ILRS Study Group
LARGE: LAser Ranging to GNSS s/c Experiment
Expanded SLR Tracking of GNSS Satellites

At the 18th International Workshop on Laser Ranging in Japan in November 2013 we agreed to expand the GNSS data coverage of the ILRS network (see Attachment 1). The objectives of this Study Group (SG) are:

1. Define an operational GNSS tracking strategy for the ILRS that addresses all proposed requirements and then tests its realization with a tracking campaign to be run as a Pilot Project.
2. Clarify outstanding ILRS and IGS issues with the GNSS satellites and ground stations.

The satellite constellations of interest with retroreflector arrays include GLONASS, BeiDou, Galileo, and GPS. The GLONASS constellation is fully populated. BeiDou and Galileo (including GIOVE) constellations are being populated. The GPS constellation will begin being populated in the 2018 timeframe. When completed, the full GNSS complex should reach about 70 – 80 satellites. At the moment we have and project the GNSS constellations, as shown in Table 1.

Table 1. GNSS Complex

Constellation	Current ILRS Roster	Available	Projected 2018 +
GLONASS	6	24	24
Galileo (+ GIOVE)	5	5	24
BeiDou	4	4	24
GPS	1	1	24
Total	16	34	96

Current ILRS policy is that GNSS passes include three sectors, taken early, middle and late in the pass, each with three normal points. Normal points are data spans covering five minutes or 1000 full-rate points if acquired in less than five minutes.

As a test, several stations have already demonstrated capacity to track all of the available GNSS satellites. The results for the period 1 November 2013 – 28 February 2014 are shown in Table 2 below for the most successful stations (see Attachment 2 for complete list and chart).

Table 2. ILRS GNSS Tracking Summary for November 2013-February 2014

Station	Number of Passes	Constellations Tracked	Number of Satellites
Altay	535	GLONASS, Galileo+ GIOVE, GPS	30
Changchun	2,533	All	35
Graz	679	All	33
Herstmonceux	641	All	32
Shanghai	602	All	33
Wettzell	1,026	All	33
Yarragadee	1,818	All	33
Zimmerwald	1,243	All	29

Station yields on some satellites were much higher and some much lower. Some station focused on one or two constellations. Stations that achieved the best results tended to be those with higher repetition rate systems and/or extremely good weather. Eight stations averaged at least 5 passes per day on GNSS satellites. As more stations upgrade to high repetition rate systems, we expect this participation to improve.

As a mechanism to achieve this objective, the ILRS has organized a Study Group made up of representatives of the ILRS Analysis Working Group, SLR practitioners, the IGS, and other interested parties to help us in this endeavor. Activities to be performed:

- Task #1: Collect the quantitative requirements with supporting documentation from each interested group (Study Group)
- Task #2: Perform any simulations necessary to justify the separate requirements (Study Group)
- Task #3: Recommend a unified tracking strategy for the network (Study Group)
- Task #4: Implement the strategy with 8 – 10 test stations and assess results (ILRS Central Bureau/SG)
- Task #5: Adjust the strategy as necessary (Study Group)
- Task #6: Clarify outstanding SLR issues with GNSS satellites and ground stations (ILRS CB)
- Task #7: Clarify outstanding radio issues with GNSS satellites and ground stations (IGS CB)

Members of the Study Group:

- Erricos Pavlis, UMBC/NASA GSFC (ILRS, Chair)
- Graham Appleby, NERC Space Geodesy Facility (ILRS)
- Rolf Dach, AIUB
- Vladimir Glotov, GLONASS-IAC-PNT (GLONASS)
- Urs Hugentobler, Technische Universitaet Muenchen (IGS)
- Georg Kirchner, Space Research Institute, Austrian Academy of Science (ILRS)
- Cinzia Luceri, e-GEOS S.p.A/ASI (ILRS)
- Steve Malys, NGA (GPS)
- Vladimir Mitrikas, GLONASS-IAC-PNT (GLONASS)
- Horst Mueller, DGFI (ILRS)
- Carey Noll, NASA GSFC (ILRS)
- Michael Pearlman, CfA/NASA GSFC (ILRS)
- Tim Springer, ESA (Galileo)
- Daniela Thaller, BKG (IERS/ILRS)
- Linda Thomas, NRL (GPS)
- Wu Bin, Shanghai Astronomical Observatory (BeiDou)
- Zhang Zhongping, Shanghai Astronomical Observatory (BeiDou)
- ROSCOSMOS Representative (1)

An ILRS mailing list (*ilrs-large@lists.nasa.gov*) consisting of the emails for the membership listed above has been established at NASA GSFC and should be used for communication within the group.

Outstanding Issues

There are a number of outstanding issues with GNSS satellites and ground stations that prevent the community from making the fullest use of the SLR and microwave data. The issues are articulated in the Appendix to Attachment 3.

Tracking Requirements

Thus far RAS/ROSCOSMOS has identified its requirement:

> Each participating station should make its best effort to provide two passes per day on each satellite in the GLONASS constellation, one pass in day-time and one pass in night-time, with

each pass having 2 normal points (1,000 full-rate observations or 5 minutes), spaced widely apart in the orbit.

Other interested groups must be polled for their requirements.

Schedule

Tasks: Milestone target dates to be determined.

Telecons: To be scheduled.

Meetings: Study Group meeting during the EGU General Assembly 2014 (propose Monday, April 28) and at the Unified Analysis Workshop in Pasadena, CA (June 2014).

Attachment 1

ILRS Workshop Resolution
18th International Workshop on Laser Ranging
November 11- 16, 2013

Resolution from the Eighteenth International Workshop on Laser Ranging

- Recognizing:
  - The increasing importance of SLR to the improvement of GNSS performance;
  - The necessity of the SLR technique to the improvement of time, frequency, and ephemeris data products from GNSS;
  - The significant contribution of GGOS to the development of GNSS measurement accuracy through co-location with SLR and other measurement techniques; and
  - The enhancement in station performance that we expect from the next generation SLR systems
  - The availability of full satellite characteristics
- The Participants of the 18th International Workshop on Laser Ranging recommend that:
  - With the example of the fully loaded GLONASS system; the ILRS develop a GNSS tracking strategy and on the basis of it, implement a mission (program) to track GNSS satellites with retroreflectors;
  - Multi-constellation GNSS receivers (GLONASS, GPS, BeiDou, etc) be co-located at all ILRS stations to improve measurement performance of GNSS and to support GGOS development;
  - All SLR stations should be members of ILRS and participate in the GGOS project.

Requirements:

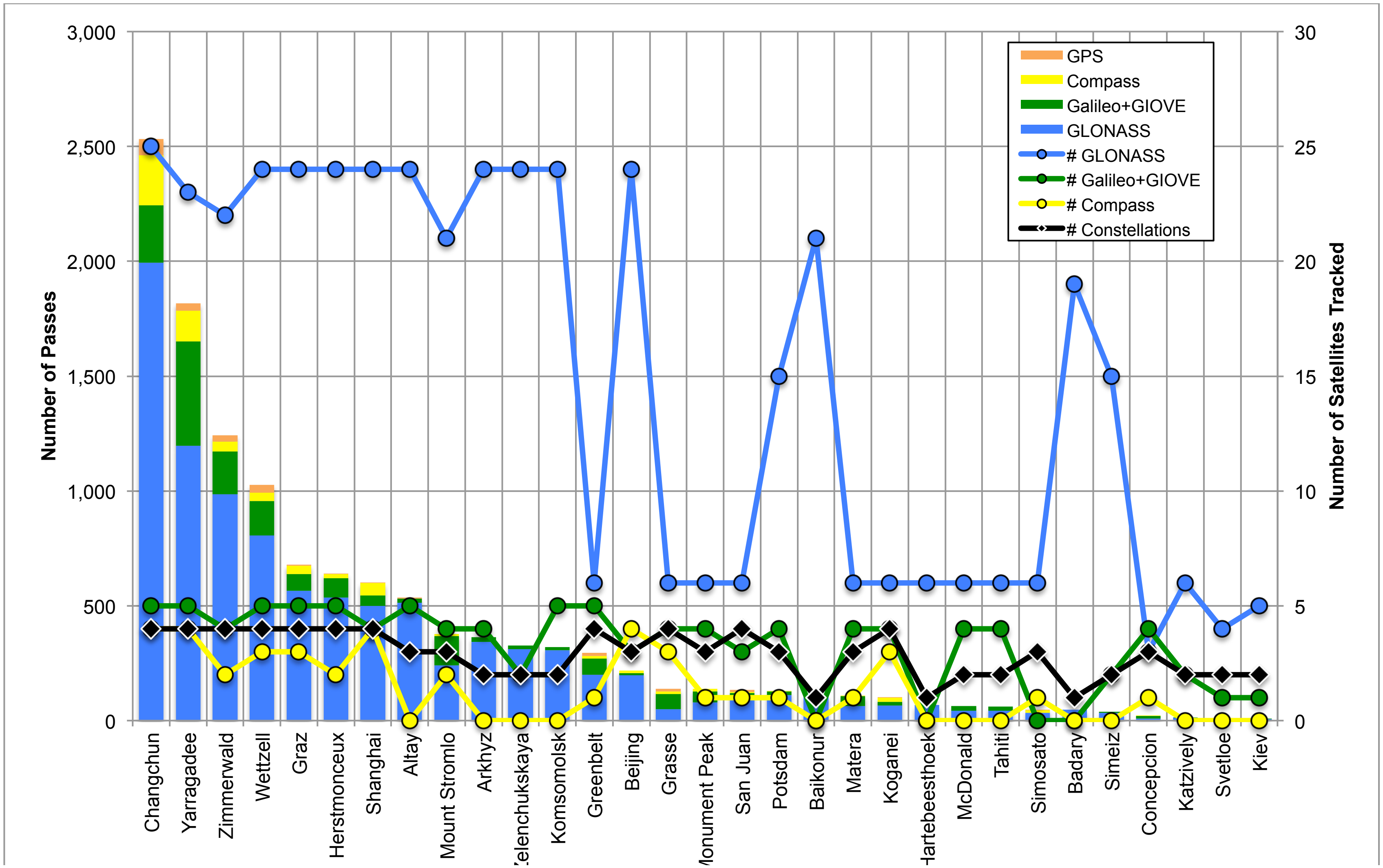
- RAS/ROSCOSMOS: Each participating station should make its best effort to provide two passes per day on each satellite in the GLONASS constellation, one pass in day-time and one pass in night-time, with each pass having 2 NP (1000 fr or 5 minutes), spaced widely apart in the orbit.

Attachment 2

GNSS Satellite SLR Normal Point Pass Summary
2013-11-01 through 2014-02-28

Site Name	Sta.	GLONASS		Galileo+GIOVE		BeiDou		GPS		Total		No. Constel.
		Passes	Sats.	Passes	Sats.	Passes	Sats.	Passes	Sats.	Passes	Sats.	
Altay	1879	513	24	19	5	0	0	3	1	535	30	3
Arequipa	7403	0	0	0	0	0	0	0	0	0	0	0
Arkhyz	1886	342	24	22	4	0	0	0	0	364	28	2
Badary	1890	47	19	0	0	0	0	0	0	47	19	1
Baikonur	1887	111	21	0	0	0	0	0	0	111	21	1
Beijing	7249	198	24	9	3	10	4	0	0	217	31	3
Changchun	7237	1,994	25	250	5	217	4	72	1	2,533	35	4
Concepcion	7405	10	3	10	4	2	1	0	0	22	8	3
Grasse	7845	49	6	66	4	11	3	13	1	139	14	4
Graz	7839	566	24	71	5	38	3	4	1	679	33	4
Greenbelt	7105	199	6	71	5	11	1	14	1	295	13	4
Haleakala	7119	0	0	0	0	0	0	0	0	0	0	0
Hartebeesthoek	7501	68	6	0	0	0	0	0	0	68	6	1
Herstmonceux	7840	535	24	84	5	20	2	2	1	641	32	4
Katzively	1893	12	6	2	2	0	0	0	0	14	8	2
Kiev	1824	7	5	1	1	0	0	0	0	8	6	2
Koganei	7308	66	6	15	4	18	3	3	1	102	14	4
Komsomolsk	1868	307	24	13	5	0	0	0	0	320	29	2
Kunming	7820	0	0	0	0	0	0	0	0	0	0	0
Matera	7941	63	6	43	4	4	1	0	0	110	11	3
McDonald	7080	42	6	21	4	0	0	0	0	63	10	2
Monument Peak	7110	80	6	48	4	11	1	0	0	139	11	3
Mount Stromlo	7825	240	21	128	4	8	2	0	0	376	27	3
Potsdam	7841	111	15	16	4	2	1	0	0	129	20	3
San Fernando	7824	0	0	0	0	0	0	0	0	0	0	0
San Juan	7406	94	6	27	3	4	1	8	1	133	11	4
Shanghai	7821	499	24	45	4	55	4	3	1	602	33	4
Simeiz	1873	35	15	3	2	0	0	0	0	38	17	2
Simosato	7838	35	6	0	0	10	1	3	1	48	8	3
Svetloe	1888	7	4	2	1	0	0	0	0	9	5	2
Tahiti	7124	44	6	17	4	0	0	0	0	61	10	2
Wettzell	8834	807	24	149	5	37	3	33	1	1,026	33	4
Yarragadee	7090	1,196	23	456	5	134	4	32	1	1,818	33	4
Zelenchukskaya	1889	311	24	15	2	0	0	0	0	326	26	2
Zimmerwald	7810	985	22	186	4	43	2	29	1	1,243	29	4
Totals:	35	9,573		1,789		635		219		12,216		

GNSS Satellite SLR Normal Point Pass Summary
2013-11-01 through 2014-02-28



Attachment 3

GGOS – RAS/ROSCOSMOS Meeting
Technical University of Vienna
Room SEM 124 (third floor)
Vienna, Austria
April 8, 2013
9:00 – 17:00

The Meeting between GGOS and the Russian Academy of Sciences (RAS)/ROSCOSMOS was held to explore synergies and strategies for cooperation in space geodesy that would enhance national and international science programs with special focus on GLONASS and Reference Frame.

Attendees: M. Pearlman (CfA), A. Ipatov (IAA-RAS), S. Revnivykh IAC-PNT/TSNIIMash), Y. Bondarenko (IAA-RAS), C. Rizos (IAG-IGS), G. Johnston (GGOS-IC), T. Herring (MIT), R. Dach (AIUB), G. Appleby (NERC/SGF), B. Richter (BKG), D. Thaller (BKG), U. Hugentobler (TUM), F. Koidl (SLR Graz), G. Bianco (ASI), C. Luceri (e-GEOS), T. Springer (ESA/ESOC), E. Pavlis (UMBC/NASA), H. Schuh (GFZ), Z. Altamimi (IGN)
Remotely connected: J. Labrecque (NASA), R. Neilan (JPL)

Desired Output:

1. Improve the determination of the GLONASS orbits and clocks through enhanced tracking by the IAG Services of IGS and ILRS and the analysis of the IERS.
2. Improve the geographic coverage on (1) LAGEOS and LARES for improvement of the reference frame and (2) GNSS constellations for improved global distribution of the reference frame.

The two interests could be very closely linked and could form the bases for very beneficial cooperation between GGOS and RAS/ROSCOSMOS.

RAS/ROSCOSMOS/GLONASS

ROSCOSMOS plans to be self-sufficient by deploying a dedicated global network of about 50 radio receivers and 6 SLR sites outside of Russia. The first radio receiver is being placed in Brazil and GLONASS would like to work with GGOS in the location of other sites. Data from these sites will be available to the general community. Data from other multi-constellation receivers would help densify their network. Current GLONASS navigation capability is about 3 meters; the future improved GLONASS M and K satellites with broader-band capability and improved modeling/analysis should improve this to about 0.6m by 2020. The soon to be launched new GLONASS M satellites will also use one and two way ranging for time transfer capability. Both RAS and ROSCOSMOC operate SLR stations; first priority is GLONASS tracking, but they are interested in increasing their support for GGOS and the ITRF.

GGOS

The main GGOS interest is the improvement in GNSS and SLR global coverage and deployment of new technology systems to improve and disseminate the ITRF. Several groups within IGS are analyzing GLONASS data; combined GLONASS final and ultra-rapid orbit and clock products continue to improve. A GPS+GLONASS combined orbit and clock data stream is available as part of the IGS Real Time Service. The addition of GLONASS data into the GNSS analysis has also improved GNSS data products. SLR Ranging experience demonstrates that the GLONASS arrays meet the ILRS standard and provide a good SLR target.

SLR Tracking of GLONASS

The ILRS has six GLONASS satellites on its current roster; some stations are tracking the full 24-satellite constellation at various levels of data-density. Capacity studies indicate that the high-repetition rate SLR systems should be able to track 12 – 24 satellites in addition to the other current ILRS tracking load. Legacy systems with lower repetition rates will be unable to support the full constellation on a daily basis, but they may be able to expand coverage over several days. As yet, only a few ILRS stations are tracking GNSS in daylight; this needs some work. The Russian SLR stations provide GLONASS data to the ILRS.

The ILRS already places high priority on the LAGEOS and LARES satellites in support of the ITRF.

Improved Quality of GLONASS Data Products

Increased quality of GLONASS Radio data products will require more satellite tracking data from the Russians stations and more information on the GLONASS spacecraft (see list attached). At some point it may be advantageous to examine multi-technique (GNSS-SLR) solutions, combining data at the observation level as a first test of the "ties in space" concept. Whatever path we follow, we must stress proper site tie procedures and documentation between co-located instruments. Without proper site ties, the individual reference frames cannot be accurately combined.

Opportunity Provided by GLONASS

GLONASS is currently the only full GNSS constellation with retroreflectors offering a good opportunity to test: (a) the concept of disseminating globally the reference frame at its full capability and (b) the stress that would be placed on the ILRS network with tracking such a large number of additional targets.

Some of the key SLR questions:

Key Items to Discuss

We agreed to organize a pilot project or a framework to proceed with activities of mutual benefit. Key items mentioned that would benefit that framework would be:

- Continue working toward interoperability and compatibility between GLONASS and the other GNSS constellations;
- Provide full participation from the GGOS and GLONASS receiving stations, with all data provided to the IGS and the ILRS respectively, for general access;
- Emphasize real-time delivery of GLONASS data into the IGS data stream;
- Provide additional information and updates on the GLONASS satellites necessary to improve the data products (see appendix);
- Test the capacity of the SLR network to expanded GLONASS tasking and expand SLR coverage on GLONASS as is practicable;

- Continue the performance and diagnostic feedback to all of the radio and SLR Stations operating on LAGEOS, LARES, and GLONASS;
- Continue the evolution of the GGOS and GNSS data products;
- Expand SLR coverage on LAGEOS and LARES for the improvement of the ITRF;
- Use simulation techniques to:
  - Help optimize the GLONASS and SLR layout of the ground-based network;
  - Examine ground systems – constellation trade-offs;
  - Estimate how many GLONASS satellites are needed to demonstrate the reference frame disseminating capability?
  - Examine how many SLR passes/day/station and how many stations would we need to demonstrate the dissemination concept?
  - Examine SLR tracking strategies for the improvement of the GLONASS data products;

Path Forward (ACTION)

- Each side should select a person who will be its lead in organizing the discussions on planning and executing future cooperative activities;
- Each side should review the items above and comment back on their content and completeness by May 31;
- We should organize Working Groups with membership on both sides:
  - GLONASS networks and data
  - SLR networks and data
  - GNSS analysis
  - Simulations
- We should plan a video telecon around June 15 to discuss our issues and plans

Appendix

Information to Improve GLONASS Data Product Quality

Tracking Data from Russian Federation Territory

- Tracking data from more GNSS stations in Russia are necessary for the densification of the IGS network for improving the quality of orbit and clock products generated for GLONASS satellites.
- Participation of Russian stations in the IGS Real Time Service and availability of real-time tracking streams from Russian stations is necessary for improving the accuracy of the real-time GLONASS orbits and clocks issued by the Service.

Mandatory for IGS operations

- Timely information and announcements on all active satellites, even unusable, including frequency channel changes, slot numbers, and advance announcement of satellite maintenance operations is essential for proper exception handling at IGS Analysis Centers that routinely process GLONASS tracking data.

Spacecraft information

The items requested in the following should be provided for EACH satellite target, rather than as general models, since most of these satellites are not exactly identical in design.

<u>Spacecraft Mechanical Reference Frame</u>

- Definition of body-fixed coordinate system (X, Y, Z)
- Definition of view-cone angles (theta, phi)

<u>Satellite Attitude</u>

Satellite attitude is essential for accurately locating the satellite navigation antenna with respect to the center of mass at any time as well as for a proper modeling of radiation pressure accelerations.

- The nominal attitude behavior and attitude algorithm is required; in particular behavior during deep eclipse seasons including noon turns, midnight turns, yaw attitude in shadow, and solar array rotation. It would also be helpful to have the tolerance with which the nominal attitude model is realized.
- Measured attitude (quaternions) with estimated uncertainties should be provided, at least for tracking campaign periods.

<u>Satellite Antenna</u>

Information on the satellite antenna phase center variations and offsets is essential for proper modeling of the observations. In particular a priori knowledge of phase center variations and offsets are mandatory for accessing the terrestrial scale.

- Confirmation of the engineering values of the navigation antenna position with respect to CoM in the satellite body frame;
- Per carrier frequency lab calibrated satellite antenna phase center variations (nadir and azimuth dependent) and offsets for a next generation of GLONASS satellites;

- Confirmation of laser retroreflector position and dimensions with respect to CoM in satellite body frame with confirmation of the accuracy.

Orbit Modeling

In order to improve non-gravitational force models it is essential that we have accurate attitude information. Other (measured or modeled) information on the satellite physical properties would also be very helpful. We need the following information:

- Dimensions, shape, optical properties (e.g. reflectivity, absorption and emission coefficients, in visible and infrared) of main surfaces (solar panels both sides, body surfaces) are required to build box-wing models for improving radiation pressure modeling (Solar radiation and Earth radiation).
- Radio emission power is required to model antenna thrust acceleration (typically amounting to about 1cm in orbit radius).
- Mass at launch (incl. propellant), mass history and effect on whole-satellite mass centre motion with respect to satellite body-fixed reference. Nominal accuracy and stability of the CoM.
- Thermal model (if available) for thermal emission modeling.
- Strategy for momentum dumping (frequency of momentum dumps, duration, magneto-torquers or thrusters) and expected impact on orbit would be helpful.

Signal characterization

- Information on group delay calibrations and expected stability.
- Information on clock characteristics (stability, thermal sensitivity)

Reference frame

- Tracking data from control stations for a consistent alignment with ITRF and contribution to the ITRF realization.