STAGES OF DEVELOPMENT OF STATIONS, NETWORKS AND SLR USAGE METHODS FOR GLOBAL SPACE GEODETIC AND NAVIGATION SYSTEMS IN RUSSIA

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At the first stage, there were developed experimental stations with ruby lasers, that allowed, in addition to laser ranging of low-orbit spacecraft with laser reflectors, to perform first laser ranging of geostationary satellites "Raduga-1 and -2" in 1976 and laser ranging of "Lunokhod-2" to determine its selenographic coordinates in 1973.

A network of 20 SLR stations "Sazhen-2" (with YAG lasers) was developed and brought to operation in 1985-1988 for astronomy-geodetic stations working with "GEOIK" geodetic S/C. In the same period of time (1980-1985), one of the world's largest optical-laser stations with two 1.1-m telescopes was developed and brought to operation on Maidanak Mountain with the best astronomical climate on Eurasian continent.

Routine use of SLR stations for GNSS first started after a network of 4 SLR stations "Sazhen-S" was created in 1987-1990 for calibration (removal of systematic errors) of the 1-st generation of "GLONASS" satellites radio systems.

Starting 1991, Russian SLR stations participate in geodetic and geodynamic projects of ILRS; coordinates of 3 stations (Altai, Baikonur, Komsomolsk-on-Amur) were used as reference ones in the International Terrestrial Reference Frame.

In the interests of the second generation of "GLONASS-M" S/C, stationary SLR stations with improved accuracy "Sazhen-T" were developed and brought to operation at stations near Moscow, at Altai optical-laser center and at Baikonur launch facility in 2000-2006.

For expansion of geographic coverage and improvement of climate resistance of Russian SLR network, in 2005 there was developed and serial production started of a compact, modular, fast-deployable SLR station "Sazhen-TM" with sub-centimeter accuracy, that became a foundation for modern Russian geodetic and navigation SLR networks. Three such stations were deployed at three VLBI stations of the Institute of Applied Astronomy RAS and they form collocation nodes together with GLONASS, GPS and DORIS receivers. One more station was brought to operation in Brasilia, Brazil, in June 2014.

In 2012, the authors proved and started implementation of the "Laser GLONASS" concept based on use of laser counter-measurements of pseudorange in the lines "satellite-satellite" and parallel measurements of pseudorange and range in the lines "ground-satellite" for improvement of accuracy of time and frequency support for "GLONASS" S/C.

Space experiments performed on 3 "GLONASS-M" S/C confirmed subnanosecond accuracy of determination of difference in time scales between space and ground standards of time and frequency.

For high-accuracy civilian navigation using PPP (Precise Point Positioning), it is necessary to create a global network of one-way radio stations with improved accuracy characteristics for calculation of high-accuracy ephemeris-time information in real time. For geodetic support and metrological check of accuracy of ephemeris-time information broadcasted by navigation S/C, it is necessary to have a global network of precise SLR stations with millimeter level of accuracy.

Development of such SLR station "Tochka" was started in 2013, with scheduled delivery of a test model in 2015. This station will make round-the-clock precise laser measurements of range and pseudorange.

It is evident that instruments necessary for solution of the above mentioned problems of improvement of global navigation accuracy are the same as the instruments necessary for achievement of goals of the global geodetic system GGOS, which is an important synergy factor for accelerated expansion of the global SLR stations, radio stations and their collocation.

A direction of satellite laser ranging using diffusive-reflective surfaces of S/C without reflectors was developing starting 2005 in the interests of space objects and space debris monitoring in parallel with SLR of retroreflector-equipped S/C. In 2010 there was completed development and state testing of the Laser Optical Ranger of the System for Monitoring of Space (LOR SMS) at Northern Caucasus. This is one of the world's most powerful solid-state laser rangers with energy potential that is at least five orders of magnitude higher than one of a regular SLR station working with retroreflectors. This ranger can work at lunar distances with a panel of retroreflectors, which was confirmed during laser ranging of radio astronomy satellite "Spektr" equipped with "GLONASS" S/C – type laser reflector array at distances up to 330,000 km.

Development of the lunar laser ranger based on 3.12m telescope at Altai optical laser center, for precise calculation of lunar ephemeris in the interests of GNSS "GLONASS", was started in 2014.