New face of the Borowiec Satellite Laser Ranging Station

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SLR, laser, satellite tracking, space debris tracking, SST, BORL, BOR1, GGOS, GNSS

Abstract

Borowiec Satellite Laser Ranging Station (7811-BORL) belongs to the Space Research Center of the Polish Academy of Sciences (SRC PAS). Due to serious failure of the laser BORL station was offline for several years since March 2010. In the year 2014 the Borowiec SLR system was modernized. In the first step a new optics was replaced in the transmitting-receiving telescope including primary and secondary mirrors of the telescope and dielectric mirrors transferring laser pulse from laser unit to telescope. In the next step two high-energy Nd:YAG pulse laser modules were installed, the standard unit used for laser observations of all satellites equipped with retroreflectors (EKSPLA PL-2250) and high-energy module (Continuum Surelite III) dedicated to laser observations of space debris. Both lasers are fully operational. And finally, a high-speed start Si photodiode FDS025 was exchanged, working in the range 400-1100 nm. The other elements of the system were not changed. In April 2016 BORL station successfully completed quarantine procedure and all results of the station were released to the public area after February 1, 2016. BORL station works at night mode and tracks all LEO satellites from ILRS list + L1/L2. Station is very active in the frame of Space Debris Study Group (SDSG). In the last few months, Borowiec has participated in several campaigns of space debris objects like ENVISAT, TOPEX/Poseidon and JASON-1. At presents, new campaigns are in progress (e.g. OICETS, ERS). Moreover, a few typical rocket bodies were observed as well. Some sample results will be presented for both laser modules.

Other new fact is that since 2015 BORL team is responsible for management of permanent geodetic GNSS BOR1 station belonging to SRC PAS. In the period 2015-2016, during the modernization of BORL station also the major changes in an activity of BOR1 station were performed. BOR1 station supports IGS and EUREF networks since 1996. The modernization of BOR1 station covered a receiver and an antenna exchange. At present BOR1 station collects signals from GPS, GLONASS, GALILEO, BEIDOU and EGNOS navigation systems that together with SLR technique significantly increases effectiveness and enhance a role of the Borowiec Astrogeodynamic Observatory in the frame of Global Geodetic Observing System (GGOS).

Introduction

Since March 2010 BORL station was offline due to laser damage. It quickly turned out that laser could not be repaired and the only solution was to buy a new device. In 2013 the Space Research Center of PAS received a financial support from Ministry of Science and Higher Education in terms of large research infrastructure. On December 12, 2013 in Borowiec Astrogeodynamic Observatory has appeared a new laser. The amount of obtained subsidy enabled to buy two laser modules, one dedicated to typical tracking of all satellites from ILRS list (EKSPLA PL-2250) and second dedicated to laser tracking of space debris targets (Continuum Surelite III).

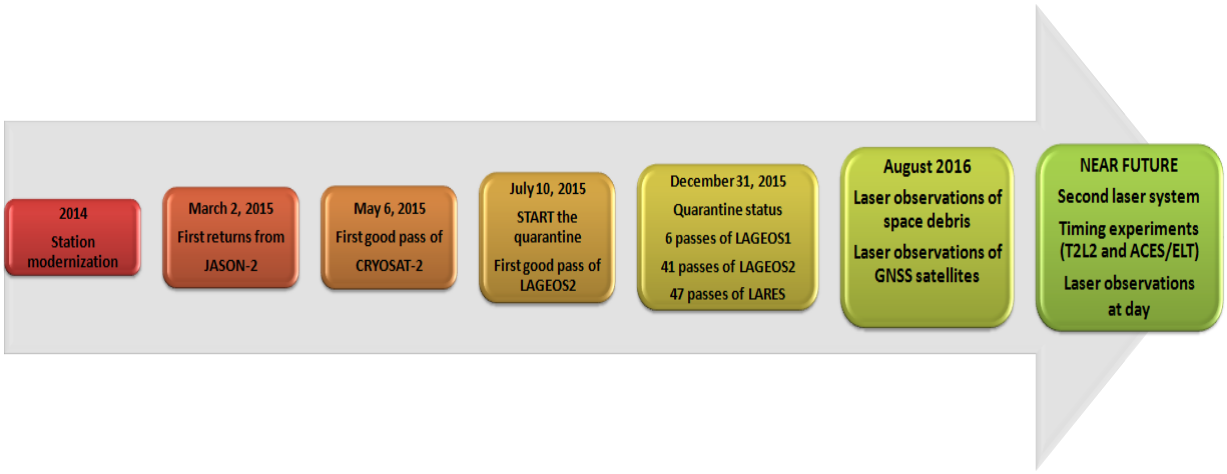

Fig.1 BORL time axis 2014-2016.

The whole year of 2014 was devoted to modernization of BORL's satellite laser ranging system. At the end of 2014 first observational tests with new laser were performed. On March 2, 2015, after 1804 days of break, BORL station gained returns from satellites. First tracked object was JASON-2 and first good observation was registered on May 6, 2015 and it was CRYOSAT-2. BORL station was ready for quarantine procedure which has started on July 10, 2015. The last two and a half years of BORL station activity presents Fig. 1.

Fig.2 General view of BORL station after modernization.

The modernization of BORL station essentially concerns the laser exchange, transmitting-receiving telescope optics exchange (primary and secondary mirrors) and dielectric mirrors of Coudé path exchange. Fig.2 shows the new look of BORL station after modernization. Additionally, a high-speed start Si photodiode FDS025 was exchanged, working in the range 400-1100 nm. The other elements of the whole SLR system were not changed.
Since 2015 Borowiec laser team is responsible for coordination and management of geodetic BOR1 station located at SRC PAS Borowiec Observatory. BOR1 station is placed roughly 78 meters from BORL station (Fig.3). The station BOR1 has been integrated with the International GNSS Service (IGS) and EUREF Permanent Network (EPN) networks since 1996 and today it is one of 504 stations worldwide and one of 175 Multi-GNSS stations.

Fig.3 General view of BOR1 and BORL stations.

It is also one of a core station of the polish geodetic ASG-EUPOS (Aktywna Siec Geodezyjna-EUropean POsition determination System) network established by the Head Office of Geodesy and Cartography in Poland. BOR1 station delivers high quality and outstanding international

reputation data. BOR1 makes a valuable contribution to global geodesy and related research in the frame of IGS. The data delivered by BOR1 are used for precise orbit computation for several top centers: Center for Orbit Determination Europe, Bern (Switzerland), GFZ – IGS Processing Centre, (Germany), JPL – IGS/FLYNN Processing Centre, Pasadena (USA), Massachutets Institute of Technology and Scripps Institution of Oceanography (USA). The task realized by BOR1 station fit into development of the Global Geodetic Observing System (GGOS) what essentially increases the role of BOR1 station in global geodesy.

BORL station modernization

In 2013 two new Nd:YAG 10 Hz lasers were bought. First, Lithuanian EXPLA PL-2250 is a standard unit used for laser tracking of all ILRS satellites. Second, a high-energy module American Continuum Surelite III dedicated to laser observations of space debris within Space Surveillance and Tracking (SST) programme, developed by European Space Agency (ESA) and European Commission (EC). The lasers were installed at the end of 2013 and at the beginning of 2014. Both lasers are fully operational (Fig.4). In Table 1 the main parameters of the laser modules are given.

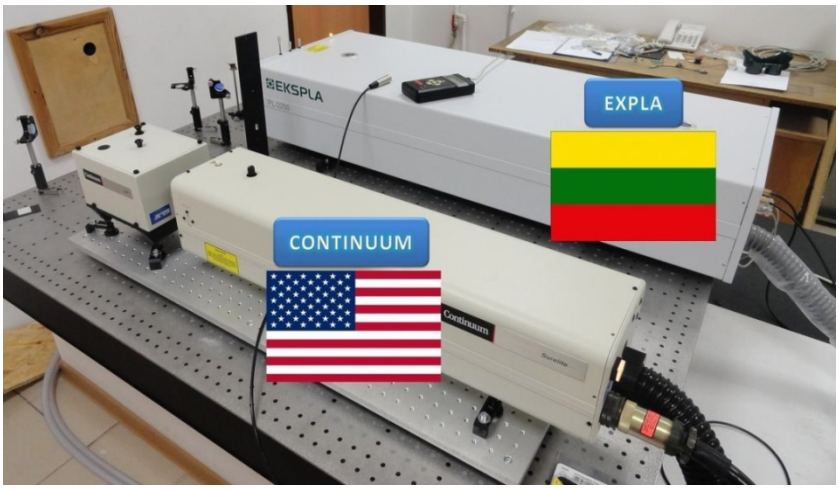

Fig.4 New lasers in Borowiec.

Table 1. The main parameters of BORL's lasers.

Parameter	**EKSPLA PL-2250**	**Continuum Surelite III**
Stand	Optical table	Optical table
Frequency	10 Hz	10 Hz
Pulse energy	0.05 J	0.45 J
Pulse length	60 ps	4 ns
Peak power	833 MW	112.5 MW
Average power	0.5 W	4.5 W

The laser beam from both modules is transmitted through the same Coudé path to the telescope and to the transmitting telescope tube.
Additionally, new optics was replaced in the transmitting-receiving telescope including primary and secondary mirrors of the telescope (Cassegrain system), presented in Fig. 5 and all dielectric mirrors from Coudé path transferring laser beam from lasers to the telescope. The sample mirror is shown in Fig. 6.

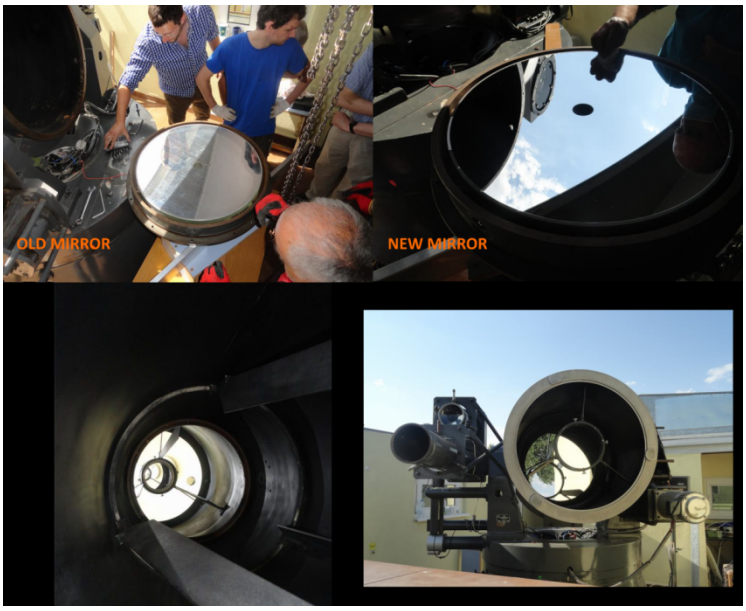

Fig. 5 New optics of the BORL's telescope.

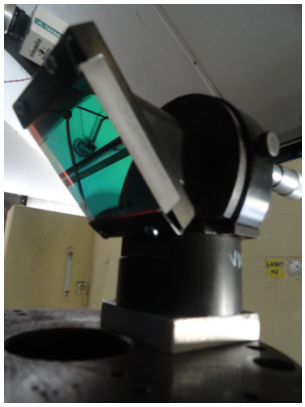
Fig. 6 A new dielectric mirror of optical path.

New laser system at Borowiec

Since 2016 SRC Borowiec station works on running a second independent laser system based on 65 cm Cassegrain telescope. AzEl mount will be driven by industrial CNC servo drive with high resolution encoders control loop (Fig.5). Service and control software are being evaluating.

Complete tool system will have component such: visualisation in real and simulate time mode, SQL objects data base, history and charts of orbital parameter, planning and observation acquisition, system calibration, ADSB monitoring, data post-processing and other functions. The system will operate 24 hours a day, 7 days a week (Fig.6). In 2016 software was in a beta version (now is transferred to UNIX platform on dedicated x3650 IBM system).

Fig.5 Second independent satellite laser system developed by SRC BORL.

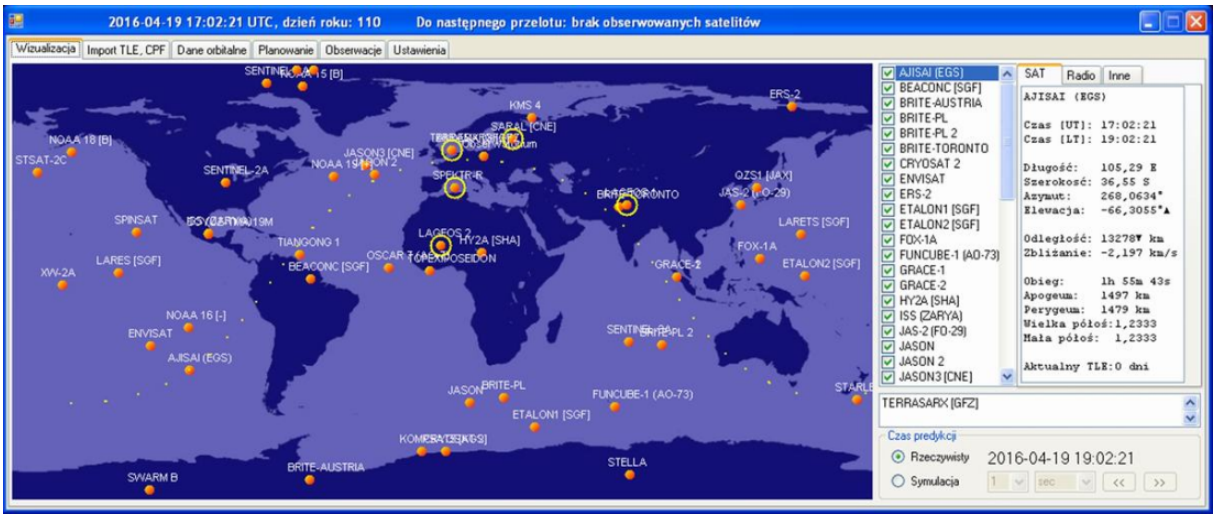

Fig.6 Screen from service-control software dedicated for new laser system.

Quarantine procedure

On July 10, 2015 BORL station has started ILRS quarantine procedure. According to the Station Change Quarantine Procedure (SCQP) at least 20 good LAGEOS-1 and -2, and LARES passes within a 60-day sliding window are required. On April 26, 2016 BORL station successfully completed quarantine procedure provided by ILRS' Analysis Standing Committee (ASC). All results collected by BORL from February 1, 2016 were released to the public area. The

quarantine bias report obtained from Joint Center for Earth System Technology/Goddard Space Flight Center (JCET/GSFC) NASA confirmed high quality of the observations of LAGEOS-1 and LAGEOS-2 provided by BORL station (Fig.7). The mean Range Bias was 11.0 mm for L1 and 12.0 mm for L2, respectively.

L1 78113802	PREC EST [mm]	RANGE BIAS [mm]
Mean	3.7	11.0
STD	1.6	15.6
RMS	4.0	18.7
Point	17	17

L2 78113802	PREC EST [mm]	RANGE BIAS [mm]
Mean	2.6	12.0
STD	0.6	11.9
RMS	2.6	16.3
Point	8	8

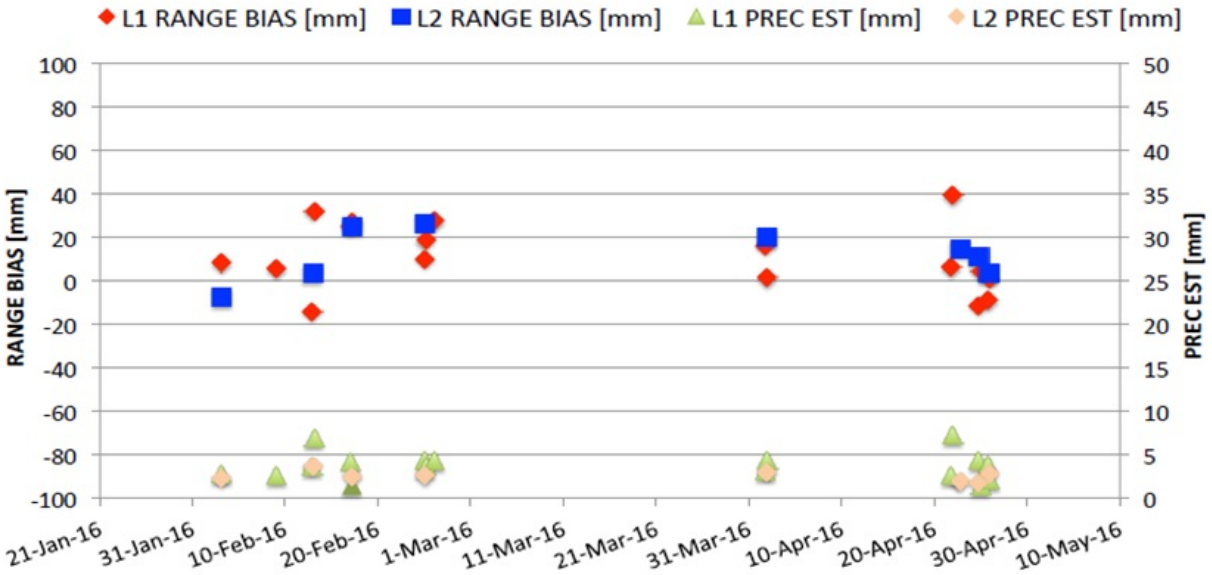

Fig.7 BORL's quarantine bias report.

After completed quarantine all BORL's log, sch and sci files were updated.

BORL results

After successful modernization BORL station is able to tracking LEO and MEO objects in a range from 350 to 25000 km (night mode). In 2016 BORL station tracked 32 satellites, 21 LEO and 11 MEO. An AVG RMS is from 1.19 to 5.54 cm (700 passes, 664599 single good shots and 10293 normal points). All results were sent to Crustal Dynamics Data Information System (CDDIS) and Eurolas Data Center (EDC). A new thing in BORL station activity is fact that all observation results performed by station are published at Borowiec website http://www.cbk.poznan.pl/stacja_laserowa/lista_obserwacji.php, just after uploading results to data banks.
In March, 2016 BORL station started with Special Mission Support (SMS) campaign of SENTINEL-3A coordinated by ILRS CB. From March to October 2016 BORL station collected 60 passes of SENTINEL-3A with 45878 single good shots and 1103 normal points.

At the end of 2014 Borowiec station was involved in Space Debris Study Group (SDSG), associating representatives of various laser centres all over the world operating at ILRS (International Laser Ranging Service). In collaboration with several partners from Poland, BORL participates actively in development of the Polish SST program (Konacki et al., 2016). In 2016 BORL station launched regular tracking of space debris objects (inactive satellites and rocket bodies). A total of 151 space debris passes were performed with the AVG RMS from 1.49 to 75.33 cm (151 passes, 137836 single good shots and 2528 normal points). All results were sent to SDSG data bank. The laser measurements of SRC BORL station supports global research in satellite and space debris rotation determination, which are essential for an improvement of the theory of artificial.

In Figures 8 and 9 the sample O-C results (after polynomial approximation) of ENVISAT and TOPEX/Poseidon are presented. The black points mean single residuals and red points mean normal points. Both objects rotate in an uncontrolled way, which with a large size of both target cause very dangerous situation. Laser measurements allow determination of their spin period (Kucharski et al., 2014; Kucharski et al., 2016; Kucharski et al., 2016). Therefore ENVISAT as well as TOPEX/Poseidon require regular tracking by many satellite sensors (radar, optical, laser) involved in SST programme.

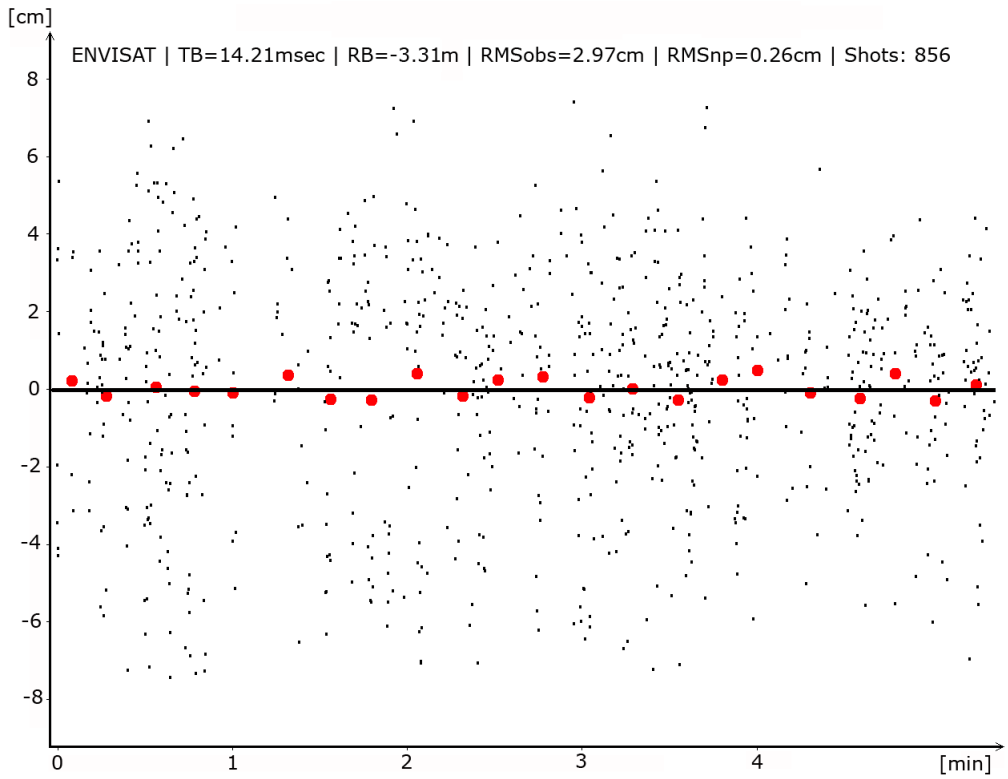

Fig.8 ENVISAT results, pass on April 22, 2015, 20:08 UTC.

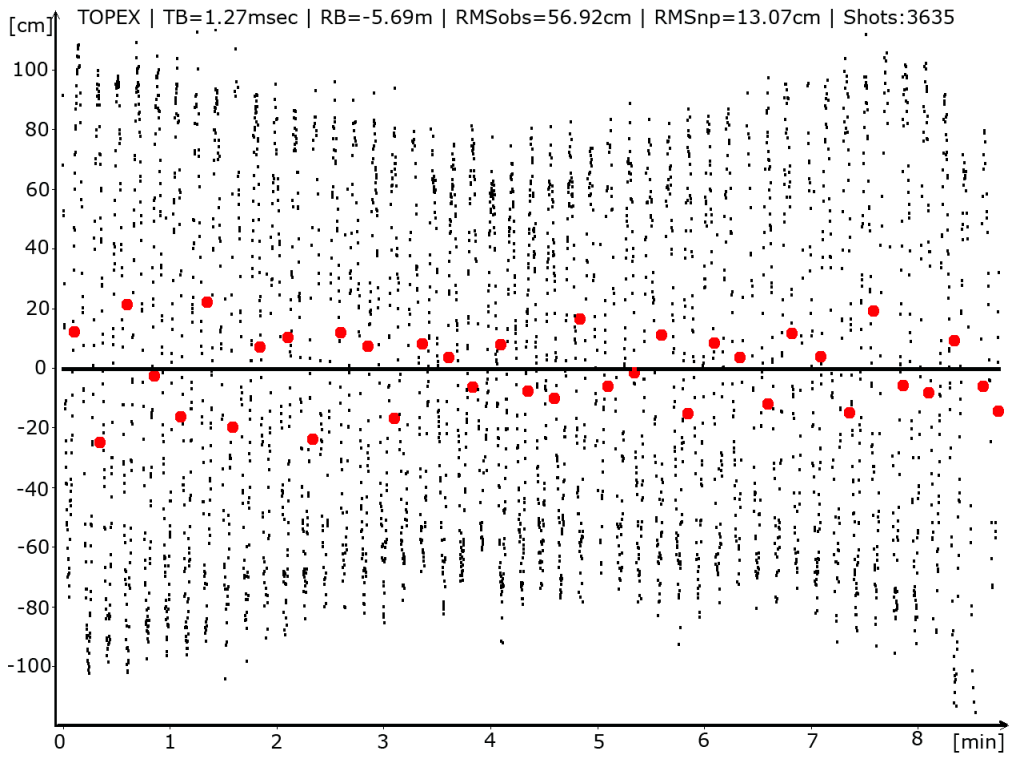

Fig.9 TOPEX/Poseidon results, pass on February 3, 2016, 02:36 UTC.

First results of BORL station for typical rocket bodies were obtained in August 2016. These observations were made with Continuum Surelite III laser dedicated to observations of space debris (uncooperative targets). Figures 10 and 11 show O-C results (after polynomial approximation) of SL14RB and SL16RB targets. As in the case of ENVISAT and TOPEX, black points are single residuals and red points are normal points.

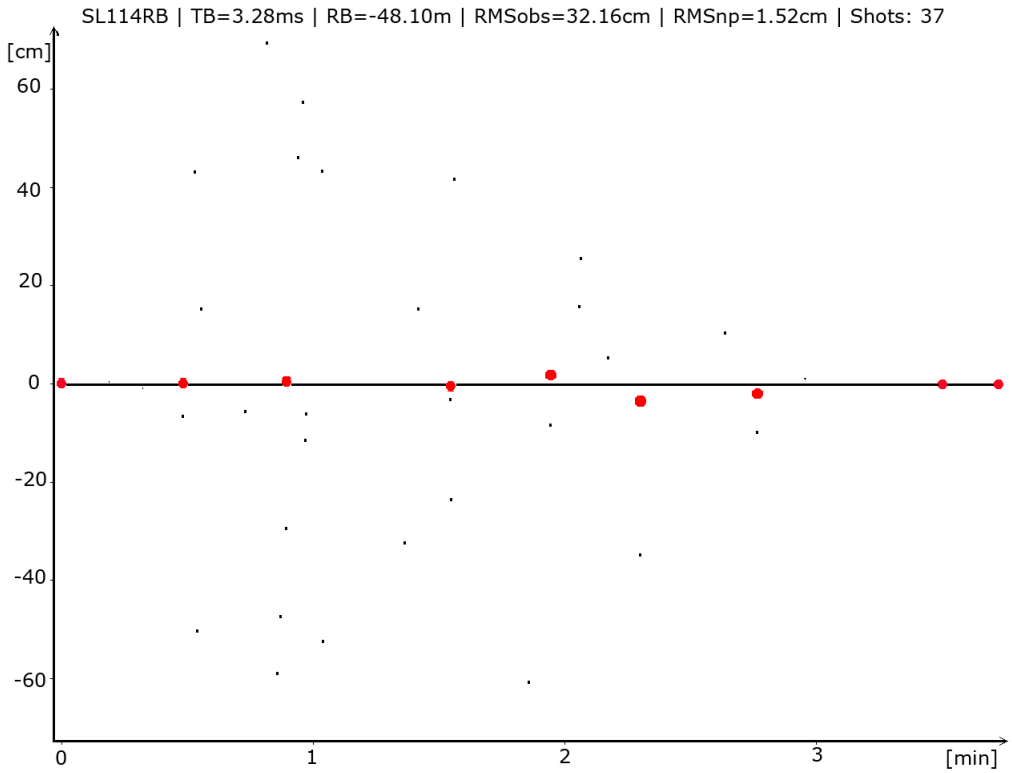

Fig. 10 SL14RB (NORAD 17912) results, pass on August 10, 2016, 01:10 UTC.

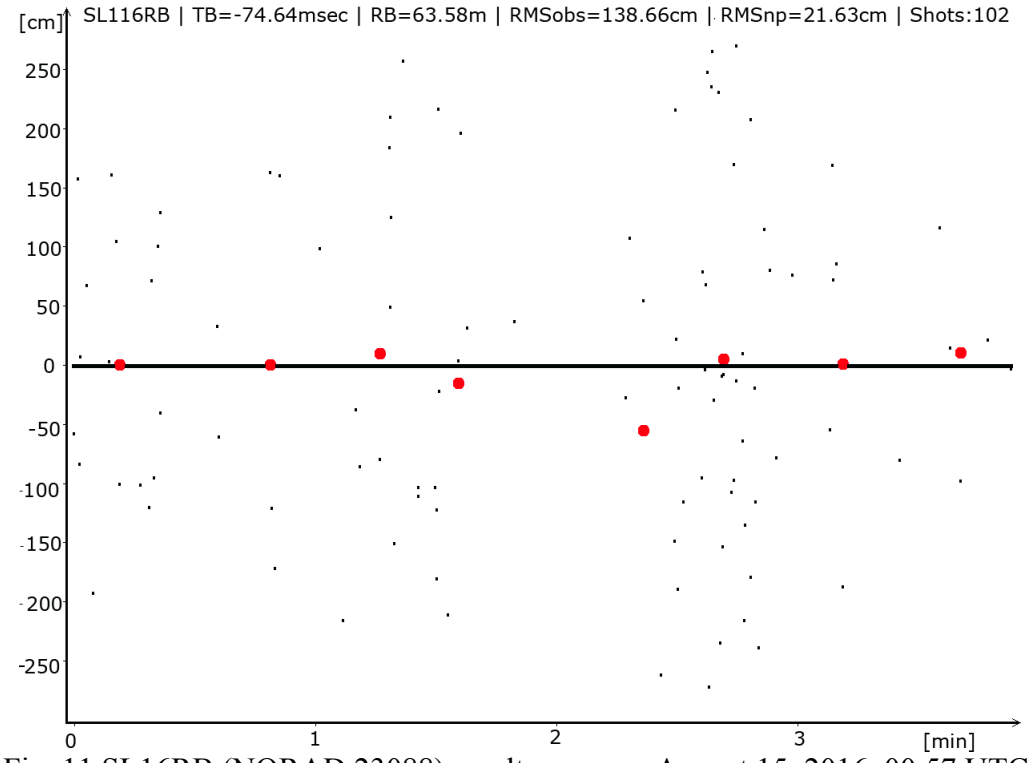

Fig. 11 SL16RB (NORAD 23088) results, pass on August 15, 2016, 00:57 UTC.

BOR1 station modernization

As was mentioned above, since 2015 BORL team coordinate the activity of the BOR1 station located at Borowiec Observatory. In the period 2015-2016 two significant changes have occurred, which increased efficiency of the BOR1 station. The first change covered a receiver. On February 5, 2015 the new multisystem Trimble NetR9 receiver was installed. It's a multichannel (440 channels) receiver capable of gathering signals simultaneously from GPS, GLONASS, GALILEO, BEIDOU, QZSS and SBAS constellations. For one and a half year this receiver has worked parallel with old Trimble NetRS receiver which collected data for GPS satellites only (Fig.4). On October 7, 2016 data sending from NetRS receiver was switched off and from that moment BOR1 station operates only with NetR9 receiver.

Fig.4 NetRS and NetR9 receivers at BOR1 station.

The second change was related to antenna exchange. The antenna was replaced on October 5, 2016. Since that time BOR1 stations uses advanced comprehensive choke ring geodetic antenna made by Trimble collecting signals from GPS, GLONASS, GALILEO, BEIDOU and SBAS systems (Fig.5).

Fig.5 New Trimble GNSS antenna working at BOR1 station.

New antenna was calibrated by GeoService GmbH in Germany (absolute GPS/GLONASS antenna calibration). During one session BOR1 station is capable for gathering signals from several dozen satellites (Fig.6).

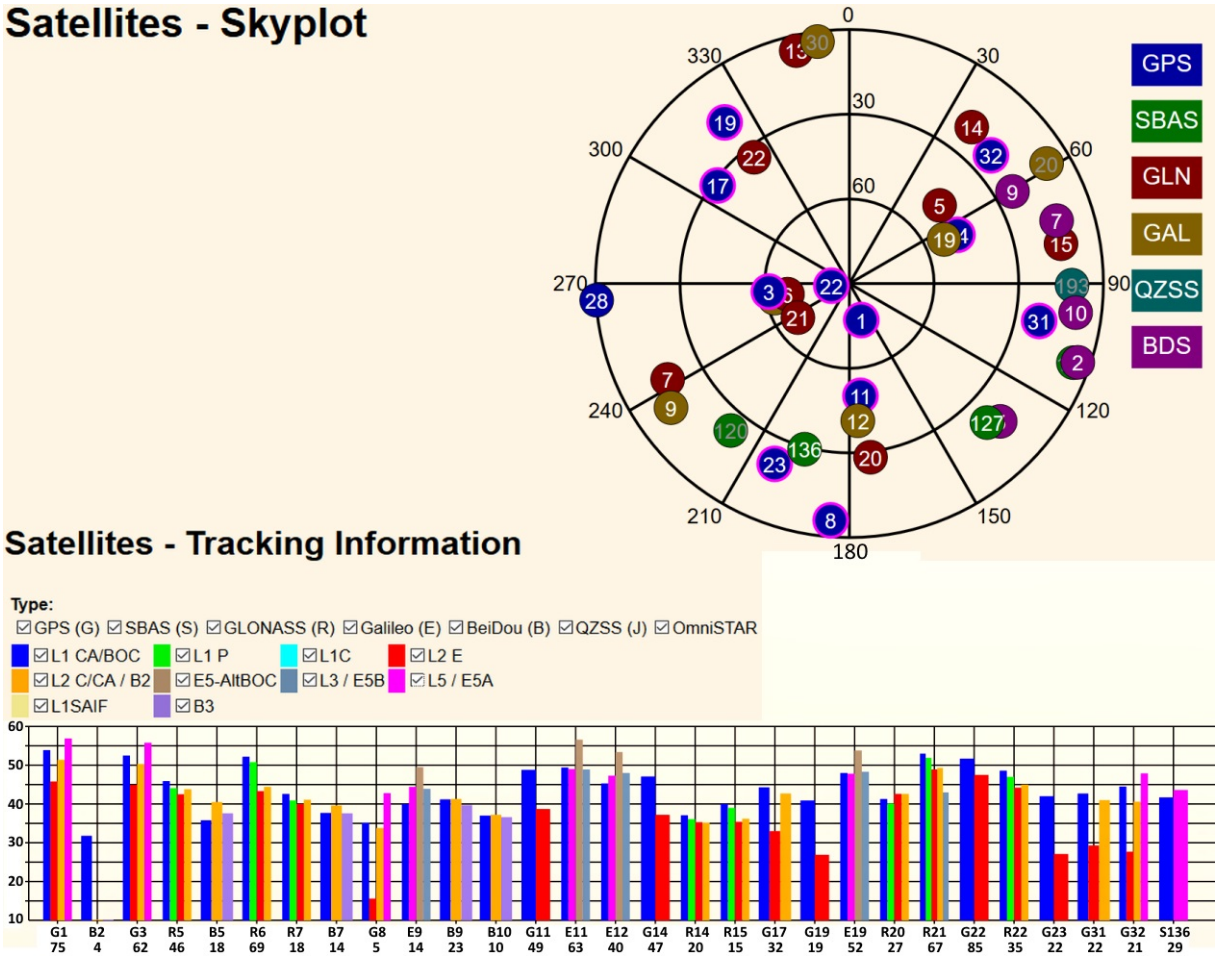

Fig.6 GNSS satellites observed by BOR1 station in real time.

Summary

After several years of break Borowiec laser station is back again to satellites tracking with new possibilities and new perspectives. At the beginning of 2016 station completed ILRS's quarantine procedure. First results gained by BORL station confirmed a high quality of observations (bias reports from AC's). An average RMS of all satellite passes collected to October 2016 is from 1.19 to 5.54 cm. BORL station is able to tracking LEO and MEO objects including ETALON's, GLONASS and GALILEO satellites. The goal for the station for next year is to achieve the range to 38000 km (IRNSS constellation).

Currently, Borowiec is one of several laser stations actively participating in observational campaigns of uncooperative targets (ENVISAT, TOPEX/Poseidon, OICETS, ERS-1, ERS-2, others inactive satellites and rocket bodies) within Space Debris Study Group and Space

Surveillance and Tracking programme developed and maintained by European Space Agency and European Commission.
In preparation is innovative Atomic Clock Ensemble in Space/European Laser Time Transfer (ACES/ELT) project in which BORL station will participate.
Together with Multi-GNSS BOR1 station, which is at present under management of Borowiec laser team, BORL station gives better contribution to Global Geodetic Observing System (GGOS), which significantly improve position of SRC Borowiec Observatory in the development of global geodesy.
Under construction is second independent laser system which will be operating 24/7. The first mechanical and optical tests of the new system are being planned in the middle of 2017.

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