion of Svetloe. Nevertheless, we tried to estimate how it influences the accuracy of EOP results (the main goal of the IVS R4 program).

Estimates of pole coordinates X_p, Y_p, Universal Time $UT1$, and nutation angles $\Delta\psi$ and $\Delta\varepsilon$ were computed both for whole network and for reduced network without Svetloe (Table 5).

Obtained results show that inclusion Svetloe in the IVS network yields substantial improvement in quality of results. Hopefully, planned participation of Svetloe observatory in IVS programs as regular station will allow us to realize more substantial progress in the accuracy of determination of EOP and TRF, and make a valuable contribution to other geodesy and astrometry investigations.

Figure 1: Typical network for IVS R4 experiments.

Table 5: EOP differences with the IERS C04 series (X_p, Y_p — pole coordinates, $UT1$ — Universal Time, X_c, Y_c — celestial pole offset).

EOP	All sessions				R4 (EOP) sessions			
	with Svetloe		w/o Svetloe		with Svetloe		w/o Svetloe	
	bias	wrms	bias	wrms	bias	wrms	bias	wrms
X_p, μas	-233	127	-219	151	-244	74	-224	92
Y_p, μas	378	141	402	148	367	134	390	134
$UT1$, μs	-79	52	-75	53	-87	16	-82	20
X_c, μas	10	37	-2	69	16	27	10	27
Y_c, μas	4	76	-18	95	-11	60	-29	74

Table 6: EOP formal errors (X_p, Y_p — pole coordinates, $UT1$ — Universal Time, X_c, Y_c — celestial pole offset), and other statistics (σ_0 — post-fit rms, C_{max} — maximum correlation between EOP).

EOP	All sessions		R4 (EOP) sessions	
	with Svetloe	w/o Svetloe	with Svetloe	w/o Svetloe
$\sigma(X_p)$, μas	140	169	110	120
$\sigma(Y_p)$, μas	120	146	80	83
$\sigma(UT1)$, μs	56	73	37	44
$\sigma(X_c)$, μas	74	83	60	61
$\sigma(Y_c)$, μas	79	91	63	65
σ_0, ps	44	47	32	34
C_{max}	0.84	0.84	0.64	0.71

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