Co-location of Space Geodetic Techniques at the “Quasar” VLBI Network Observatories

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Abstract The current status of the co-location of space geodetic techniques at the observatories of the “Quasar” VLBI network is considered. The main technical characteristics, co-located high-precision observational instruments, and their systems as well as some results of sessions are presented.

Keywords VLBI, SLR, GNSS, DORIS, co-location

1 Co-location stations of the “Quasar” VLBI Network

The “Quasar” VLBI network is a unique astronomical instrument in Russia created in the Institute of Applied Astronomy. The network consists of three radio astronomical observatories—Svetloe near St. Petersburg, Badary in Eastern Siberia, and Zelenchukskaya in the North Caucasus attached to the Correlation processing center in St. Petersburg (Figure 1). All observatories have been linked by optical fiber lines with 1 Gb/s average data transfer rate, providing operational determinations of Universal time in e-VLBI mode.

2 VLBI Systems

The main instrument in each of three observatories is a 32-m radio telescope (RT-32), which provides a completely automatic process of observing the radio sources and satellites. The main technical characteristics of the antennas are presented in Table 1. Sessions can be carried out both in radiometric mode, when the telescope is working alone, and in radio interferometric mode, when several telescopes operate synchronously in the same network. The data obtained by the “Quasar” VLBI network are equivalent to the space-time resolution of a radio telescope having a mirror diameter of about 5,000 km. One of the fundamental problems solved by using the “Quasar” VLBI network is a high-precision monitoring of the Earth’s rotational irregularity. The data obtained by “Quasar” are used for implementation of a number of space projects, including support of the operation of global navigation satellite systems GLONASS.

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Table 1 RT-32 specifications.

Configuration	Cassegrain (with asymmetrical subreflector)
Mount	AZEL
Main reflector diameter	32 m
Subreflector diameter	4 m
Focal length	11.4 m
Azimuth range	$\pm 270°$ (from south)
Elevation range	from $-5°$ to $95°$
Max. velocity AZ	0.83 °/s
Max. velocity EL	0.5 °/s
Pointing accuracy	$< 10''$
Frequency range	1.4–22 GHz

The radio telescopes meet all the international standards and work as part of the global radio interferometric networks. The observatories have actively participated in both international (IVS, EVN) and domestic (Ru) observation programs since 2006. Activities of the observatories in VLBI programs in 2013 are presented in Table 2.

Fig. 1 Co-location stations of the "Quasar" VLBI Network.

Table 2 VLBI observations in 2013.

Programs		**Svetloe**		**Zelenchukskaya**		**Badary**	
		days	sessions	days	sessions	days	sessions
IVS	24h	29	29	31	31	31	31
	1h	1.5	36	–	–	–	–
EVN		16.5	75	16.2	78	15	73
Ru	24h	48	48	48	48	48	48
	1h	0.9	23	14.7	353	14.3	344

3 The Combined GNSS Receivers and the DORIS Antenna

The combined GNSS (GPS/GLONASS/Galileo) receivers have performed continuous observations in the framework of IGS global and European permanent networks since 1996, sending the observational data in daily and hourly regimes. In 1991, the DORIS equipment was installed at Badary observatory. The same year, the station (BADA) was included in the International DORIS Service (IDS). Receiving and pre-processing of radio signals is performed on satellites of the DORIS system.

4 SLR Systems

The new satellite laser ranging systems "Sazhen-TM" by "Precision Systems and Instruments" company were installed at all observatories of the "Quasar" Network in 2011. SLR is designed to obtain high-precision range and angular coordinates of geodetic and navigation satellites (Lageos 1, Lageos 2, GLONASS, etc.). The optical mounts of SLR systems were installed on concrete pillars inside of specially built towers covered with the "Astro Haven" dome. The towers are 2–4 m in height and are located at distances 2–35 m from the laboratory buildings of the observatories. These locations provide a full view in all azimuths at elevations more than 20°. Electronic blocks of the SLR systems, including the equipment for laser pumping, control and management, are installed in laboratory buildings of the observatories. The main technical characteristics of the “Sazhen-TM” system are presented in Table 3.

Table 3 “Sazhen-TM” specifications.

Ranging distance (night)	400–23000 km
Ranging distance (day)	400–6000 km
Aperture	25 cm
Wavelength	532 nm
Beam divergence	5″
Laser pulse frequency	300 Hz
Laser pulse width	150 ps
Pulse energy	2.5 mJ
Mass	120 kg
Normal points precision	1 cm
Angular precision	1–2″

All stations of the “Quasar” Network joined ILRS in 2012. Activities of SLR stations in 2013 are presented in Table 4.

5 Observatories Equipment

All of the observatories are equipped with the identical time standards and meteorological stations which are used when carrying out all types of observations. The automatic digital weather transmitter “Vaisala” is used to obtain meteorological data in real time. A water vapor radiometer being designed at the Institute of Applied Astronomy is currently working at the Svetloe observatory. It is planned to equip all stations with the analogous radiometers. The water vapor radiometer is designed to measure the effective radiation temperature of the atmosphere.

6 Co-located Instruments of the Observatories

These days, each observatory of the “Quasar” network is supplied with at least three co-located instruments of different techniques: VLBI, GPS/GLONASS, SLR and DORIS (Table 5). The Svetloe and Zelenchukskaya observatories are the co-location stations with three types of high precision space geodetic instruments, while the Badary observatory is one of those few stations with four types of instruments.

The status of the observatories as the stations of different global and continental space geodetic networks is presented in Table 6.

7 Reference Points of Instruments

The local geodetic network of the observatory is designed for monitoring the displacement of radio telescope reference points and GPS antennas caused by constructions deformation and local ground motions. Local tie parameters between reference points of the VLBI antenna (intersection of axis taking into account axis offset), SLR system (intersection of axis taking into account height of the system mount), GNSS, and DORIS antenna markers were determined with about 2 mm accuracy. Consistency of VLBI- and GNSS-derived coordinates with local geodetic measurements is about 5 mm. As a result, all three observatories were approved to be included in the list of GGOS Legacy Co-location Sites, which means that they were acknowledged as operational, well calibrated systems with episodic intersystem vector determinations. Values of eccentricity vectors from GNSS markers to VLBI antenna reference points are presented in Table 7.

8 Radio Interferometer of New Generation

Under the state program of VLBI network “Quasar” modernization, construction of two 13-m radio telescopes (RT-13) are planned up to 2015 of the new generation (at the Zelenchukskaya and Badary observatories) for operational and high-precision polar coordinates and Universal Time data support of the GLONASS system, and for communication with the international VLBI network and other international agencies. Construction of the new 13.2-m radio telescopes have already begun at the Badary and Zelenchukskaya observatories. The main specifications of the RT-13 antenna system are presented in Table 8. These new antennas will meet all requirements of the VGOS program.

Table 4 SLR observations in 2013.

Observatory	GLONASS, etc		Lageos 1 and 2		Total	
	sat. passes	NP	sat. passes	NP	sat. passes	NP
Badary	1100	10285	178	1145	1278	11430
Zelenchukskaya	581	3468	163	1254	744	4722
Svetloe	234	2215	119	825	353	3040

Table 5 Observatories' co-located instruments.

Technique	Svetloe	Zelenchukskaya	Badary
VLBI	Radio telescope with 32-m antenna (circular polarization L, C, S\X, K cryogenic receivers, Mark 5B+ recorder, DAS P1002M)		
GNSS	Javad GNSS Delta-G3T (Javad RingAnt-DM)		
	Topcon GNSS NET-G3 (Choke Ring CR-G3)		
SLR	"Sazhen-TM" (25-cm aperture, 300 ps pulse, 300 Hz)		
DORIS	–	–	DORIS Beacon model 3.0 (Starec 52291)
Other equipment	Time synchronization system (Active Hydrogen Maser VCH-1003M)		
	Vaisala WXT 510 automatic digital weather transmitter		
	Water vapor radiometer		

Table 6 Global and regional network stations.

Technique	Network	Svetloe	Zelenchukskaya	Badary
VLBI	IVS	Sv(2003)	Zc(2005)	Bd(2006)
	EVN	7380(2003)	7381(2005)	7382(2006)
GNSS	IGS	SVTL(2004)	ZECK(1997)	BADG(2001)
	EPN			
SLR	ILRS	1888(2012)	1889(2012)	1890(2012)
DORIS	IDS	–	–	BADB(1992)

Table 7 Eccentricity vectors VLBI-GNSS.

Difference	Sv-SVTL	Zc-ZECK	Bd-BADG
ΔN	-57.5932 ± 0.002 m	-64.7489 ± 0.003 m	61.8824 ± 0.002 m
ΔE	58.4824 ± 0.002 m	7.9544 ± 0.003 m	-73.4973 ± 0.002 m
ΔH	9.3495 ± 0.003 m	8.7813 ± 0.003 m	10.2001 ± 0.002 m

Table 8 RT-13 specifications.

Manufacturer	Vertex Antennentechnik GmbH
Mount	alt-azimuth
Main reflector diameter	13.2 m
Azimuth speed	12 °/s
Elevation speed	6 °/s
Tracking accuracy	16 arcsec
Frequency range	2–40 GHz
Surface accuracy	0.2 mm

9 Conclusion

Implementation of the new technologies and the improved procedures allows the “Quasar” VLBI Network observatories to achieve the status of the “New Technology Sites”, which implies that we strive for millimeter level accuracy in our data products.